31. Grassland diversification

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1. Description of the practice

Grassland diversification includes a set of practices such as the incorporation of legumes and other favourable forage grasses into grazed grasslands the planting of scattered trees in grassland or the rotation of crops with pasture. Species-rich grasslands are of high conservation value because of the diverse floral and faunal assemblages they support, and of the capacity to improve water and nutrient use. Besides creating shadow areas for grazing livestock, scattered trees may have local and global benefits such as the creation of microclimate, increased soil nutrient concentration and a more favourable water balance locally, increased plant species richness and habitat for animals, which will promote larger-scale ecosystem restoration. These benefits facilitate adaptive responses to climate change, particularly in modified landscapes (Manning, Gibbon and Lindenmayer, 2009). Rotating crops with pastures increases weed control and reduces greenhouse gas emissions from fields. However, as Donnison and Fraser (2016) explain, grasslands are experiencing the biggest threat to date in terms of loss of land area to other uses, including expansion of the built environment as well as from cropland, forestry and energy production (e.g. solar, biofuels).

The above-mentioned practices have two main objectives: (1) to increase the botanical diversity of species-poor grassland to restore and enhance this habitat so as to ameliorate the negative effects of isolation, fragmentation and scrub species encroachment (EC, 1992) and (2) to increase the profit-earning capacity of marginally economic or uneconomic grasslands by diversification of grass-derived products and by increasing pasture production through the incorporation of nitrogen-fixing species and perennial grassland species.

2. Range of applicability

The practice is applicable worldwide under a wide range of pedo-climatic conditions. The most suitable locations are those with low soil fertility and low/no weed burden.

3. Impacts on soil organic carbon stocks

For a given climate regime, grassland often has higher soil carbon (C) contents than other vegetation types. Therefore, a lack of interest about their use can cause serious impacts in terms of the C balance. Grassland diversification, both to restore environmental values and to enhance the economic value of the land could be a good tool to ensure soil conservation and, thereby, the value of the land as a C sink (**Table 136**). A great number of studies have demonstrated that increasing plant diversity increases soil C storage, both directly and indirectly (e.g. Chen *et al.*, 2017; Lange *et al.*, 2015, Teixeira *et al.*, 2011).

Table 136. Evolution of SOC stocks with grassland diversification

NA: Not available.

Location	Climate zone	Soil type	Baseline C stock (tC/ha)	Additional C storage (range) (tC/ha/yr)	Duration (Years)	Depth (cm)	More information	Reference
Global	Various	Various	NA	0.75	From 5 to 9	Various up to 100 cm	N=6 Introduction of legumes.	Conant, Paustian and Elliot (2001)
	Various	Various	NA	Up to 3.04	From 4 to 15		N=5 Improved grass species.	
France	Temperate	Luvisol/ Fluvisol	NA	0.24 (0.09-0.46)	From 6 to 41	0-30	Incorporation of trees (Agroforestry).	Cardinael *et al.* (2017)
Spain	Mediterranean	Cambisol, Luvisol	72.0	0.83	22	NA	Scattering trees-extensive farming.	Llorente *et al.* (2019)
Sardinia, Italy		Cambisol	42.9	1.24	37	0-20	Alternating spontaneous vegetation-hay crops.	Francaviglia *et al.* (2017)
Minnesota, United States of America	Humid Continental	Sandy	NA	0.69	12	0-100	Combination of key C4 grass-legume species on degraded soils.	Fornara and Tilman (2008)
Mato Grosso, Brazil	Tropical	Kaolinitic oxisol	NA	0.32-1.57	NA		Agrosilvopastoralism; Incorporation of trees.	Oliveira *et al.* (2018)

4. Other benefits of the practice

4.1. Improvement of soil properties

Plant interactions and feedbacks with soil biota is an important determinant of ecosystem functioning and primary productivity in terrestrial habitats. Above-ground species diversity influences below-ground diversity and regulates microbial decomposition pathways (Wagg *et al.*, 2014). Experiments across different ecosystems indicate that soil organic matter tends to decline as local species richness in grassland decreases (Cardinael *et al.*, 2017).

4.2. Minimization of threats to soil functions

Table 137. Soil threats

Soil threats	
Soil erosion	Soil cover control on soil surface runoff.
Nutrient imbalance and cycles	Species richness improves nitrogen fixation, use and cycling, allowing a better coupling of C and N cycles within vegetation, soil organic matter and soil microbial biomass.
Soil biodiversity loss	Above-ground species diversity influences below-ground diversity.
Soil compaction	Improves soil structure via a greater incorporation of SOM and by covering soil surface.
Soil water management	Control of water runoff, increasing soil water retention and infiltration rates.

4.3. Increases in production (e.g. food/fuel/feed/timber/fibre)

Diversification of grassland products, including the processing and fractionation of biomass for feed, food, energy and other non-food applications, presents a positive opportunity to improve the options for grassland users and their communities.

4.4. Mitigation of and adaptation to climate change

Long-term biodiversity restoration practices in grasslands increase soil C and therefore soil mitigation capacity. Moreover, the preservation or sowing of biodiverse pastures has proven to sequester more C with related co-benefits (Teixeira *et al.*, 2011). These greater rates of C accumulation look to be associated with reduction of ecosystem respiration, increase of soil organic matter inputs and improvement of soil structure (De Deyn *et al.,* 2011).

4.5. Socio-economic benefits

Embracing the diversification of grassland functions is in many instances an important step to ensure grassland survival and protection from the onslaught of competition for land from urbanization and from other agricultural and forestry-based land uses.

5. Potential drawbacks to the practice

5.1. Tradeoffs with other threats to soil functions

The benefits of enhancing the richness of species must be balanced with the risk of erosion during land intervention. Careful selection of plant species is important to avoid possible risks like soil desertification due to excess water extraction or unwanted pH modifications.

5.2. Increases in greenhouse gas emissions

Tillage and compaction of soil for seed incorporation could speed up organic matter mineralization with the consequent increase of soil greenhouse gas emissions. For example, Yamulki and Jarvis (2002) measured increases on N_2O, NO, CO_2 and CH_4 fluxes after tillage and compaction of grassland.

5.3. Conflict with other practice(s)

Investment in diversification of grasslands can be in competition with investments in more profitable land uses like cropland, forestry, or energy production.

5.4. Other conflicts

A conflict can arise if introduced new botanical species become weeds and they can potentially have a negative impact on biodiversity. Seeds must be carefully chosen for each particular site.

6. Recommendations before implementing the practice

Agronomy support is imperative as well as sound complementary policies and good governance. Public extension services, in collaboration with the private sector remain crucial to the success of agrarian new practices.

7. Potential barriers for adoption

Improving grassland through introduction of grass varieties has to be adopted together with adequate management practices. New grass and legume varieties, diversification technology options and agronomy support are needed.

Photo of the practice

Photo 40. Showing grass growth difference between diversified (left) vs. monocultured (right) grasslands.

Table 138. Related cases studies available in volumes 3 and 5.

Title	Region	Duration of study (Years)	Volume	Case-study No.
Mediterranean savanna-like agrosilvopastoral grassland system in Spain, Italy and Portugal	Europe	4, 22 and 37	3	17

References

Cardinael, R., Chevallier, T., Cambou, A., Beral, C., Barthès, B.G., Dupraz, C., Durand, C., Kouakoua, E. & Chenu, C. 2017. Increased soil organic carbon stocks under agroforestry: A survey of six different sites in France. *Agriculture, Ecosystems and Environment*, 236: 243–255. https://doi.org/10.1016/j.agee.2016.12.011

Chen, H., Mommer, L., Ruijven, J. van, Kroon, H. de, Fischer, C., Gessler, A., Hildebrandt, A., Scherer-Lorenzen, M., Wirth, C. & Weigelt, A. 2017. Plant species richness negatively affects root decomposition in grasslands. *Journal of Ecology*, 105(1): 209–218. https://doi.org/10.1111/1365-2745.12650

Conant, R.T., Paustian, K. & Elliot, E.T. 2001. Grassland management and conversion into grassland: Effects on soil carbon. *Ecological Applications*, 11: 343-355. https://doi.org/10.1890/1051-0761(2001)011[0343:GMACIG]2.0.CO;2

De Deyn, G.B., Shiel, R.S., Ostle, N.J., McNamara, N.P., Oakley, S., Young, I., Freeman, C., Fenner, N., Quirk, H. & Bardgett, R.D. 2011. Additional carbon sequestration benefits of grassland diversity restoration. *Journal of Applied Ecology*, 48: 600-608. https://doi.org/10.1111/j.1365-2664.2010.01925.x

Donnison, I.S. & Fraser, M.D. 2016. Diversification and use of bioenergy to maintain future grasslands. *Food and Energy security*, 5: 67-75. https://doi.org/10.1002/fes3.75

EC. 1992. The Conservation of Natural Habitats and of Wild Fauna and Flora. Council Directive 92/43/EEC. The Council of European Communities, Brussels, Belgium. https://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm

Fornara, A. & Tilman, D. 2008. Plant functional composition influences rates of soil carbon and nitrogen accumulation. *Journal of Ecology*, 96: 314-322. https://doi.org/10.1111/j.1365-2745.2007.01345.x

Francaviglia, R., Renzi, G., Ledda, L. & Benedetti, A. 2017. Organic carbon pools and soil biological fertility are affected by land use intensity in Mediterranean ecosystems of Sardinia, Italy. *Science of the Total Environment*, 599: 789-796. https://doi.org/10.1016/j.scitotenv.2017.05.021

Lange, M., Eisenhauer, N., Sierra, C.A., Bessler, H., Engels, C., Griffiths, R.I., Mellado-Vázquez, P.G., Malik, A.A., Roy, J., Scheu, S., Steinbeiss, S., Thomson, B.C., Trumbore, S.E. & Gleixner, G. 2015. Plant diversity increases soil microbial activity and soil carbon storage. *Nature Communications*, 6(1): 6707. https://doi.org/10.1038/ncomms7707

Llorente, M., Moreno, G. Pulido, M. & González-Cascón, R. 2019. *Factors determining distribution and temporal changes in soil carbon in Iberian Dehesa*. Geophysical Research Abstracts. EGU General Assembly 2019. (also available at: https://meetingorganizer.copernicus.org/EGU2019/EGU2019-1962.pdf)

Manning, A.D., Gibbon, P. & Lindenmayer, D.B. 2009. Scattered trees: a complementary strategy for facilitating adaptive responses to climate change in modified landscapes? *Journal of Applied Ecology*, 46: 915-919. https://doi.org/10.1111/j.1365-2664.2009.01657.x

Oliveira, J.D., Madari, B.E., Carvalho, M.T.D., Ramos, C. Rodrigues, A.L., Lima, M.L., Wruck F.J., Medeiros, J.C. & Oliveira, P.L. 2018. Integrated farming systems for improving soil carbon balance in the southern Amazon of Brazil. *Regional Environmental Change,* 18: 105–116. https://doi.org/10.1007/s10113-017-1146-0

Teixeira, R.F.M., Domingos, T., Costa, A.P.S.V., Oliveira, R., Farropas, L., Calouro, F., Barradas, A.M. & Carneiro, J.P.B.G. 2011. Soil organic matter dynamics in Portuguese natural and sown rainfed grasslands. *Ecological Modelling*, 222(4): 993–1001. https://doi.org/10.1016/j.ecolmodel.2010.11.013

Yamulki, S. & Jarvis, S.C. 2002. Short-term effects of tillage and compaction on nitrous oxide, nitric oxide, nitrogen dioxide, methane and carbon dioxide fluxes from grassland. *Biology and Fertility of Soils*, 36: 224-231. https://doi.org/10.1007/s00374-002-0530-0

Wagg, C., Bender, S.F., Widmer, F. & Van der Heijden, M.G.A. 2014. Soil biodiversity and soil community composition determine ecosystem multifunctionality. *Proceedings of the National Academy of Sciences of the United States of America*, 111: 5266–5270. https://doi.org/10.1073/pnas.1320054111