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POTENTIAL LAND-SAVING EFFECTS FROM INTEGRATED CROP-LIVESTOCK-FORESTRY SYSTEMS

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ABSTRACT

A bold sustainable intensification strategy involves a multiple approach combining increased yields, cropping intensity, and resource-use efficiency. Well-designed and implemented integrated crop-livestock-forestry systems (ICLS) can achieve those goals. In this paper I discuss the potential land-saving effects arising from the recovery of low-productive pastures through ICLS and the potential land-saving effects from productive livestock systems already in rotation with high-yielding soybean crops. The recovery of low productive pastures offers an impressive way of sparing land from cultivation. Land-saving effects resulting from turning low productivity pastures into productive ones through ICLS may reach 11 ha spared/ha recovered but figures around 3 to 5 ha spared/ha recovered would probably be more realistic. The potential for generating land-saving effects in high-productive ICLS is lower (up 1.40 ha spared/ha) because land-productivity is close to or is already at the attainable yield level. However, productive ICLS have a higher potential to deliver environmental benefits and their already high levels of land-productivity indicate that associated rebound effects are unlikely. Thus, productive ICLS will likely promote land-sparing effects with no leakage.

Key words: agricultural R&D; Jevons' paradox; land-use change; sustainable intensification

INTRODUCTION

Population and per capita income are the two most important shifters of agricultural demand curve. In the past decades (1960-2006), population growth explained around 80% of the variation in global agricultural demand. In the horizon up to 2050, the increase in world's population, whilst at decreasing rates, will still be quite relevant (55% of the variation in agricultural demand). Per capita income is projected to gain relevance, and for the 2006-2050 period it will account for 45% of the agricultural demand growth (HERTEL; BALDOS, 2016).

On the one hand, population and per capita income growth, combined with changes in eating habits resulting from the expansion of the world middle class and the growing rate of urbanization, will keep the demand for agricultural products with higher income-elasticities, such as animal protein, fruits, and legumes, at high growth rates over the next decade. On the other hand, the progressive aging of population associated with possible changes in consumers' preferences, motivated by health and environmental issues, could reduce that potential rate of increase in animal protein demand. Structural and large-scale transformations, however, are complex processes, and generally encompass several decades to be more fully observed.

Brazil is a major player in feed and animal protein production, and it is projected to supply a substantial share of these products to meet global demand over the next decade (OECD-FAO, 2020). Despite such positive prospects, maintaining and/or expanding that market share is not trivial. In addition to inherent challenges of expanding production (biophysical, market, infrastructure, and institutional related issues), Brazilian agriculture will face increasing scrutiny by consumers and other governments who will require more detailed information about the agricultural production processes and their potential impacts on the environmental and social dimensions of sustainability. It is of

Brazil's agriculture interest to critically analyze sound-based recommendations and to pursue alternatives for improvement whenever necessary. The country must also invest in better communicating scientific evidence, allowing for different stakeholders in Brazil and abroad to clearly understand the facts that are really known and those that are not yet well established.

Brazilian agriculture has proven to being following a science-based approach over the past decades (MARTHA JR.; ALVES, 2018). In spite of localized problems, the most noted one is the deforestation pressure at the borders of Cerrado and Amazon biomes, it is worth of noting that two-thirds of Brazil's immense territory is still covered with native vegetation (MAPBIOMAS, 2021). A successful past history, however, is no guarantee for grand achievements in the future. Brazil must clearly intensify its efforts into the sustainability path. Such approach requires increasing agricultural production with low pressure on natural resources and biodiversity, and with minimal land area expansion (e.g. leakage) to other regions.

A bold sustainable intensification strategy would involve a multiple approach combining increased yields, cropping intensity, and resource-use efficiency. Well-designed and implemented integrated crop-livestock-forestry systems (ICLS) in Brazil can achieve those goals.

Consider, for example, ICLS with a focus on soybean, corn and beef production. Depending on the agroecological region considered it is possible to have a cropping intensity as high as three crops per year under rainfed conditions. In such systems, during the rainy season, a short-cycle soybean crop is followed by a second-season corn crop, known as "safrinha", in which corn is established together with the grass pasture. For both crop seasons, a no-till planting approach is used. Once the second-season corn is harvested, the already established pasture allows for a third "cattle crop" during the dry season. In the next growing season, the farmer is well positioned to choose between another crop-livestock cycle or depending on farmer's objectives and prevailing relative prices (crops, livestock, inputs), the farmer may decide to keep the pasture for a few more months (or even years).

In well-managed ICLS it has been observed the disruption of pest and disease cycles, and over the medium to long-run those systems operate with greater nutrient-use efficiencies (CORDEIRO et al., 2015). The ICLS with the greatest potential from a technological and economic perspective, with expected positive impacts on social and environmental dimensions, are those managing their "crop" and "livestock" components with a focus on high productivity (coupled with high resource-use efficiency) (MARTHA JR. et al., 2011).

But, what determines land-productivity? In a given agroecological region, the potential yield of a crop is defined primarily by climate parameters (radiation, temperature, etc.), considering an environment under no water or nutrient constraint. For rainfed conditions, the water-limited yield potential, a situation in which soil water capture and storage is optimal and nutrient constraints are eliminated, is generally preferred. "Achievable (or attainable) yields" are generally lower than that potential because plant growth is frequently limited by lack of water and/or nutrients relative to its needs during the growth cycle. In practice, other reducing factors, such as pests, diseases, weeds, and other management limitations additionally constrain crop growth so "actual yields" are usually lower than "attainable yields" (TITTONELL; GILLER, 2013; DIJK et al., 2017).

Actual yields, even if they are at a point of technical efficiency (e.g. when the maximum amount of output is produced for a given amount of inputs), may or may not be at an economic optimum point. For that to occur, it is necessary to additionally meet a condition of allocative efficiency, observed when inputs and outputs are combined to achieve their highest possible net value (HEADY, 1960; BEDDOW et al., 2014; DIJK et al., 2017). At such allocative efficient condition, the price ratio (price of factor/price of product) must equal the transformation ratio (marginal productivity of the resource). Thus, as relative prices changes, so does the economic optimum yield level. As the price of the factor becomes smaller relative to the price of the product, the price ratio line becomes flatter and the use of a higher level of the factor is advantageous (HEADY, 1960). Needless to say, that increasing the level of inputs use to achieve higher yields must also consider resource-use efficiency and best-practice recommendations to avoid negative externalities such as pollution to soil, water, and air.

Land productivity gain complexity in pastoral systems under both a technological and an economic perspective. In addition to forage production, two additional partial efficiencies are relevant to grazing systems: the grazing efficiency (e.g. the proportion of herbage dry mass (DM) that is actually consumed by the grazing animals); and the conversion efficiency (e.g. the portion of consumed herbage DM that is converted into animal product, such as kg DM/kg live weight gain (LWG)). In pasture-based systems, productivity (kg LWG/ha) is therefore given by the product between animal performance (kg LWG/head) and stocking rates (head/hectare). Animal production (kg LWG) is then the product between area (ha) and productivity (kg LWG/ha) (MARTHA JR. et al., 2012).

Considering only one of the productivity's components (e.g. animal performance or stocking rates) and ignoring the other in the estimation of productivity in pastoral systems might lead to misleading conclusions. If stocking rates increase to a level that significantly reduce animal performance, animal productivity and economic performance are jeopardized (besides, with a lower animal performance the intensity of methane emissions increases). Likewise, if a higher level of animal performance is associated with a very low stocking rate, again, technical and economic performances are compromised. Therefore, from an economic viewpoint, there is no rule of thumb, e.g. increasing stocking rates (head/ha) or animal performance (kg LWG/head) might be – or might be not – profitable. Each situation must be evaluated carefully and the allocative efficiency in pastoral systems must take into account price and transformation ratios for both productivity components, stocking rates and animal performance, including the possibility of using supplements for the grazing animals.

Agronomic and economic decisions regarding land productivity levels also have implications to land use. For a given output level, the higher the land productivity (output per unit area) – the intensive margin – the lower is the demand for agricultural land expansion – the extensive margin. Such reasoning provides the basis for the so called "land-saving effect", that is, the area of land left uncultivated due to technological progress increasing agricultural output per unit of area (e.g. yields) instead (MARTHA JR.; ALVES, 2018).

Following this extended introduction, in the remainder of this article I consider the potential land-saving effects for ICLS in the Brazilian Cerrado, with a focus on soybean (crop phase) and, especially, on beef production (livestock phase). In a final section, I bring to attention some of the policy challenges to increase land-productivity and, hence, to further expanding the potential land-saving effects.

MATERIAL AND METHODS

In this article I discuss the potential land-saving effects arising from the recovery of low-productive pastures through ICLS. I also present the potential land-saving effects from productive livestock systems already in rotation with a high-yielding soybean crop. For the two cases, the impact of varying the proportion of cropland and pastureland on land-savings is discussed. Details about land-saving calculations were presented by Martha Jr. et al. (2012).

Typical productivity ranges for soybean and beef production in ICLS were considered. For soybean, an average yield of 3000 kg/ha was assumed for an "exclusive-soybean" production system. For its counterpart in ICLS, I considered an average yield of 3500 kg/ha. That yield difference (e.g. 500 kg/ha) between the two systems is compatible with the results presented by Reis et al. (2019). Land-saving effects arising from the recovery of low-productive pastures considered an initial animal productivity of 54 kg LWG/ha/year (e.g. 90 kg LWG/head/year * 0,60 head/ha/year). Then, I estimated the land-saving effects when animal performance and stocking rates are improved up to 180 kg/head/year and 3,6 head/ha/year, respectively. It is worth of noting that an annual stocking rate of 3,6 head/ha/year is compatible with 1,8 head/ha during the dry season (120 days), and 4,5 head/ha during the rainy season (245 days). For the productive system scenario, animal performance and stocking rates ranged from 150 to 180 kg/head/year, and from 2,5 to 5 head/ha/year, respectively. An annual stocking rate of 5 head/ha/year is compatible with 2,2 head/ha during the dry season (120 days), and 6,4 head/ha during the rainy season (245 days). For the exercise with varying proportions of cropland and pastureland I considered an animal productivity of 450 kg LWG/ha/year (e.g. 150 kg LWG/head/year * 3 head/ha/year) for both the low-productivity and the productive scenarios. It is assumed in these calculations that supplementation of grazing animals, if it occurs, has no significant effect neither on animal performance nor on stocking rates.

RESULTS AND DISCUSSIONS

The land-saving effect arising from productivity gains in ICLS-soybeans, as compared to "exclusive-soybean" production systems (3,5 t/ha vs. 3,0 t/ha), is small, approximately 0,14 ha spared/ha. That reduced effect reflects the already relatively high yield level in "exclusive-soybean" systems, meaning that the opportunities for closing the yield gap between the two systems is narrow. Nonetheless, if achieving the highest possible net value for a given level of resource-use is focused, that "narrow yield gap" between the two soybean systems might be quite relevant from an economic perspective. Considering current soybean prices and the exchange rates in Brazil (e.g. R$ 165,00/60-kg sac; R$ 5,6456/US$ 1; 07/April/2021) an extra revenue of US$ 243,55/ha would be gained in the ICLS-soybean. That figure approaches a net value gain, since costs of production are not expected to vary significantly between the two soybean production systems.

The recovery of low productive pastures offers an impressive way of sparing land from cultivation. The information presented in Table 1 shows that improving both animal performance and stocking rates play a very important role, but the latter, as expected, provides a greater land-saving potential. It is worth of noting that an interacting effect occurs, which reflects the combined results of animal performance and stocking rates on productivity levels. The land-saving effect arising from animal performance increases from 1 to 6 ha spared/ha recovered as stocking rates increase from 0,60 to 3,6 head/ha/year. The land-saving effect arising from stocking rates increases from 5 to 10 ha spared/ha recovered as animal performance rises from 90 to 180 kg LWG/head/year. Combined, land-saving effects resulting from turning low productivity pastures into productive ones through ICLS may reach 11 ha spared/ha recovered but figures around 3 to 5 ha spared/ha recovered would probably be more realistic.

Table 1. Potential land-saving effects resulting from the recovery of low productivity pastures through ICLS.

Liveweight gain (kg/hd/yr)	Average stocking rate (head/ha/year)					
	0,60	1,20	1,80	2,40	3,00	3,60
	ha spared/ha recovered					
90	0,00	1,00	2,00	3,00	4,00	5,00
120	0,33	1,67	3,00	4,33	5,67	7,00
150	0,67	2,33	4,00	5,67	7,33	9,00
180	1,00	3,00	5,00	7,00	9,00	11,00

Source: Author's calculation and elaboration.

As the pasture proportion in ICLS declines so does the land-saving potential (Table 2), as a higher area of productive soybean implies in a lower opportunity to closing the yield gaps. However, even in a situation in which 75% of the area is allocated to high-yielding soybeans (e.g. 25% of pasture in the area), a land-saving effect of around 1,5 to 2 ha spared/ha recovered would probably be observed in those ICLS.

Table 2. Potential land-saving effects resulting from different proportions of pastureland to cropland in ICLS.

%pasture in the area	Average stocking rate (head/ha/year)					
	0,60	1,20	1,80	2,40	3,00	3,60
	ha spared/ha recovered					
100%	0,67	2,33	4,00	5,67	7,33	9,00
75%	0,53	1,78	3,03	4,28	5,53	6,78
50%	0,40	1,24	2,07	2,90	3,74	4,57
25%	0,27	0,69	1,10	1,52	1,94	2,35

Source: Author's calculation and elaboration. For the livestock phase it is considered a stocking rate of 3 head/ha/year and an animal performance of 150 kg LWG/hd/year.

As productive pastures sustaining high animal performances and stocking rates enter into the rotation with productive crops, both phases in ICLS now operate with smaller yield gaps. Therefore, the potential for generating land-saving effects substantially decreases (Table 3). For a starting productivity condition of 375 kg LWG/ha/year (e.g. 150 kg LWG/head/year * 2,5 head/ha/year) in the livestock phase, a land-saving effect of up 1,4 ha spared/ha would be observed, but a figure of less than 1,0 ha spared/ha would reflect a more common situation. As the pasture proportion in ICLS declines, the resulting land saving-effects decline even further (not shown).

Table 3. Potential land-saving effects resulting from high productive ICLS.

Liveweight gain (kg/hd/yr)	Average stocking rate (head/ha/year)					
	2,50	3,00	3,50	4,00	4,50	5,00
	ha spared/ha					
150	0,00	0,20	0,40	0,60	0,80	1,00
160	0,07	0,28	0,49	0,71	0,92	1,13
170	0,13	0,36	0,59	0,81	1,04	1,27
180	0,20	0,44	0,68	0,92	1,16	1,40

Source: Author's calculation and elaboration.

The potential for generating land-saving effects in high-productive ICLS is low because land-productivity is close to or is already at the attainable yield level. The high cost of production in those systems (MARTHA JR. et al., 2011) reinforce the need for farmers to manage their resources according to technical and allocative efficiencies. The chosen yield level will vary as farmers respond to changes in relative prices in order to meet the allocative efficiency condition.

In well-managed ICLS it is possible to observe a more resilient condition for crop and livestock production over time, given the progressive improvements in soil quality (CORDEIRO et al., 2015). Such condition contributes for reducing farmers' risk perception and, hence, their selected discount rates for future benefits. A lower discount rate favors the adoption of sustainable practices with a longer-term pay-off. From a society's perspective, in addition to the increase in the potential flow of environmental benefits, a greater and more resilient crop and livestock output contributes to the industry and service sectors through multiplier effects in the economy.

An important consideration relates to the possible existence of a rebound effect (also referred to as "Jevons' Paradox"), in which an increase in agricultural productivity will be accompanied by an expansion in land area. Hertel et al. (2014) and Hertel (2016) comprehensively reviewed that matter and found that the direction of land use change in an innovating region, in response to an improvement in agricultural technology, will be related to the absolute value of the price elasticity of excess demand facing producers in that region. The elasticity of excess demand is determined by three factors, (a) the responsiveness of consumer demand around the world to changes in the product price; (b) the potential for producers in the rest of the world to respond to price changes; and c) the share of global supply provided by the innovating region. When the price elasticity of excess demand is higher than 1, increasing productivity will lead to agricultural land expansion in the innovating region, and when it is lower than 1, the price depressing effect of output expansion will restrain expansion (HERTEL et al., 2014; HERTEL, 2016). The authors additionally found that Jevons' Paradox is most likely to happen when global food demand is price responsive and land-productivity in the innovating region is far lower than the world average. From that reasoning it is reasonable to say that rebound effects are likely to occur when the "innovating region" has very low relative crop and livestock land-productivities. In contrast, when high-productive ICLS are considered, the observed high land-productivity levels, close to or already at achievable yields, will likely promote land-sparing effects with no leakage.

Looking ahead, a preliminary exercise reveals the potential of expanding productive ICLS in the Brazilian Cerrado. Considering the additional increase in corn (+ 25.256 kt), soybean (+ 21.846 kt), and beef (+ 678 kt cwe) production in Brazil for the 2020-2029 horizon (OECD, 2020), implementing productive ICLS in 9 Mha (~ 15% of the pasture area in the Cerrado) would contribute with 126%, 81%, and 400% of that projected increase in production (Table 4).

Table 4. Potential impact of expanding productive ICLS in the Brazilian Cerrado.*

	Avg. productivity		Additional increase in output (2029)		
	2020	2029	OECD-FAO (1)	+ 9 Mha ICLS (2)	Contribution (2)/(1)
	kg/ha/year		kt or kt cwe		% increase
corn	-	3.905	25.256	31.838	126%
soybean	-	7.040	21.846	17.660	81%
beef	188	788	678	2.713	400%

Source: Author's calculation and elaboration.

*Yields for ICLS-corn and ICLS-soybean are 10% higher than the values projected by OECD-FAO (2020). Initial beef productivity considered a stocking rate of 1,5 hd/ha and an animal performance of 125 kg LWG/hd. For the 2029 projection, ICLS-beef productivity considered 4,5 hd/ha and an animal performance of 175 kg LWG/hd.

At last, but certainly not least, agricultural R&D is a crucial determinant of agricultural productivity and production. Hence, strengthening the sustainability and competitiveness of Brazilian agriculture involves a sustained, solid base of agricultural R&D expenditures. Strategically, R&D expenditures in the country should be equivalent to the main international players. Developed countries invested, on average, 3% of agricultural gross domestic product (GDP) in public agricultural R&D over the 2009 – 2013 period (HEISEY; FUGLIE, 2018). Brazil invested approximately 1,8% of agricultural GDP in research, mostly public, in the 1990s up to 2013 (MARTHA JR.; ALVES, 2018). The gap in research intensity between Brazil and developed countries has probably increased in the recent past. The fiscal policy space in Brazil, necessary to boost (or at least to sustain) public agricultural R&D

expenditures was squeezed by the 2014-2016 recession and the weak economic recovery in the following years. That scenario has been additionally aggravated by the Covid-19 pandemic (2020-2021) and the need for a large fiscal stimulus to cope with the resulting health and economic crisis. A slowdown in Brazilian agricultural R&D will negatively impact future productivity growth, leading to a reduced agricultural output level in the country and increased food prices in Brazil and the world (LIMA et al., 2021). Such combination is a “perfect storm” to inflationary and food insecurity pressures. Therefore, it is of Brazil’s interest to find ways to keep up with agricultural R&D investments. In addition to strengthening public agricultural R&D, a successful strategy should encourage an increased private sector engagement in order to expand agricultural R&D intensity in Brazil to the levels observed in developed countries.

CONCLUSIONS

Observed land productivity levels reflect choices made by farmers (technology, inputs, management) conditioned by uncontrolled elements in the natural environment (BEDDOW et al., 2014). Those choices are unique to a given farmer-farm combination because the quantity and quality of resources and inputs available (land, labor, physical and human capital), their relative prices, and farmers’ individual values vary on a case-by-case basis so, thus, farmers' opportunity costs and perceived risks (MARTHA JR., 2020).

Brazilian farmers are exposed to market forces. The level of incentives (“producer support estimate”) they receive is low and averaged only 1,6% of gross revenue at farm level for the 1995-2017 period (OECD, 2018). Consequently, Brazilian farmers will consider adopting new technologies or recommended practices if they recognize them as having potential to delivering positive benefit/cost ratios. Under favorable relative prices (and/or incentives), conducive to technology adoption, several technological approaches for closing the land-productivity gap in ICLS might be considered. Those strategies are quite diverse as they involve different biological components (crops, livestock, forest) and their multiple interactions to each other and to the surrounding production environment. Improvements in plant and animal genetics (advanced biology), as well as on input- and resource-use efficiency, through new products and/or techniques, should be pursued. Farmers will increasingly benefit from proven digital solutions that can increase overall efficiency gains, improve resource- and input- use efficiency, and lower costs of production in agriculture (MARTHA JR., 2020).

Furthermore, closing each one of those gaps – e.g from actual yields to allocative efficient and/or technically feasible yields, and from that yield level to the (water-limited) yield potential – requires different policy strategies (BEDDOW et al., 2014). Farmers with actual yield levels lower than those achieved by farmers implementing best practices in their most productive fields in a given region may benefit from policies that promote technical and allocative efficiency improvements, such as educational extension programs and dissemination of market information to aid decisions (TITTONELL; GILLER, 2013; BEDDOW et al., 2014).

There is also scope for closing the gap between the allocative efficient yield level and the technically feasible yield level (given the best available technology). That gap is expected to be larger in less developed regions, within a country or across countries, because of market imperfections (DIJK et al., 2017; MARTHA JR.; ALVES, 2018). As emphasized by Martha Jr. & Alves (2018), *“... one of the greatest barriers to ensure modern technology will be more broadly and effectively adopted is market imperfection, which alters relative prices and the returns to investment in technologies. Reducing market imperfections is a necessary condition for expanding production in a more inclusive way, and to increase the effectiveness of policies targeting technology adoption by farmers*”. Policies resulting in more favorable relative prices to technology adoption, e.g. reduced unit costs of inputs or increased unit value of outputs, might be considered to close that gap. However, such policies need to be carefully evaluated and might only be justified if they are targeted to correct some form of market distortion (BEDDOW et al., 2014).

Closing the yield gap from technically feasible yield levels to (water-limited) yield potential involves shifting the production possibility frontier upward, meaning that advanced technologies need to be successfully implemented (BELLOW et al., 2014; DIJK et al., 2017). Such transformations encompass broader institutional, technological, economic and social factors (DIJK et al., 2017). A key cornerstone for such strategy involves strengthening agricultural R&D to provide knowledge and problem-solving technologies to sustain total factor productivity gains at high levels over the medium- to long-run (MARTHA JR.; ALVES, 2018). A R&D intensity goal of 3% is often recommended (CARVALHO, 2018).

Those already challenging relationships will gain further complexity in face of climate change, that will inevitably lead to a less predictable and a riskier production environment, making yields – and associated land-saving effects – more difficult to anticipate. Agriculture in the tropics may be severely jeopardized if technological progress does not keep pace with such changes in the production environment, reinforcing the critical role of R&D for a sustainable and resilient agriculture in the future. Embrapa has been putting a high priority to adapt, develop and promote products, practices, and systems that aid in both mitigation purposes and adaptation strategies, such as the continuous development and improvement of ICLS.

As a final remark, under a political-economic perspective, protection of the environment and climate change actions are not costless. Those measures have an opportunity cost, since scarce resources used for environmental protection or for mitigation/adaptation actions could have been alternatively used in other ways. Governments, thus, "*... play the essential role in putting into place policies that ensure that resources contribute to the long-term economic development and not only to short-term revenue generation*" (OECD, 2011).

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