Visual assessment of soil structure as an early indicator of soil quality in response to intensive rotational grazing

Teutscherova, N[*]; Vazquez, E[†]; Baquero, D[¥]; Velasquez-Ruiz, NE[Ф]; Pulleman, M[£]; Arango, J[£].
* Czech University of Life Sciences Prague; † University of Bayreuth; [¥]Centro de negocios ganaderos, Colombia; [Ф]Never+SAS; [£]International Centre for Tropical Agriculture (CIAT)

Key words: cattle grazing; earthworms; grasslands; visual examination; management

Abstract
Grasslands can play a crucial role in mitigation of global warming by serving as carbon sink. Nevertheless, to achieve the grasslands' potential, sustainable management is of the utmost importance as it determines system's productivity and ecosystem services. Due to the increasing demand for animal products in developing countries, grazed areas increase exponentially in the tropics, mainly due to unsustainable management leading to low productivity and soil degradation. We evaluated the impact of intensive rotational grazing management (IRG) on early indicators of soil quality following land-use change based on on-farm observations of visual soil characteristics using two different widely used assessment methods: visual soil assessment-VSA and visual evaluation of soil structure-VESS. Correlation of visual methods were combined with measurements of soil macrofauna abundance and physical properties (*e.g.* bulk density, soil porosity). The IRG established in two study sites in Colombia was compared with traditional long-term continuous grazing with low stocking rate (1 LU ha^{-1}). The IRG was based on rapid (1 day) cattle grazing in paddocks with high stocking rate (180 LU ha^{-1}) followed by 60 days of recovery. In both study sites, IRG increased considerably total stocking rate to 4 LU ha^{-1} while improving grassland composition by enabling more valuable species, which contributed to soil quality and increased grassland productivity. Both VSA and VESS discriminated IRG-managed sites in less than one year after IRG adoption. Our results demonstrate that visual soil assessment is a useful mean for evaluation of soil quality and grassland productivity. Furthermore, VSA and VESS seemed to be more suitable in discriminating among management in early stages, when compared to commonly used soil physical properties, and were strongly correlated mainly to the abundance of earthworms. Furthermore, our study confirms the importance of grazing management in soil quality and ecosystem productivity/sustainability.

Introduction
To satisfy the growing demand for animal products in recent years, particularly in developing countries, large areas have been deforested and converted to pastures (Lerner et al. 2017). Consequently, over 30% of Colombia's surface (similarly to other tropical countries) is currently covered by grazed grasslands with mean animal stocking rates as low as 0.6 livestock units (LU) ha^{-1} (Murgueitio et al. 2011; Lerner et al. 2017). As further deforestation is recently no longer a socially, environmentally and economically acceptable option to increase the production, it is essential to increase the outputs per unit of land area, while simultaneously reverting soil degradation (Lerner et al. 2017).
As a promising alternative to common continuous grazing, short-duration intensive rotational grazing (IRG) across multiple paddocks has been successfully used to increase animal productivity (to >4 LU ha^{-1}) without detectable negative impact on soil quality within one year after the IRG adoption (Teutscherová et al. 2021). The IRG consists of high stocking rates within the rather small paddocks, short periods of grazing and long periods of pasture recovery (Teague et al. 2013). Besides the increased animal and pasture productivity, the most commonly discussed environmental benefits of IRG are increased soil organic carbon (SOC) content, reduced soil compaction, higher soil water retention and improved soil aggregation (Teague et al. 2013; Park et al. 2017; Waters et al. 2017; McDonald et al. 2018), and the increase of soil macrofauna (Teutscherová et al. 2021).
Nevertheless, to provide robust scientific evidence of IRG benefits is challenging due to the lack of replicated experiments, and the limited results differ greatly form the on-farm observations (Conant et al. 2017). In the Colombian Eastern Plains (Teutscherová et al. 2021), similarly to other tropical areas (Alfaro-Arguello et al. 2010; Ferguson et al. 2013), some farmers initiated to manage their farms more holistically by adopting IRG management, observing increases of both forage and animal productivity. As large areas of grazed grasslands in the tropics are located in remote areas, where soil analysis is logistically and economically unfeasible, on-farm observations and soil assessments have been gaining on importance in evaluation of the management impacts on soil quality (Guimarães et al. 2011, 2017; Emmet-Booth et al. 2016). Here we focused on variables, which can be assessed by farmers or local agronomists on field to evaluate the effect of IRG using paired farms comparisons. Visual evaluation of soil structure (VESS) and visual soil assessment (VSA) were applied and

compared with the analysis of selected soil physical properties (bulk density and soil porosity, which are often the most representative variables indicating soil compaction) and with the abundance of ecosystems engineers (earthworms, termites and ants), reported in previous studies, to evaluate its usefulness for grasping the impact of grazing management in early stages after their adoption. We hypothesize that (i) VSA and VESS will differ between IRG and traditionally-managed farms, and (ii) both visual techniques will correlate with soil macrofauna and soil physical properties.

Methods and Study Site

The study was performed at two sites, which were described previously (Teutscherová et al. 2021), both located in Colombian Eastern Plains. At each site, paired adjacent farms were selected for the comparison of IRG management with high stocking rate (>4.2 LU ha^{-1}), with traditionally managed reference farm with low (<1 LU ha^{-1}) stocking rate. The traditional management consisted of continuous grazing (Morichal site) or one week of grazing followed by two weeks of pasture recovery (Villasol site). The IRG management (on both sites) was based on short grazing period (1 day) and long pasture recovery (60 days) with high stocking rates within paddocks (>180 LU ha^{-1}). A transect was laid across each of the our farms and soil and macrofauna samples were collected along each transect at least 100 m apart. Whole four samples were collected in each of the reference farms, eight samples were taken in each IRG farm due observed higher variability.

Visual soil assessment (VSA) as described by (Shepherd 2003) was performed by scoring observations of soil texture, structure after a drop test, visible soil porosity, soil color and mottling, earthworm activity, rooting depth, surface ponding and crusting, soil erosion and surface microrelief to produce an overall score of soil condition. The structure after a drop test (drop/shatter test) was determined by dropping a block of soil (20 x 20 x 5 cm) three times from a height of one meter onto a large tray. Soil aggregates were then organized based on their size and scored 0 (degraded) to 2 (favorable conditions). The assessment of VESS followed the methodology described by (Guimarães et al. 2011). In brief, soil blocks at least 15 cm thick were extracted from the sides of the macrofauna monolith (to a 20 cm depth) with a spade and manually broken down along the natural fracture lines on top of a plastic tray. Soil layers with distinct properties were identified and their depth was measured to be scored separately. Then, scores were assigned by comparing the size and appearance of aggregates, visible soil porosity and roots, appearance of soil after break-up, and the appearance of soil aggregates (approximately 1.5 cm in diameter) of the sample with the VESS chart (Guimarães et al. 2011). Each property was scored from 1 (optimal structure) to 5 (very poor structure) separately in each soil layer. The score of the whole soil block was calculated as a weighted mean of both layers.

Data on soil macrofauna (earthworms, ants and termites, which can be easily recognized by farmers) and on soil bulk density and porosity were obtained from previously published work (Teutscherová et al. 2021). Briefly, soil macrofauna was manually extracted from 0-10 cm and 10-20 cm soil layer using soil monoliths (25 x 25 x 20 cm depth) according to Tropical Soil Biology and Fertility Institute (TSBF) method. In this study, we report the mean sum of both soil layers, thus, referring to macrofauna abundance as the number of individuals per square meter to the depth of 20 cm. Bulk density and porosity were determined using metal soil cores.

For the statistical analysis, data from both sites were combined and the differences between IRG and traditional management were assessed by linear mixed model with the grazing management (IRG and TM) as fixed factor and site as random factor. The level of significance was set at $p<0.05$. The correlation between soil macrofauna and soil properties with VESS and VSA was evaluated according to Person's correlation coefficient using SPSS 22.0.

Results

The VSA scores and VESS scores were higher and lower ($p<0.001$), respectively, in IRG-managed farms compared to traditionally-managed adjacent farms. Both VSA and VESS correlated with the abundance of earthworms (Fig. 1), while VESS was also correlated with the abundance of termites ($r=-0.603$; $p<0.001$) and soil bulk density ($r=0.735$; $p<0.001$). Strong correlation was also observed between bulk density earthworms ($r=0.665$; $p<0.001$), termites ($r=-0.457$; $p<0.01$), and total macrofauna abundance ($r=-0.451$; $p<0.05$).

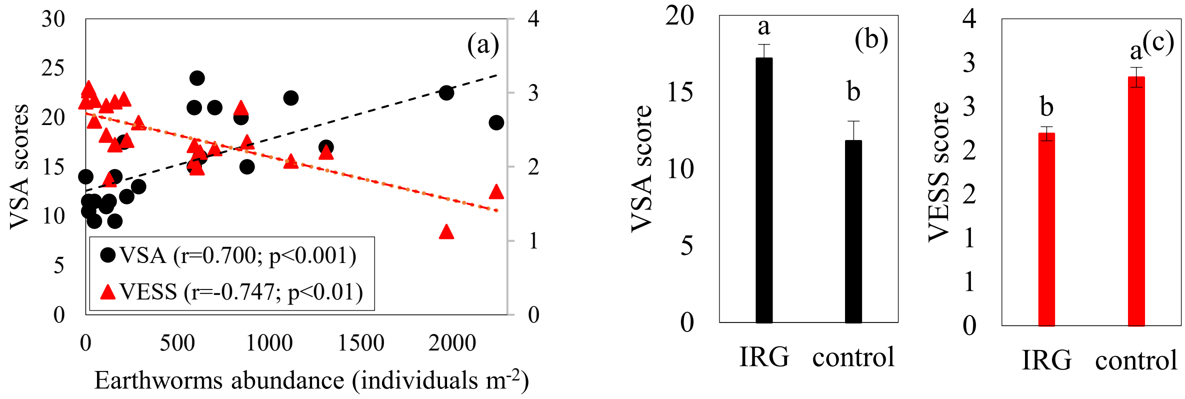

Fig.1. Pearson's correlations of earthworm abundance with visual soil assessment (VSA) and visual evaluation of soil structure (VESS) scores (a); the scores of VSA under intensive rotational grazing (IRG) and traditional grazing (control) (b); the scores of VESS under IRG and control grazing management (c).

Discussion

Both VSA and VESS distinguished clearly IRG from the traditionally-managed farms with better soil structure under IRG. While other authors have demonstrated the positive effect of grazing intensification on soil macroinvertebrates in the tropics (Decaëns et al. 2004; Webster et al. 2019), to the best of our knowledge, no studies have assessed the capacity of visual soil evaluation techniques (either VSA or VESS) to detect impacts of grazing management in such an early stage since its adoption on soil structure.

A previous study has identified a positive link between the abundance of soil macrofauna (particularly earthworms) and improved soil physical properties (Teutscherová et al. 2021), which was also confirmed by the present study, where strong correlation of earthworms abundance with both VSA and VESS was also observed, clearly indicating the crucial role of earthworms in soil structure formation, hence for soil functioning (Lavelle et al. 2006). Nevertheless, it remains unclear whether the improved structure is the result of (i) reduced compaction by the IRG, which allows for higher abundance of earthworms and forage productivity, or (ii) increased forage production translated in higher root decay and dung and urine input, which in turn promote higher abundance of soil macroinvertebrates reducing soil compaction (Decaëns et al. 2004), as discussed previously (Teutscherová et al. 2021). Similarly, the higher incidence and extension of mottles and redoximorphic colors as observed visually during VSA evaluation under IRG, may indicate lower vulnerability of IRG-managed farms to waterlogging, which may be attributed to (or be a result of) higher abundance of earthworms and higher root density.

Regardless of the causal links, IRG was associated with both higher animal productivity and better soil quality, hence confirming potential to improved forage-based agriculture in the Colombian Eastern Plains, where cattle grazing is the most common agricultural activity. Furthermore, the capacity of visual techniques of soil evaluation is of crucial importance in this remote areas, especially in the early stages after the IRG management adoption because early visible results are an additional motivation for local farmers and agronomists to adopt sustainable intensification strategies preventing degradation processes.

Acknowledgements

This work was implemented as part of the CGIAR Research Program (CRP) on Climate Change, Agriculture and Food Security (CCAFS), and the Livestock CRP which are carried out with support from CGIAR Fund Donors and through bilateral funding agreements. For details please visit https://ccafs.cgiar.org/donors. The views expressed in this document cannot be taken to reflect the official opinions of these organizations. Financial support was also obtained from Integral Grant Agency of Czech University of Life Science Prague (no. 20205003). The authors would like to acknowledge support from the UK Research and Innovation (UKRI) Global Challenges Research Fund (GCRF) GROW Colombia grant via the UK's Biotechnology and Biological Sciences Research Council (BB/P028098/1).

References

Alfaro-Arguello, R., Diemont, S.A.W., Ferguson, B.G., Martin, J.F., Nahed-Toral, J., Alvarez-Solis, D., Pinto Ruiz, R. 2010. Steps toward sustainable ranching: An emergy evaluation of conventional and holistic management in Chiapas, Mexico. *Agric. Syst.*, 103:639–646.

Conant, R.T., Cerri, C.E.P., Osborne, B.B., Paustian, K. 2017. Grassland management impacts on soil carbon stocks: A new synthesis. *A. Ecol. Appl*., 27:662–668.

Decaëns, T., Jiménez, J.J., Barros, E., Chauvel, A., Blanchart, E., Fragoso, C., Lavelle, P. 2004. Soil macrofaunal communities in permanent pastures derived from tropical forest or savanna. *Agric. Ecosyst. Environ*., 103:301–312.

Emmet-Booth, J.P., Forristal, P.D., Fenton, O., Ball, B.C., Holden, N.M. 2016. A review of visual soil evaluation techniques for soil structure. *Soil Use Manag.,* 32: 623-634.

Ferguson, B.G., Diemont, S.A.W., Alfaro-Arguello, R., Martin, J.F., Nahed-Toral, J., Alvarez-Solis, D., Pinto-Ruiz, R. 2013. Sustainability of holistic and conventional cattle ranching in the seasonally dry tropics of Chiapas, Mexico. *Agric. Syst*., 120:38–48.

Guimarães, R.M.L., Ball, B.C., Tormena, C.A. 2011. Improvements in the visual evaluation of soil structure. *Soil Use Manag*., 27: 395-403.

Guimarães, R.M.L., Neves Junior, A.F., Silva, W.G., Rogers, C.D., Ball, B.C., Montes, C.R., Pereira, B.F.F. 2017. The merits of the Visual Evaluation of Soil Structure method (VESS) for assessing soil physical quality in the remote, undeveloped regions of the Amazon basin. *Soil Tillage Res*., 173:75-82.

Lavelle, P., Decaëns, T., Aubert, M., Barot, S., Blouin, M., Bureau, F., Margerie ,P., Mora, P., Rossi, J.-P. 2006. Soil Invertebrates and Ecosystem Services. *Eur. J. Soil Biol.* 42:S3–S15.

Lerner, A.M., Zuluaga, A.F., Chará, J., Etter, A., Searchinger, T. 2017 Sustainable Cattle Ranching in Practice: Moving from Theory to Planning in Colombia's Livestock Sector. *Environ. Manage*., 60:176–184.

McDonald, S.E., Reid, N., Waters, C.M., Smith, R., Hunter, J. 2018 Improving ground cover and landscape function in a semi-arid rangeland through alternative grazing management. *Agric. Ecosyst. Environ*., 268:8–14.

Murgueitio, E., Calle, Z., Uribe, F., Calle, A., Solorio, B. 2011. Native trees and shrubs for the productive rehabilitation of tropical cattle ranching lands. *For. Ecol. Manage*., 261:1654–1663.

Park, J.Y., Ale, S., Teague, W.R., Dowhower, S.L. 2017. Simulating hydrologic responses to alternate grazing management practices at the ranch and watershed scales. *J. Soil Water Conserv*., 72:102–121.

Shepherd, T.G. 2003 Assessing soil quality using Visual Soil Assessment. In: *Tools for nutrient and pollutant management: Applications to agriculture and environmental quality*. L.D. Currie and J.A. Hanly (eds). Occasional Report no. 17. Fertilizer and Lime Research Centre, Massey University, Palmerston North, pp 153-166.

Teague, R., Provenza, F., Kreuter, U., Steffens, T., Barnes, M. 2013. Multi-paddock grazing on rangelands: Why the perceptual dichotomy between research results and rancher experience? *J. Environ. Manage*., 128:699–717.

Teutscherová, N., Vázquez, E., Sotelo, M., Villegas, D., Velasquez, N., Baquero, D., Pulleman, M. 2021. Intensive short-duration rotational grazing is associated with improved soil quality within one year after establishment in Colombia. *Appl. Soil Ecol*., 159:103835.

Waters, C.M., Orgill, S.E., Melville, G.J., Toole, I.D., Smith, W.J. 2017. Management of Grazing Intensity in the Semi-Arid Rangelands of Southern Australia: Effects on Soil and Biodiversity. *L. Degrad. Dev*., 28:1363–1375.

Webster, E., Gaudin, A.C.M., Pulleman, M., Siles, P., Fonte, S.J. 2019. Improved Pastures Support Early Indicators of Soil Restoration in Low-input Agroecosystems of Nicaragua. *Environ. Manage.,* 64:201–212.