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Soil organic carbon and total nitrogen in a *Leucaena leucocephala* silvopastoral system in the Chaco region, Argentina

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Abstract

The introduction of leucaena (*Leucaena leucocephala*) into hedgerow silvopastoral systems increases animal production and improves soil fertility, through biological nitrogen fixation and deep-rooted leguminous trees. There is limited information on carbon and nitrogen dynamics in hedgerow silvopastoral systems, particularly in long term periods and subsoil profiles. The concentrations and vertical distribution of organic carbon (OC) and total nitrogen (TN), and their fractions (particulate and associate forms) in the soil profile (0–100 cm), with and without leucaena were compared 10 years after leucaena establishment into a 24-year-old tropical pasture (*Urochloa brizantha-Chloris gayana*). Leucaena increased the OC concentration in the deepest horizon (50–100 cm) by 73% (from 0.40 to 0.69%), particularly the stable form (associate OC). This was attributed to a greater abundance of leucaena roots deeper in the profile than in the pure grass pasture. Leucaena also enhanced by 12% the TN concentration in the topsoil (0–20 cm) (from 0.133 to 0.149%) and by 21% in deepest horizon (from 0.049 to 0.059%) associated with leaf deposition, recycling of animal feces and nodule-N turnover from N fixation. Although TN increased in the leucaena topsoil and it is expected that OC follows the same pattern, OC concentration decreased in the topsoil. The low OC content in the topsoil of the leucaena pasture was closely linked to the poor grass cover observed ($r^2 = 0.82$). The loss in grass cover was attributed to the excessive grazing pressure imposed to control the height of leucaena hedgerows. Leucaena establishment has the potential to improve soil fertility and hence availability of N to companion grass growth, and can be utilized as a greenhouse gas mitigation strategy. However, to achieve the potential productivity and carbon sequestration of leucaena in silvopastoral systems, grass persistence needs to be evaluated under different management practices and grazing regimes.

Introduction

Adequate management of soils used for livestock production plays an important role in OC sequestration and, consequently, in climate change mitigation (Lal 2004; Soussana and Menaire 2014). Leucaena (*Leucaena leucocephala* ssp. *glabrata*), introduction into grass pastures contributes to increase livestock productivity (Radrizzani and Nasca 2014) as well as enhancing soil OC and TN (Radrizzani et al. 2011; Conrad et al. 2017) contributing to mitigate greenhouse gases emitted by livestock (Franzluebbers and Stuedemann 2009). The quantity and vertical distribution of OC and total nitrogen (TN) stocks, and their fractions (particulate and associate forms), in the soil profile (0–100 cm) of a 9-year-old leucaena-grass pasture, were compared with those in soil of the adjacent pure tropical grass pasture in the Argentinean Chaco region.

Methods and Study Site

This study was carried out at the Animal Research Institute of the Semi-arid Chaco Region (IIACS), operated by the National Institute of Agricultural Technology (INTA), in the west of the Chaco region (27°11' S, 65°14' W; 335 masl), Northwest Argentina. The climate is subtropical sub-humid with a dry season from April to September and average annual rainfall of 880 mm (75% in October-March). Soil type is Fluvaquentic Haplustoll, US Soil Taxonomy System (Soil Survey Staff 1999).

Soil samples were collected from 4 parcels of 1 ha each: 2 parcels with pure grass pasture (PP) and the other 2 with leucaena-grass pasture (LP). Both pastures (PP and LP) have been rotationally grazed at a variable stocking rate from early spring (October) to late autumn (June). For most of the grazing periods, LP was heavily grazed with a stocking rate around 3 times than PP, in order to restrict height growth of leucaena, leading to overgrazed inter-row grass. Soil samples were collected in both pastures in March 2019 from 12 transects 10 m in length (3 in each parcel; 6 per treatment). In the leucaena pasture, transects were placed obliquely from leucaena hedgerows to the middle of the inter-row (2.5 m from the hedgerow) following the sampling procedure described by Radrizzani et al. (2011). Along each transect, 5 soil cores (0 to 1 m deep) divided into 3 depths (0-20 cm, 20-50 cm and 50-100 cm) were collected at equal distances along the 2.5 m (i.e. in the leucaena pasture: 0, 0.63, 1.25, 1.88 and 2.50 m from hedgerow). The 5 soil samples collected for each depth were mixed to form 1 composite sample per depth and transect. The assumption underlying the comparisons was that both the LP and PP pastures had similar soil properties before leucaena establishment. Therefore, the difference in soil fertility parameters between pastures could be attributed to the introduction of leucaena into the pure grass pasture. Soil samples were air-dried (40 °C), and sieved by a 2-mm sieve. Organic carbon (OC) concentration was determined by Walkey Black (Nelson and Sommers 1996). Total nitrogen (TN) concentration was determined by Kjeldahl (Bremner 1965). Fractions of OC and TN were measured following the technique described by Cambardella and Elliot (1992).

Basal grass cover (the percentage of ground cover occupied by plant bases of individual species) was used to measure changes in botanical composition in relation to pasture treatment. Basal grass cover was estimated by recording the lengths of the string transected by sown grasses (*Urochloa brizantha* and *Chloris gayana)* from 12 transects 10 m in length (3 in each parcel; 6 per treatment). The total length of the intercepts along the 10 m transect represents the proportion of ground surface occupied by these species.

Analysis of variance of soil fertility parameters (OC, POC, AOC, TN, PTN and ATN) and mean comparisons (Tukey, $P<0.05$) within pastures were performed to assess the effects of leucaena introduction. Correlation analysis between basal grass cover and soil OC was performed using Pearson test. All statistical analyses were carried out using InfoStat software (Di Rienzo et al. 2016).

Results

In the topsoil horizon (0-20 cm), values of soil OC were higher in PP than in PL (1.38±0.04% vs 1.21±0.05%, respectively). In contrast, in the deepest horizon (50-100 cm), OC contents were higher in PL than in PP (0.69±0.03% vs 0.40±0.02%, respectively). Stratification of OC was more pronounced in soil supporting PP than in soil supporting LP, since OC concentrations continued to decline with depth (20-100 cm) in PP but no differences were observed between subsoil depths (20-50 and 50-100 cm) in LP (Figure 1). Following a similar trend, the content of the labile OC form (POC) was higher in PP than in PL in the topsoil (0-20 cm) (0.68±0.02% vs 0.60±0.02%, respectively) while in the subsoil (20-100 cm) POC contents were higher in PL than in PP (Figure 1). In both pastures, POC form represented about 50% of the OC in the topsoil (0-20 cm). The stable OC form (AOC) was different only in the deepest horizon (50-100cm) with higher contentes in PL than in PP (0.35±0.03 vs 0.22±0.04). The subsoil horizons (20-100 cm) AOC form contained 59% of OC for LP and 47% of OC for PP.

Concentrations of TN followed a similar trend to OC (Figure 1). However, in the topsoil horizon TN was higher in LP than in PP (0.149±0.02% vs 0.133±0.03%, respectively). In the deepest horizon (50-100 cm), similar to OC, TN was also higher in PL than in PP (0.059±0.003% vs 0.049±0.003%, respectively) and no differences were observed between pastures in the intermediate horizon (20-50 cm). Concentrations of the labile ON form (PON) were also stratified in both pasture soil profiles but followed different patterns from those for the TN concentrations in the subsoil (Figure 1). In the topsoil (0-20 cm) PON was greater in LP than in PP (0.103±0.003% vs 0.073±0.0025%, respectively), however in the same horizon, the stable ON form (AON) was greater in PP than in PL (0.06±0.0025% vs 0.046±0.003&, respectively). Most of the TN in this horizon was in the labile ON form (PON).

Grass basal cover of sown grasses (*Urochloa brizantha* and *Chloris gayana*) was higher in PP than in PL, being 1.90±0.31 and 0.13±0.05 respectively. The PL pasture was dominated by *Cynodon dactylon* and broadleaf weeds. Bare ground was not observed in any of the pastures. The correlation analysis showed a high relationship between OC and grass cover ($r^2 = 0.82$).

Discussion

Results showed the effect of the introduction of a forage tree legume into a tropical grass pasture on soil OC and TN contents and its fractions, related to residue cycling and grazing regime. The vertical distribution of OC and TN, and their fractions in soil pastures showed similar tendencies as the previous study (Banegas et al. 2019). The greater OC contents in the topsoil (0-20 cm) of PP in comparison to PL is related to the loss in sown grass cover in PL ($r^2 = 0.82$). Poor grass cover was attributed to the higher stocking rate imposed in PL to control the height of leucaena hedgerows (Radrizzani and Nasca 2014). The lack of grass cover reduces grass litter deposition and grass root turnover, and consequently leucaena potential to capture OC in the topsoil (Radrizzani et al. 2011). In contrast, good grass cover promotes litter deposition and root turnover in the topsoil since there is a higher root proportion (about 70%) in the first 30 cm of the soil profile (Banegas et al. 2020). The higher OC content in the deepest horizon (50-100 cm) in PL could be attributed to leucaena's deep-root system since a larger proportion of leucaena fine roots (>60%) have been observed below 40 cm in soil, compared with the adjacent pure grass pastures (Radrizzani 2011). This result is consistent with studies that show that root turnover in deep soil enhances the pool of stable OC (Fisher et al. 1994; Follett et al. 2003) and can serve as a long-term greenhouse gas mitigation strategy.

Like soil OC concentrations, soil TN declined with depth in both pastures, since most of the N (~90%) was bound up with OC in organic matter. Differences between pastures were observed mainly in the topsoil that could be attributed to both recycling of N-rich residues and biological N fixation after legume introductions. These results are consistent with the higher soil TN concentrations in topsoil (0–15 cm) of leucaena-grass silvopastoral systems, reported by Radrizzani et al. (2011) and Conrad et al. (2017). The poor grass cover in PL could increase N losses from the grazing system. Much of the N recycled via urine and dung is susceptible to loss. Ferreira et al. (1995) estimated N losses from urine of about 34% under dense grass cover and up to 76% in areas of bare soil in tropical Brazil.

For the same soil mass (2640 Mg/ha), PP stored higher OC than PL (36.43 Mg OC/ha vs 32 Mg OC/ha, respectively). This unexpected result has been attributed to poor grass cover in PL, highlighting the importance of promoting adequate grass persistency in silvopastoral systems (Radrizzani et al. 2019). In comparison to the previous soil survey, done in the same pastures 5 years after leucaena establishment (2014) (Banegas et al. 2019), OC content increased 1.77 Mg/ha, reaching an annual increment rate of 0.35 Mg/ha/year, whereas the level of OC in PL remained stable. The annual increment rate in PP is consistent with other results observed by Conant et al. (2017), who reported an average OC increment of 0.47 Mg/ha/year in grazed grass pastures. In contrast to OC, the increment of TN content during the same period of time was higher in PL than in PP (0.10 Mg/ha vs 0.07 Mg/ha), leading to an increment rate of 0.020 and 0.014 Mg/ha/year for PL and PP, respectively. This rate of TN in PL is consistent with values reported by Radrizzani et al. (2011) in Australia, in a 20, 31 and 38-year-old leucaena-grass pastures (0.017, 0.011 and 0.014 Mg/ha/year, respectively).

Even though leucaena introduction into a grass pasture promoted substantial capture of OC in the deepest horizon and enhanced N concentration in the topsoil (0–20 cm), grass overgrazing to control the height of leucaena hedgerows leaded to significant losses in sown grass cover, limiting leucaena potential to capture OC. Grass persistence in the inter-row needs to be evaluated under different management practices and grazing regimes in hedgerow leucaena silvopastoral systems

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References

Banegas N., Corbella R., Viruel E., Plasencia A., Roig B., Radrizzani A. 2019. *Leucaena leucocephala* introduction into a tropical pasture in the Chaco region of Argentina. Effects on soil carbon and total nitrogen. Tropical Grasslands-Forrajes Tropicales 7:295–302. doi: 10.17138/ TGFT(7)295-302

Bremner J.M. 1965. Total nitrogen. In: Norman AG, ed. Methods of soil analysis, Part 2, Chemical and Micro- biological Properties. Agronomy Monograph 9.2. ASA and SSSA, Madison, WI, USA. p. 595–624. doi: 10.2134/ agronmonogr9.2.c32

Cambardella C.A., Elliott E.T. 1992. Particulate soil organic-matter changes across a grassland cultivation sequence. Soil Science Society of America Journal 56:777–783. doi: 10.2136/sssaj1992.03615995005600030017x

Conant R, Cerri C, Osborne B, Paustian K. 2017. Grassland management impacts on soil carbon stocks: a new synthesis. Ecological Applications, 27(2), 2017, pp. 662–668

Conrad K.A., Dalal R.C., Dalzell S.A., Allen D.E., Menzies N.W. 2017. The sequestration and turnover of soil organic carbon in subtropical Leucaena-grass pastures. Agriculture, Ecosystems & Environment 248:38–47. doi: 10.1016/ j.agee.2017.07.020

Di Rienzo J.A., Casanoves F., Balzarini M.G., González L., Tablada M., Robledo C.W. 2016. InfoStat, Versión 2016. Grupo InfoStat, F.C.A., Universidad Nacional de Córdoba, Argentina. www.infostat.com.ar

Fisher M.J., Rao I.M., Ayarza M.A., Lascano C.E., Sanz J.I., Thomas R.J., Vera R.R. 1994. Carbon storage by introduced deep-rooted grasses in the South America savannas. Nature 371:236–238. doi: 10.1038/371236a0.

Ferreira, E., Alves, B.J.R., Urquiaga, S., and Boddey, R.M. (1995). Perdas de N derivado das fezes bovinas depositadas na superficie do solo, pp. 125-126. Proceedings of the XXXII Reuniao Anual da Sociedade Brasileira de Zootecnia, Brasilia, Brazil.

Follett R.F., Leavitt S.W., Kimball J.M., Pruessner E.G. 2003. Paleo-environmental inferences from d^{13}C of soil organic C in ^{14}C-dated profiles in the U.S. Great Plains. In: XVI INQUA Congress, Reno, NV, USA, 23–30 July 2003. goo.gl/mc6ch1

Franzluebbers A.J., Stuedemann J.A. 2009. Soil-profile organic carbon and total nitrogen during 12 years of pasture management in the Southern Piedmont USA. Agriculture, Ecosystem & Environment 129:28–36. doi: 10.1016/j.agee. 2008.06.013 Lal R. Soil erosion and the global carbon budget. Environ. Int. 29, 437–450 (2003).

Lal R. 2004. Agricultural activities and de global carbon cycle. Nutrient cycling in Agroecosystems. 70: 103-116

Nelson D., Sommers L.E. 1996. Total carbon, organic carbon, and organic matter. In: Sparks DL; Page AL; Helmke PA; Loeppert RH, eds. Methods of soil analysis, Part 3, Chemical Methods. ASA and SSSA, Madison, WI, USA. p. 961–1010. doi: 10.2136/sssabookser5.3.c34

Radrizzani A., Shelton H.M., Dalzell S.A., Kirchhof G. 2011. Soil organic carbon and total nitrogen under *Leucaena leucocephala* pastures in Queensland. Crop and Pasture Science 62:337–345. doi: 10.1071/CP10115

Radrizzani A., Nasca J.A. 2014. The effect of *Leucaena leucocephala* on beef production and its toxicity in the Chaco Region of Argentina. Tropical Grasslands-Forrajes Tropicales 2:127–129. doi: 10.17138/tgft(2)127-129

Radrizzani A., Pachas A.N.A., Gándara L., Nenning F., Pueyo D. (2019). Leucaena feeding systems in Argentina. II. Current uses and future research priorities. Tropical Grasslands-Forrajes Tropicales 7:389–396. doi: 10.17138/TGFT(7)389-396

Soil Survey Staff. 1999. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. 2nd Ed^{n}. Natural Resources Conservation Service, USA. Department of Agriculture Handbook 436. goo.gl/uDh7Ji

Soussana J.F., Menaire G. 2014. Coupling carbon and nitrogen cycles for environmentally sustainable intensification of grasslands and crop-livestock systems. / Agriculture, Ecosystems and Environment 190 (2014) 9–17

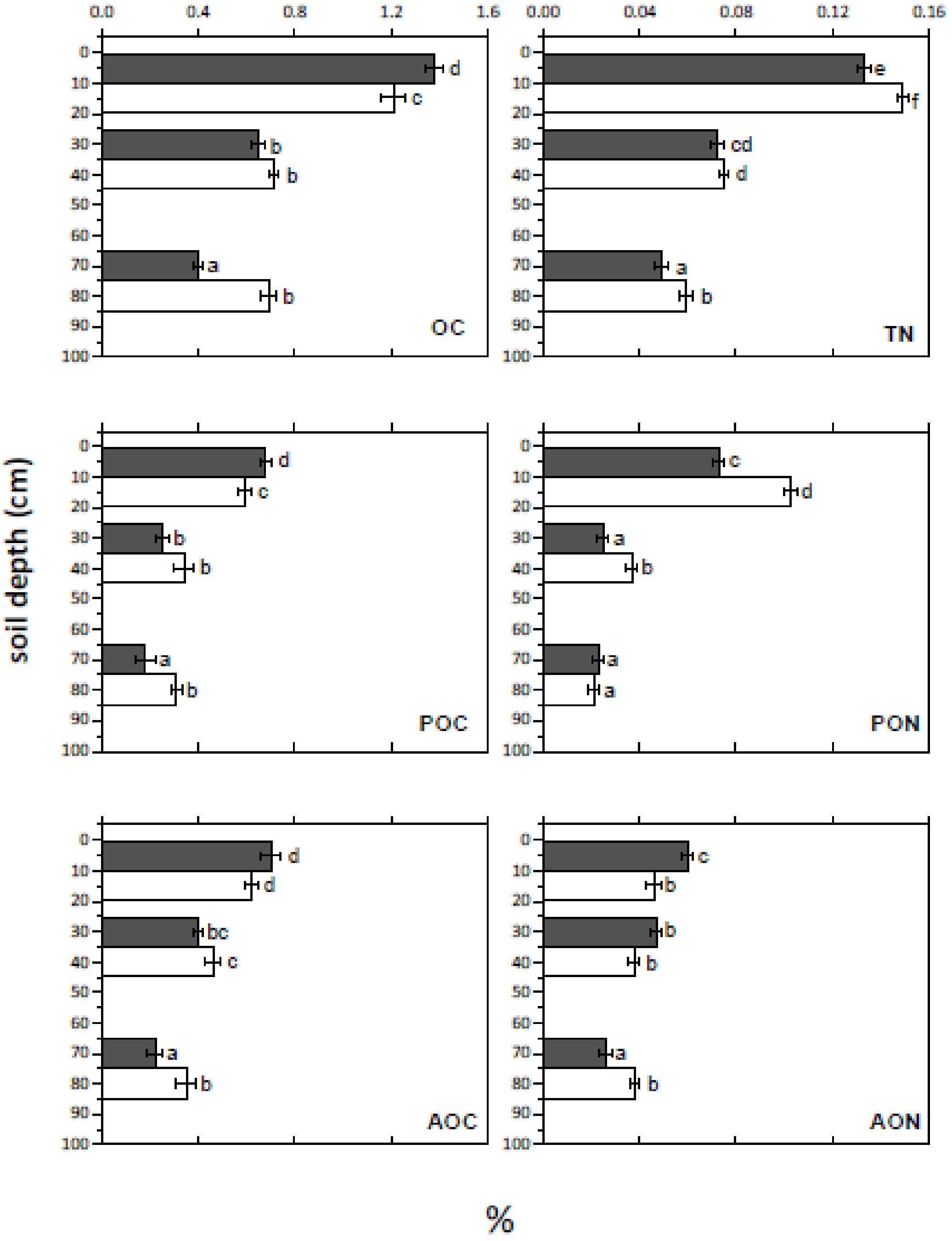

Figure 1. Concentrations of: organic carbon (OC); particulate OC (POC); associate OC (AOC); total nitrogen (TN); particulate organic nitrogen (PON); and associate organic nitrogen (AON), in relation to soil depth (0–20, 20–50 and 50–100 cm horizons) in soils under leucaena-grass pasture (open squares) and pure grass pasture (filled squares) at IIACS-INTA. Means followed by different letters are significantly different ($P<0.05$); bars represent standard error.