41. Syntropic Agriculture

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1. Description of the practice

Syntropic Agriculture (SA), also known as Successional Agroforestry21, is a set of principles and practices created by the Swiss geneticist and farmer Ernst Götsch, who has lived in Brazil since 1982. It conciliates food production and ecosystem regeneration by incorporating ecological succession and plant stratification into planning and management of croplands. As a result, layers of vegetation are harmonized with their life cycle, one after another, respecting the timeline of successional consortia: placenta (annual and biannual species), secondary (trees and shrubs of short and medium lifecycle), climax (long lifecycle), and transitional (very long lifecycle), according to Ernst Götsch's classification (Figure 14). All designs and techniques aim to optimize photosynthesis and biomass production, by placing each cultivated plant in its "just right" position in space (strata) and in time (succession).

Each consortium of each successional step is divided into vertical layers of occupancy based on plants' relative height and sunlight demands. In general, the degree of occupation in each layer follows the pattern of 20 percent of emergent species, 40 percent of canopy species, 60 percent of medium strata, 80 percent of lower layer, and 15-20 percent of ground cover species, considering overlaps between different strata (Figure 15). The constant pruning and positioning of the vegetation are key practices to guarantee enough biomass production to keep the ground covered all year, which feeds the soil′s fauna and protects it from direct rain, overheating, and erosion. It also replaces the need for herbicides, since the optimum occupation of all strata and the mulch provided by their pruning leave no niche for non-desired plants.

[21] According to ICRAF′s definition, agroforestry is a land-use system in which woody perennials are integrated with crops and/or animals, simultaneously or not (Nair, 1993). An approach based, therefore, essentially on consortia and crop rotation. Syntropic Agriculture (SA) differs from agroforestry because its main pillars are (1) succession, (2) stratification, and (3) the notion of syntropy applied to ecosystem dynamics. Although SA embraces tree-species succession in most designs, its approach can also be applied to non-forest environments.

SA is a process-based rather than an input-based approach. Organisms behave as open systems that overcome the tendency to increase entropy by converting environmental resources (food, oxygen, water) into growth, reproduction and differentiation. This capacity (that is present in biological systems) results in hierarchically broader organizational levels throughout succession, which culminates in the emergence of increasingly complex biological structures. In short, while entropy governs thermodynamic transformations that release energy at the expense of complexity, syntropy governs life, which accumulates and organizes energy, for example, in organic molecules, resulting in progressively more complex forms (Andrade, Pasini and Scarano, 2020). Life processes are cumulative; therefore, each successional step "uses" the accumulated resources of previous cycles to grow, and in turn, delivers a more complex environment to the next one. Just like in natural ecosystems, each assemblage within a successional stage is an inseparable entity of biotic and abiotic elements, arranged and distributed to favor synergistic relationships that result in higher accumulation of energy by the system, which translates into fertility for cultivated plants.

2. Range of applicability

Since 1993, Ernst Götsch's approach began to spread among Brazilian farmers mainly through practical courses and with specific channels on the internet. Estimates are that at least 5000 family farms have adopted this practice (or some aspects of it) all across the country (Andrade, 2019), under different terminologies such as Successional Agroforestry, Dynamic Agroforestry, Analog Regenerative Agroforestry, and since 2013, as Syntropic Agriculture (SA). It has also been exported to other countries in Latin America (the Plurinational State of Bolivia, Colombia, Chile, Mexico), The Caribbean (Martinique, Curacao Islands), Europe (Portugal, Spain, France, Germany, Italy, Greece), Africa (Mozambique), and Oceania (Australia) (Andrade, Pasini and Scarano, 2020).

3. Impact on soil organic carbon stocks

Given the heterogeneity of SA and its application, it remains challenging to state its overall potential to stock carbon. It is possible though to infer that highly diverse tree-based and successional designs promote carbon sequestration both aboveground (embedded in the biomass of trees) and belowground (with the increase of organic matter and biologic activity in the soil). Despite the increasing number of adopters in the past three decades, SA (or Successional Agroforestry) received little consideration from formal investigation institutes and universities in its early years. The practice has only recently attracted academic communities′ attention, given the escalation of agriculture-related environmental impacts and the general recognition that innovative approaches can also emerge from farmers′ experiences. As SA spreads to other countries, such as Germany, Spain, and Portugal, we expect to see more research relating the practice with specific environmental benefits.

4. Other benefits of the practice

4.1. Improvement of soil properties and benefits to soil threats

One of the premises of SA is the permanence of soil cover with living plants and mulch all year long. To achieve that without using external inputs, the system must produce high quantities of biomass yearly.

This practice has proven beneficial for the following reasons:

(A) It prevents humidity loss and soil erosion. It increases soil permeability and its capacity to retain water (Primavesi, 2002);
(B) It protects the soil from direct rain and sun exposure, favoring the proliferation of organisms responsible for soil structuring and humus formation;
(C) The diversity of biomass sources increases nutrient availability. A soil sample from a 12-year old system on Ernst Götsch's farm (Bahia, Brazil) contained seven times more phosphorus available than an adjacent unmanaged site (Peneireiro, 1999);
(D) The same study showed that the constant pruning and mulching increased nutrient flow when compared to a natural forest. Furthermore, both vegetation and soil macrofauna were in more advanced stages of succession when compared to a natural regeneration site of the same age;
(E) The high quantity of wood decomposition favors the proliferation of beneficial fungi, which helps create more stable forms of carbon in the soil, enhancing structure and fertility (Tugel, Lewandowski and Happe-vonArb, 2000);
(F) Multilayer vegetation works as a windbreak and prevents soil drying. Multistrata root occupation holds soil together and avoids erosion (Primavesi, 2002);
(G) Layers of vegetation mean layers of photosynthesis. Since photosynthesis is an endothermal process, the gradual difference in a layer's occupation – denser at the bottom and sparser in the upper strata – works as a heat sink. It creates a temperature gradient that helps maintain moisture in the soil (Coats, 2001);
(H) Multicrop designs based on species succession associated with a year-long soil cover also triggers the succession of soil organisms (Tugel, Lewandowski and Happe-vonArb, 2000);
(I) Since the system is mainly occupied by perennial species and the soil is constantly covered by mulch, there is no need to use herbicides;
(J) Biomass cycling combined with a multilevel root occupancy favor water infiltration and soil structure, which allows the occupation of deeper layers of soil by beneficial microorganisms;
(K) Having plants performing vegetative growth in different development stages guarantees a constant food supply via exudates, favoring beneficial soil organisms;

Table 181 shows how each of the soil properties above are related to soil threats.

Table 181. Soil properties in relation to soil threats

Soil threats	Related soil property
Soil erosion	(A), (B), (F), (I)
Nutrient imbalance and cycles	(C)
Soil salinization and alkalization	(B), (E)
Soil contamination/pollution	(I)
Soil acidification	(B), (E)
Soil biodiversity loss	(B), (E), (H), (J), (K)
Soil sealing	NA
Soil compaction	(A), (J)
Soil water management	(A), (G)

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

One advantage of successional models is their potential to generate multiple harvests as the system evolves, which improve farmer's resilience to market fluctuations, environmental variables, and self-sufficiency (Miccolis *et al.*, 2016). This can be a key factor when establishing tree-based plantations (fruits, timber, oil), providing the farmer with short-term yields until the main crops enter production. An experiment of successional agroforestry associated with palm-oil plantation in the Brazilian Amazon has shown that small hold farmers can benefit from adding short-cycle crops in the first years, before the palm trees start producing (Kato *et al.*, 2011). The same experiment also included slow-growing timber and nut trees to become the main products after the decline of palm-oil yields (25 years).

In Brazilian semiarid zones, it was a common practice even for small hold farmers to grow castor-oil plant (*Ricinus communis*) in monoculture designs. When the project "Policultura no Semi-Árido" (Del Arco Sanches, 2009) introduced the successional agroforestry approach in the 1990's, 750 families started combining castor-oil with other plants, both with shorter cycles (beans, corn, watermelon, sesame) and longer cycles (fruit trees, prickly pear and timber). In addition to diversified harvests, some farmers also saw an increase in castor-oil production. Previously, the average in the region was 800 kg/ha of castor seeds. Within the project, some farmers harvested as much as 2 100 kg/ha, with the benefit of inheriting a fruit and timber plantation after the castor-oil yield, instead of empty and exposed soil.

Hoffmann (2013) compared economic data from eight agroforestry systems in Brazil and found that the average yields projected for 25 years in two SA sites were 16 and 21 t/ha/yr. Other agroforestry systems produced between 2 and 13 t/ha/yr. Successional systems were an advantageous alternative in southeast of Brazil when compared to conventional agriculture. Rebeschini (2008), by collecting data from four family farms that implemented succession-based agroforestry designs at Ribeira valley, showed that these systems produce more and for longer in less space. They concluded that in order to achieve the same economic productivity, the conventional grains (soybean and corn) and milk production would require at least 10 times more land.

4.3. Mitigation of and adaptation to climate change

Multi-layer successional tree-based designs aim to mimic natural forest dynamics and therefore deliver all environmental services associated with that (see also 4.1). The higher the metabolism and photosynthetic rate, the greater the carbon absorption by plants (Ramachandran Nair *et al.,* 2010; Miccolis *et al.*, 2016). Therefore, there is great potential for carbon sequestration in SA practices, although we are unaware of studies in this respect. Similarly, SA has a large potential for climate-change adaptation. Since it both mimics successional processes and fosters ecosystem regeneration, it seems it can be framed as a type of ecosystem-based adaptation to climate change (EbA). The United Nations Convention of Biological Diversity (CBD, 2009) broadly defines this adaptation practice as "the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change". It refers to the use of natural capital by people to adapt to climate change impacts, which can also have multiple co-benefits for mitigation, protection of livelihoods and poverty alleviation (Munang *et al.*, 2013). It has also been argued that practices that fit within the EbA framework can be important in the transition to sustainability (Scarano, 2017). In this sense, SA as a practice can simultaneously address multiple Sustainable Development Goals of the 2030 Agenda, such as poverty reduction (SDG1), ending hunger and malnutrition (2), promoting health and wellbeing (3), climate action (13), and land biodiversity conservation and restoration (15).

4.4. Socio-economic benefits

A set of interviews reported in Andrade, 2019 allows an understanding of the socio-economic implications derived from the adoption of SA's framework. Different profiles of practitioners mentioned: (1) new kinds of engagement in innovative ways of commerce and service exchange, favoring community rather than individualistic values; (2) establishment of a horizontal network of mutual support, where practitioners can exchange knowledge and resources; (3) changed perception of natural processes related to farming, which creates another level of attachment and intimacy with land, now seen as an organism; (4) changes towards healthier eating habits of the family, based on their own production; and (5) "joy" and "pride", in the personal dimension, as a result of implementing the new practices and seeing the result in coping with extreme weather conditions such as hurricanes and drought.

Luz (2015) assessed the economic viability of a successional system in central Brazil focused on horticulture for later fruit and coffee production. Payback happened after 1.1 month. In one year, benefits surpassed costs in 82 percent.

5. Potential drawbacks to the practice

5.1. Conflict with other practice(s)

SA relies on ecological succession and stratification as a replacement for fertilizers and defensives. Therefore, it conflicts with all practices that interrupt succession, being it conventional or organic.

5.2. Decreases in production (e.g. food/fuel/feed/timber/fibre)

Despite several studies show that successional tree-based designs do not impact production (Luz, 2015; Hoffmann, 2013; Rebeschini, 2008; Schneider *et al.,* 2017; Schulz, Becker and Götsch, 1994), it is challenging to scale it up because of the constrictions listed next, in item 7.

6. Recommendations before implementing the practice

An ideal syntropic design includes a stratified consortium of plants for each successional step. Therefore, farmers should identify the species suitable to fill all gaps in space and time based on their behavior and life cycle. All consortia - be it placenta, secondary, or climax - must have species occupying most of their layers: lower, medium, canopy, and emergent, in a distribution ratio described in Figure 15. The strata are related to plants' sunlight demand and their shade tolerance, not their height. For example, corn is emergent from placenta II consortia, eucalypt is emergent from secondary I consortia, and cork oak tree is also emergent but from climax consortia. Ideally, all species from all strata and succession steps are planted together to cause minimum soil disturbance and enhance synergistic relationships, and each consortium is succeeded by the next according to their growing speed. For example, a placenta consortium of arugula or black beans (lower-medium layer), lettuce (medium), broccoli (canopy), and crotalaria (emergent) can be succeeded by a longer cycle consortium of watermelon (lower), carrot (medium), tomato (canopy) and corn or sunflower (emergent). It is still possible to go further in the placenta stage with ginger or pineapple (lower), garlic, taro, green pepper, (medium), manioc (canopy), castor-oil, and/or papaya (emergent). After the placenta stage, which can take up to 24 months, the secondary plants take over the area, following the same stratification pattern, for example, rosemary (lower), pomegranate (medium), avocado (canopy), and eucalypt (emergent), and so on until reaching the next longer lifecycle consortium. In some cases, technical pruning might be necessary to synchronize plant's growth and production. In each step, there should be plants to produce biomass enough to keep the soil covered all year through pruning and mulching. In deciduous and semideciduous environments, it is possible to include placenta species every year as the trees drop their leaves. In evergreen forests, the repetition of placenta cycles (annuals and biannuals) is possible (though not always recommended) by promoting severe pruning in the trees.

7. Potential barriers for adoption

Despite the environmental, social and economic advantages described above, farmers face several challenges in adopting SA practices (Table 182).

Since there is no machinery suitable for managing stratified and biodiverse designs, most of SA operations are still performed manually. This increases labor costs and turns it inviable for large-scale enterprises.

SA does not have a toolkit easily applicable to all conditions. Diagnosing and decision-making processes require transdisciplinary education articulated with SA's particularities. The required knowledge, that is regarding the management of multiple species, goes against the trend towards specialization normally imposed by the market and educational institutions.

The establishment of a biodiverse system requires specific planning and logistics. Farmers need forestry and agricultural materials, of all successional stages at their disposal at the moment of implementation.

Table 182. Barriers to adoption

Barrier	YES/NO	
Cultural	Yes	Diversified forest-based systems are culturally detached from current monoculture paradigm (Andrade, 2019; Pasini, 2017).
Social	No	In the household level, the adoption of innovative agricultural practices is perceived as a risk (Valdivia, Barbieri and Gold, 2012). Transitions in the scale of a territory require governance with participatory approaches.
Economic	Yes	Difficulty to access credit and subsidies. High cost to implement a new system (Hoffmann, 2013).
Institutional	Yes	In general, Institutions responsible for rural extension, technical and theoretical education, and related to access to credit are still not prepared to assist farmers in complex agroforestry designs (Rebeschini, 2008).
Legal (Right to soil)	Yes	Long-term cultivation designs can be difficult when farmers do not have safe and legal access to the land.
Knowledge	Yes	Lack of educational material and accessible training facilities.
Technology	Yes	Scaling up is difficult because specialized machinery is not available in the market (Andrade, 2019).

Representations of the practice

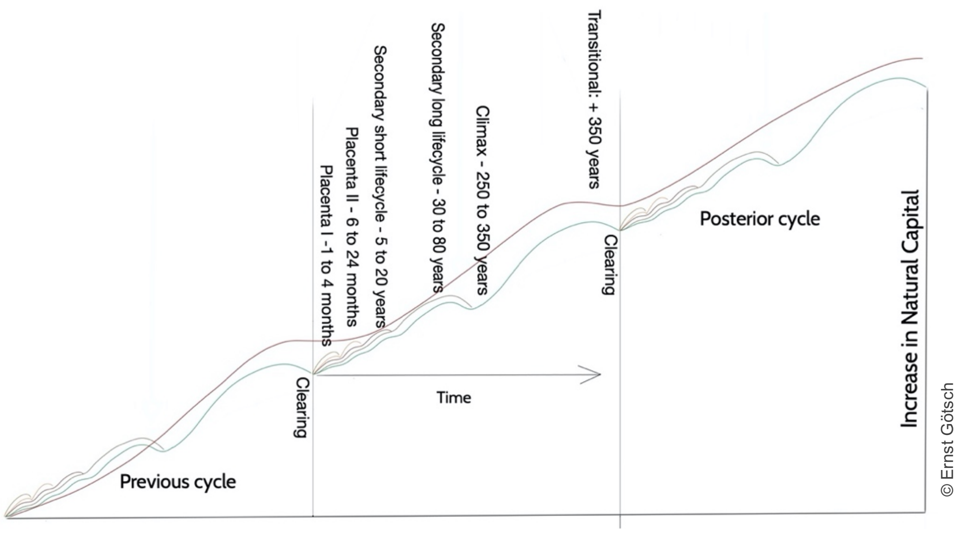

Figure 14. Succession scheme proposed by Ernst Götsch that illustrates the intervals of successional consortia occupation (placenta, secondary, climax and transitional) between disturbances (clearings) under natural conditions

In managed systems, it's possible to accelerate succession through pruning and removal of aged vegetation

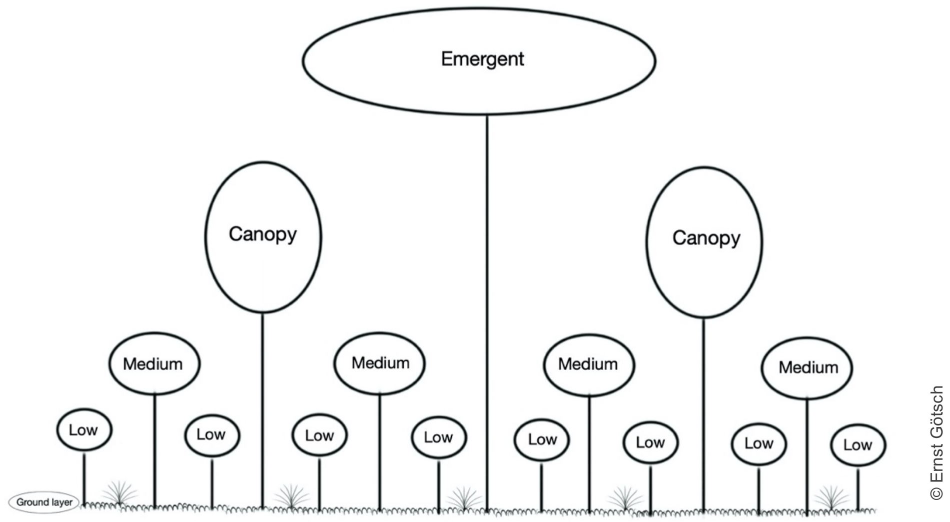

Figure 15. Strata occupation proposed by Ernst Götsch with approximately 20 percent cover of emergent layer, 40 percent canopy, 60 percent medium, 80 percent low and 15-20 percent ground layer

Such distribution increases the photosynthesis rate per area and facilitates cooling-down thermodynamic processes and water retention

Photo 55. Stratified system at Fazenda da Toca, Brazil. Eucalypts, banana, citrus and grass.

Photo 56. Scheme for grains/vegetables cultivation between tree-lines.

The area in the photo (CEPEAS, Brazil, 2019) aims to grow soybeans in single lines amongst grass stripes (Panicum maximum), which maintain the soil covered all year and provide mulch for soybeans. The trees are heavily pruned before seeding the grains, mimicking the dynamics of a forest clearing to allow the addition of placenta species.

Table 183. Related cases studies available in volumes 3 and 5

Title	Region	Duration of study (Years)	Volume	Case-study No.
Syntropic Agriculture in a Mediterranean Context	Europe	2	3	23

References

Andrade, D.V.P. 2019. *Agricultura, meio ambiente e sociedade: um estudo sobre a adotabilidade da agricultura sintrópica*. Rio de Janeiro, Brazil. Núcleo em Ecologia em Desenvolvimento Sócio-Ambiental, Universidade Federal do Rio de Janeiro. (PhD Thesis)

Andrade, D., Pasini, F. & Scarano, F.R. 2020. Syntropy and innovation in agriculture. *Current Opinion in Environmental Sustainability*, 45: 20–24. https://doi.org/10.1016/j.cosust.2020.08.003

Convention of Biological Diversity (CBD). 2009. Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change. CBD Technical Series 41, Montreal, Canada. (also available at: https://www.cbd.int/doc/publications/cbd-ts-41-en.pdf)

Coats, C. 2001. *Living Energies*. Dublin, Gateway Press.

Del Arco Sanches, C. 2009. Projeto Policultura no Semi-Árido. *Revista Brasileira de Agroecologia*, 4(2): 2348-2352.

FAO. 2017. Agroforestry for landscape restoration. [online]. [Cited 15 June 2020]. http://www.fao.org/3/b-i7374e.pdf

Hoffmann, M. 2013. *Sistemas Agroflorestais para Agricultura Familiar: análise econômica*. Departamento Agronegócios, Universidade de Brasília (MSc. Dissertation).

Kato, O.R., Vasconcelos, S.S., Capela, C.J., Miranda, I.S., Lemos, W.P, Maues, M.M., Azevedo, R., Castellani, D.C. & Thom, G. 2011. Projeto Dendê em sistemas agroflorestais na agricultura familiar. *In* Porro, R., Kanashiro, M., Ferreira, M.S.G., Sampaio, L.S., Sousa, G.F. (Eds.) *Congresso Brasileiro de Sistemas Agroflorestais*. Anais. Pará, Brasil, Embrapa Amazônia oriental, UFRA, CEPLAC, EMATER, ICRAF.

Luz, I.S.B. 2015. *Sistemas agroflorestais sucessionais: viabilidade financeira para a agricultura familiar*. Departamento de Engenharia Florestal, Universidade de Brasília. (MSc. Dissertation).

Miccolis, A., Peneireiro, F.M., Marques, H.R., Vieira, D.L.M., Arco-Verde, M.F., Hoffman, M.R., Rehder, T. & Pereira, A.V.B.. 2016. *Restauração ecológica com sistemas agroflorestais: como conciliar conservação com produção. Opções para Cerrado e Caatinga*. Instituto Sociedade, População e Natureza – ISPN/Centro Internacional de Pesquisa Agroflorestal. Brasília, Brasil. ICRAF.

Munang, R., Thiaw, I., Alverson, K., Mumba, M., Liu, J. & Rivington, M. 2013. Climate change and Ecosystem-based Adaptation: a new pragmatic approach to buffering climate change impacts. *Current Opinion in Environmental Sustainability*, 5(1): 67–71.

Nair, P.K.R. 1993. *An introduction to agroforestry*. Kluwer Academic Publishv cers. Dordrecht, Netherlands.

Pasini, F.S. 2017. *A Agricultura Sintrópica de Ernst Götsch: história, fundamentos e seu nicho no universo da Agricultura Sustentável*. Núcleo em Ecologia em Desenvolvimento Sócio-Ambiental, Universidade Federal do Rio de Janeiro. (MSc. Dissertation).

Peneireiro, F.M. 1999. *Sistemas Agroflorestais Dirigidos Pela Sucessão Natural: Um Estudo De Caso*. Escola superior de Agricultura, Area Ciências Florestais, Universidade de São Paulo. (MSc. Dissertation).

Primavesi, A. 2002. *Manejo ecológico do solo: a agricultura em regiões tropicais*. São Paulo, Nobel.

Ramachandran Nair, P.K., Nair, V., Kumar, B.M. & Showalter, J.M. 2010. Carbon sequestration in agroforestry systems. *In* Sparks, D.L. (Ed.) *Advances in Agronomy*. San Diego, USA, Academic Press of Elsevier, 108: 237-307.

Rebeschini, A.P. 2008. *Construção participativa de Indicadores de Sustentabilidade em Sistemas Agroflorestais no Vale do Ribeira*. Registro, Brasil, Porter.

Sanches, C.D.A. 2011. *A contribuição da sistematização de experiências para o fortalecimento do campo agroecológico e da agricultura familiar no Brasil*. Departamento Ciências Agrárias, Universidade Federal de São Carlos. (MSc. Dissertation).

Scarano, F.R. 2017. Ecosystem-based adaptation to climate change: concept, scalability and a role for conservation science. *Perspectives in Ecology and Conservation*, 15(2): 65-73.

Schneider, M., Andres, C., Trujillo, G., Alcon, F., Amurrio, P., Perez, E. & Milz, J. 2017. Cocoa and total system yields of organic and conventional agroforestry vs. monoculture systems in a long-term field trial in Bolivia. *Experimental Agriculture*, 53(3): 351–374.

Schulz, B., Becker, B. & Götsch, E. 1994. Indigenous knowledge in a "modern" sustainable agroforestry system - a case study from eastern Brazil. *Agroforestry Systems*, 25(1): 59–69.

Tugel, A.J., Lewandowski, A.M. & Happe-vonArb, D. 2000. *Soil Biology Primer*. Iowa, USA, Ankeny.

Valdivia, C., Barbieri, C. & Gold, M.A. 2012. Between Forestry and Farming: policy and environmental implications of the barriers to agroforestry adoption. *Canadian Journal of Agricultural Economics/Revue Canadienne d'Agroeconomie*, 60(2) : 155–175. https://doi.org/10.1111/j.1744-7976.2012.01248.x