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EVOLUTION OF INTEGRATED CROP-LIVESTOCK AND CROP-LIVESTOCK-FORESTRY SYSTEMS IN BRAZIL

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ABSTRACT

The use of integrated systems in Brazil started in the beginning of 20th Century. Since then, with the evolution of researches focused on the soil-plant-animal-forest interactions, several integrated systems have been shaped in association to farmers. The main benefits provided by the synergies among crops and pastures are: increase animal productivity by restoring pasture yields, increase crop productivities by improvements in the soil's physical, chemical and biological properties and the interruption of biotic cycles of weeds, pests and diseases. The main positive impacts on the environment are related to soil and water conservation, increases in soil organic carbon and land-saving effect. From an economic standpoint, mixed systems allow a more rational use of inputs, improvements in cash flow and reduction of the economic risks. The greater nutrients cycling from forages associated to more efficient use of fertilizers by crops saves fertilizers and reduce the production costs. Integrated crop-livestock (ICL) and crop-livestock-forestry systems (ICLF) might be considered as a key strategy to promote sustainable intensification in agriculture.

Key words: sustainable intensification; soil conservation; land-saving; Brazilian Cerrado

INTRODUCTION

The conversion of monocultures (the dominant practice) to polycultures should be understood as a gradual process of transformation to a more complex productive model. This complexity results from several positive and negative interactions between the integrated agricultural system's components (annual crops, pastures and trees). The increasing interest in crop, livestock forest integration is based on the potential benefits that result from synergies between the systems. Some examples of these effects are improvements in soil physical, chemical and biological properties; greater infiltration levels, greater soil water stocking levels as well as improved carbon sequestration resulting from increased soil organic matter; soil erosion decreases as well as less soil nutrient losses resulting from greater plant coverage levels and improved soil structures resulting from productive pastures; greater fertilizer use efficiency resulting from greater nutrients cycling by the system's perennial components (forages and trees); greenhouse gas emissions mitigation as well as other results.

In this context, integrated crop, livestock forest systems (ICLF), in its various modalities, is considered a key strategy to maximize the use of natural resources, by combining increased productivity with environmental conservation of already deforested land use in Brazil. Crop, livestock, forest integration is a production system that integrates, in consortium, rotation or succession, different agricultural, livestock and forest productive systems, in the same area, in such a way that there exist synergies between the components (the total is greater than the sum of the parts). Nowadays, the total area cultivated with integrated systems in Brazil is estimated at 15 million hectares (REDE ILPF, 2021).

The beginning of the researche in integrated systems: the Brazilian Cerrado perspective

Crop-livestock integration (ICL) has been used since 17th century in Europe to increase agricultural production. However, most likely, the intensive use of fertilizers and mechanization reduced the need for integration (LEMAIRE et al., 2014). In Brazil, the use of integrated crop-livestock production systems started by influence of European immigrants, when they adapted this concept to subtropical and tropical conditions. At the beginning of the 20th Century, in Rio Grande do Sul state, the integration started with cattle grazing the stubble of lowland irrigated rice. This integrated system model has been used until these days. Since the 1970s, other crop-livestock models have been developed in the northern region of the state, integrating soybean and maize crops with winter pastures for grazing beef and later with dairy cattle. In the 1990s, the first research on silvopastoral and agrosilvopastoral integration started, expanding knowledge, and developing technologies focused on the management of soil-plant-animal-forest interactions (RIO GRANDE DO SUL, 2017).

At Embrapa, since its inception, research has been carried out to evaluate production systems of annual crops such as soybeans, corn and rice in rotation with pastures. Embrapa Cerrados, in its beginning, had already consolidated in its research philosophy the need to develop "alternative agricultural production systems, which mitigate risks and maximize results through a continuous activity able to use (all year) the resources of land, capital and, mainly, labor, with man as the ultimate concern". Since then, Embrapa has included in its "research, for food and fiber production, the entire agro-silvo-pastoral-socio-economic spectrum" (EMBRAPA, 1978).

The consortium of forage grasses with grain crops, a common practice in crop-livestock integration, was first adopted in Cerrado for establishing pastures at the beginning of agricultural development of the region (Table 1). The intercropping of upland rice with forage grasses was one of the agricultural practices adopted by ranchers for the establishment of pastures (EMBRAPA 1978). They also seeded forage grasses in succession to upland rice crop with or without fertilization. In more fertile soils, *Panicum maximum* cv. Colonião was simultaneous cropped with maize (MACEDO; ZIMMER, 1993). After the establishment, the pastures were usually overgrazed and consequently the degradation process started. The areas located in more fertile soils close to roads and warehouses started to grow annual soybean crops in the summer, and nothing was planted in the autumn-winter (dry period). At that time, the practices of crop rotation or the maize crop in offseason was not usual (MACEDO, 2009). The plows and harrows were used for soil preparation. This system accelerated the occurrence of pests, diseases, and soil degradation. In order to restore the productivity of these pastures implanted through rice-pasture integration, the upland rice crop was, again, the pioneer in the recovery of degraded pastures in the Cerrado. However, this type of production system was not named "Crop-Livestock Integration". The terms "sequence of crops or crop-pasture rotation" were used.

Table 1. Timeline of cropping systems in a 4 years long experiment at Embrapa Cerrados

System/Year	Year 1	Year 2	Year 3	Year 4
S1	Pasture	Pasture	Pasture	Pasture
S2	Rice + Pasture	Pasture	Pasture	Pasture
S3	Rice	Rice	Rice + Pasture	Pasture
S4	Soybean	Soybean	Soybean	Rice

Source: Annual Technical Report of the Cerrado Agricultural Research Center: 1976-1977. Embrapa (1978).

In the 1980s, the practice most used by ranchers to recover degraded pastures was only plowing, which actually provided positive effects only in the short term with a subsequent and rapid decrease in the pastures yields (VILELA et al. 1989). As a result, in 1988 a study was conducted at Embrapa Cerrados whose objectives were to evaluate the effects and final costs of different consortium strategies of grain crops with forage for recovering degraded pasture of *Brachiaria decumbens* (CARVALHO et al., 1990). The main results found in this work were that the use of plowing, by itself, did not provide effects on pasture recovery. However, this practice associated to the application of limestone and corrective fertilization was feasible, from a technical point of view. Among the crops, corn presented the highest grain production, due to its greater capacity to compete with forage in the initial development phase.

In the same period, Embrapa Arroz e Feijão also started studies on the renewal of pastures with the rice, corn or sorghum intercropped with *Brachiaria brizantha* cv. Marandu. Parallel to these studies and following the strategy recommended by this Embrapa unit, validation of the pasture renewal system through the rice consortium with *B. brizantha* was implemented at Fazenda Barreirão, in Piracanjuba, state of Goiás. In honor of this farm, the system was named the Barreirão System (KLUTHCOUSKI et al., 1991). Due to the success of this recovery / renewal system for degraded pastures, the states of Mato Grosso, Minas Gerais and Goiás adopted the Barreirão System as an official government program (YOKOYAMA; STONE, 2003).

The deficit of forage in the off-season ("dry season") and the production of straw in quantity and quality for No-Tillage were the main drivers for the development of another crop-livestock integration system, named Santa Fé. The Santa Fé System is another Embrapa Technology honoring a farm, located in Santa Helena de Goiás, GO. (KLUTHCOUSKI et al., 2000). This system recommends the intercropping of grains (corn and sorghum) with *Brachiaria* genus forages. However, due to problems of forage competition with soybeans and difficulties in harvesting, this crop was not included in the Santa Fé system. Since then, the oversowing of *Brachiaria* seeds in soybeans has been considered one of the alternatives to overcome these problems. The consortium of forage grasses with annual crops has become an usual practice to anticipate the establishment of pasture in rotation with grain crops in ICL systems. These days, the main ICL alternatives are: sowing forage grasses (*Brachiaria sp., Panicum maximum*) between the lines of the soybean crop (KLUTHCOUSKI et al. 2000; Machado, 2017); and oversowing of forage grasses at the end of the soybean cycle (KORNELIUS et al., 1987). The oversowing of these forages in the corn crop (stages V2 to V4 and R4 to R5) has also been successfully adopted by farmers.

The Barreirão and Santa Fé systems attracted the attention of technicians, researchers and research and teaching institutions. Since then, numerous researches were developed on the ICL theme, focusing mainly on the synergism of the system's components (crop and livestock). The São Mateus System innovates in the strategy of recovering degraded pastures in sandy soils through crop-livestock integration, focusing on the chemical, physical and biological correction of the soil (Salton et. al., 2013). Initially, the chemical correction of the soil is carried out and a temporary pasture of *Brachiaria brizantha* is implanted aiming at improvements in soil's physical and biological traits (due to the development of the forage roots) and straw production for soil no-till of soybean crop. The accumulated forage mass might also be used for grazing throughout 6 to 9 months and, in this case, the meat production can partially or fully offsets the initial costs. At the beginning of the rains, the pasture is desiccated with herbicide and, 20 days later, soybean is sown.

The Santa Terezinha farm, in Uberlândia, MG, has practiced, in sandy soils, the crop-livestock integration since 1984 (Table 2). In early 1978 beef cattle ranching was the only activity in the farm. From 1984 on, grain crops were grown in rotation with pastures in order to recover degraded pastures. The main rotation system consisted of conventional soil preparation to crop soybeans during the first two years, followed by the establishing the forage grass intercropped with maize in the third year.

Table 2. Evolution of crop-pasture rotation and pasture stocking rate at Santa Terezinha farm*, Uberlândia, MG.

Year	Area (%)			Heard	Stocking rate[2]
	Degraded pasture	Crops	Recovered pasture	(head)	(head/ha)
1983	100[1]	0	0	1,094	1.1
1988	29	42	29	821	1.4
1992	0	59	41	1,150	2.8
1996	0	64	36	1,200	3.2
2003	0	30	70	1,800	2.6

[1]The initial grazing area equal to 1,000 ha. [2]Estimated stocking rate for the rainy season, during the dry season the animals also occupy the crop areas to use the corn and soybean remains. [*]In the farm, the soil Neossolo Quartzarênico (Areia Quartzosa) predominates. Adapted from Vilela et al. (2008).

In the early 1990s, due to the reduction of soil organic matter contents (convetional tilling) associated to the need to simplify soil preparation and planting operations, the no-till system started to be used in the farm. The Santa Terezinha (Uberlândia, MG state) and Cabeceiras (Maracaju, MS state) farms were the first to adopt the ICL system in the Cerrado, contemplating crop-pasture rotation in time and space.

In the Santa Brígida system (OLIVEIRA et al., 2010) the forage legumes (pigeon pea) were incorporated into the *Brachiaria* maize consortium, another evolution in ICL systems. This system aims to produce forage with greater nutritional value and also to increase the nitrogen supply in the soil through the biological fixation of legumes, which potentially reduce the need for nitrogen fertilizers in the next crops.

Currently in the Cerrado there are several crop-livestock integration systems, modulated according to the profile and objectives of the farm and to the regional and farm peculiarities, such as: climate and soil conditions, infrastructure, producer experience and available technology. In this region, three types of crop-livestock integration stand out: a) livestock farms in which the introduction of grain crops (rice, corn, sorghum, soy) in pasture areas aims to recover pasture productivity at lower costs (amortization of recovery costs through the sale of grains); b) farms specialized in grain crops that adopt forage grasses to improve the soil cover for the no-tillage system and, in the off-season, they can use the forage for cattle feeding ("off-season cattle"); and c) farms that systematically adopt pasture and crop rotation to intensify land use and benefit from the synergism between the two activities (VILELA et al., 2011).

In 2017, the amount of roundwood extracted for industry and fuel from native forests in Brazil was 40.7 million m^3 and of planted forests was 226.6 million m^3 (SFB, 2019). Nowadays, the forests planted area for commercial purposes in Brazil is around 10 million hectares (1.17% of the Brazilian territory) (IBGE, 2019). By 2030, the estimated world consumption of logs will be 2.4 billion m^3, which means an increase of approximately 45% in relation to consumption in 2005 (FAO, 2009). Therefore, the major question is not whether there will be wood in the future, but where it will come from, who will produce it and how it will be produced?

Given this scenario, the crop-livestock-forestry integration systems become a viable alternative for the recovery of low productive or degraded areas. The tree component is an advancement in crop-livestock integration, and it takes place in the initial phase of implementation of the system, usually with agriculture (PULROLNIK et al. 2019).

The modal ICL system in the Cerrado region: the off-season cattle model

In an analogy to the second cropping period (planting maize just after the soybean harvesting), this double cropping system with cattle has been named "off-season cattle" or "off-season pasture". The “Off-season Cattle” model refers to cattle feeding (breeding, raising and fattening) by taking advantage of the forages accumulated from the consortium with maize or soybean after harvesting (Vilela et. al. 2018). The main "Off-season cattle" alternatives used by producers can be seen in Figure 1. The choice of one these alternatives depend on the operational characteristics of the farm such as infrastructure, fences, waterworks, etc. and climatic conditions which are favorable to maize, sorghum and soybean crops.

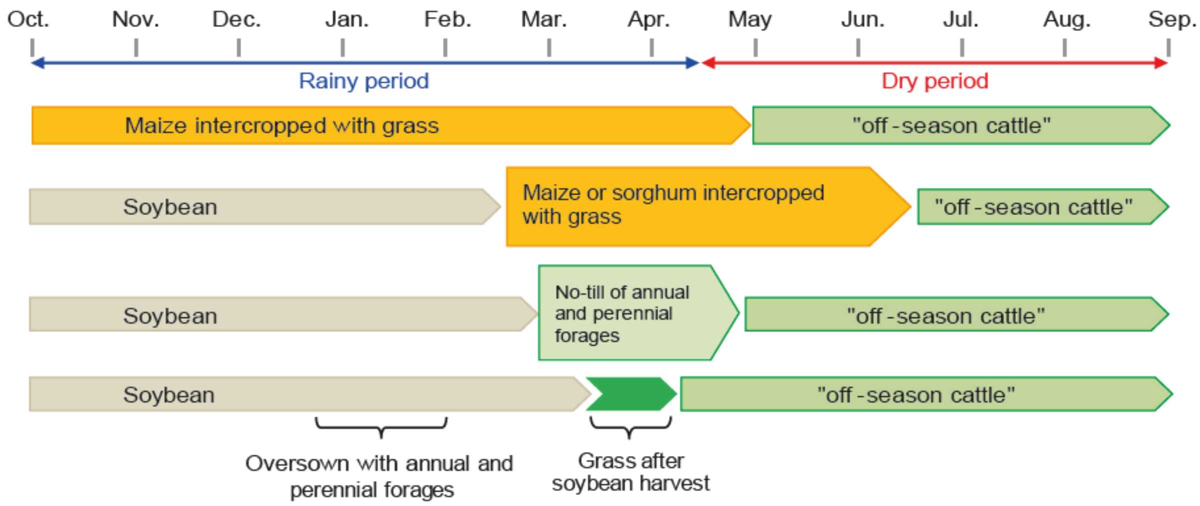

Figure 1. Potential arrangements of integrated crop-livestock in the “off-season cattle” model in different regions of the Cerrado.

This system has increased in Cerrado region because of benefits of pastures, as cover crop, on soybean productivity (up to 780 kg/ha more) in succession and also because the possibility to produce up to 6.9 @ of beef carcass in the fallow. Taking advantage of this some crop farmers have started to raise cattle because of the extra income provided by livestock in the off-season. This is another ICL case of land use diversification and intensification. Currently, the land occupied with this ICL system in the Cerrado region is estimated at 3 million hectares (EMBRAPA, 2020).

Potential benefits of ICLF systems

In well-managed systems in Brazil, positive impacts of integrated crop-livestock systems include: a) increases by 15 to 20% in soil organic matter in comparison to organic matter levels of native Cerrado; b) increases by 90% in phosphorous use efficiency, in the long term, in comparison to that verified in soybean-corn rotation; c) productivity gains of soybeans by 10 to 15% when in succession to fertilized and higher productivity pastures; d) average increases in animal productivity in the fattening stage by about 4 times (600 kg of liveweight/hectare/year in relation to the breeding-fattening stage of tradition livestock (120-150 kg of live weight hectare/year; e) animal productivity average increases in the breeding stage by about three times (300 kg of weaned calves/hectare/year in comparison to traditional livestock (85-110 kg of weaned calves/hectare/year.

In environmental terms, there are medium and long-term benefits of pastures on grain crops, among others, due to positive impacts on conservation of natural resources and to improvements in soil quality observed during the pasture phase. Therefore, soil and water conservation tend to benefit from crop-pasture integration, since water and soil losses are substantially lower than those verified in conventional planting crop cultivation systems (soil plowing) and no till planting; therefore, leading to greater water table recharge. Gains in productivity and efficiency provided by integrated systems also positively impact the use of natural resources, by reducing pressure to clear new areas of native vegetation and minimizing competition for land use (land-saving effect). Because of the numerous benefits provided by forages (grasses and legumes), these should be also be considered as key components in the development of new plant and livestock systems.

CONCLUSIONS AND PERSPECTIVES

Research results in integrated crop, livestock, and forest systems throughout Brazil allow us to conclude that crop and pasture rotation in grain production systems is an effective solution to improve soil chemical, physical and biological qualities. Such externalities occur as a result of increases in organic matter and improvements in soil structure. Verified synergies between crops and pastures are responsible for grain and meat productivity gains taking place in these mixed systems.

In livestock production, integrated crop-livestock systems are an interesting alternative that enables correction of soil fertility in Brazil. The positive effect that pastures have on subsequent grain crops can also be directly observed by higher grain productivity levels, in particular when pastures fertilization takes place in the livestock phase.

From an economic standpoint, increases in crop and pasture productivity should be considered as well as more rational use of inputs, machinery and labor, improvements in cash flow and increases in liquidity. As a result of the greater diversification of activities in rural properties, it is possible to reduce the risks that the business faces. For example, without irrigation it is possible to obtain up to four harvests per year: soybeans and short cycle corn planted together with forages and pastures during the dry season – straw for soil coverage in no till. The possibility of having a smaller demand for use of inputs such as fungicides, herbicides and insecticides in integrated crop-livestock systems brings short-term economic benefits that are easily estimated. Similarly, nutrients cycling by forages and the greater efficiency in soil nutrients use by grain crops in integrated crop-livestock systems, in comparison to that of single crops, generates savings in fertilizer use and, as a result, leads to reductions in production costs.

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