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RECONNECTING NATURE AND AGRICULTURAL PRODUCTION: MIXED CROPPING SYSTEMS AS A WAY FORWARD SUSTAINABLE INTENSIFICATION

Paulo César de Faccio Carvalho,
Universidade Federal do Rio Grande do Sul, Departamento de Plantas Forrageiras e Agrometeorologia, Porto Alegre, Rio Grande do Sul, Brazil,
https://orcid.org/0000-0002-7020-3001
Corresponding author: paulocfc@ufrgs.br

Edicarlos Damacena de Souza,
Universidade Federal de Rondonópolis, Instituto de Ciências Agrárias e Tecnológicas, Rondonópolis, Mato Grosso, Brazil,
https://orcid.org/0000-0003-3719-8615

Luiz Gustavo de Oliveira Denardin,
Universidade Federal de Rondonópolis, Instituto de Ciências Agrárias e Tecnológicas, Rondonópolis, Mato Grosso, Brazil,
https://orcid.org/0000-0002-0751-056X

Taise Robinson Kunrath,
Aliança SIPA, Porto Alegre, Rio Grande do Sul, Brazil,
https://orcid.org/0000-0002-9874-0511

Débora Rubin Machado,
Universidade Federal do Rio Grande do Sul, Departamento de Plantas Forrageiras e Agrometeorologia, Porto Alegre, Rio Grande do Sul, Brazil,
https://orcid.org/0000-0003-1555-5562

William de Souza Filho,
Universidade Federal do Rio Grande do Sul, Departamento de Plantas Forrageiras e Agrometeorologia, Porto Alegre, Rio Grande do Sul, Brazil,
https://orcid.org/0000-0002-2677-6873

Amanda Posselt Martins,
Universidade Federal do Rio Grande do Sul, Departamento de Solos, Porto Alegre, Rio Grande do Sul, Brazil,
https://orcid.org/0000-0001-9180-2508

Tales Tiecher,
Universidade Federal do Rio Grande do Sul, Departamento de Solos, Porto Alegre, Rio Grande do Sul, Brazil,
https://orcid.org/0000-0001-5612-2849

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Abstract

In the last decades, population growth worldwide boosts agricultural demand for food production. This huge driver rendered global food production more and more specialized, so agricultural landscapes became uniform and monotonic. The loss of diversity is a strong evidence of how modern agricultural landscapes have been disconnecting from nature. Evidence of environmental side-effects from this pathway are abundant in literature. Now, society is pressing towards changing practices aiming for healthy diets and sustainable food production systems. This raises the question: how to reconnect nature and agriculture in the context of future food production? In this review we propose a reconnection process based on the principles of ecological intensification or sustainable intensification. The integrated crop-livestock systems (ICLS) are the most consolidated technological pathway to reconcile crop production with natural processes. These systems are diverse and can partially mimic natural ecosystems exploring the synergies of natural biological processes, while achieving high levels of food production. ICLS promote soil improvements and mitigate greenhouse gas (GHG) emissions, reducing the agricultural share of global warming and climate change. Besides, these systems are more efficient in the use of nutrients and can optimize the use of other inputs such as pesticides. We present evidence of soil health and biogeochemical cycle restoration in addition to system stability improvement, and assume those symptoms as evidence of mixing crops and livestock fostering reconnection with natural processes.

Key words

environment, integrated crop-livestock system, landscape, mixed crop-livestock, sustainability.

THE CONTEXT

Agricultural production covers 38% of the land surface worldwide (FOLEY et al., 2011). Considering only grain production, 62% of the 1.53 billion ha are destined for human consumption, 35% for animal consumption, and 3% for biofuels. Between 2000 and 2010, annual global grain production increased 2%, while the annual expansion of harvesting areas was 0.8% (CARLSON et al., 2017). The gaining rates of yield in grain production have been decreasing with the expansion of agricultural areas (FOLEY et al., 2011). Conversely, there is a population growth on the planet boosting agricultural demand and a better distribution of agricultural products. This new century of human adventure on Earth arises the technical and social debate about the feasibility of feeding the 9.7 billion people projected to inhabit our planet by 2050 (FAO, 2017).

In this sense, the United Nations raised the responsibility of the agricultural sector to produce food and nourish people (WHO, 2017). The contingent of malnourished people reaches approximately 2.5 billion. The complexity of this issue, therefore, becomes not only the amount of food needed in 2050, estimated in the doubling of meat production and a 70% increase in grain production, but also its form of production (sustainable production systems) and the consequences on collective health (diverse and healthy foods), claiming for more spatial and temporal diversified way of food production.

The Brazilian Ministry of Agriculture (MAPA, 2017) led a recent study that projected, for the next ten years, an additional 51 million tons of grain considering the 2016/17 harvest as a baseline when Brazil harvested 237 million tons. In the livestock sector, the projected increase is even noteworthy, at 7.5 million tons of meat, 28% higher than the 2016/2017 harvest. The sector is recognized as a “buffer of financial crises” in Brazil and demonstrates that it can meet part of the global need to increase food production. There are projections that Brazil will be responsible for 1/3 of this increase in food production in the world, which places Brazilian agriculture in a remarkable position as a global player. However, what options are there to conciliate increments in food production without expanding land and at the same time minimizing the environmental impact?

The agricultural sector should be recognized by society as capital for the human population. At the same time that society relies on the agricultural sector for its persistence, it has been disconnecting from rurality. It should be recognized that the environmental impacts of contemporary agricultural production models are in evidence and society requires paths to replace the specialized systems that have a high environmental footprint. Food production development has led to creating production systems where the commitment to controlling pests and diseases has become our (human) entire responsibility (i.e, basic ecological contract, *sensu* O'REAGAIN and SCHWARTZ, 1995), as plant breeding emphasizes primary production and commercial plant species lose their ability to persist in uncontrolled environments. Thus, agricultural systems, increasingly specialized and uniform, become disconnected from nature, which is complex and diverse.

Agricultural ecosystems disconnected from natural ecosystems

In the very early days of agriculture, production was closely connected to nature (GORDON et al., 2017). The use of animal's waste for fertilization purposes and crop rotations were "technologies" that, although rudimentary, were process-based. As agricultural systems developed, with the commercialization of commodities between countries and particularly after the Green Revolution, the intensification process associated with specialization has been pushing agriculture away from nature. Contemporary agriculture has been changing towards input-based technologies not guided by natural processes and ecosystem services that naturally occurs with food production (Figure 1). The natural process of food production was transformed into industrial process, which has been an important part of this detachment process, as food production is no longer part of people's lives.

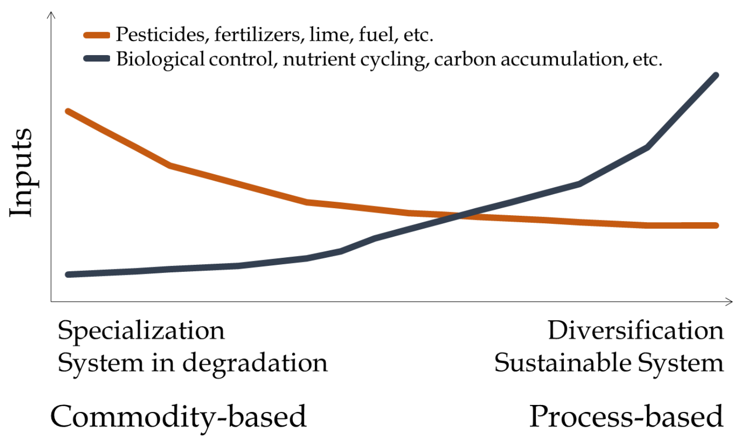

Figure 1. Relationship between the inputs and type of food production system. In this scheme, sustainable food production systems are conceptualized as those in which the dependence on material inputs (in red) is lower, with a preponderance of the use of management inputs (in green). Source: Adapted from Stinner, B.R. & House, G.J. 1987.

According to Lemaire et al. (2015), agricultural intensification combined with specialization caused strong negative impacts on the environment, including the contamination of the soil, waterbodies and groundwater, the emission of GHG, the erosion and soil dysfunction, the loss of biodiversity, etc. This is a global perspective, and there are huge differences between production system variants in the world, but the basic environmental footprint process is unambiguous. There is a need to increase food production, and an expectation that the impact on the environment will increase in the same proportion. This paradox between production and preservation demands an important debate on current production systems.

Global warming is one of the main environmental impacts caused by the increase in GHG emissions. The average intensity of carbon monoxide (CO_2) emission (emission per unit of food produced) from agricultural systems on a global scale is 0.16 Mg CO_2eq./Mkcal (CARLSON et al., 2017). Excluding emissions from the livestock sector, as well as those associated with changes in land use, emissions from grain production areas reach 4.5% of total anthropogenic emissions. But there are crops such as rice, whose emission reaches 0.58 Mg CO_2eq./Mkcal. Although rice fills 15% of the total calories supplied by global grain production, its methane emissions contribute 48% for the total emissions from cultivated croplands (CARLSON et al., 2017). In this context, the logic of sustainable intensification is transversal to all production systems. The emission of GHG is just one important and current parameter, but several others describe the environmental liability of current agricultural models.

How to reconnect nature and crop production in the context of future food production?

The reconnection of agriculture to nature evokes the prevailing understanding of protecting nature from the impacts of specialized agriculture, exploring opportunities for conciliating approaches. The services that nature provides can benefit agriculture and vice versa. We assume that this reconnection process is based on the principles of ecological intensification or sustainable intensification (*sensu* GARNETT et al., 2013), whose pillar is the intensification of the functionalities of natural processes that agricultural ecosystems can offer (DORÉ et al., 2011), without detriment to increases in productivity (Figure 2). The reconnection assumes that we can, for example, mimic biological processes that replace chemical inputs, reducing economic and environmental costs. In this context, the design of agricultural systems (MORAINE et al., 2014), which seek synergies of natural processes, would be the application of the concept at a practical level.

To develop this rationale, it is worth noting that there is a dispute about assuming agricultural ecosystems that mimic natural processes are necessarily superior (DENISON and MACGUIRE, 2015) (Figure 2). Besides, it should be considered that there are few examples of this rationale reported in the literature (DORÉ et al., 2011). As an example of controversy, wild ancestors of crops such as rice and wheat apparently grew in a spatial arrangement similar to that of monocultures, which evokes current models of modern agriculture. Nevertheless, the pillars of conservative agriculture (GILLER et al., 2015) have a reasonable consensus, as do the pillars of diversification and agroecology, when grounded in science (RYSCHAWY et al., 2017). Therefore, reconciling agriculture with natural processes is robustly justified. So, how to move forward within this concept? We believe that integrated systems are the most consolidated example of this possibility. Although there is an important debate on ways for food production systems at a global level (eg, FOLEY et al., 2011), this manuscript will focus on an option endorsed by FAO (2010): the Integrated Crop Livestock Systems (ICLS).

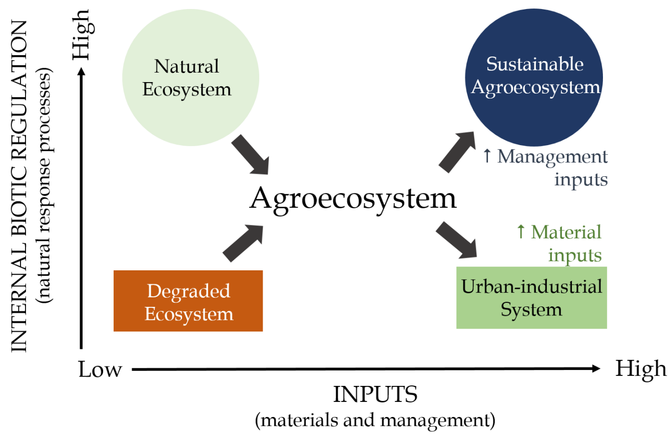

Figure 2. Relationship between material and management inputs and internal biotic regulation, in order to achieve a sustainable agroecosystem. Source: Adapted from House & Brust (1989).

The ICLS have been presented as a possible conciliatory solution with reduced environmental footprint (LEMAIRE et al., 2015). They are systems that mimic natural ecosystems (BONAUDO et al., 2014) and designed to exploit synergies of natural biological processes (ANGHINONI et al., 2013) achieving high levels of production (ALVES et al., 2017), at the same time in which they leverage various parameters that are indicators of soil quality (MARTINS et al., 2015) and system stability (DE ALBUQUERQUE NUNES et al., 2021). Boosted nutrient cycling is one of the most recognized characteristics of these systems (CARVALHO et al., 2010), as well as their diversity (BONAUDO et al., 2014). According to Moraine et al. (2016), these processes can not only be designed at the farm level, but also at the territory level, where their benefits would reach a new level of spatial impact.

Table 1 illustrates parameters where integrated systems would contribute to the recovery of services provided by natural ecosystems. The degree of mimicry of natural ICLS processes depends on the spatiotemporal scale of interactions between the system components (ANGHINONI et al., 2013). For example, the tree component is present in less than 20% of the ICLS in use in Brazil. Only 9% of the ICLS have the higher diversity level, such as grain-producing plants, pastures with grazing animals and trees (Crop-Livestock-Forest Integration net). The lower the diversity of the system and the greater the physical distance for direct interaction between components, decreases the potential for the occurrence of emergent properties (CARVALHO et al., 2018b).

Table 1. Impact of agricultural systems model on some natural processes and ecosystem services.

Natural Processes and Ecosystem Services	Production systems	
	Intensive and Specialized	Mixed and Integrated
Food production	++	++
Carbon sequestration	-+	++
Pollination	-	+
Nutrient cycling	-+	+
Water quality	-+	+
Biodiversity (specific diversity)	-	+
Biodiversity (functional diversity)	-	++

The symbols - and + are used as qualitative indicators of negative and positive trend, respectively.

Evidence of reconnection at the agro-ecosystem level

One of the main environmental liabilities today is global warming, directly related to GHG emissions in nature. The agricultural and forestry sectors are responsible for almost a third of GHG emissions (TUBIELLO et al., 2014). In this context, livestock production has suffered severe criticism due to enteric fermentation and deposition of the waste left by ruminants in pastures (GREGORICH et al., 2005). Beauchemin et al. (2010) evaluated the life cycle with beef cattle and identified that enteric CH_4 emissions represent up to 63% of global warming potential (GWP) emissions.

However, according to Buller et al. (2015), the adoption of ICLS can promote soil improvements and mitigate GHG emissions, reducing its impact on global warming and climate change. Scientific advances (SAVIAN et al., 2014; 2018) have identified efficient alternatives for reducing CH_4 emissions per animal through a grazing management strategy based on the ingestive behavior of the animal. This concept of grazing management places animals as protagonists of pasture management and reconnects grazing animals to its natural forage resource (see CARVALHO, 2013), thus reducing the stress during the feeding process (ZUBIETA et al., 2021). Besides, these results corroborate the importance of proper pasture planning in ICLS, as grazing management influences GHG emissions (DE SOUZA FILHO et al., 2019).

GWP is considered the net carbon (C) emission. In addition to CH_4 emissions, nitrous oxide (N_2O) emissions and the soil organic C balance are considered. Soil ecosystem can act as a source or drain of atmospheric C. Agricultural soils in Brazil have shown a predominance (80% of the balance) of organic C sequestration in conservation production systems (PIVA et al., 2012; NICOLOSO et al., 2008). Considering the adoption of no-till management system, the simple conversion of systems with conventional soil tillage to no-till system can results in sequestration of 0.48 Mg C/ha/year in the Brazilian subtropical region (BAYER et al., 2006). This is the reason why ICLS must be designed under no-tillage practices.

The accumulation of C in the soil caused by the absence of tillage is closely related to soil aggregation (SIX et al., 1999), which also tends to increase with the adoption of ICLS (SOUZA et al., 2010). Furthermore, the increase in the net primary production of crops and their contribution to biomass are fundamental factors for the increase in C sequestration in soils. In this sense, the ability to increase the input of residues above and below the ground surface using pastures and/or trees can be a strategy to sequester atmospheric CO_2 (SALTON et al., 2011). The adoption of ICLS in agricultural areas cultivated with crop succession showed evidence that this system has the potential to sequester C, with accumulation rates that can reach

2.58 Mg ha/ year (CARVALHO et al., 2010).

The accumulation of C due to grazing is another positive aspect of using ICLS. Grazing, despite reducing the instantaneous shoot residue at crop seeding, favors greater root growth and may benefit the contribution of C in the soil profile (SOUZA et al., 2008; LÓPES-MÁRSICO et al., 2015). In this context, stocking rate is a determining factor in the accumulation of C in ICLS. Moderate grazing intensities have greater potential to accumulate C in the soil, due to the high amount of residues and manure brought to the surface and also because of the rate of pasture renewal and root development is favored by moderate grazing (REEDER & SCHUMAN, 2002; CARVALHO et al., 2010; SALTON et al., 2011).

The addition of the tree component can further contribute to the reconnection with nature. Conceição et al. (2017) observed that a ICLS with trees promoted greater accumulations of C when compared to crops (10.4%), in a short-term experiment. Dieckow et al. (2020) found C-CO_2 mitigation potential in ICLS with crop, livestock and trees, when compared to crop area. In this system, the inclusion of trees provided an emission reduction of approximately 0.14 Mg C-CO_2/ha/year (DIECKOW et al., 2020). However, long-term experiments are still needed to confirm the effect of trees into the system and its effects on soil C.

The reconnection assumes that we can reconcile intensive food production with a reduction in environmental impact. The ICLS can increase both individual crop production and overall system production, reducing environmental risks and impacts (CARVALHO et al., 2018a). According to Moraes et al. (2014) and Carvalho et al. (2018a), the grain yield of annual crops cultivated in succession or rotation with pastures is superior when compared to ungrazed areas.

In crops, whose perception by society is of high environmental liability, such as rice, there are also solutions. As in rainfed crops, changing cropping systems (e.g. minimum tillage and no-till) provides increases in organic C stocks (BAYER et al., 2015; DENARDIN et al., 2019; NASCIMENTO et al., 2009). In systems where there is crop diversification/rotation, including pastures in integrated systems, there is a reduction in the environmental impact at the level of the agricultural system. Rotation with pastures and the effect of grazing provide new routes and nutrient flow rates in production systems (CARVALHO et al., 2010).

One of the aspects that most value and justify the use of ICLS is, precisely, their efficiency in the use of nutrients supplied through fertilizers and limestone. According to Farias et al. (2020), an ICLS arrangement with soybean cultivation in summer and winter pastures is, on average, 16% more efficient in the use of nitrogen and phosphate fertilizers and 32% more efficient in the use of potassium fertilizer, compared to a specialized system that contains only cover crops in winter. Likewise, the use efficiency of nutrients such as nitrogen (N), phosphorus (P) and potassium (K) is superior in livestock production systems (DENARDIN et al., 2020), in addition to improving the soil biological attributes (MARTINS et al., 2017) and reducing the incidence of weeds. The higher nutrient use efficiency of ICLS also decreases the soil acidification rate (MARTINS et al., 2014).

In addition to fertilizers, ICLS can optimize the use of other inputs. Due to changes in the spatial distribution of resources over time, ICLS can alter communities of natural enemies. On a small scale, grazing produces micro-habitats through actions such as trampling (HOPKINS & HOLZ, 2006) or the deposition of manure (ANGHINONI et al., 2013), which serve as secondary habitats. The introduction of a pasture area and the fraction it represents within the production system positively impacts natural pest control, resulting in less use of pesticides and benefiting other ecosystem services, such as pollination (MONTOYA et al., 2020; PERROT; et al., 2021).

The diversification of systems not only creates a greater capacity to recover from stresses such as outbreaks of pests, diseases and weeds (MARTINS et al., 2015), but makes them more resistant when compared to specialized systems. Despite showing different results in relation to the pasture management strategy, according to Szymczak et al. (2020), systems with greater efficiency in the use of available resources reduce climate impacts and increase overall resilience, also providing opportunities for greater economic security.

The design and planning of crops and pastures are crucial for achieving these positive results. Species must be strategically designed for their characteristics and functions within the system, maximizing and optimizing synergy such as the availability of nitrogen from a leguminous plant to a non-legume plant. The combinations that occur through the spatio-temporal arrangements in ICLS, therefore, make these models an alternative to intensify food production in a sustainable way, providing, at different scales, the reconnection of agricultural landscapes with the principles of natural ecosystem functioning (GABA et al., 2015).

CONCLUDING REMARKS

Integrated crop-livestock systems are presented as a way of reconnecting agriculture with nature, as integrated systems have, at their origin, the pillar of mimicking nature (soil-crop-tree-herbivores component). Agricultural landscapes with high environmental liabilities have much to gain in diversifying production, resilience and public image from this reconnection. However, it must be recognized that management complexity is higher, with a reduction in the current control we exercise via inputs. Nature is complex. Complexity generates misunderstanding and insecurity, whose reaction is simplification and control (contemporary agriculture). Would we be prepared to reverse the meaning of our interventions and get back to living with landscape complexity? Possibly not. Unless we do this gradually, with intelligence and strategy, reconnecting modern agriculture and natural processes, without harming production and productivity, reconciling wealth generation and sustainability in the same production and business model. In this regard, it cannot be overstated that the ICLS also represents the possibility of greater economic return from agricultural operations. Here is a viable path for the future of food production.

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