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Determinants of crop-livestock integration in Brazil: Evidence from the household and regional levels

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ABSTRACT

Integrated crop-livestock systems (iCL) are advocated as a promising strategy to increase agricultural production and rehabilitate degraded pastures while mitigating GHG emissions. Although iCL in Brazil has increased over the past few years, it still occupies a small share of the country's total agricultural area. We investigate the determinants of iCL occurrence in Mato Grosso state, a globally important producer of beef cattle and grains that has experienced rapid land cover change and environmental degradation in recent decades. Our analysis encompasses two typical cases of iCL in Mato Grosso (the rotation of soy followed by pasture, and soy followed by maize and pasture) as well as biophysical, socioeconomic, and institutional factors observable at the household and/or municipality levels that may influence the wide-scale occurrence of iCL. Evidence at both scales suggests that knowledge and supply chain infrastructure play an important role in early occurrence of iCL, as they are more common in regions closer to iCL research stations and processing facilities of grains and cattle. On average iCL adopters are more educated and have better access to technical assistance and sector information than specialized farmers or ranchers. Most iCLs are concentrated near established soy areas and greater similarity exists between municipalities with iCL and soy-dominant municipalities vs. pasture-dominant municipalities. Our findings reveal the importance of specific conditions for iCL occurrence and iCL promotion in livestock-dominant regions. Incentives targeted at ranchers are crucial for the achievement of the Brazilian Government's goal to restore degraded pastures through agricultural intensification.

1. Introduction

Deforestation for export-oriented agricultural expansion has become a leading driver of environmental change in tropical regions (Lambin and Meyfroidt, 2011; DeFries et al., 2013). This trend has been particularly concerning in the Brazilian Amazon and Cerrado biomes, which contain globally significant repositories of carbon and biodiversity and play a critical role in regional hydrological cycles (Klink and Machado, 2005; Peres et al., 2010; Davidson et al., 2012; Spera et al., 2016). Since 2004, when deforestation reached its peak, agricultural production in Brazil has appeared increasingly decoupled from forest clearance as a result of improved public and private anti-deforestation policies (Nepstad et al., 2014; Soares-Filho et al., 2010; Assunção et al., 2012; Macedo et al., 2012; Gibbs et al., 2015). However, low levels of deforestation for agriculture persist in many Amazonian regions (Godar et al., 2014; INPE, 2015) and the rapid clearing of the Cerrado for the expansion of commodity agriculture remains a pressing conservation challenge (Spera et al., 2016).

In an effort to prevent further deforestation and associated greenhouse gases (GHG) emissions, the Brazilian Federal Government has been investing in technologies able to increase crop and livestock productivity while restoring degraded lands (Government of Brazil, 2014). Particular attention has been directed at the cattle sector, where the largest opportunities to improve productivity exist, since roughly 20% of Brazil's total land area is devoted to pastures that support on average less than one animal per hectare (IBGE, 2006; Cohn et al., 2014; Strassburg et al., 2014). Although improved productivity cannot always guarantee land sparing (Angelsen and Kaimowitz, 2008), it is considered a necessary complement to more direct conservation policies for the maintenance of agricultural production growth (Godfray et al., 2010; Tilman et al., 2011).

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One promising strategy to improve livestock productivity in Brazil is the use of integrated crop-livestock systems (iCL), here defined as the periodic rotation of crops, pasture, and livestock on the same land area. The combination of farming and grazing within the same area leads to synergies between system components that can generate higher outputs, cost savings and enhanced ecosystem services. In particular, iCL have been shown to improve crop and pasture yields and subsequent animal growth through enhanced soil fertility (Salton et al., 2014; Carvalho et al., 2014; Lemaire et al., 2014). iCL can also reduce net GHG emissions and nutrient runoff per unit of agricultural production by better recycling animal manure and crop residues and decreasing the time needed for cattle to reach slaughter weight (Alvim et al., 2015). As a consequence, iCL may offer increased resilience against economic and biophysical stresses versus specialized (e.g. continuous) cropping or pasture operations (FAO, 2007; Thornton and Herrero, 2015). Nevertheless, some forms of iCL such as integrated beef-maize production may involve high levels of synthetic inputs and low species and habitat diversity as compared to other mixed systems (Bungenstab, 2012).

Due to their theoretical economic and ecological advantages, iCL have been proposed as a strategy to stem agricultural expansion, pasture degradation and deforestation reduction. This is particularly true in the Brazilian state of Mato Grosso, which spans the Amazon and Cerrado biomes and has the largest soybean area (8.6 million hectares), pasture area (26 million hectares) and cattle herd (28 million animals) in the country (CONAB, 2014; IMEA, 2010). At least 2 million hectares of this pasture area are categorized as degraded (IMEA, 2010) and most support cattle stocking rates as low as 0.5 animal per hectare in some regions, resulting in high GHG emissions (IMEA, 2010; Galford et al., 2010). It has been proposed that the use of iCL in place of extensive, specialized pasture management could more than double the stocking rates of degraded pastures and improve soil quality where organic matter has been lost after years of monoculture (Observatorio ABC, 2014a,b; Peron and Evangelista, 2004; Oliveira et al., 2003).

In order to boost adoption of iCL and promote cattle intensification, Brazilian authorities approved the National Policy of Integrated Crop-Livestock-Forestry Systems (Government of Brazil, 2013) and created a new EMBRAPA[1] unit exclusively dedicated to the research and development of integrated systems. In addition, the Ministry of Agriculture launched the Low-Carbon Agricultural Plan (or simply "ABC Plan") in 2010 to facilitate capacity building, improve technical assistance and provide special credit lines to farmers adopting low-carbon agricultural practices – including iCL, no-till farming, biological nitrogen fixation, restoration of degraded pastures, commercial forest plantations and treatment of animal residues (Government of Brazil, 2011). The Plan is part of the country's National Policy for Climate Change, which defines a voluntary target for GHG emissions reduction of 36.1%–38.9% by 2020 relative to emissions projections for that year (Government of Brazil, 2009). Among other goals, the ABC Plan aims to increase the use of integrated systems by 4 million hectares, which is expected to avoid the emission of 18–22 million tons of carbon dioxide equivalent (CNA, 2012).

According to official estimates based on PROBIO[2] data, the potential area for integrated system expansion in the entire country is greater than 67 million hectares, but until 2010 these systems occupied only 1.5 million hectares (Balbino et al., 2011). The adoption of integrated systems across Mato Grosso has been particularly slow, reaching only 90,000 ha (or 0.4% of the state's agricultural area in 2010) (Balbino et al., 2011). Additionally, less than 5% of all ABC loans issued by 2014 had been allocated to integrated systems (Observatorio ABC, 2013).

Understanding the drivers and constraints of iCL occurrence within Brazil is essential for the successful implementation of climate-related policies put forward by the Brazilian Government. It may also offer insights into their potential viability as a climate smart, sustainable intensification strategy in regions where extensive cattle ranching persists. Yet, to the best of our knowledge, no study has ever tried to capture the aggregate effect of biophysical, socioeconomic and institutional requirements for iCL occurrence or its spatial variation in the region. Existing case studies of individual farms and localized experiments offer important insights into the economic and environmental benefits of agricultural integration under specific conditions, but do not elucidate the barriers to scaling up integrated production.

In this paper we examine the main factors associated with the occurrence of iCL in Mato Grosso. We argue that iCL systems have unique characteristics that distinguish them from specialized agricultural systems, and propose an analytical framework based on specific adoption determinants that arise from these characteristics. We test the extent to which variables observable at the household and municipality scales are associated with iCL occurrence and then compare the findings from both scales. We conclude by discussing these findings in light of past research on agricultural land use decisions, and identify potential leverage points for promoting iCL from a public policy perspective.

2. Background and analytical framework

The literature on the numerous factors influencing land use decisions is abundant. Such factors include prices of agricultural products and inputs (Richards et al., 2012; Garrett et al., 2013a); agricultural, environmental, and fiscal policies (Schnepf et al., 2001; Garrett et al., 2013b); soils, topography, and climate (Vera-Diaz et al., 2008; Mann et al., 2014; Spera et al., 2014); transportation costs (Walker et al., 2009); and household socioeconomic conditions, such as land tenure, indebtedness, age, education, experience and farm size (Lee, 2005; Knowler and Bradshaw, 2007). However, few studies have attempted to assess the determinants of more specific land management practices (e.g. crop-livestock rotations, fertilizer usage, no-till planting, or irrigation) in Brazil.

The decision of whether to manage the land via iCL versus specialized systems (specifically continuous cropland or pasture) involves many utility tradeoffs. These may include, among others, trading increased resilience to climate and market shocks and higher payouts in the long run for simplicity, lower labor needs, as well as certain payouts in the short run (Garrett et al., 2015). Because iCL involve more than one type of agricultural production, they may require greater labor intensity and higher investment costs than specialized systems. As such, labor availability, tenure security and farmers' preferences concerning risk and leisure are all factors that may influence the adoption of iCL (Sulc and Tracy, 2007; Garrett et al., 2015; Bonaudo et al., 2014; Lemaire et al., 2014; Alves et al., 2015; Thornton and Herrero, 2015). The level of local supply chain infrastructure (e.g. transportation networks, storage facilities and input retailers) is a crucial limitation of agricultural development in Brazil (Bowman et al., 2012; Garrett et al., 2013a; VanWey et al., 2013) and may co-determine the economic feasibility of crop-livestock integration. Access to information and technical assistance via formal channels (e.g. state research agencies), social networks (e.g. neighbors and cooperatives) or local agribusinesses

[1] EMBRAPA (in Portuguese, "Empresa Brasileira de Pesquisa Agropecuária") is the Brazilian National Agricultural Research Institute.

[2] PROBIO (in Portuguese, "Projeto de Conservação e Utilização Sustentável da Diversidade Biológica Brasileira") is a project for the conservation and sustainable use of the Brazilian biological diversity for which land cover maps of all Brazilian biomes were generated. PROBIO is conducted by the Brazilian Ministry of Environment and co-funded by the Brazilian Federal Government, the Global Environmental Facility (GEF), and the World Bank.