DOI: https://doi.org/10.14393/REE-v37n2a2022-61294
Instituto de Economia e Relações Internacionais – Universidade Federal de Uberlândia

economia
ensaios

Determinants for agricultural fertilizer use in Brazilian Amazon: a one-decade analysis

Determinantes do uso de fertilizantes agrícolas na Amazônia Brasileira: uma década de análise.

Marcos Rodrigues [a]
Wladimir Colman de Azevedo Junior [b]
David Costa Correia Silva [c]

Abstract: This manuscript compares one decade of fertilizer use in Legal Amazon municipalities, determining the main factors that incentive the adoption of this technology. We gathered data from Brazilian Agricultural Census for both 2006 and 2017 and estimated a multinomial logit model (MLM) to differentiate classes of fertilizer use. Our results shows that cattle ranching and rural credit are negatively correlated with fertilizer use. Large agricultural commodities production, rural mechanization, and the use of limestone are factors that contribute widely to use of fertilizers. Diffusion of knowledge to farmers, wider access to rural policies, and the agricultural private sector incentives could contribute to spread the use of fertilizer throughout Amazon.

Palavras-chave: logit model, Agricultural Census, cattle ranching, mechanization, technology
JEL Classification: Q13, R11.

Resumo: Neste artigo foi comparado uma década de uso de fertilizantes em municípios da Amazônia Legal, determinando os principais fatores que incentivam a adoção dessa tecnologia. Dados do Censo Agropecuário Brasileiro para 2006 e 2017 foram utilizados para estimar um modelo logit multinomial (MLM), diferenciando as classes de uso de fertilizantes. Os resultados demostram que a pecuária e o crédito rural estão negativamente correlacionados com o uso de fertilizantes. Commodities agrícolas de larga escala, mecanização rural e uso de calcário são fatores que contribuem para a adoção de fertilizantes. A difusão do conhecimento aos agricultores, maior acesso às políticas rurais e incentivos do setor privado agrícola podem contribuir para o uso de fertilizantes em toda a Amazônia.

Keywords: Modelo logit, Censo Agropecuário, pecuária, mecanização, tecnologia.
Classificação JEL: Q13, R11.

[a] Docente na Universidade Federal Rural da Amazônia. E-mail: marcos.rodrigues.adm@gmail.com.
[b] Docente na Universidade Federal de Mato Grosso. E-mail: azevedocolman@gmail.com
[c] Docente na Universidade Federal Rural da Amazônia. E-mail: davidcorreiasilva@hotmail.com

1. Introduction

The Brazilian Amazon occupation accelerated in the last decades through settlements projects. Mining, logging, and agricultural activities drove the economic path of development is this region (MENDONÇA; LOUREIRO; SACHSIDA, 2012). Cattle ranching is the most present and extensive activity in municipalities. However, its model of production is inefficient and have low potential of innovation (CARVALHO; DE AGUIAR; AMARAL, 2020; MERRY; SOARES-FILHO, 2017), in relation to agricultural commodities (as soybean, maize, cotton, sugarcane) developed in *Cerrado* areas (SANO, 2019), even though recent initiatives lead by supply chain large enterprises has notable potential to change this scenario (NEPSTAD; STICKLER; ALMEIDA, 2006).

Soil availability in the Amazon and the expansion of the agricultural frontier may result in a process of regional economic growth based on increased agricultural productivity. A similar process was observed in the *Cerrado* during the 1970s. The rise in agricultural productivity generates benefits for other economic activities (MCARTHUR; MCCORD, 2017; SCHULTZ, 1965), reducing the price of food and raw materials, increasing demand for machinery and equipment, expanding of transfers between different economic sectors, consequence of payment of taxes and of labor market, and boosting foreign exchange (KUZNETS, 1968). In this sense, policies can be adopted to encourage the adoption of modern technologies in rural areas, especially regarding the use of inorganic fertilizers (MCARTHUR; MCCORD, 2017).

As in the *Cerrado*, the expansion of the agricultural frontier to the Amazon depends on the use of technological packages. These packages integrate a highly verticalized supply chains that incorporates agricultural management based in extensive use of inputs (fertilizers, pesticides, quality seeds), mechanization (e.g. tractors and harvesters), infrastructure (silos and sheds), as well as more elaborate elements such as genetic improvements (GUDYNAS, 2008; JEPSON; BROWN; KOEPPE, 2008). The effects of these resources enable large agricultural production and encourage increased productivity.

However, some rural activities are not sufficiently integrated in these highly verticalized supply chains or do not receive enough support from policies or market institutions. Consequently, they are less prone to use modern inputs, including fertilizers. These activities include the low efficiency pasture areas (BOWMAN et al., 2012) based in extensive production; the low productive regional agriculture, which are supported only by local communities or agencies; and small farming systems (ROZON et al., 2015), with low use of capital and modern inputs, except for farms integrated to industries (SILVA; NAVEGANTES-ALVES, 2018). The existence of properties with these characteristics delays the economic development of some regions in the Brazilian Amazon, also negatively contributing to the agricultural production.

This research aims to identify the use of fertilizers to raise production by improving the soil by nutrients (nitrogen, phosphorus, and potassium) and its correlation to the presence of technologies and practices throughout the Amazon, as the correction of soil acidity or alkalinity, machinery density, social and financial capital, and available land. We seek to answer: i) are inorganic fertilizers being widely used in agricultural production in Legal Amazon? ii) which are the main factors that contribute the adoption of inorganic fertilizer in municipalities of the Legal Amazon? Our hypothesis states that the use of fertilizer in Amazon municipalities is concentrated in regions with large scale agriculture and commodities productions, where technology and innovation diffusion are accessible by farmers.

2. Material and Methods

2.1. Data

To answers these questions, our approach was based in data gathered from Brazilian Legal Amazon 771 municipalities, which considers eight states (Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima e Tocantins) and part of Maranhão. To compare one decade of agricultural development, 771 municipalities of the Legal Amazon were considered in this study.

Data were gathered from Brazilian Agricultural Census of years 2006 and 2017 (IBGE, 2006, 2017). Rural credit data was obtained in Brazilian Central Bank (BCB, 2020), and deforestation from the *Projeto de Monitoramento do Desmatamento na Amazônia Legal por Satélite* (PRODES) project, from Brazilian National Institute for Spatial Research (INPE, 2020). Variables in Brazilian currency were updated to 2017 prices using the IGP-DI index from Getúlio Vargas Foundation.

2.2. Statistical Model

Brazilian Agricultural Census data for fertilizer use in municipalities is aggregated in count of rural properties that use or do not use fertilizer in their production. Even though Agricultural Census do not provide the amount of fertilizer used (in tons), we classified municipalities in group of technology adoption according to relative number of farms that use fertilizers.

To estimate the factors that influence the adoption of this technology, we used a multinomial logit model (MLM). This method is widely applied in several areas were dependent variables is presented in multiple options (DOU et al., 2017; NDORO; MUDHARA; CHIMONYO, 2015; PANDA; SREEKUMAR, 2012).

The MLM applies a logit method simultaneously to a reference class. Let c the classes of municipalities farm adoption of fertilizers and for each municipality I, π_{ij} represent the probability of being in class j (with j = 1, 2, …, c). Then is possible to pair responses in log ratio as function of k independent variables (x) and its their parameters (β) in (1) (AGRESTI, 2015):

$$log\frac{\pi_{ij}}{\pi_{ic}} = \sum_{k=1}^{p} \beta_{jk} x_{ik} \ , \qquad j = 1, 2, \dots, c-1 \tag{1}$$

With the $c - 1$ equation it is possible to estimate the equations for each pair of categories (2):

$$log\frac{\pi_{ia}}{\pi_{ib}} = \ log\ \frac{\pi_{ia}}{\pi_{ic}} - log\ \frac{\pi_{ib}}{\pi_{ic}} \ = \ \sum_{k=1}^{p} (\beta_{ak} - \beta_{bk}) x_{ik} \tag{2}$$

Fertilizers use in agricultural production in Legal Amazon was classified in three categories: 1) low adoption of fertilizer – municipalities where the count of properties that use fertilizer is 25% or less; 2) moderate adoption of fertilizer– municipalities with more than 25% and 50% or less of properties using fertilizer; and 3) high adoption of fertilizer– more than 50% of properties declared to use fertilizer. The class ‘low adoption of fertilizer use’ was set as reference to estimate the MLM.

The variable area of production is the sum of the cultivated area (in hectares) for vegetal activities, regardless of the crop. According to IBGE data, in 2006, soy, corn and rice occupied 80% of the cultivated area in Brazilian Amazon and raised to 87% in 2017 (IBGE, 2021). These crops represented about 64% of the total fertilizer consumed in Brazil in 2015 (ANDA, 2016). Cattle ranching by its turn represent the most part of animal production in Brazilian Amazon, and the greater area use since the extensive system in the most diffused method. Independent variables are presented in Table 1.

Table 1: Independent variables and metrics for the MLM.

Variable	Description	Metric
ACR	Area of cattle ranching	In thousand hectares
AVP	Area of vegetal production	In thousand hectares
RC	Rural Credit	In Millions of Brazilian currency
TD	Tractor Density	Tractors / thousand hectares
TAC	Technical Assistance class	Class 1: low adoption (25% or less of properties in municipality) Class 2: moderate adoption (between 25% and 50% of properties in municipality) Class 3: high adoption (more than 50% of properties in municipality)
AC	Association class	
PC	Pesticides class	
DC	Deforestation class	
LC	Limestone class	Class 1: low adoption (10% or less of properties in municipality) Class 2: moderate adoption (between 10% and 25% of properties in municipality)

		Class 3: high adoption (more than 25% of properties in municipality)

Class variables (Technical assistance, pesticides use, part of association and deforestation of forest areas) followed the same classification of fertilizer. Limestone use is an exception, since it is relatively less adopted by farms in the Legal Amazon. Thus, we established this new class category: 1) low adoption of limestone– municipalities were 10% or less of total properties use fertilizer; 2) moderate adoption of limestone– municipalities with more than 10% and lower than 25% of properties using fertilizer; and 3) high adoption of limestone – 25% or more of properties use fertilizer.

3. Results

Overall, fertilizer use in Amazon farms increased from 10.4% of rural properties in 2006 to 20.4% in 2017. Non-family farms relatively adopted more fertilizer use (22.3%) than family farms (18.3%) in 2017. Family farms that declared to not use fertilizer in 2017 represents 68.2% of total Amazonian farms. Even though non-family farms represent just 19% of Amazonian Brazilian properties, they correspond to 78% of total rural area and concentrate most part of the agricultural commodities production (96.6% of soybean and 97.5% of maize production in 2017), consequently are more prone to use fertilizer.

MLM was performed to both Agricultural Census (2006 and 2017) in 771 municipalities of the Brazilian Legal Amazon (considering nine states: Acre, Amazonas, Amapá, Maranhão, Mato Grosso, Pará, Rondônia, Roraima and Tocantins). Parameters estimates are presented in Table 2 and low adoption of fertilizer was used as base.

Cattle ranching area was negative and significant or both years and models. These results were expected, the increase in pastureland decreases the probability of municipalities to higher class of fertilizer adoption in rural properties (between 0.4% and 2.2% of decrease in chance of fertilizer use for each additional 1000 hectares). Positive and significant coefficient for crop areas in 2017 shows that an additional of 1000 hectares would increase probability of more properties using fertilizers by 0.8% from low to moderate adoption and 1.7% from low to high adoption.

Rural credit negative coefficient in 2017 indicated an inverse relation between funding and adoption of fertilizer use, an increase of 1 million (Brazilian currency) in new contracts would reduce the change of municipality from being in moderate adoption by 0.6% and by 1.1% in high adoption.

Two technological and important variables showed positive and significant coefficients to higher adoption of fertilizer use in both analyzed years: tractor density and limestone use. An increase of one tractor per thousand hectares in 2006 increase the change of municipalities shift from moderate to high fertilizer adoption by 6.9%. However, in 2017, this raised to 88.9%. Limestone use was strongly correlated to higher level of fertilizer use. However, only 3,6% of Amazonian rural properties used limestone in 2006. In 11 years, the relative number of properties that use limestone duplicated (7,2% in 2017).

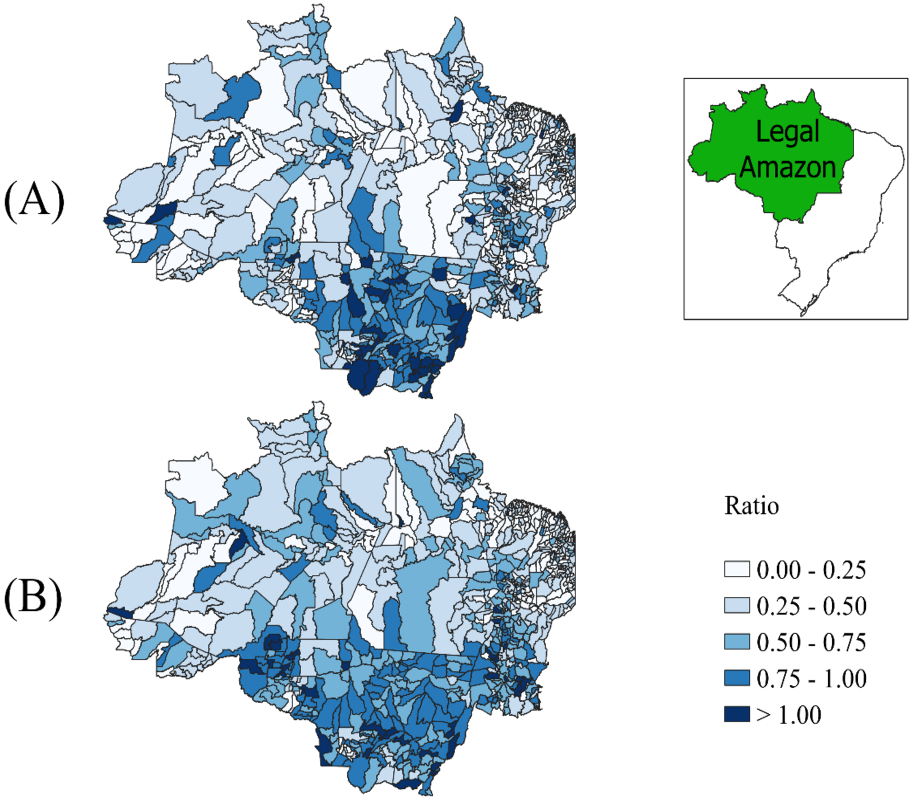
Table 2: Coefficients of MLM for fertilizer use in Amazon.

	2006		2017	
Y = fertilizer use Low adoption (base)	**High adoption of fertilizer**	**Moderate adoption of fertilizer**	**High adoption of fertilizer**	**Moderate adoption of fertilizer**
(Intercept)	-3.942 ** (0.505)	-2.540** (0.277)	-5.286** (0.677)	-2.474** (0.265)
ACR	-0.011 ** (0.004)	-0.004 ** (0.001)	-0.022** (0.006)	-0.004** (0.001)
AVP	0.004 (0.005)	0.003 (0.003)	0.017** (0.005)	0.008** (0.003)
RC	-0.019 (0.014)	-0.015 (0.011)	-0.011** (0.005)	-0.006* (0.004)
TD	0.835 ** (0.21)	0.768 ** (0.188)	1.362** (0.231)	0.726** (0.164)
TAC – class 2	-1.331 * (0.722)	0.036 (0.339)	-1.082 (0.708)	0.344 (0.337)
TAC – class 3	0.016 (0.84)	1.100** (0.484)	2.929** (1.276)	0.742 (1.157)
AC – class 2	0.780 (0.558)	0.113 (0.307)	-0.629 (0.727)	-0.652** (0.355)
AC – class 3	-0.388 (0.809)	-0.754* (0.436)	-3.738** (2.03)	-1.626** (0.948)
PC – class 2	1.375** (0.558)	0.930** (0.339)	-0.538 (0.645)	0.17 (0.292)
PC – class 3	2.053** (0.985)	-0.58 (1.015)	0.717 (0.659)	0.656** (0.331)
DC – class 2	-0.617 ** (0.668)	-0.453 ** (0.399)	-0.674 (0.802)	-0.371 (0.352)
DC – class 3	-1.300 (0.646)	-0.664 (0.354)	0.656 (0.621)	-0.399 (0.287)
LC – class 2	2.420** (0.596)	2.135** (0.337)	2.174** (0.59)	1.214** (0.263)
LC – class 3	7.532** (1.366)	5.426** (1.197)	7.171** (1.384)	4.658**** (1.133)

Note: ACR: Area of cattle ranching; AVP: Area of vegetal production; RC: Rural Credit; TD: Tractor Density; TAC: Technical assistance class; AC: Association class; PC: Pesticides class; DC: Deforestation class; LC: Limestone class.
Note: Standard errors in parentheses. p-values: ** significant at 5%; * significant at 10%.

Correction of soil pH is vital for the efficiency of inorganic fertilizers, so it is expected that the ratio between properties using fertilizer in conjunction with limestone is close to 1. Between 2006 and 2017, the ratio above 0.75 increased from 37.6% to 45.5 %, a moderate expansion of limestone use, however, mainly concentrated in regions with large agricultural commodities production (Figure 1).

Fig. 1: Comparative of ratio between limestone and fertilizer use in Brazilian Legal Amazon – 2006 and 2017.



Source: IBGE (IBGE, 2006, 2017).

Note: (A) 2006 Agricultural Census; (B) 2017 Agricultural Census.

For classes variables, technical assistance in 2017 was relevant to increase adoption of fertilizer (however, in 2017 only 10.4% of rural properties declared to receive technical assistance), while pesticides use was more significant in 2006. Capital social was represented by participation in associations and cooperatives and the negative coefficient showed inverse correlation to fertilizer use, mainly for 2017. Deforestation showed a negative correlation to fertilizer use only in 2006 in municipalities classes with less than 50% of deforested area.

4. Discussion

Agricultural expansion in the Amazon after the 1960's followed a model of extensive livestock ranching to consolidate land rights (DEININGER; BYERLEE, 2012; JEPSON, 2006). In recent years, new areas of cattle ranching in the Amazon have taken place mainly in edges of expansion of agricultural frontier (MÜLLER-HANSEN et al., 2019), where deforestation clear areas for pasture that in long-term are abandoned due to degradation or substituted by crops (SILVA et al., 2018). In expansion areas, production increases through clearing new areas, leading to deforestation, reducing immobilization of capital in modern machinery, equipment, processes, and inputs, such as fertilizers. This is a possible due to fertilizers not being correlated with the expansion of the frontier.

The use of fire release nutrients in the soil (DAVIDSON et al., 2008), which facilitate the development of pasture and cattle ranching appears as an economic activity that do not require highly developed markets or capital investment. Poor systems management, consequently, leads this activity to an inefficient path of development in the Brazilian Amazon (SILVA et al., 2018), while the lower use of fertilizers and poor systems management increases the degraded areas in Amazon, with negative externalities for social and environmental perspectives. However, market initiatives and policies to increase efficiency and reduce environmental impacts in cattle ranching may change the long-term sustainability and technology use in beef supply chain (NEPSTAD; STICKLER; ALMEIDA, 2006; VALE et al., 2019).

The non-periodically restore of soil fertility through fertilization causes degradation of pastures and soil (DIAS-FILHO, 2015), resulting in loss of productivity (MEURER, 2006). Fertilizers should also be used in livestock activities in order to make them more efficient and to avoid soil degradation and the consequent negative externalities (DIAS-FILHO, 2017; MEURER, 2006; VITOUSEK et al., 2009). Even though cattle ranching is not an efficient activity in Amazon, its area increased more in the last decade (7.2 million hectares) than cropping area (6.7 million hectares).

Although the development of agriculture in the Amazon has incorporated a series of technologies, notably with the use of fertilizers, aiming to increase the supply and productivity of grains, the same cannot be said about livestock. Cattle farming in the Amazon still follows a rustic logic of using large areas (extensive production). Fertilizers use consequently do not increase widely through Amazon since cattle ranching remains the predominant rural activity and has low use of fertilizer.

Amazonian agricultural expansion is based in increased use of fertilizers, mainly in large scale commodities production (as soybean, maize, and cotton). These crops occurs mainly in the *Cerrado* areas where some authors argue that the acidity and the low nutrient content in the soil, require use of lime and fertilizer (CATTELAN; DALL'AGNOL, 2018). Also, high integrated markets are predominant, patterns of production and quality are very developed and diffused in the international supply chain through technological packages (WESZ JR, 2016), homogenizing practices and input uses.

Our results showed that large areas of agriculture lead to higher chances of increase in fertilizer use by farmers in Amazon municipalities. Fertilizer use is positive correlated with increasing farms efficiency in Brazil (BARBOSA et al., 2013). However, intensive use of fertilizers in agriculture is not always associated with increase in production. Soil management without attention to its resilience is subject to physical and chemical depletion, such as compaction, erosion, salinization, acidification, and low fertility (JANKOWSKI et al., 2018). Examples of eutrophication occurs in the Gulf of Mexico from excess N and P used by American farming upstream in the Mississippi River watershed and in the northern Europe, where the excesses of nutrients caused air and water pollution (VITOUSEK et al., 2009). Insufficient nutrient replacement and soil acidification is also evident in Africa (COBO; DERCON; CADISCH, 2010). Insufficient fertilizer management is detrimental to production efficiency, food security, and the environment, requiring attention from the government and farmers.

Due to the characteristics of the Brazilian soil, the use of limestone should be very associated with the use of fertilizers, as it becomes necessary to reduce the acidity of the soil. The intensive use of the soil can cause the reduction of its fertility, harming the yields of the producer, and accelerating the process of acidification of the soil. In this situation, the use of fertilizers would only be effective after liming, because without load sites available, nutrients tend to leach to the ground water (MEURER, 2006).

In the Amazon, although the relative number of properties that use limestone duplicated in one decade, the adoption of this technology is still reduced, concentrating in areas that have modern agriculture as its main economic driver, mainly for soybean. In municipalities such as Campos de Júlio (MT), Primavera do Leste (MT), Lucas do Rio Verde, Sorriso (MT), Sapezal (MT), Dom Eliseu (PA), more than 40% of farmers used limestone. However, in regions where vegetal activities are based in regional products with less demand of inputs or without access of technology and/or technical assistance, the use of limestone is low, as in the Amazonas's municipalities, where, according to the IBGE, cassava production exceeds 60% of the harvested area.

Our results showed a tiny increment in the ratio between limestone and fertilizer use in rural properties. Amazon logistics seems to one reason for low adoption of limestone in farms, the physiographic characteristics of the region and the great distances to be traveled to the big centers, configure a situation of low integration with the supply chains (OLIVEIRA et al., 2015). These clusters, when oriented to technology use, increase the demand for inputs and at same time the output, which also require logistics to export the production (ITO; ZYLBERSZTAJN, 2018; ZYLBERSZTAJN; FAVA NEVES; CALEMAN, 2015). Regions with weak logistics, mainly based in cattle ranching or production to local markets have lower ratio of limestone and fertilizer use. Policies can increase agricultural efficiency connecting modern input markets to these regions through the development of logistics, phenomenon that occurred in the *Cerrado* since 70s.

Use of fertilizers, mainly in regions with predominance of large-scale commodities production, require machinery to increase labor productivity. Tractor density showed a strong correlation with high use of fertilizer in municipalities in the Amazon. Some studies demonstrated that mechanization increase efficiency in fertilizer use and productivity in crop productions (SINGH; RAMTEKE; KHAN, 2016). Policies to mechanization may improve the density of tractors and use of fertilizer.

The Brazilian Rural Credit Program is important to agricultural production since it subsides funding rates and provide financial support to development of rural activities. Our coefficient showed a negative correlation between fertilizer use and credit. Agricultural production in Amazon municipalities is based in a large set of animal and vegetal and a diversity of contracts. Consequently, rural credit is subject for a variety of uses and policies initiatives.

Large scale agricultural productions that use more inputs (as soybeans, maize, cotton, sugar cane), the amount of financial resources available in official rural credit is insufficient, requiring that farmers gather resources from private agencies, which occurs frequently in commodities (soybean, maize, cotton) and some animals production. Barter contracts are main drivers of private credit and significantly improve access of technology for farmers (RODRIGUES; MARQUEZIN, 2014), reducing effectiveness of official rural credit. For cattle ranching, the credit facilitates the acquisition and formation of herds, while investments for system management are precarious.

For small farmers, especial Programs like The National Program for Strengthening Family Farming (PRONAF) are insufficient to fulfill farms demand for financial resources, sometimes concentrating investments in farms that are more productive (MAIA; EUSÉBIO; DA SILVEIRA, 2019). Official rural credit is also subsided to reach poorer farmers, with low access to technologies, including those far from technical assistance to purchase or be guided to acquire fertilizers.

Fertilizer use is not widely distributed throughout the Brazilian Amazon. Regions with predominance of large-scale agricultural production showed that farmers are more inclined to adopt fertilizers. Morello at al. (2018) investigated the use of fertilizer by small-farmers in Amazon and noticed that knowledge diffusion to farmers is an important strategy, however, supply market in some regions in the Amazon must be also incentivized. Small-scale farming require the technical assistance to avoid incorrect use of fertilizer (PAN; ZHANG, 2018). Technical assistance presented a single correlation with fertilizer use in this study, demonstrating that policies for knowledge must be improved to reach more farmers –since only 10% of farmers declared to receive assistance in 2017.

While large farms are connected to highly verticalized markets with large technological diffusion, family farmers are concentrated in local supply chain with lower technology use. Family farms do not use fertilizer correspond to more than 68% of rural properties in Brazilian Amazon.

The inverse relationship between associativism and fertilizer use corroborate these results. Cooperatives and associations could contribute to the diffusion of knowledge and technologies through community participation. Nonetheless, innovations and technology are more prone to reach farms thought market.

Conclusion

Through the data from Brazilian Agricultural Census, one decade of inorganic fertilizer use change in Amazon was analyzed. This study identified that, even though the number of farms that use fertilizer duplicated between 2006 and 2017, its use is still relatively restrict, and it is not widely distributed throughout the Amazon region. Large scale agricultural production (as soybean, maize, and cotton) is responsible to the most part of fertilizer demand, since these crops are connected to highly verticalized supply chains. In this sense, the inferences produced from these data are limited to generalization, requiring detailed future studies for each state characteristics. Cattle ranching presence decrease the probability of farmers adopt fertilizers, as this activity in the Amazon is historically extensive and present low efficient.

Rural credit showed negative correlation to fertilizer use. However, it is subject to regional productions and policies, which interfere in its effectiveness to diffuse technology access. Bond to associations also showed a reduce in the chance of farms to use fertilizer. Technological variables, as limestone and tractor density increase use of fertilizer. Deforestation and the use of fertilizers are not correlated, due to the low technological use in expansion areas.

Policies to increase the use of inorganic fertilizer, aiming to improve farms efficiency, could focus on (i) the diffusion of knowledge and technology, mainly to family farms, which represent most part of Amazonian farms; (ii) access to limestone, whose availability in some regions is very low; and (iii) mechanisms to intensify the use of machines, responsible to increase labor productivity. Expanding fertilizer use in the most inefficient activities could contribute to the increase of productivity as well as the better management and conservation of the soil.

References

AGRESTI, A. **Foundations of Linear and Generalized Linear Models**. New Jersey: John Wiley & Sons, 2015.

ANDA, A. N. PARA D. DE A. **Anuário Estatístico do Setor de Fertilizantes, 2015**São PauloNagy, 2016.

BARBOSA, W. DE F. et al. Technical efficiency of agriculture in the regions of Brazil and its determinants. **Ciencia Rural**, v. 43, n. 11, p. 2115–2121, 30 out. 2013.

BCB. **Matriz de Dados do Crédito Rural**, 2020. Disponível em: <https://www.bcb.gov.br/estabilidadefinanceira/creditorural>. Acesso em: 31 mar. 2020

BOWMAN, M. S. et al. Persistence of cattle ranching in the Brazilian Amazon: A spatial analysis of the rationale for beef production. **Land Use Policy**, v.29, n.3, p. 58–568, 2012.

DOI: https://doi.org/https://doi.org/10.1016/j.landusepol.2011.09.009

CARVALHO, R.; DE AGUIAR, A. P. D.; AMARAL, S. Diversity of cattle raising systems and its effects over forest regrowth in a core region of cattle production in the Brazilian Amazon. **Regional Environmental Change**, v. 20, n. 2, p. 44, 2020. DOI: https://doi.org/10.1007/s10113-020-01626-5

CATTELAN, A. J.; DALL'AGNOL, A. The rapid soybean growth in Brazil. **OCL**, v. 25, n. 1, p. 1–12, 2018. DOI: https://doi.org/10.1051/ocl/2017058

COBO, J. G.; DERCON, G.; CADISCH, G. Nutrient balances in African land use systems across different spatial scales: A review of approaches, challenges and progress. **Agriculture, Ecosystems & Environment**, v. 136, n. 1, p. 1–15, 2010. DOI: https://doi.org/https://doi.org/10.1016/j.agee.2009.11.006

DAVIDSON, E. A. et al. An integrated greenhouse gas assessment of an alternative to slash-and-burn agriculture in eastern Amazonia. **Global Change Biology**, v. 14, n. 5, p. 998–1007, 2008. DOI: https://doi.org/10.1111/j.1365-2486.2008.01542.x

DEININGER, K.; BYERLEE, D. The rise of large farms in land abundant countries: Do they have a future? **World Development**, v. 40, n. 4, p. 701–714, 2012. DOI: https://doi.org/10.1016/j.worlddev.2011.04.030

DIAS-FILHO, M. B. Estratégias de recuperação de pastagens degradadas na Amazônia Brasileira. **Documentos / Embrapa Amazônia Oriental**, v. Junho, p. 25, 2015.

DIAS-FILHO, M. B. **Degradação de Pastagens : o que é e como evitar**. 1. ed. Brasília, DF: EMBRAPA, 2017.

DOU, Y. et al. Impacts of Cash Transfer Programs on Rural Livelihoods: a Case Study in the Brazilian Amazon Estuary. **Human Ecology**, v. 45, n. 5, p. 697–710, 2017. DOI: https://doi.org/10.1007/s10745-017-9934-1

GUDYNAS, E. The New Bonfire of Vanities: Soybean cultivation and globalization in South America. **Development**, v. 51, n. 4, p. 512–518, 2008. DOI: https://doi.org/10.1057/dev.2008.55

IBGE. **Censo Agropecuário 2006Segunda Apuração**, 2006. Disponível em: <https://sidra.ibge.gov.br/pesquisa/censo-agropecuario/censo-agropecuario-2006/segunda-apuracao>. Acesso em: 31 mar. 2020

IBGE. **Censo Agropecuário 2017Resultados Definitivos**, 2017. Disponível em: <https://sidra.ibge.gov.br/pesquisa/censo-agropecuario/censo-agropecuario-2017>. Acesso em: 11 ago. 2021

IBGE. **Produção Agrícola Municipal, 2017. Série Histórica das Culturas Temporárias e Permanentes 1974-2012.** Disponível em: <https://sidra.ibge.gov.br/pesquisa/pam/tabelas>. Acesso em: 13 out. 2021.

INPE. **Prodes: Monitoramento da floresta Amazônica por satélite**, 2020. Disponível em: <http://www.obt.inpe.br/OBT/assuntos/programas/amazonia/prodes>. Acesso em: 1 abr. 2020

ITO, N. C.; ZYLBERSZTAJN, D. Vertical integration in the Brazilian orange juice sector: Power and transaction costs. **International Food and Agribusiness Management Review**, v. 21, n. 1, p. 1–16, 2018. DOI: https://doi.org/10.22434/IFAMR2016.0071

JANKOWSKI, K. et al. Deep soils modify environmental consequences of increased nitrogen fertilizer use in intensifying Amazon agriculture. **Scientific Reports**, v. 8, n. 1, p. 13478, 2018. DOI: https://doi.org/10.1038/s41598-018-31175-1

JEPSON, W. Private agricultural colonization on a Brazilian frontier, 1970-1980. **Journal of Historical Geography**, v. 32, p. 839–863, 2006. DOI: https://doi.org/10.1016/j.jhg.2004.12.019

JEPSON, W.; BROWN, J. C.; KOEPPE, M. Agricultural Intensification on Brazil's Amazonian Soybean Frontier. In: **Land Change Science in the Tropics: Changing Agricultural Landscapes**. Boston, MA: Springer US, 2008. p. 73–92. DOI: https://doi.org/10.1007/978-0-387-78864-7_5

KUZNETS, S. **Toward a Theory of Economic Growth with Reflections on the Economic Growth of Modern Nations**. Nova York: Norton, 1968.

MAIA, A. G.; EUSÉBIO, G. DOS S.; DA SILVEIRA, R. L. F. Can credit help small family farming? Evidence from Brazil. **Agricultural Finance Review**, v. 80, n. 2, p. 212–230, 2019. DOI: https://doi.org/10.1108/AFR-10-2018-0087

MCARTHUR, J. W.; MCCORD, G. C. Fertilizing growth: Agricultural inputs and their effects in economic development. **Journal of Development Economics**, v. 127, n. September 2016, p. 133–152, 2017. DOI: https://doi.org/10.1016/j.jdeveco.2017.02.007

MENDONÇA, M. J.; LOUREIRO, P. R. A; SACHSIDA, A. The dynamics of land-use in Brazilian Amazon. **Ecological Economics**, v. 84, p. 23–36, 2012. DOI: https://doi.org/10.1016/j.ecolecon.2012.08.014

MERRY, F.; SOARES-FILHO, B. Will intensification of beef production deliver conservation outcomes in the Brazilian Amazon? **Elem Sci Anth**, v. 5, p. 24, 2017. DOI: https://doi.org/10.1525/elementa.224

MEURER, E. J. **Fundamentos de Química do Solo**. Porto Alegre: Evangraf, 2006.

MORELLO, T. F. et al. Fertilizer Adoption by Smallholders in the Brazilian Amazon: Farm-level Evidence. **Ecological Economics**, v. 144, p. 278–291, 2018.

DOI: https://doi.org/https://doi.org/10.1016/j.ecolecon.2017.08.010

MÜLLER-HANSEN, F. et al. Can Intensification of Cattle Ranching Reduce Deforestation in the Amazon? Insights From an Agent-based Social-Ecological Model. **Ecological economics**, v. 159, p. 198–211, 2019. DOI: https://doi.org/10.1016/j.ecolecon.2018.12.025

NDORO, J. T.; MUDHARA, M.; CHIMONYO, M. Farmers' choice of cattle marketing channels under transaction cost in rural South Africa: a multinomial logit model. **African Journal of Range & Forage Science**, v. 32, n. 4, p. 243–252, 2 out. 2015. DOI: https://doi.org/10.2989/10220119.2014.959056

NEPSTAD, D. C.; STICKLER, C. M.; ALMEIDA, O. T. Globalization of the Amazon soy and beef industries: Opportunities for conservation. **Conservation Biology**, v. 20, n. 6, p. 1595–1603, 2006. DOI: https://doi.org/10.1111/j.1523-1739.2006.00510.x

OLIVEIRA, R. R. DE et al. Desafios Logísticos na Amazônia Legal: Estudo de caso em uma Agroindústria. **Espacios**, v. 36, n. 5, p. 8, 2015.

PAN, D.; ZHANG, N. The Role of Agricultural Training on Fertilizer Use Knowledge: A Randomized Controlled Experiment. **Ecological Economics**, v. 148, p. 77–91, 2018. DOI: https://doi.org/https://doi.org/10.1016/j.ecolecon.2018.02.004

PANDA, R. K.; SREEKUMAR. Marketing Channel Choice and Marketing Efficiency Assessment in Agribusiness. **Journal of International Food & Agribusiness Marketing**, v. 24, n. 3, p. 213–230, 1 jul. 2012. DOI: https://doi.org/10.1080/08974438.2012.691812

RODRIGUES, M.; MARQUEZIN, W. R. CPR como um instrumento de crédito e comercialização. **Revista de Política Agrícola**, v. 23, n. 2, p. 40–50, 2014.

ROZON, C. et al. Spatial and temporal evolution of family-farming land use in the Tapajós region of the Brazilian Amazon. **Acta Amazonica**, v. 45, p. 203–214, 2015.

SANO, E. E. Land Use Expansion in the Brazilian Cerrado. In: HOSONO, A.; HAMAGUCHI, N.; BOJANIC, A. (Eds.). . **Innovation with Spatial Impact: Sustainable Development of the Brazilian Cerrado**. Singapore: Springer Singapore, 2019. p. 137–162. DOI: https://doi.org/10.1007/978-981-13-6182-1_5

SCHULTZ, T. W. **A Tranformação da Agricultura Tradicional**. Rio de Janeiro: Zahar Editores, 1965.

SILVA, E. M.; NAVEGANTES-ALVES, L. F. Organization and diversity of family farmers' production systems integrated agribusiness palm northeast Pará. **Revista Brasileira de Gestao e Desenvolvimento Regional**, v. 14, n. 1, p. 166–192, 2018.

SILVA, M. A. et al. Achieving low-carbon cattle ranching in the Amazon: ‘Pasture sudden death’ as a window of opportunity. **Land Degradation & Development**, v. 29, n. 10, p. 3535–3543, 2018.
DOI: https://doi.org/10.1002/ldr.3087

SINGH, D.; RAMTEKE, R.; KHAN, I. R. Yield Enhancement Through Fertilizer Placement by Machine Below the Seed in Rain-fed Soybean Crop Under Vertisols. **Agricultural Research**, v. 5, n. 1, p. 104–108, 2016.
DOI: https://doi.org/10.1007/s40003-015-0193-3

VALE, P. et al. The Expansion of Intensive Beef Farming to the Brazilian Amazon. **Global Environmental Change**, v. 57, p. 101922, 2019.
DOI: https://doi.org/https://doi.org/10.1016/j.gloenvcha.2019.05.006

VITOUSEK, P. M. et al. **Nutrient imbalances in agricultural developmentScience**, jun. 2009.
DOI: https://doi.org/10.1126/science.1170261

WESZ JR, V. J. Strategies and hybrid dynamics of soy transnational companies in the Southern Cone. **The Journal of Peasant Studies**, v. 43, n. 2, p. 286–312, mar. 2016.
DOI: https://doi.org/10.1080/03066150.2015.1129496

ZYLBERSZTAJN, D.; FAVA NEVES, M.; CALEMAN, S. M. DE Q. **Gestão de Sistemas de Agronegócios**. 1. ed. São Paulo: Atlas, 2015.