International Journal of Agriculture and Environmental Research

ISSN: 2455-6939

Volume:02, Issue:06

WHY SHOULD FARMERS IN BRAZIL CHANGE TO INTEGRATED AGRICULTURAL PRODUCTION SYSTEMS ?

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ABSTRACT

Increasing demand for food relies on sustainable agriculture practices to feed the worldwide population. Brazil, as a key producer of agricultural commodities, plays an important role in overcoming environmental challenges and promoting sustainability. In this context, integrated agricultural production systems (IAPS) rise as an alternative to increase agricultural efficiency due to its potential benefits such as soil fertility, higher productivity, lower use of agrochemicals, interruption of pest and disease cycles as well as income diversification. The main goal stands for strategically changing land use by integrating sustainable production of agricultural, livestock and forestry activities in the same area, through intercropping, succession or rotation, by seeking the synergistic effects between each production system component. Despite current efforts from the Brazilian Government to boost IAPS adoption, those systems have not yet been adopted in a large scale. Therefore, this study aims to identify potential synergy effects, which are more likely to be explored by Brazilian farmers. Subsequently, this paper provides insights for farmers' decision making and comprehension about the interaction of IAPS components.

Keywords: Integrated systems, Land-use change, Synergy effects, Crop-livestock-forestry

1. INTRODUCTION

The Brazilian agricultural sector has propped up the nation amongst the ten worldwide economies (FAO & OECD, 2015). Ongoing investments in technology stimulated agricultural production over 76 million hectares of arable land, boosting production over the last 30 years (Rada & Valdes, 2012). Agricultural commodities summed up 36% of the total exports, strengthening the importance of Brazil towards the international market (FAO & OECD, 2015).

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According to FAO & OECD (2015) the agricultural frontier expansion in the central-west and northern regions is key for production of commodities for international markets, such as grains, sugar, beef and tropical fruits. In this context, the State of Mato Grosso is the biggest producer of grains and holds the largest cattle herd in Brazil (CONAB, 2016). For the harvest year of 2015/2016, the state of Mato Grosso produced 24.42% of total Brazilian agricultural commodities, 24% of maize and 28% of soy (CONAB, 2016).

Intensifying monoculture of grains and livestock under plow-based agriculture in the Cerrado and Southern Amazon triggered massive environmental degradation. Despite high levels of deforestation (FAO & OECD, 2015), the lack of conservation practices deal with erosion, loss of soil nutrients, range degradations (Macedo, 2009), higher incidence of pests (Balbino et al. , 2011), as well as high emissions of carbon dioxide (Sawyer, 2009).

Subsequently, no-tillage system and integrated agricultural production systems (IAPS) emerged as alternative production systems thought to ease environmental challenges, increase yield and, maintain Brazil's top rank internationally, by promoting long term sustainable agriculture (Macedo, 2009).

In this context, IAPS can be defined as a wide set of sustainable systems promoting the combination of agricultural activities that enable complex interactions among soil-plant-animal-and atmosphere. The system supports husbandry and agricultural production in the same productive space (Anghinoni et al., 2013). The Brazilian scientific community perceives IAPS as part of conservation agriculture that along with no-till systems and crop rotation result in a series of environmental and economic benefits (Anghinoni et al., 2013).

Although IAPS are currently acknowledged as innovation, Roman scripts dated from the century I a. C. documented the use of integrated techniques to grow fruits and timber (Balbino et al., 2011). In the tropics, prior to European colonization, indigenous communities applied techniques of cultivating different crops altogether. European immigrants, in turn, cultivated different species adapted accordingly to tropical and subtropical characteristics. For instance, in the state of Rio Grande do Sul, in southern region of Brazil, different models of IAPS have been used for decades (Balbino et al., 2012).

However, during the second half of the twentieth century, the Green Revolution changed the agricultural production system in Brazil. The goal was to increase food supply by investing in large-scale agriculture and intensifying production into mono cropping models. This system was consequently criticized for triggering environmental and economic impacts and due to the increasing aim for sustainable agriculture.

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Brazil hosts several types of IAPS (Ministério da Agricultura, 2008) to produce fruits and vegetables (Fachinello, 2009) and even aquaculture (Marchezan et al., 2016). Nevertheless, models of integration of crop-livestock-forestry have been the target of investments to produce beef and cash crops such as soybeans, cotton, maize, eucalyptus and rice (Anghinoni et al., 2013).

Integrated crop-livestock (iCL) and integrated crop-livestock-forestry (iCLF) systems were included in the national Low Carbon Emission Agricultural Plan (ABC plan). The ABC plan aims to reduce carbon emissions in the agricultural sector by offering credit lines to stimulate low carbon agricultural practices such as no-till agriculture, range recovering and, IS (Carvalho et al., 2014).

Although there is historical evidence of the economic and environmental benefits of IAPS, it is still a challenge to stimulate an increasing adoption of IAPS in Brazil. This is especially due to the asymmetry of information about these systems, bureaucracy to access agricultural loans (Gil et al., 2015) and also lack of scientific studies over the economic and environmental gains generated by IAPS (Cassol Flores, 2004). Additionally, it is costly and time-consuming to run experiments and computing results, insofar as research needs long term investments to provide reliable outcomes from IAPS (Macedo, 2009). The present work, therefore, aims at providing qualitative and quantitative evidence of why Brazilian producers should adopt integrated models such as crop-livestock (iCL), integrated crop-livestock forestry (iCLF), integrated crop-forestry (iCF) and integrated livestock-forestry (iLF).

2. INTEGRATED AGRICULTURAL PRODUCTION SYSTEMS IN BRAZIL

The increasing demand for agricultural goods relies on sustainable agriculture practices to feed the worldwide population (Carvalho et al., 2014). This way, IAPS rise as an alternative to ease environmental problems and increase agricultural efficiency (Carvalho et al., 2014; Gonçalves & Franquini, 2007; Macedo, 2009). It is because they are part of conservation agriculture (Balbino et al., 2012; Fernando et al., 2011) that, in turn, follows five premises:

1. "Improving efficiency in the use of resources is crucial to sustainable agriculture".
2. "Sustainability requires direct action to conserve, protect and enhance natural resources".
3 "Agriculture that fails to protect and improve rural livelihoods, equity and social well-being is unsustainable".
4. "Enhanced resilience of people, communities and ecosystems is key to sustainable agriculture".
5. "Sustainable food and agriculture requires responsible and effective governance

ISSN: 2455-6939

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mechanisms".
(Balbino et al., 2012; Campbell, 2004).

According to Balbino et al. (2012), integration of crop-livestock-forestry elements, in their diverse set of arrangements, is defined as the diversification, rotation and combination of agricultural activities in a common productive space. The elements become part of one single system that, due to synergy, improves production of all parts. The main goal stands for changing land use structure by integrating productive components which will maximize positive effects on the environment, increase productivity and recover natural resources in degraded areas (Balbino et al., 2012).

The integration incorporate several placement models (Gil et al, 2015) that are related in a matter of time or space. For the time integration design, agricultural activities rotate in the same productive space over the year, producing, in turn, a single output. On the other hand, the spatial integration enables the simultaneous combination of different production activities in the same space. To exemplify, Figure 1 depicts an example of integration in time of iCL in which the productive space is used by livestock in the first harvest year, followed by crop in the second year. The figure also shows the integration in space of iCF, in which forestry and livestock activities interact at the time and space.

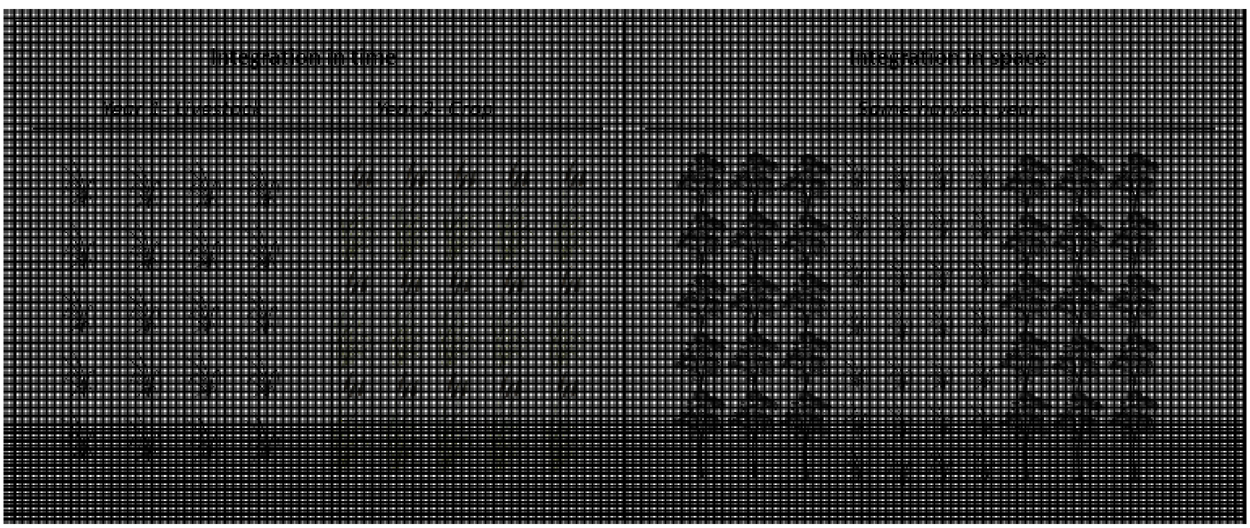

Figure 1: Exemplification of integration in time of iCL systems and integration in space of iCF system. Source (formulated by the authors).

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The integration of cash crops such as soybean, maize, cotton, beef and eucalyptus as well as non-timber products originates four predominant models of IAPS in Brazil: iCL, iFL, iCF, iCLF (Balbino et al., 2012; Gil et al., 2015).

1. Integrated Crop Livestock Systems (iCL):

The system aims at integrating different species of annual or perennial crops and grass to produce grains, animal feed and animals. Figure 2 exemplifies an iCL model in which crop and grass species rotate within four plots. Every harvest year a single plot produces a different product, either grain or grass for cattle ranching.

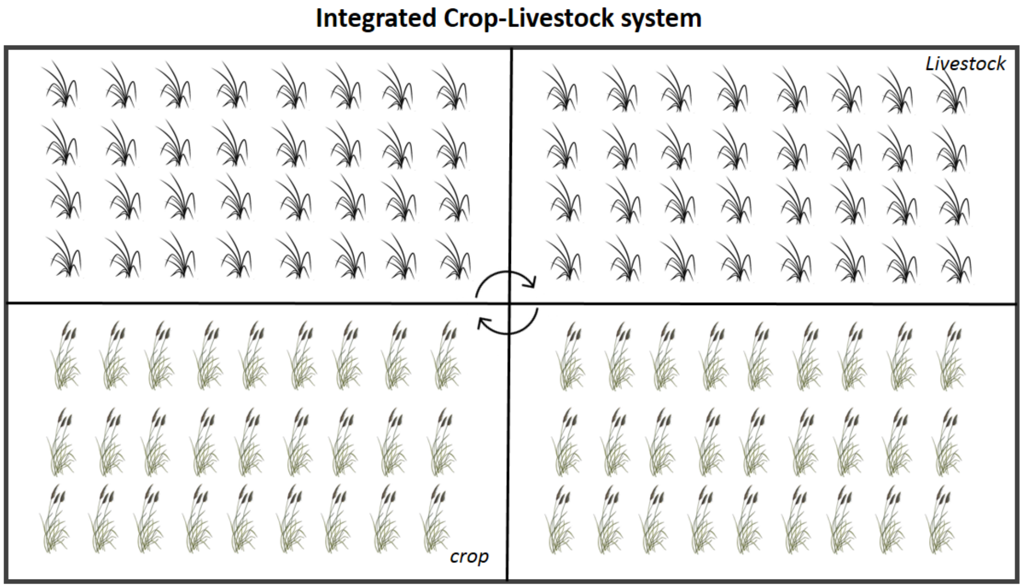

Figure 2: iCL system rotating in four plots per harvest year.

Source: formulated by the authors.

2. Integrated Forestry - Livestock systems (iFL):

The system integrates forestry and grass species to produce timber and/or non-timber products, as well as animal feed and animal products. Figure 3 depicts integration in space of grass and forestry products, enabling pastures between forestry rows.

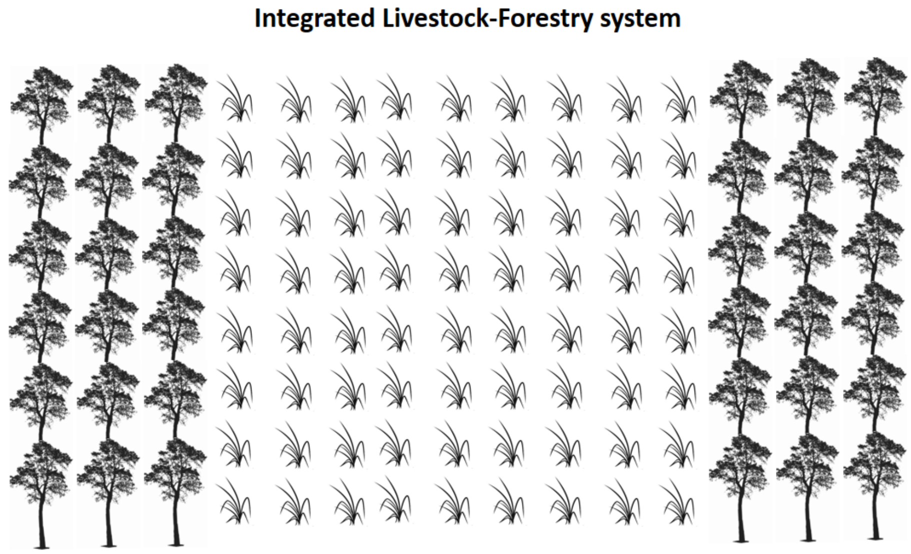

Figure 3: iFL system. Source (formulated by the authors).

3. Integrated Crop-Forestry systems (iCF)

The system integrates forestry and crop species to produce both timber and/or non-timber products and grains. Figure 4 illustrates an arrangement for iCF system. The model is similar to the one presented previously, however the aim is producing grains instead of fodder.

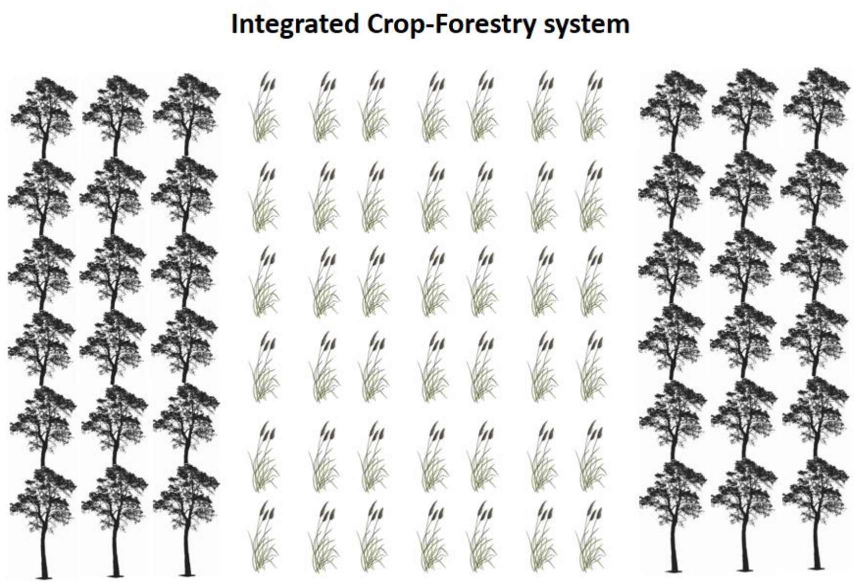

Figure 4: iCF system. Source (formulated by the authors).

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4. Integrated Crop-Livestock-Forestry systems (iCLF)

The system integrates forestry, crop and grass species to produce timber and/or non-timber products, grains, animal feed and animals. Among all models above, the iCLF system presents the highest level of complexity for combining three different activities. Figure 5 provides an example of iCLF design in which crops and livestock are integrated in time and forestry integrated in space with both of them. In case crops and grasses are placed together, production may be jeopardized for possible cattle ranching in cropping areas. To avoid this competition, crop and livestock rotate over time in an area of forestry.

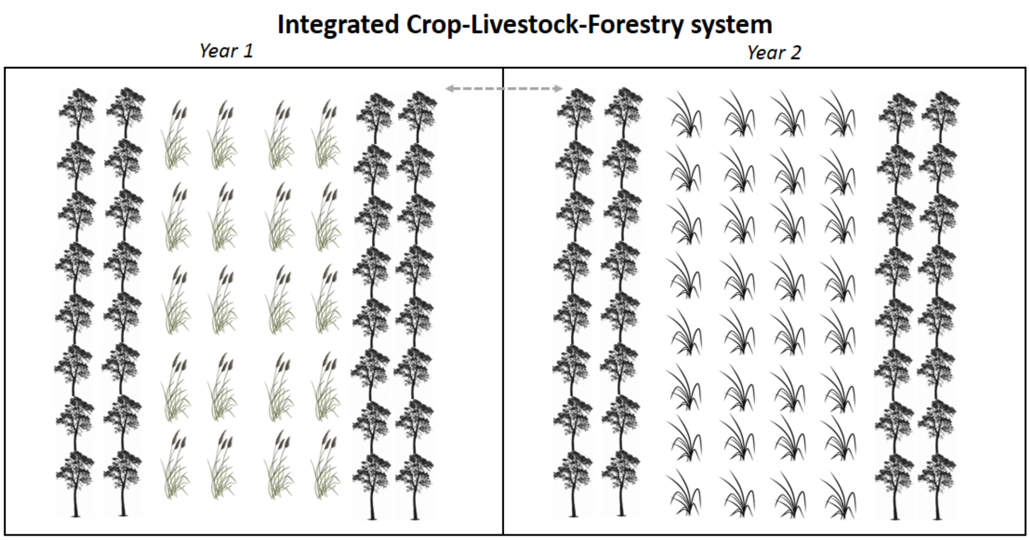

Figure 5: iCLF system. Source (formulated by the authors).

Integration models differ across regions according to climate, soil, farm size, own-funding, access to credits, technical assistance and market to purchase inputs, production outflow, level of expertise and land availability (Dias-Filho, 2007; Vilela et al., 2001).

The eventual rotation of crops and grass species is a common practice in many regions of Brazil due to the potential of range recovery and maintenance. After labeling of these practices as iCL systems, producers switched to a simultaneous rotation that resulted in income diversification (Macedo, 2009).

From that, farmers more involved in livestock production, perceive crop integration as a means of strategically maintain pastures and produce cash crops for markets. The same happens for grain farmers who seek economic advantages of diversifying production and improving land use

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by establishing pasture and animals, for milk, meat and fodder production (Anghinoni et al., 2013).

Integrating forestry activities to iCL models mentioned above results in iCLF systems that consequently generate higher income diversification, which in turn results in a complex set of interactions among all the elements in the production system. In addition, he systems tend to fulfill requirements of environmental compliancy provided by the Brazilian Forest Code (Balbino et al., 2012).

Even with an increased effort to boost the adoption of IAPS, it is still happening at a low rate (Balbino et al., 2011). As a result of a survey regarding adoption of the four models mentioned above, Gil et al. (2015) provides the ranked reasons of adoption in Mato Grosso (figure 6).

Figure 6: Ranking the most to least attractive criterion to adopt IS in the State of Mato Grosso. Adapted from (Gil et al., 2015).

As shown in Figure 6, farmers ranked the "potential of higher income" as the most attractive reason for adopting IAPS while "improvement of environmental conditions in the farm as a whole" was the least attractive. With that, a possible strategy to improve the adoption of IAPS in Brazil is promoting their economic benefits, as well as offering subsidies or other financial incentives producers to adopting them.

3. LOW CARBON AGRICULTURE (ABC PROGRAM)

The 15th Conference of the Parties (COP-15), held in December 2009 in Denmark, set up negotiations for the joint reduction of greenhouse gasses (GHG) emission and climate change in the short and long term (UFNCCC, 2009).

Brazil was one of the signatory countries promising to reduce GHG emissions by 36.1% to 38.9% by 2020, an estimation of 1 billion tons of carbon dioxide equivalent (Balbino et al., 2012; MMA). From that, a section for reducing GHG emissions in agriculture and other production sectors was added in the Federal Law n° 12.187/2009 (MMA).

ABC-Plan was, then, created to be the foremost strategy to stimulate low carbon emission agricultural practices and meet the goal for the agricultural sector (MMA). Due to recognized potential of reduced GHG emissions (Balbino et al., 2011), the implementation of integrated crop-livestock-forestry systems, represent one of the six activities included in the ABC-Plan targeting an increase of 4 million hectares by 2020, which accounts for 18 to 22 million tons of carbon dioxide equivalent (MAPA, 2012).

To achieve this, the Brazilian government offers credit lines with reduced interest rates and several terms of payment, according to the financial conditions of producers as well as the quality of the project presented for request the loan (BNDES, 2015).

From that, producers are requested to present to the bank a general plan of production that meets the ABC requirements for low carbon emissions in agriculture (BNDES, 2015) . There are several banks enrolled in the program, which enables the accessibility to the program in the national territory.

4. RESULTS

By assessing several experiments on IAPS in Brazil, the present paper compiles qualitative and quantitative information about integrated models to assess the level of benefits and limitations integrated systems present within the national territory.

The first step of the data compilation refers to the findings of Table 1, which shows advantages and disadvantages of IAPS on the basis of economic, environmental and social criteria.

Table 1: Advantages and disadvantages of integrated agricultural production systems

Area	*Advantages*	*Disadvantages*
Environmental	Interruption pest cycle [1],[5],[6],[8],[10] Lower env. Pressure [1],[10] Pasture & soil resources recovery [2], [3],[6],[8],[7] Reduced soil degradation [2] Reduced soil compaction [2],[9] Higher organic matter [2],[3][8],[10] Carbon sequestration [2],[3],[4],[8],[10] Increase soil fertility [3],[8],[9] Prevent deforestation [3] Ecosystem services [3],[4] Weed control [5],[10] Improve livestock performance [8]	Soil compaction due to cattle treading [6][10]

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Social	Creation of cooperatives [1] Better rural conditions [1],[4],[10] Job creation [2],[4] higher food supply [10] Food security [4]	Information Asymmetry [3] Higher labor expertise Use of different machinery Few research
Economic	Income diversification [1],[6],[7] Higher machinery efficiency [1],[4] Higher labor efficiency [1],[4] Lower production costs [2], [4],[7] Higher farm income [2],[6],[10] Less use of agrochemicals [2],[4],[8],[7],[10] Higher yield [2],[4],[5],[8],[9] Efficient input management [6],[8]	Lowe yield due to shade of trees [3] Costs land use conversion [3]

Source: Formulated by the authors.

From that, the second step of data management refers to the outcome of Table 2, which depicts the quantitative measurement of the positive or negative impacts of integrated agricultural production systems.

Table 2: Magnitude of IAPS impacts

System	*Criterion*	*Magnitude*	*Reference*
iCL	**Animal performance**	8,8%-28% higher animal weight	[10]
		20% weight gain in low land conditions	[10]
		582.0 (kg ha−1)	[8]
		3 times higher animal stock	[10]
		38 - 50% less time to slaughter	[13]
		54% higher birth rates	[13]
		50% less heifer mortality	[13]
		36% less farrowing interval	[13]
	Crop Yield	Additional 6 bushels of soybean ha−1	[10]
		41% reduction fodder (B. decumbens)	[10]
		24% increase rice productivity – RS	[10]
		10% higher yield for maize	[12]
		127kg/soybean/year of pasture	[10]
		18% gain soybean without additional fert.	[11]
	Soil traits	Org. matter loss: Conv. 540kg/ha; iCL	[10]

		80kg/ha soy/pasture 30% more org. matter	[10]
	Cost	39% less costly live weight-1 Positive energy balance of 3,9 J21:M30GJ	[10] [10]
iLF	**Soil traits**	increase 1.2% organic matter first layer	[10]
iCLF	**Crop Yield**	41% reduction fodder (B. decumbens) 44% reduction nutritional value (B. decumbens)	[10] [10]

Source: Formulated by the authors.

5. DISCUSSION

The scientific literature highlights the contribution of IAPS on environmental, social and economic levels. Despite variations in terminologies and element arrangement, they basically represent the same system (Carvalho et al., 2014). Nevertheless, complexity and synergism change accordingly with the amount of integrated activities.

The four major categories of IAPS assessed in this paper potentially trigger advantages and limitations to adopters. The positive aspects shown in Table 1 are often intertwined, leading to gains to the farm, the environment as a whole, and to business profitability. More economic stability leads to a series of social benefits to the household or even to a macro level.

Prior to the analysis of impacts, it is key to understand that farmers differ in a series of characteristics and, therefore, the adoption of productive systems should be done accordingly. This way, models of integration potentially adapt to the farm characteristics and generate benefits to farmers.

To illustrate the impacts of IAPS we take an example of a cattleman. The foremost activity is production of grass as animal feed and, consequently, live animals. The ongoing production of grass, often *Brachiaria decumbens*, in conjunction with animal activity on the soil, trigger losses in productivity of animals and grass, due to soil compaction and nutrient losses.

In this situation, the adoption of iCL would enable rotation of crop and the well-established livestock activity in the farm. As shown in Table 1, the potential impact would be recovery of soil and pasture, reduced soil degradation, increased soil fertility, prevention of deforestation of additional areas as increased grazing land as well as income diversification. Rotation with soybean, for instance, promotes biological fixation of nitrogen, which in turn, reduces the demand for fertilizers.

From table 2 it is possible to observe the magnitude of the benefits of IAPS. Integrating crop and livestock activities improves nutritional levels of forage, which enables better animal performance at different levels. Animal weight increases by 28%, potential for animal stock triples, mortality rate decreases 50%, and birth rate increases 54%. All these factors potentially reduce production cost by 39%.

Farmers who predominantly produce soybean, maize, rice and cotton, also have livestock integration as an option for income diversification and for improving farm environmental conditions. Differently from mono cropping systems, integrating livestock interrupts insect and disease cycles and promotes weed control. This way, agrochemical application reduces, leading to lower input costs. Roots of *Brachiaria decumbens* explore deeper layers of soil, which improves soil aggregation.

As shown in table 2, due to iCL, experiments found an increase in crop yield by 10% for maize, 24% for rice and 6 additional bushels of soybean per hectare. Fertility from crops and grass rotation resulted in 18% increase of soybean yield without demanding additional fertilizers.

When producing under no-tillage systems, the use of fewer mechanical operations reduce soil compaction, improve water infiltration, and increase organic matter and carbon stock in the soil. The synergism among systems enhances physical and chemical characteristics of the soil, leading to higher animal and plant production. From table 2, organic matter losses can be as high as 540 kilograms per hectare in conventional systems, while in iCL the losses are reduced to 80 kilograms per hectare.

The adoption of forestry activities in farms of livestock and crops, improves the process of carbon sequestration; the shade of the trees is proven to be beneficial for animal performance since animals tend to graze and ruminate more under the trees. It also accounts for higher income diversification by enabling production of timber and non-timber goods.

By adopting IAPS producers can adjust production accordingly to market characteristics. In other words, income diversification reduces the risks of businesses since it does not rely on one single product; rather, producers are able to supply different outputs to the market and focus on those with higher value. Moreover, due to production diversification, in case of natural hazards such as hail, flooding and droughts, IAPS potentially reduce the risks of economic losses.

Social benefits are related to higher economic potential of IAPS. From the scientific literature, IAPS stimulate job generation, improve rural conditions for living and producing, and guarantee

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food security. Within this frame, IAPS stimulated the creation of small cooperatives in different rural areas in Brazil due to higher food surplus. Therefore, this represents a cyclical process where producers reap continuous economic and social benefits.

Nevertheless, Brazilian producers lack key information on how implementing IAPS, leading to misgiving and fear towards adoption. Although it has not been scientifically proven, many producers believe that cattle treading triggers soil compaction and affects production. IAPS are more complex than conventional agriculture, as they require higher labor expertise to define suitable amount of inputs, animal stock, trees arrangement to promote less costly mechanical operations and market “know-how”.

Although IAPS are applicable for any farm size and region (Balbino et al., 2012), in order to adopt different integration models it is necessary to adapt machinery, labor and farm structure accordingly to production system (Macedo, 2009).

Integrating forestry demands strategic tree arrangement since tree shades may block the sun light for crops, leading to lower productivity. In this sense, when compared to multiple rows of trees, single rows are expected to be more beneficial for enabling light incidence on crops and pasture. Table 2 shows that shade affected fodder production by 41% and nutritional value by 44% in *Brachiaria decumbens*. In contrast, another experiment shows that already in the first year, soil organic matter increased by 1.2% due to the presence of trees.

In addition, converting land use from mono cropping to integrated models is costly and requires strategic planning. As a result, small and big producers need governmental support to stimulate the adoption of IAPS, however, programs such as the ABC-plan have shown considerable bureaucracy to offer financial means for potential adopters.

Despite the effort to meet the goals of the program, there are hindrances to access credit lines (MAPA, 2012). In the State of Pará, which presents the second highest level of pasture degradation in the Legal-Amazon area, producers evaluated the program positively insofar as loan conditions are attractive to implement IAPS and pasture recovery. Nevertheless, land ownership is an issue in the Amazon, as the federal government lacks efforts towards legal land regularization, and land distribution, which hampers possibilities for developing sustainable agriculture in the region (MAPA, 2012).

On the other hand, those who succeeded claim that the credit amount is insufficient to implement IAPS and maintain them (MAPA, 2012). The ABC-Plan enables farmers to request credits only once, therefore those who implemented IAPS, for instance, are not eligible for additional governmental support for maintaining the new system (MAPA, 2012).

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Another challenge stands for the lack of environmental regulation for the majority of producers interviewed. They state a significant absence of technical assistance and advisory services in the Amazon region. A feasible solution, therefore, could be the creation of a credit line for hiring these services (MAPA, 2012).

As for the state of Mato Grosso, the survey from (Gil et al., 2015) shows that only 17% of the farmers interviewed applied for a credit line, but even fewer (5.9%) succeeded. Producers reported that bureaucracy was the major challenge for application. Although the ABC credit lines were attractive even for producers with enough own capital, they opted for not requesting the loans due to the amount of requested documents as well as the need to comply with environmental laws.

This suggests that in order for the ABC-plan to succeed, additional government efforts toward environmental awareness are needed. Legal regulation and redistribution of land ownership, provision of advisory services to small and big producers, improving information symmetry as well as enforcing environmental regulation according to the Brazilian Forestry Code are key elements to trigger higher adoption of IAPS.

The literature also states the lack of scientific experiments over benefits and improvements of integrated models. It is especially because results rely on long-term experiments, demanding high costs and ongoing labor.

6. CONCLUSION

Lack of experiments is indeed a key challenge to the development of IAPS in Brazil. Although studies argue about general benefits of integrated models, few experiments show quantitative results especially for iCL and iCLF. Other types of integrated models for cash crops are often not mentioned.

The ABC-plan shifted national attention to IAPS and, in fact, provides attractive credit conditions to producers. However, bureaucracy and the pending governmental efforts to land regulation hamper access to loans. Moreover, adopters claim that maintenance of IAPS are somewhat costly and more governmental support could be a good approach for long-lasting upkeep.

IAPS are key to meeting agricultural demands and increasing productivity within the sustainable agriculture premises. Integrated agriculture succeeded in adapting to a series of natural conditions. If applied respecting the synergism and interaction of elements, IAPS result in economic, social and environmental gains for the household and rural area as a whole.

This way, boosting IAPS in Brazil demands governmental efforts that go beyond the current scope the ABC-plan. Investments on long-term research and advisory services for promoting IAPS would be key to stimulate adoption and empower producers into sustainable agriculture. Moreover, the gap towards legal land ownership and land distribution is still to be tackled by the Brazilian government; otherwise, it may jeopardize the success of financial programs and sustainable agriculture as a whole.

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Appendix I

Reference list for table 1 and table 2.

[1] (Macedo, 2009)

[2] (Balbino et al., 2011)

[3] (Juliana Gil et al., 2015)

[4] (Carvalho et al., 2014)

[5] (Assmann, 2004)

[6] (Cassol Flores, 2004)

[7] (Chan, 1985)

[8] (Salton et al., 2014)

[9] (Chioderoli et al., 2012)

[10] (Balbino et al., 2012)

[11] (Martha jr, Vilela & Sousa, 2010)

[12] (Landers, 2007)

[13] (Cobucci, 2007)

