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Agro-Pastoral Expansion and Land Use/Land Cover Change Dynamics in Mato Grosso, Brazil

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Abstract: Large-scale land use/land cover changes have occurred in Mato Grosso State (hereafter MT), Brazil, following the introduction of extensive mechanized agriculture and pastoral activities since the 1980s. Author investigated what kind of agro-pastoral activities which are both cattle ranching and top five crops (soybean, sugarcane, corn, cotton and rice) that are closely related to land use change on lands experiencing conversion land use change (such as deforestation and the increase in deeply anthropogenically influenced areas) at each municipal district in MT. Then, this study identifies the volume of exports including contribution ratio by municipal districts where land use changed due to agro-pastoral activities. The patterns of vegetation change indicated that cattle ranching, corn, cotton, rice croplands in the northwest, and soybean and sugarcane fields in the central areas are the main contributors to deforestation. It is shown that land use change due to soybean or corn cultivation occurs mainly in the west and the southeast, respectively. Corn cultivation is associated with a greater increase in anthropogenically influenced areas than soybean cultivation. The municipal districts that export each agro-pastoral product with land use change are limited. Exports of soybeans, corn, and cotton in the municipal districts associated with deforestation had increased dramatically after experienced land use change. For example, Sapezal, which has experienced deforestation, was the only municipal district associated with export of corn to only Switzerland. Since 2007, the number of export partners has increased to 56 countries with the export volume increased 2300 times. These findings highlight the overall non-sustainability of environmental resource development activities in MT.

Keywords: cattle ranching; deforestation; land use change; mechanized agriculture

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1. Introduction

Deforestation, which is a major cause of land use change, in the southern and eastern Brazilian Amazon continues to spread along with population growth [1], expanding road networks [2], uncontrolled slash-and-burn cultivation, large-scale mechanized agriculture and cattle ranching [3], commercial timber harvesting, mining and selective logging [4]. Demands for farmland and pasture are the key immediate drivers of land use change in Brazil, and there is little evidence that agricultural and pastoral expansion is grinding to a halt [5]. Brazil holds the greatest potential for further agricultural and pastoral expansion in the 21st century [6]. Soybean, currently produced by large-scale mechanized agriculture, and meat by cattle ranching, are major contributors to the Brazilian economy [7]. Although agricultural and pastoral expansion alone explain the deforestation rates observed in the past [8], both processes of agricultural and pastoral expansion and deforestation have long been connected in Brazil [9–11]. In fact, vast areas of forests and savannahs have been converted into farmland and pasture [11].

The Brazilian state of Mato Grosso (hereafter MT) is the world's largest soybean and beef production area. During the 1970s, soybean production began a vigorous expansion in southern MT where cerrado is dominant [12]. Rudorff et al. [7] detected the presence of soybean crops in deforested areas during the period 2007–2009. The production is reported to have increased annually and was accelerated by the entrance of foreign- financed companies into the regions due the demands of the world market. The increase in cattle herd in MT accounts for the bulk of the deforestation expansion in the north [13–15]. The increase in cattle herd in the Brazilian Amazon is due to growing demand for Brazilian beef in the domestic market and the surge in demand for Brazilian beef for export [16] following the bovine spongiform encephalopathy (BSE) crisis, which reduced demand from the United States and Europe along with a drop in supply from Australia and Argentina [17]. Nepstad et al. [9] showed that Amazon beef and soybean industries are increasingly responsive to economic signals emanating from around the world, such as those associated with BSE outbreaks and China's economic growth.

Soybean production began to increase dramatically from the 1990s, and it has been the most profitable cash crop exported from Brazil since 1997 [18,19]. Through the early 2000s, Amazon deforestation became far more sensitive to global influences as commodity market conditions and technological advances favored the first large-scale expansion of soy and other mechanized crops into the region [9,19]. Morton et al. [3] showed that the mean annual soybean price during 2000–2004 and the amount of deforestation for cropland in MT were strongly positively correlated. They also found that cropland deforestation was on average twice as large as the area of forests cleared for pasture. Fearnside [20] noted that soybean production was the biggest threat to Amazon forests. Brown et al. [21] and Barona et al. [22] used estimations of deforestation based on LANDSAT data provided from the National Institute for Space Research (INPE) to highlight the indirect effects of soybean production on deforestation. They showed that the expansion of soybean plantation areas often occurs in pre-deforested areas in MT, where part of the deforested areas that were used as pastures have been transformed into soybean plantations. Ferrante and Fearnside [23] stated that cattle ranchers in MT have been selling their pasture for high prices to soybean growers and buying cheap land farther north to deforest for beef production. Kusching et al. [24] stated that the expansion of agricultural land is indirectly driving deforestation where forests lose 8 ha for every 1 ha of soybean production and 0.15% per 1 km^2 for every 1% increase in cattle density. After all, it is safe to assume that soybean cultivation has indirectly caused deforestation.

Some Brazilian croplands, including those in MT, have been shifting to corn or sugarcane for biofuel production [11,25], with a large number of factories built for that purpose. The changes in the Brazilian agro-industry have been tremendous, though many questions about the nature of these transformations and their drivers remain unanswered. Cattle pasture and soybean plantation are surely by far the largest replacements from amazon forests [22]. Spillover effects from cattle pasture and soybean plantation are the main empirical driver of continued deforestation surely confirmed statistically by Arima et al. [26]. Despite these facts that we know, the clear increase in deforestation shows no signs of stopping in MT [27]. In the Brazilian amazon, people must strategically apply diverse and innovative mechanisms to conserve ecosystems [28,29]. Recent studies have sought to distinct restoration strategies [30,31]. However, a continuous and sustainable strategy has not been developed.

Then, author have three questions as follows; (1) Are soybean production and cattle ranching really the only influences on land use change? (2) Do other crops have an impact on land use change or not? (3) Where are the crops harvested on land that has been converted from forest to agricultural area consumed? For answering these questions, the author set the objective to identify agro-pastoral activities that are closely related to land use change on lands experiencing conversion at each municipal district in MT. The agro-pastoral activities covered here are cattle ranching and agriculture of the top five farm products (soybean, corn, cotton, rice, and sugarcane). Then, this study identifies the volume of exports by municipal districts where land use change due to agro-pastoral activities has been observed, and even the countries (including contribution ratio) to which they are exported. The land use change includes both deforestation (changes from dense forest to sparse forest and from sparse forest to areas of human activity) and the increase in deeply anthropogenically influenced areas (changes from forests and areas of human activity to savanna regions). The period covered in this study was 1990–2001, a period less affected by government interventions to control deforestation which are the designation of new conservation areas for indigenous people [32,33], elevated penalties against and enforcement of deforestation restrictions [34], sanctions directed at local jurisdictions [35,36], Amazon Soy Moratorium (ASM) [37], and cattle agreements (CA) [19,38].

2. Study Site Description

Since 1988, the study area in MT (Figure 1) in central western Brazil has been the site of the most rapid deforestation in the Legal Amazon [39]. Although the Território Indígena do Xingu in the MT is protected area, which is one of the most culturally diverse Indigenous lands of the Amazon, the areas also have been highly threatened by deforestation [40]. MT is divided into 141 municipal districts. Cuiabá, the MT state capital, is a highly populated city within the Brazilian Amazon. It located in southern part of MT at the junction of BR-163, BR-070 and BR-174 highways. Many highways have been built in the region since the 1980s, such as BR-163 (Rio Grande do Sul to Para state) and BR-364 (São Paulo to Acre state). These highways have attracted developers to the area [2]. Vegetation in MT is characterized by latitudinal variation along the climatic divides: forests in the north (Amazonia), ecotones between forests and cerrado in the middle, Cerrado in the south [41] and Pantanal which is a natural region encompassing the world's largest tropical wetland area in the south-west. The Pantanal have large populations of species that are considered rare or endangered in South America [42]. MT represents a tropical-to-temperate climate zone with two well-defined seasons: rainy (October to April) and dry (May to September). Total annual rainfall varies from approximately 1200 to 2000 mm with higher levels in the northern and mid-northern MT and in regions with altitudes close to 800 m [43]. The average annual temperatures are between 23 and 27 degrees. In MT, vast amounts of forest have changed to agricultural lands, which are predominantly used for the production of soybean and cattle, since the turn of the century. Due to these rapid changes, its economic importance, varied geography, and the heterogeneous political climate [24], MT is an extremely important region for the management of agro-pastoral activities within the Amazon.

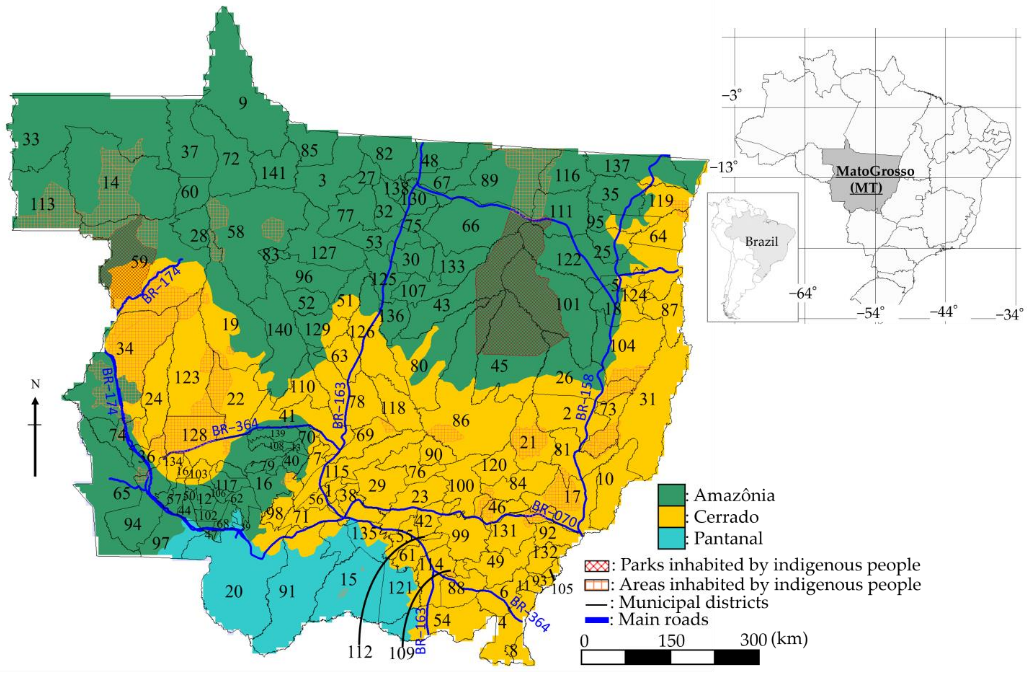

Figure 1. The study site: Mato Grosso (MT) State in the southern Brazilian Amazon. The colors indicate the biomes map (Amazonia, Cerrado and Pantanal) by MMA/IBGE (2004) [44]. The numbers

in the figure indicate the municipal districts. The names of municipalities indicated in this paper are shown: 9—Apiacás; 20—Cáceres; 22—Campo Novo do Parecis; 24—Campos de Júlio; 35—Confresa; 37—Cotriguaçu; 40—Denise; 41—Diamantino; 54—Itiquira; 55—Jaciara; 59—Juína; 61—Juscimeira; 63—Lucas do Rio Verde; 77—Nova Canãdo Norte; 78—Nova Mutum; 79—Nova Olímpia; 80—Nova Ubiratã; 82—Novo Mundo; 90—Planalto da Serra; 112—São Pedro da Cipa; 114—Rondonópolis; 123—Sapezal; 126—Sorriso; 129—Tapurah.

3. Data Sources and Materials

The data sets and other important materials utilized in this paper are summarized in Table 1, and are described below.

Table 1. List of data sources and materials.

Data Set	Periods	Spatial Scale
5-year DVM Maps (Phase I, II, III and IV) [45]	1981–2001	0.1 degree × 0.1 degree
SIDRA, Municipal Livestock Survey, IBGE [46]	1981–2001	144 municipal districts
SIDRA, Municipal Agricultural Production, IBGE [47]	1990–2001	144 municipal districts
Comex Stat, Exports and imports of Cities, MDIC [48]	1997–2001	144 municipal districts
State boundary, Malha Municipal Digital, IBGE (line)	1997	1:5,000,000
River, main road, park and area inhabited by indigenous people maps, Mapa da Série Brasil Geográfico, IBGE (line)	2002	1:5,000,000

3.1. 5-Year DVM Maps

Various techniques are used to determine land use change as typified by deforestation in the tropics for environmental monitoring and impact assessment at the regional and global levels [15–17,27]. Yoshikawa and Sanga-Ngoie [45] analyzed the state of, and the changes in, the type of tropical rainforest cover in the Brazilian Amazon over the two decades from 1981 to 2001, in MT.

In Yoshikawa and Sanga-Ngoie [45], a set of four vegetation maps, the 5-year Digital Vegetation Model (DVM) Maps Phase I (July 1981–June 1986), Phase II (July 1986–June 1991), Phase III (July 1991–June 1996), and Phase IV (July 1996–June 2001), were created for every 5-year period between 1981 and 2001, using the first components of the principal components analysis (PCA) of NOAA/AVHRR multi-spectral data and Geo-graphic Information System (GIS) as the analytical platform. All of 5-year mean DVM maps at 0.1-degree spatial resolution had overall good agreement in accuracy which were more than 70% compared with IBGE vegetation map [44]. Yoshikawa and Sanga-Ngoie [45] noted that the INPE deforestation data using LANDSAT data [39] did not consider errors due to climate effects because it include kind of snapshot of particular situation in particular time. It is susceptible to a change in climate condition such as El Ninõ and La Niña which is oscillation phenomena between wet to neutral or dry conditions on average every 3–4 years. This was the reason of uncertainty in INPE deforestation data why there are overestimation in the drier year than normal year and under estimation in the wetter year than normal year. To avoid this problem, they applied PCA to extract the dominant characteristics of the vegetation distribution over a 5-year period (excluding short-period phenomena such as El Ninõ and La Niña) from the original time series data of NOAA/AVHRR.

These data were classified into the following seven land use/land cover types: Evergreen Broadleaf Forests (EBF), Semi-deciduous Seasonal Forests (SdF), Broadleaf and Seasonal Forests (BS), Savanna Woodlands (SW), Savanna Grasslands (SG), Savanna (S) and Deeply Altered Areas (DAA). Both EBF and BSF are dense forests, while SW includes sparse forests. EBF is found in wet climates with more than nine months of rainfall. BSF prevails in areas with a dry season lasting 3–5 months. SW and other savanna biomes are found in drier regions with a dry season of 4–5 months. SG includes grasslands prevailing over areas flooded during the wet season, while S includes tropical grasslands covering drier places, including abandoned croplands. DAA includes areas affected by human activities such as ranches, croplands, slash-and-burn agriculture, and urban areas. Vegetation change statistics were computed based on these digital vegetation maps for every 5-year period between 1981 and 2001. They identified a sustained decrease in dense forests and sparse forests, coupled with a strong increase in savanna and DAA areas. These maps were used as land use change data for comparing with agro-pastoral activity.

3.2. SIDRA/IBGE Data

Pastoral and agricultural statistical data for Brazil were taken from the Sistem IBGE de Recuperação Automática (SIDRA) within the Brazilian Institute of Geography and Statistics (IBGE). For this analysis, author downloaded tables of annual pastoral and agricultural data for MT. The pastoral data included the cattle herd in each municipal district of MT from 1974 to 2012 [46]. The agricultural data included the planted areas of each product in each municipal district of MT from 1990 to 2020 [47]. The data were selected for the five most important farm products (soybean, corn, cotton, rice, and sugarcane) in MT for analysis.

3.3. Export Data

Export net weight data from each municipal district to each exporting country were downloaded from Comex Stat, Ministério do Desenvolvimento, Indústria, e Comércio Exterior (MDIC) [48]. Cattle herd was compared with the data of 'meat of bovine animals, frozen'. The soybean-planted area was compared with the data of 'Soya beans, whether or not broken'. Corn- and sugarcane-planted areas were compared with the data of 'Maize (corn)' and 'Cane or beet sugar and chemically pure sucrose, in solid form'. Cotton- and rice-planted areas were compared with the data of 'Cotton, not carded or combed' and 'Rice'. Processed products for export were not dealt with in this study.

4. Analysis Method

The analysis was based on the 5-year DVM Maps spanning the 20 years between 1981 and 2001 developed by Yoshikawa and Sanga-Ngoie [45], with special attention given to the four land cover types with the most dramatic changes at a 0.1-degree spatial resolution. The four maps (Phases I–IV) were reclassified from their initial seven land cover types into the following four types: EBF instead to *f1*; SdF, BSF and SW instead of *f2*; SG and S instead of *Sv*; DAA, equivalent to *DAA*. The author could identify the types of changes that were dominant when passing from one phase to another for each municipal district.

Data on the number of cattle herds and the planted area of the top five products (soybean, corn, cotton, rice and sugarcane) for each municipal district of MT were analyzed for each of the four phases between 1981 and 2001. The 5-year mean number of cattle herds from Phase I to IV, as well as the planted area from phase II to IV, were calculated for each period and each district. It should be noted that, because data related to planted areas were only available from 1990, author used the 1990 data for planted areas to represent phase II. The spatial autocorrelation (Global Moran's I) for each municipal district for each 5-year agro-pastoral data were calculated through GeoDa software [49]. The range was from 0.04 to 0.34, which were no autocorrelation. Therefore, the boundary of the municipal district was used as a delimitation for data analysis.

Finally, correlation coefficients (r) between the areas covered by each one of the four main vegetation types (*f1*, *f2*, *Sv*, and *DAA*) in the 5-year DVM Maps following the findings presented in Yoshikawa and Sanga-Ngoie [45], and the changes in the 5-year mean number of cattle herds, 5-year mean soybean-, corn-, sugarcane-, cotton-, and rice-planted areas between the different phases of the study period were calculated. The relationship between vegetation changes and each one of the changes in the agro-pastoral data were obtained by direct comparison and by the conducting Pearson product–moment correlation coefficient test. Significant correlation coefficients had a p-value below 0.05 following a t-test. This made it possible to shed new light on the geographical factors of changes in land cover over MT in both space and time. Then, total export weight and exporting country in the municipal district which are land use change due to agro-pastoral activity were clarified.

5. Results

5.1. Overall Vegetation Changes

The following features were observed from the reclassified maps (figures not shown here): A dominance of the *f1* vegetation type from the central part of MT to the northern areas through all periods; *f2* vegetation types spread over the north-eastern, central and south-western regions; *Sv* and *DAA* vegetation types over southern MT, especially in the east and the central region.

These DVM Maps (summarized in Table 2) were characterized by a sharp decrease in the *f1* vegetation type throughout the analysis period (from 345,000 km^2 in Phase I to 125,000 km^2 in Phase IV). The *f2* vegetation type underwent a remarkable increase (from 387,000 km^2 in Phase I to 495,000 km^2 in Phase III and 391,000 km^2 in Phase IV), after a sustained expansion in the previous phase, most likely in association with the decrease in the *f1* vegetation type. The *DAA* vegetation type did not change to the same extent (from 136,000 km^2 in Phase I to 187,000 km^2 in Phase IV). However, it should be noted that there was a sharp increase in *Sv* especially from Phase II onward (from 44,000 km^2 in Phase II to 203,000 km^2 in Phase IV).

Table 2. The area for each one of the four land cover types obtained from the 5-year DVM maps (Phases I–IV), expressed in km^2.

Land Cover Types	Phase I (July 1981–June 1986)	Phase II (July 1986–June 1991)	Phase III (July 1991–June 1996)	Phase IV (July 1996–June 2001)
f1	345,000	167,000	149,000	125,000
f2	387,000	529,000	495,000	391,000
DAA	136,000	166,000	153,000	187,000
Sv	35,000	44,000	109,000	203,000
Total	906,000	906,000	906,000	906,000

5.2. Cattle Ranching

In Brazil, cattle herds have increased 2.3 times from 92,495 thousand cows in 1974 to 211,279 thousand cows in 2012. The total head counts in MT were 3888 thousand (1978) and 28,741 thousand (2012) based on SIDRA/IBGE statistical data. Therefore, the proportion of cattle in MT to the total in Brazil has increased rapidly from 3.6% in 1978 to 13.6% in 2012. Yoshikawa and Sanga-Ngoie [45] showed distribution maps for 5-year mean cattle counts in every municipal district in MT. The maps indicated the following general patterns of spatial and temporal change. Large cattle counts were initially concentrated in the southern part of MT before the ranching activities spread northward and intensified to cover all of the state. By Phase IV, municipal districts with more than 200 thousand cows could be identified everywhere in the state. In Cáceres (No. 20 in Figure 1), in southern MT, cattle counts increased by 1.2 times during the 20-year period, from 454 thousand cows in Phase I to 549 thousand cows in Phase IV. Nova Cañado Norte (No. 77 in Figure 1), in the far north, experienced sharp changes in pastoral activities. There were no cows in Phase I but the head count increased 6.0 times from 35 thousand cows in Phase II to 217 thousand cows in Phase IV. This suggests that, in northern MT, pastoral activities spread widely toward even those areas located far away from main roads.

5.3. Cropland

In 2001, the acreages of the five most planted crops in Brazil were 140,000 km^2 for soybean, 130,000 km^2 for corn, 50,000 km^2 for sugarcane, 40,000 km^2 for kidney bean, and 30,000 km^2 for rice. As for MT, the planted areas were 30,000 km^2 for soybean, 5000 km^2 for corn, 4000 km^2 for rice, 4000 km^2 for cotton, and 2000 km^2 for sugarcane. These top five products (described in the next sections) also make up most of the agricultural production in MT.

5.3.1. Soybean

Soybean is the largest agricultural product in MT, accounting for about 50% of the total planted area. This area increased from 20,000 km^2 in 1990 to 30,000 km^2 in 2001 and to 60,000 km^2 in 2005, which is equivalent to a 3.9 fold increase.

Figure 2a shows changing ratio of the 5-year mean planted area for soybean to each municipal district area from Phases II to IV. The planted areas in Phase II were concentrated in central and southeast areas of MT, mostly along highways BR-163, BR-070, and BR-364. In Phase IV, the planted areas expanded into Campo Novo do Parecis (No. 22 in Figure 1), Campos de Júlio (No. 24 in Figure 1), Diamantino (No. 41, in Figure 1), Lucas do Rio Verde (No. 63 in Figure 1), Nova Mutum (No. 78 in Figure 1), Sapezal (No. 123 in Figure 1), Sorriso (No. 126 in Figure 1), and Tapurah (No. 129 in Figure 1) which are central western district MT. In the Campo Novo do Parecis, a district in the central western district along BR-364, near Sapezal, where many silos of the André Maggi Group are located [50], planted areas increased by 10% from 2010 km^2 in Phase II to 2380 km^2 in Phase IV (Table A1 in Appendix A). In the central district of Sorriso along BR-163, the planted areas increased by 15% [45]. The expansion of these planted areas is particularly intense in these areas because of the easy access to São Paulo and to other centers connected by paved roads. In the Nova Ubiratã (No. 80 in Figure 1) in central MT which had less road access compared with the Sorriso, there were almost no soybean-planted areas until Phase III, but there were 390 km^2 by Phase IV. The results identified an expansion in the soybean-planted areas, in particular along BR-163 and BR-364 and toward northern and western MT.

5.3.2. Corn

The total planted area of corn in MT increased by 1.6 times from 2700 km^2 to 4500 km^2 during the decade from 1990 to 2001. It increased to 10,800 km^2 in 2006, i.e., more than doubling in just 5 years. The changing patterns (Figure 2b) are similar to those of cattle ranching and soybean production and distribution areas [45] although with lower values. Corn-planted areas tended to be concentrated in the central, central north, and central south regions of MT. In the Campo Novo do Parecis, corn-planted areas decreased −3.8% (from 250 km^2 in Phase II to 200 km^2 in Phase IV) in Figure 2b, while in the Sorriso and Lucas do Rio Verde, along highway BR-163, the area increased by 5.3% and 14.3%, respectively, during the same period. In the Cotriguaçu (No. 37 Figure 1) in northern MT where pastoral activities prevail in northern MT and the Sapezal where the expansion area of soybean plantation, corn-planted areas increased from 0 km^2 in Phase II to 10 and 187 km^2 in Phase IV (Figure 2a).

The distribution of corn-planted areas is similar to those of cattle ranching and soybean-planted areas. There were fewer corn areas than soybean areas in MT because of the higher production costs and lower demand for corn than for soybeans in this region. In general, grass-fed ranching for beef and soybeans for export prevail in the central west [51]. Nonetheless, Brazil is currently the third largest corn producer behind the United State and Argentina, exporting 5.5 and 102 billion kg of corn in 2007 and 2020.

5.3.3. Sugarcane

Total planted area of sugarcane increased by 3.1 times from 650 km^2 to 2020 km^2 during the 15 years between 1990 and 2006. The 5-year mean area of planted sugarcane in Phases II, III, and IV (Figure 2c) steadily expanded starting in 1990 within a limited number of municipal districts in southwest MT. In particular, the planted areas spread to the northern and the central districts, which are located between BR-364 and BR-174, to the south-central districts located between BR-070 and BR-163, such as Nova Olimpia (No. 79 in Figure 1) Jaciara (No. 55 in Figure 1), Juscimeira (No. 61 in Figure 1), and São Pedro da

Cipa (No. 112 in Figure 1), and to Confresa (No. 35 in Figure 1) in the north-eastern part of MT along BR–158.

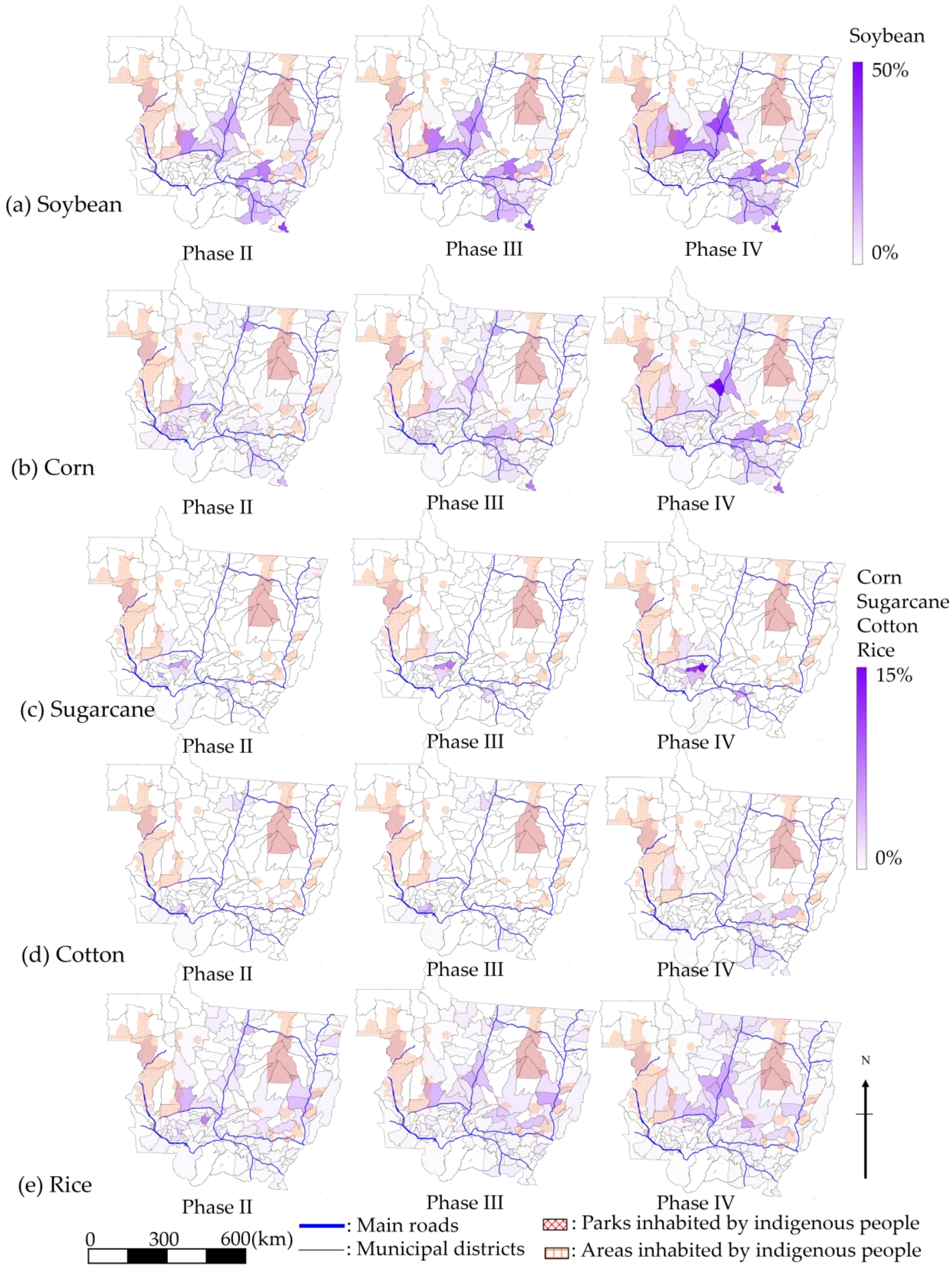

Figure 2. Ratio of 5-year mean planted areas (Phases II, III, and IV) and changing ratio (from Phases II to Phase IV) of the area to each municipal district area for (**a**) soybean, (**b**) corn, (**c**) sugarcane, (**d**) cotton, and (**e**) rice of MT, expressed in percentage.

In the Campo Novo do Parecis in the central south-western part of MT along BR-364, the total planted area almost doubled from 84.5 km^2 in Phase II to 173 km^2 in Phase IV (Figure 2c). In Denise (No. 40 in Figure 1), in the south-western MT between BR-364 and BR-174, the planted area increased by 12.2% (from 50.6 km^2 in Phase II to 206 km^2 in Phase IV in Figure 2c), while in the Jaciara district in southern MT along the BR-163, there was a remarkable increase from 40 km^2 to 124 km^2 between Phases II and IV.

Quantity of sugarcane production accounts for more than 40% of the total agricultural production in MT. It increased by 4.5 times from 3 billion kg to 14 billion kg between 1990 and 2006 [47]. Since the 1970s, there has been a tendency in Brazil to increase sugarcane production for biofuel production [52]. MT has experienced a limited expansion of sugarcane-planted areas compared with soybean-planted areas, although it is the state's second largest crop after soybeans. It should be noted that the area planted with sugarcane expanded slowly in MT between Phases II and IV of this study.

5.3.4. Cotton and Rice

The total area planted with cotton in MT increased by nine times from 430 km^2 to 3920 km^2 between 1990 and 2006. In the Campo Verde and Novo Sao Joaquim in the south-eastern part of MT along BR-070, the cotton-planted area increased 2.4% and 3.3% (from 0 km^2 in Phase II to 141 and 169 km2 in Phase IV). In the Itiquira (No. 54 in Figure 1) in the south part of MT traversing BR-163, the cotton-planted area increased from 0 km^2 in Phase II to 100 km^2 in Phase IV. The distribution of cotton areas expanded in south and south eastern regions along BR-163 and BR-070.

The total planted area with rice did not change substantially, with a decrease from 3810 km^2 to 2870 km^2 over 1990 and 2006. The distribution of rice areas expanded in central regions along BR-163. In the Planalto da Serra (No. 90 in Figure 1) and Sorriso in the central of MT along BR-163, the rice-planted area increased 5.4% and 3.8% (from 0 and 100 km^2 in Phase II to 132 and 462 km^2 in Phase IV).

5.4. Land Use Change Patterns

Figure 3a–d show correlation coefficients (r) between the areas covered by each one of the four main vegetation types (*f1*, *f2*, *Sv*, and *DAA*) in the 5-year DVM Maps, and the changes in the 5-year mean number of cattle herd (Figure 3a), 5-year mean soybean (Figure 3b), corn (Figure 3c), and sugarcane-planted areas (Figure 3d) between the different phases of the study period.

Mean cattle counts were highly positively correlated with *f2* vegetation and highly negatively correlated with *f1* vegetation in the Apiacas (No. 9 in Figure 1), Cotriguaçu, and Juìna (No. 59 in Figure 1) districts around the Juruena River basin in northwest MT. This may suggest that the *f1* vegetation type is being destroyed whenever cattle ranching increases, along with the construction of new road networks, starting from the Juruena River basin. This is evidenced by the new roads extending from the BR-174 highway. This highway, which is advancing from the eastern part of Rondônia, was not a paved road. The highway leading to Venezuela are still under construction toward north.

Croplands expanding from south to north are also a serious threat to forests in MT. The mean soybean and sugarcane areas were highly negatively correlated with *f2* vegetation and highly positively correlated with *Sv* and *DAA* vegetation in Sorriso along BR-364 in central MT and in Sapezal in western MT. These areas hardly contain virgin forests (*f1*) but are mostly covered by *f2* vegetation, which is often a degraded by-product of virgin forests, after their replacement by cattle ranching in these regions. Pasture were replacing to soybean-planted areas.

Mean corn areas were highly positively correlated with *f2* vegetation and highly negatively correlated with *f1* vegetation in Cotriguaçu and Novo Mundo (No. 82 in Figure 1) of northwest MT, which is a similar land cover pattern as that produced from the increasing cattle counts. Alternatively, in Porto Estrela in southern MT and Sapezal in the west, mean corn areas were highly negatively correlated with *f2* vegetation and highly positively correlated with *Sv* vegetation, suggesting that in the south and west of MT, the expansion of corn-planted areas has increased the number of *DAA* in the same way as the increase in soybean plantations.

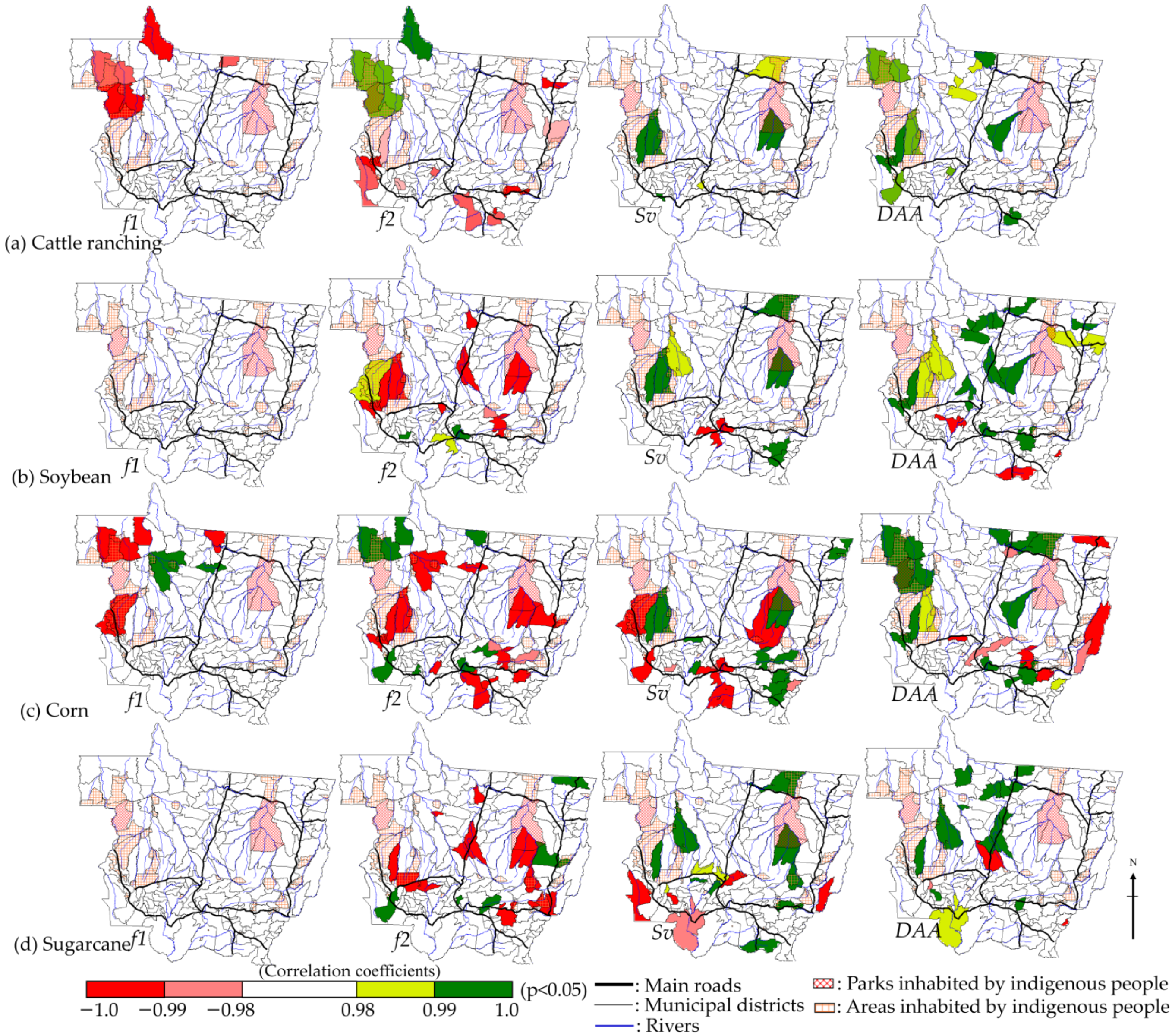

Figure 3. Distribution maps of correlation coefficient between agro-pastoral activity ((**a**) cattle ranching, (**b**) soybean, (**c**) corn and (**d**) sugarcane) and the area of four vegetation types (*f1*, *f2*, *Sv*, and *DAA*) in every municipal district of MT.

In general, the territorial distribution of the main factors of deforestation and the increase in the amount of *DAA* in every municipal district of MT (Figure 4a,b) indicate that they are highly positively correlated with *f2* and *Sv* vegetation, and also strongly negatively correlated with *f1* and *f2* vegetation, respectively. In northern and southern MT, deforestation has been largely associated with cattle ranching and agriculture. In particular, the development of multiple farms and cattle ranching in Campos de Júlio and Sapezal increased *DAA*. In south and west MT, an increase in the amount of *DAA* has occurred largely due to agriculture. In the municipal districts along BR-364, an increase in the amount of *DAA* has occurred mostly because of corn planting.

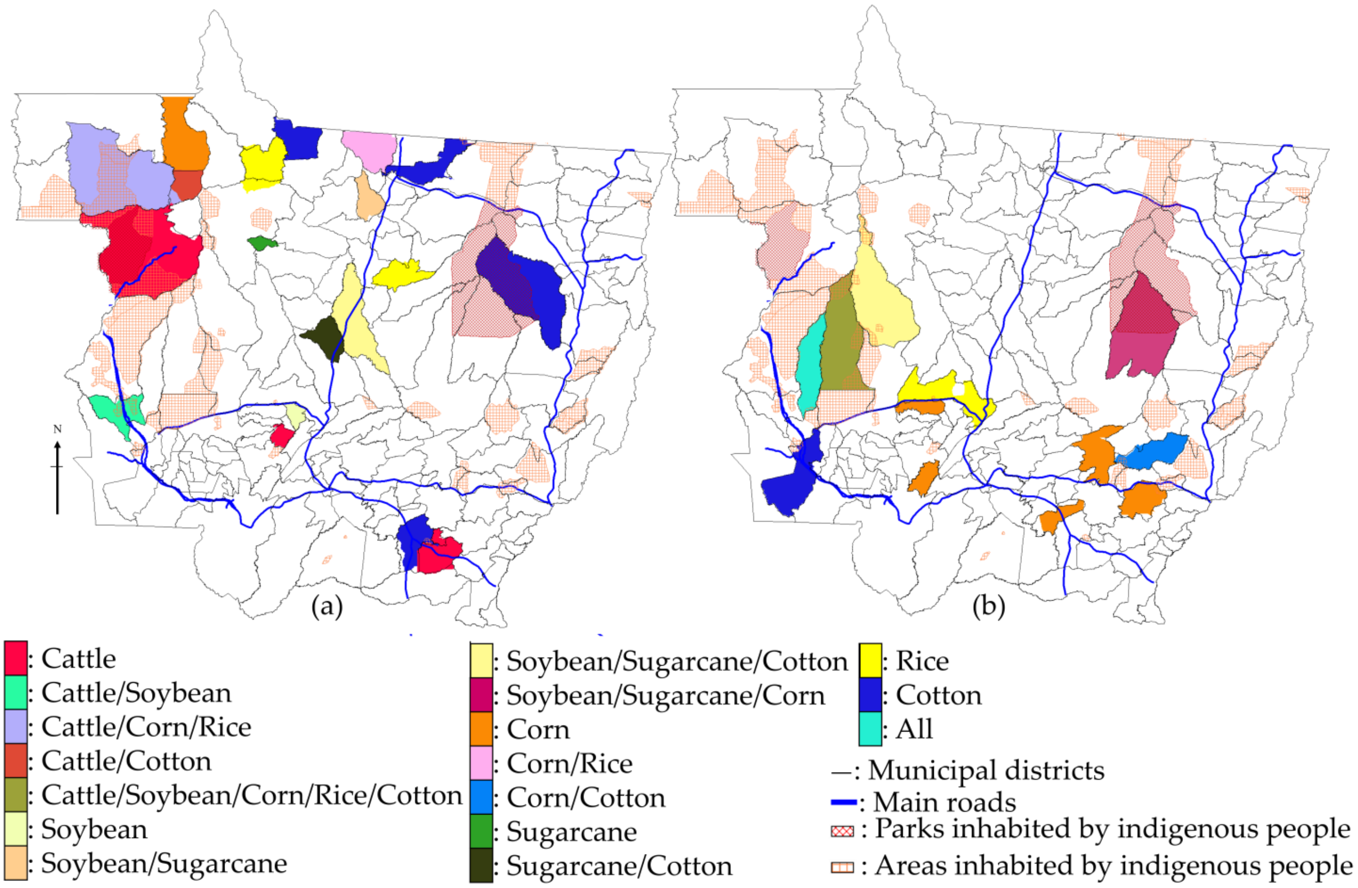

Figure 4. Territorial features for the main factors related to (**a**) deforestation and (**b**) the increase in areas deeply influenced by anthropogenic activities in every municipal district of MT.

5.5. Relevance to the Global Market

There are a few municipal districts that export each agro-pastoral products with land use change (details in Table A2, Appendix B). Denise was the only municipal district associated with the global market for cattle with deforestation until 2001. There were only five export destinations which were Saudi Arabia (53.6%), the Netherlands (19.4%), Hong Kong (14.6%), Germany (6.5%), and Lebanon (5.9%). Denise has seen no export of beef except for 1999.

The municipal district associated with deforestation (the increase in *DAA*) and soybean development was only Sorriso (Campos de Julio). The export partners from Sorriso were eight countries which were Netherlands (35.8%), United Kingdom (24.9%), Germany (20.4%), Belgium (11.87%), Italy (2.6%), Portugal (2.6%), Spain (1.3%) and Uzbekistan (0.5%). Since 2002, the export volume has increased 280 times. Then, the number of export partners has increased to 43 countries. Soybean exported from Campos de Julio to Bolivia (98.7%) and Uruguay (1.3%). Since 2004, the number of export partners has increased to 35 countries.

Sapezal which related deforestation was the only municipal district associated with export of corn to only Switzerland. Since 2007, the export volume has increased 2300 times. The number of export partners has also increased to 56 countries.

The municipal districts associated with deforestation and cotton production were Lucas do Rio Verde, Rondonopolis (No. 114 in Figure 1), and Sorriso. There were only four export destinations from Lucas do Rio Verde which were Germany (25.1%), India (24.5%), Indonesia (35.9%) and Thailand (14.4%). The export partners of Sorriso were two countries which were Germany (60%) and Indonesia (40%). On the other hand, Rondonopolis was already doing business with 59 countries including Indonesia (31.3%), India (15.4%), Pakistan (12.8%) and Portugal (6.6%). Since 2002, the volume of exports has increased 65–453 times (Table A2 in Appendix B), and the number of export partners has increased 3–12 times.

6. Discussion and Concluding Remarks

By comparing cattle head counts and changes in agricultural planted areas with land use/land cover changes (Figure 4a,b), the following patterns can be observed:

1. In north and central MT, the *f1* vegetation type has decreased wherever cattle ranching and corn, rice- and cotton-planted areas have increased. Similarly, the *f2* vegetation type has decreased wherever soybean and sugarcane planting have increased. Therefore, it is clear that cattle ranching and corn cropping have large and direct associations with the deforestation of virgin forests *f1*. Soybean and sugarcane production affects the deforestation process through the cutting of *f2* forests. These factors have a strong relationship with the steadily increasing amount of *DAA* over MT.
2. Wherever areas of planted soybean, sugarcane, and corn have increased, the *f2* and *DAA* vegetation types have decreased while *Sv* vegetation has increased, especially in south and west MT. In western MT, the main factors leading to an increase in the amount of *DAA* were the expansion of soybean, corn, sugarcane, rice and cotton areas. The increase in *DAA* along BR-364 is likely to have occurred due to the expansion of corn fields in this area.

Some consequences of these changes in land use are discussed below. Since the 1980s, many environmental assessments of the Amazon forest area have been published, e.g., [3,5,7–11,24,26,27,39,45,53]. The progress of development, especially in MT, which seems to strongly promote vegetation destruction, increased during the period 2001–2004 [13] but then declined dramatically from 2006 to 2010 [54]. Unfortunately, deforestation has increased again since 2013 [39]. Although the dynamics of deforestation in the Brazilian Amazon are complex, cattle ranching is the biggest cause of deforestation [3,21,22,55]. Cattle herd within the Legal Amazon rapidly increased from 1990 to 2001 toward north, with the rate of increase being highest in MT. Certainly this results are consistent with previous studies. There was little export of pastoral cattle associated with land use conversion. Most are for domestic consumption, which could be supported Bonti-Ankomah and Fox [56].

Even if the cause of deforestation was mainly cattle ranching, Soybean production is another likely factor contributing to land use change. By focusing on the expansion of soybean production and searching for only relationships of this activity with deforestation, Morton et al. [3] showed that deforestation for large-scale croplands accounted for 17% of total forest loss during the period from 2001 to 2004 in MT. Macededo et al. [54] found little evidence of direct soybean expansion into cerrado in Mato Grosso during the late 2000s, although indirect land-use changes and expansion to more distant regions were possible. Leite et al. [57] showed that the intensity of agricultural activity expanded along federal highways BR-364 and BR-158 in MT during the period 1975–1995. In this paper, an expansion in the soybean-planted areas, which is larger than that reported by Leite et al. [57], was identified along BR-163 and BR-364 and toward northern and western. Soybean exports during 1997–2001 from areas where there have been land use changes are not very large. It means that much soy production was for domestic consumption. However, after 2002, soybean production in MT increased substantially following the involvement of major multinational grain firms after 2002 in MT [58]. The export volume of soybean has also increased (in Appendix B). Fearnside [59] mentioned that the Amazon forest cleared to produce soybean is for export to mostly China and Europe rather than to feed the Brazilian people. With the expansion of production for export, soybean producers are purchasing land where cattle ranchers already had cleared in MT [59]. This indicates that soybean production is inextricably linked to cattle ranching, the main cause of deforestation.

The reasons for soybean expansion are not only related to the above, but also to local politics. Richards et al. [60] trace the expansion of Brazil's soybean production to the devaluation of the real in the late 1990s and early 2000s. During this time, politicians and businesspeople from Lucas do Rio Verde worked with many other stakeholders to attract outside investments profitable to agriculture in Lucas do Rio Verde. These included Cargill's construction of the soybean export processing facility in Santarém at the northern end of the BR-163 highway, federal investment in the paving of the BR-163 between Lucas do Rio Verde and Santarém, the installation of confined chicken-raising facilities, the installation in Lucas do Rio Verde of an incubator capable of hatching 1 million chicks per day in 2005, and the construction in Lucas do Rio Verde of a meatpacking plant capable of processing 500,000 chickens per day in 2007 [61]. Greenpeace [50] discovered that one of the largest soybean producers in the world borrowed a large amount of funds from public and private banks in Europe, Japan, and the World Bank to undertake mass soybean cultivation in the Amazon. These banks have also given financial help to suppliers and infrastructural developers for the storage and transportation of soybeans. One of the largest private companies in the United States produces soybeans in Rondonia and MT to export to Europe, and has built new ports for this purpose in Santarém and Porto Velho. The author can foresee that, when highway BR-163 (especially from Cuiabá to Santarém) opens (begun in the early 2000s but still incomplete), the ease of soybean transportation will increase, and the deforestation process will intensify. Similar scenarios have also been presented in previous studies [2,4].

The expansion of sugarcane-planted areas was limited compared with soybean-planted areas. There are no exports from municipal districts that expand cultivated land with land use change. Jusys [62] found both Sugarcane and soybean expansion is indirectly associated with landuse change during 2002–2012. The growth pattern is similar between soybean and sugarcane. However, each farmer has invested huge capital (like machine, silo) suitable for each production. It is very unlikely that soybean farmers will give up this capital or start sugarcane planting themselves. Sugarcane, which is a highly mechanized crop, may compete for space with soybeans which are already consolidated because there are no sanctions imposed on sugarcane production with a decree that cancels a 10-year ban on sugarcane cultivation in the Amazon rainforest [63].

Corn, cotton, and rice cultivation were found to be affected by land use change in several municipal districts. The relationship with deforestation, especially in the northern part of MT where produced for domestic demand and the central part where there are export production, was evident. In MT, cattle ranching and soybean cultivation have occupied large areas, and mostly previous research had focused on both. MT is the largest corn producer in Brazil. Much of these areas are cultivated in soybean-planted areas as crop rotations [61]. MT already have five ethanol plants based corn of 12 ethanol plants [63]. By 2021, there are planning to operate five more corn plants [64]. Lima et al. [63] pointed out that it is likely to become greater financial return for the producer and a greater value of soybean productive lands which are double-crop due to a higher demand for corn production. Cotton production in soybean produced areas is most profitable system might become low profitability due to climate change [65]. This implied farmers might be necessary for shifting towards generating new farmlands including further deforestation.

Since 2006, ASM has helped to nearly eliminate direct deforestation for soybean plantation, and contributed to forest conservation [37,50]. CA was not effective, with failures [38]. Heilmayr et al. [37] suggested that public deforestation monitoring and property registration were essential preconditions for the ASM's success. However, there are opposites from farmers to the ASM and Brazil's Forest Code as an inequitable and undemocratic breach of Brazil's Forest Code by multinational corporations [66]. It might inspire efforts to end these land use restrictions, which have intensified under the Bolsonaro administration [66,67]. The Brazilian government has sought to weaken conservation requirements in the Forest Code. In 2022, the government also will stop monitoring deforestation in the Cerrado [67]. If public deforestation monitoring is essential for deforestation management, then a deterrent to deforestation may have already begun to collapse.

7. Conclusions

In this study, both the 5-year mean number of cattle herd and the 5-year mean planted areas of soybean, corn and sugarcane increased substantially in the 1980s, and then spread further throughout the 1990s at the municipal district level. Cattle ranching in particular has spread towards northern MT, while soybean areas have spread over central MT, and corn areas have increased in almost the same areas as cattle ranching. Furthermore, most sugarcane areas are distributed over the same regions where soybean fields have increased, especially between highways BR-174 and BR-364, while few such changes have been observed in other areas.

This study's findings have to be accompanied by several caveats. It should be noted that there is uncertainty in the comparison of cattle head counts and changes in agricultural planted areas with land use/land cover changes. With this method, the author showed definite correlation coefficients for cattle head counts and agricultural planted areas with changes in land use/land cover. This does not necessarily indicate a causal relationship, however. It also should be noted that there is uncertainty in the 5-year DVM maps when using NOAA/AVHRR data. Land use changes at scales smaller than 0.1 degrees are likely not identified in the 5-year DVM maps. Mayaux and Lambin [68] noted that the AVHRR data produced over- and underestimations of forest changes compared to LANDSAT data due to spatial aggregation. In addition, this method does not consider forest fires, which impact land degradation [69]. As a next step, the impact of forest fires is an additional factor to consider. The limitations of this study are that it is difficult to clarify the relationships at a higher spatial resolution because statistical data related to agriculture, livestock, and trade are at the municipal level. With the findings and methods from this work and those from recent studies [2,5,8,10], the author intends to further investigate these issues using long-spanning remote sensing data, e.g., [70], to identify recent land use/land cover changes and their underlying dynamics at a higher time resolution, not only in MT but also in surrounding states, especially Pará, where land development following the felling of Amazonian primary forests has been a serious issue.

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Data Availability Statement: Data are contained within the article and Appendix A.

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Conflicts of Interest: The author declare no conflict of interest.

Appendix A

Table A1 shows the average planted area in five crops (soybean, corn, sugarcane, cotton and rice) every five years for each municipal district. The cropped areas of each crop vary greatly between municipal districts.

Table A1. The 5-year mean planted areas in each municipal districts, expressed in km^2.

No.	Name	Soybean			Corn			Sugarcane			Cotton			Rice		
		II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV
1	Acorizal	0	0	0	9.00	5.65	5.19	0.30	0.39	0.22	0	0	0	6.00	4.38	3.70
2	Agua Boa	350	142.84	166.04	25.00	25.60	33.33	0	0	0.20	0	0	0.02	282.00	370.77	197.34
3	Alta Floresta	0	0	0.80	52.50	61.98	21.00	0	0	0.47	6.00	30.38	3.70	84.00	93.40	70.20
4	Alto Araguaia	60	47.31	111.57	20	12.83	20.39	0	0	1.85	0	0	0	25.00	11.70	10.62
5	Alto Boa Vista	0	0	0	0	7.60	14.90	0	0	0	0	0	0	0	12.00	15.45
6	Alto Garcas	345.00	366.78	582.00	30	31.47	74.45	4.60	0.84	0.10	0	0.08	18.06	5.82	7.19	7.31
7	Alto Paraguai	25.00	18.34	18.83	5.60	4.07	5.55	1.50	1.02	13.58	0	0.02	0	18.00	14.98	7.10
8	Alto Taquari	540	567.14	587.18	60	110.99	133.38	0	0.04	0.03	0	0.04	13.71	2.00	5.27	12.40
9	Apiacas	0	0	0	6.50	7.71	14.60	0	0	0.10	0	0.01	0.32	6.00	5.68	12.00
10	Araguaiana	7.00	1.30	2.34	0.80	2.08	1.54	0.05	0.05	0	0	0	0	11.20	20.33	7.80
11	Araguainha	0	0	0	0.50	0.92	0.78	0	0.12	0	0	0	0	0.60	1.07	1.15
12	Araputanga	0	0	0	32.50	37.00	29.40	0.20	0.20	0.16	1.50	3.00	0.90	5.00	6.59	4.20
13	Arenapolis	85.00	23.30	4.49	12.00	2.62	2.33	0.20	0.08	0	0.80	0.60	0	9.00	5.50	4.46
14	Aripuana	0	0	0	12.00	12.40	28.39	1.50	2.10	2.10	0	0.94	0.40	10	11.24	28.90
15	Barao de Melgaco	0	0	0	7.00	5.53	4.80	0.50	0.58	0.40	0.31	0.13	0.02	5.00	4.03	2.79
16	Barra do Bugres	0	0.12	0	10	5.84	7.30	107.00	128.23	237.65	3.50	3.26	0.30	17.50	9.01	3.34
17	Barra do Garcas	75.50	44.91	19.12	8.00	4.46	6.17	0.25	0.26	0.50	0	0	0	34.20	80.07	16.39
18	Bom Jesus do Araguaia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Brasnorte	161.22	209.79	448.12	65.00	79.43	63.50	0	0	0.21	1.04	1.12	18.14	115.00	85.53	56.53
20	Caceres	1.00	1.03	0.31	84.84	75.37	56.00	27.94	9.33	4.06	42.17	63.50	15.20	89.23	50.57	27.70
21	Campinapolis	20	3.20	0.68	60	29.46	14.00	0.30	0.58	2.20	0	0	0	36.00	37.33	26.10
22	Campo Novo do Parecis	2008.00	2381.96	2901.14	246.90	199.42	200.74	84.50	116.15	172.83	20	57.06	47.99	400	394.39	225.14
23	Campo Verde	1018.20	910.27	984.98	101.00	235.38	327.49	0	0	1.27	0	0.83	141.05	53.00	74.00	45.82
24	Campos de Julio	0	0	787.37	0	0	68.62	0	0	7.39	0	0	16.50	0	0	70.96
25	Canabrava do Norte	0	0	0	0	10.20	17.96	0	0	0	0	0	0	0	19.50	17.80
26	Canarana	386.50	210.80	290.49	18.60	21.70	28.74	2.00	1.41	0.29	0	0	0	230	180.56	103.65
27	Carlinda	0	0	0.12	0	0	11.60	0	0	0.14	0	0	2.08	0	0	49.00
28	Castanheira	0	0	0	10	12.20	9.94	0.20	0.20	0.11	2.50	2.26	1.23	8.00	6.92	5.02
29	Chapada dos Guimaraes	38.30	57.20	47.07	14.00	26.88	30.28	0.50	0.50	0.50	0.30	0.16	0	12.00	20.47	16.64
30	Claudia	1.00	0	0.85	3.00	2.29	3.84	0	0	0	0.10	0	0.07	4.00	1.72	23.89
31	Cocalinho	0	1.60	0.58	95.00	5.96	4.88	0.05	0.05	0.05	0	0	0	81.30	117.53	30.68
32	Colier	0	0.12	2.10	20	44.00	22.10	0	0	0.32	70	66.32	11.40	12.50	31.66	33.00
33	Colniza	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	Comodoro	250	358.00	173.48	12.00	39.50	35.40	0	4.09	0	0.12	0.22	0.11	79.00	118.14	21.40
35	Confresa	0	0	0	0	11.83	68.00	0	26.61	41.94	0	0	0.03	0	41.80	54.60
36	Conquista D'Oeste	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	Cotriguacu	0	0	0	0	3.84	8.84	0	0.60	0.60	0	0.14	0.82	0	2.47	8.16
38	Cuiaba	11.00	5.40	0	15.00	9.84	6.01	3.80	2.84	0.32	0	0	0	20	7.83	2.01
39	Curvelandia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	Denise	30	0.28	0	52.00	7.40	3.44	50.60	98.69	206.32	10.50	7.55	0.08	91.50	8.22	4.91
41	Diamantino	10.00	1512.22	1906.02	50	96.28	138.78	0	13.66	47.91	0	6.64	14.70	150.56	158.70	310.50
42	Dom Aquino	0	203.27	255.15	5.85	65.12	84.82	20.60	23.34	18.17	0	3.40	18.98	5.20	27.21	14.84
43	Feliz Natal	0	0	1.09	0	0	1.60	0	0	0	0	0	0	0	0	10.13
44	Figueiropolis D'Oeste	0	0	0	24.76	24.41	26.60	0.40	0.18	0.40	4.80	7.38	1.01	8.76	9.05	8.42
45	Gaucha do Norte	0	0	31.31	0	0	2.61	0	0	0.68	0	0	0	0	0	22.61
46	General Carneiro	108.80	188.26	317.36	7.00	18.46	37.00	0.05	0.05	0.08	0	0	2.80	25.00	48.58	12.40
47	Gloria D'Oeste	0	0.24	0	0	10.25	15.20	0	0.78	0.03	0	34.00	13.10	0	2.75	5.10
48	Guaranta do Norte	0	0	0	56.00	77.20	51.50	0.10	0.10	0.25	0	4.46	1.51	35.00	40	64.00
49	Guiratinga	294.72	277.31	424.50	15.00	18.52	62.66	0.15	0.15	0.15	0	0.52	2.91	15.00	15.51	13.40

Table A1. *Cont.*

No.	Name	Soybean			Corn			Sugarcane			Cotton			Rice		
		II	III	IV	II	III	IV	II	III	IV	II	III	IV	II	III	IV
50	Indiavai	0	0	0	5.00	4.34	6.82	0.09	0.09	0.10	2.00	1.48	0.30	4.00	1.89	1.00
51	Ipiranga do Norte	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	Itanhang	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	Itauba	0	0	7.42	13.00	10.80	10.90	0	0	0.12	10	2.22	0.52	16.00	6.96	17.54
54	Itiquira	1174.39	1183.88	1178.77	69.29	133.29	157.50	2.50	2.60	3.20	0	28.28	100.11	24.65	88.79	33.83
55	Jaciara	228.00	208.31	223.18	24.00	37.06	72.72	39.55	62.03	124.14	0.80	0.12	9.95	4.50	13.31	12.14
56	Jangada	1.40	1.28	5.17	3.80	10.46	7.58	11.00	6.90	1.73	0.92	1.34	0	6.00	10.07	6.60
57	Jauru	0	0	0	58.50	30.14	8.80	1.40	0.56	0.20	6.00	1.96	1.10	17.50	7.52	1.70
58	Juara	0	0	0	60	18.67	18.21	0	0	0.04	1.00	0.74	0.45	50	22.37	16.80
59	Juina	0	0	0	25.00	24.80	43.20	0.90	1.16	0.76	0.40	0.83	2.97	15.00	10.60	15.96
60	Juruena	0	0	0	15.00	5.40	10.78	0	0	0.12	0	0.66	0.65	7.22	4.00	5.24
61	Juscimeira	80.80	73.54	125.53	12.00	23.60	40.40	21.80	25.98	23.64	3.60	6.70	1.81	8.00	14.15	9.24
62	Lambari D'Oeste	0	0	0.03	0	9.93	12.40	0	12.07	40.73	0	8.12	4.43	0	6.40	5.40
63	Lucas do Rio Verde	653.51	867.52	1315.08	20	150.49	545.24	0	0	0.12	1.30	2.60	50.56	50	165.57	179.15
64	Luciara	7.84	1.00	0	13.80	5.56	0.50	0	0	0	0	0	0	82.98	53.36	4.58
65	Vila Bela da Santissima Trindade	0	1.20	0	15.00	32.87	45.30	0.70	0.14	0	1.40	3.27	2.08	12.00	8.60	10.10
66	Marcelandia	0	0	0	3.00	4.30	7.76	0	0	0.28	1.00	0.81	0.10	3.00	2.63	13.50
67	Matupa	0	0	0.47	13.50	13.10	27.20	1.50	1.20	0	0	0.48	0.24	8.80	8.46	98.00
68	Mirassol d'Oeste	0	0	0	25.00	12.56	16.72	21.81	8.58	0.07	55.00	55.54	10.50	15.00	7.99	7.82
69	Nobres	290	118.03	33.42	22.00	23.40	14.62	0.47	0.47	0.08	0	2.16	1.38	40	33.98	21.27
70	Nortelandia	12.00	28.20	54.91	3.50	1.90	15.23	0.10	0.10	0	0	0.03	0	8.00	5.12	15.76
71	Nossa Senhora do Livramento	3.80	0.96	0.40	32.00	15.69	11.58	3.50	3.18	3.35	0	0.16	0.02	24.00	12.79	7.56
72	Nova Bandeirantes	0	0	0	0	3.50	12.26	0	0.03	0.12	0	1.56	0	0	8.15	19.00
73	Nova Nazare	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74	Nova Lacerda	0	0	3.20	0	0	4.20	0	0	0	0	0	0.25	0	0	3.82
75	Nova Santa Helena	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	Nova Brasilandia	15.00	1.60	5.20	20	31.80	8.00	0.45	0.36	0.20	0	1.03	0.51	20	101.40	57.86
77	Nova Canaã do Norte	0	0	0.05	25.00	21.24	11.68	0	0	0.15	42.00	34.54	21.36	25.00	18.20	21.32
78	Nova Mutum	668.70	1132.12	1338.66	13.00	90.47	202.34	0.10	0.10	0.02	0	2.27	41.64	27.25	124.09	231.00
79	Nova Olimpia	0	0	5.66	5.00	7.60	7.62	72.84	87.03	168.22	0	0.42	0.10	20	5.32	8.48
80	Nova Ubirata	0	0	391.99	0	0	54.95	0	0	0	0	0	14.78	0	0	87.22
81	Nova Xavantina	250	128.07	134.14	15.00	14.64	13.47	1.00	0.39	1.14	0	0	0.50	75.00	79.41	20
82	Novo Mundo	0	0	0	0	0	12.10	0	0	0	0	0	0.86	0	0	56.73
83	Novo Horizonte do Norte	0	0	0	4.00	9.74	4.90	0	0	0.16	0.35	1.95	0.59	5.00	6.94	9.50
84	Novo Sao Joaquim	321.35	743.39	958.67	11.35	30.08	152.24	0.15	0.38	0.50	0	0.24	169.63	100	168.04	103.68
85	Paranaita	0	0	0.40	21.00	18.38	17.46	0	0	0.18	0.04	0.89	0.07	25.00	21.58	65.92
86	Paranatinga	60	30.61	46.73	32.20	29.40	9.40	0.30	2.00	1.28	0	0	0	180	280.08	279.18
87	Novo Santo Antonio	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	Pedra Preta	357.61	464.59	467.08	49.25	68.54	83.56	0	0.70	0.70	15.00	20.58	61.99	18.37	17.87	12.35
89	Peixoto de Azevedo	0	0	0.06	10	19.10	17.95	0	0	0.20	0	0	0.32	8.00	13.30	55.40
90	Planalto da Serra	0	8.40	5.30	0	12.00	11.10	0	0.24	0.28	0	0	0	0	72.00	131.54
91	Pocone	0	0.80	0	10	8.52	5.04	65.00	19.95	45.82	0	0.02	0	10.03	7.71	2.84
92	Pontal do Araguaia	0	0	0	0	1.62	0.69	0	0	0	0	0	0	0	5.13	1.16
93	Ponte Branca	36.00	3.40	0	2.00	2.54	0.96	0	0.02	0	0	0	0	5.20	7.79	1.48
94	Pontes e Lacerda	0	1.30	0	70	39.84	30.10	0.70	0.46	0.30	21.00	10.04	8.10	30	30.60	13.90
95	Porto Alegre do Norte	0.70	0	0.04	10	14.60	12.41	0	0	0.02	0	0	0	49.50	19.30	19.20
96	Porto dos Gauchos	1.50	0.16	4.68	5.00	10.76	7.70	0.10	0.10	0.06	0.35	0.15	0.29	6.13	10.70	21.44

Table A1. *Cont.*

No.	Name	Soybean			Corn			Sugarcane			Cotton			Rice		
		II	**III**	**IV**	**II**	**III**	**IV**	**II**	**III**	**IV**	**II**	**III**	**IV**	**II**	**III**	**IV**
97	Porto Esperidiao	1.00	5.00	0	32.50	30.51	20.50	0.15	0.23	0.15	26.00	31.71	9.56	30	23.99	8.40
98	Porto Estrela	0	0	0	0	3.00	3.50	0	0.22	0.50	0	5.26	1.78	0	3.34	4.56
99	Poxoreo	226.46	272.40	326.82	16.66	36.45	74.04	0	0	0.36	0	2.38	25.74	32.83	35.67	35.57
100	Primavera do Leste	1367.33	1458.03	1531.36	31.52	151.20	332.51	0	0	0	0	0.83	73.98	81.40	102.24	98.46
101	Querencia	0	35.58	107.71	0	3.22	8.00	0	0.20	0.23	0	0	1.14	0	13.99	74.00
102	Sao Jose dos Quatro Marcos	0.34	0	0	35.00	32.38	20.20	2.00	1.34	0.12	24.00	43.19	11.10	22.80	9.89	7.20
103	Reserva do Cabacal	0	0	0	16.40	2.47	2.68	0.70	0.34	0.10	0.30	0.07	0	8.75	1.23	1.59
104	Ribeirao Cascalheira	25.00	0	0.10	15.60	12.30	13.35	0	0.03	0.01	0	0	0	50	35.40	18.20
105	Ribeiraozinho	0	3.23	35.25	0	1.57	1.02	0	0	0.06	0	0	0	0	5.17	5.85
106	Rio Branco	0	0	0	21.00	11.74	4.00	27.21	11.18	0	7.50	4.22	0	18.00	7.27	2.10
107	Santa Carmem	0	6.88	29.50	0	3.96	13.03	0	0	0	0	0	0	0	6.39	39.91
108	Santo Afonso	0	5.70	3.80	0	2.45	5.58	0	0.80	27.24	0	1.12	0.54	0	1.56	25.67
109	Sao Jose do Povo	0	0	0	0	7.20	7.20	0	0	0.04	0	12.76	12.40	0	6.60	5.60
110	Sao Jose do Rio Claro	195.00	181.39	298.57	25.00	73.34	21.11	2.00	22.64	40.76	0.30	1.50	10.31	28.00	61.60	62.38
111	Sao Jose do Xingu	0	0	1.24	0	4.00	9.40	0	0	0	0	0	0	0	8.00	7.74
112	Sao Pedro da Cipa	0	0	0	0	2.00	2.04	0	12.42	20.89	0	0.21	0.10	0	1.14	1.50
113	Rondolandia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
114	Rondonopolis	697.36	508.42	498.91	94.16	109.69	110.04	0.90	1.26	1.60	23.00	30.48	98.36	26.65	31.08	25.45
115	Rosario Oeste	50	15.57	6.60	15.00	18.63	16.70	0.47	0.47	0.47	0	4.10	0.03	21.50	24.10	14.46
116	Santa Cruz do Xingu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
117	Salto do Ceu	0	0	0	26.00	20.30	14.55	1.00	0.49	0.13	0.50	0	0	24.50	16.00	5.46
118	Santa Rita do Trivelato	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
119	Santa Terezinha	0.80	0	0.14	8.00	7.51	8.66	47.08	12.28	0	0	0	0	32.00	16.23	8.96
120	Santo Antonio do Leste	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
121	Santo Antonio do Leverger	5.00	12.07	20.16	12.00	13.02	15.08	1.37	1.51	1.16	0	0.05	1.56	10	14.57	11.54
122	Sao Felix do Araguaia	3.70	0	0	20	6.00	13.60	0	0	0	0	0	0	48.50	37.40	19.80
123	Sapezal	0	0	1582.30	0	0	186.95	0	0	0	0	0	143.00	0	0	160.55
124	Serra Nova Dourada	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
125	Sinop	58.88	38.89	98.80	7.50	23.24	49.60	0	0	0.56	0	0	7.90	60	57.33	138.00
126	Sorriso	1400	1618.65	2742.56	33.00	170.48	528.06	0	0	0.21	0	1.10	48.95	100	312.78	461.91
127	Tabapora	0	0	6.20	0	2.05	6.29	0	0.09	0	0	0	0.15	0	2.36	24.84
128	Tangara da Serra	168.00	224.60	261.30	112.00	99.00	76.00	14.00	1.89	66.08	4.20	10.60	2.98	40	57.25	81.22
129	Tapurah	216.00	253.88	390	7.00	54.76	78.46	0	0	0	0	0	7.35	22.80	43.54	220.60
130	Terra Nova do Norte	0	0.02	0	120	105.65	29.97	0	0	0.36	22.50	18.96	4.72	80	69.22	38.34
131	Tesouro	47.42	68.30	108.40	3.00	2.56	8.28	0	0	0	0	0	0	5.00	13.10	4.78
132	Torixoreu	33.00	5.26	28.78	5.00	4.22	1.10	0.05	0.05	0.37	0	0	0.21	13.20	26.17	5.02
133	Uniao do Sul	0	0	0	0	0	0.94	0	0	0	0	0	0	0	0	1.68
134	Vale de Sao Domingos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
135	Varzea Grande	0	0	0	1.53	1.11	0.63	0.16	0.79	0.52	0	0	0	1.60	1.85	0.20
136	Vera	54.97	31.65	64.98	13.70	9.74	16.09	0	0	0	0.12	2.40	2.69	50.84	21.67	80.34
137	Vila Rica	0	0	0	80	78.60	37.00	0	0.50	0.01	0	0.42	0	12.00	11.80	8.22
138	Nova Guarita	0	0.04	0	0	19.60	14.80	0	0	0	0	2.99	3.76	0	9.00	13.66
139	Nova Marilandia	0	59.08	85.92	0	0.46	16.30	0	0	0	0	0	0	0	2.79	12.96
140	Nova Maringa	0	11.00	69.00	0	0.63	15.09	0	0	0.02	0	0	0	0	7.14	23.45
141	Nova Monte Verde	0	0	0	0	8.72	16.40	0	0	0.12	0	0.80	0.07	0	9.94	8.20

Appendix B

Table A2 shows the total export volume of each agro-pastoral product during 1997–2001 in the municipal districts which are subject to deforestation and the increase in *DAA* due to agro-pastoral activity. The districts indicated as zero and not shown Table A2 might be produced for domestic consumption.

Table A2. Total net weight for exports during 1997–2001 for each agro-pastoral product in the municipal districts which are (a) subject to deforestation and (b) the increase in *DAA*, expressed in kilograms. '-' means that there is no related deforestation and increase in *DAA*.

No	Name	Cattle	Soybean	Corn	Sugarcane	Cotton	Rice
(a) The municipal district associated with deforestation							
14	Aripuana	0	-	0	-	-	0
32	Colier	-	0	-	0	-	-
37	Cotriguacu	-	-	0	-	-	-
40	Denise	216,622	-	-	-	-	-
41	Diamantino	-	-	-	-	-	0
59	Juina	0	-	-	-	-	-
60	Juruena	-	-	-	-	0	-
63	Lucas do Rio Verde	-	-	-	0	417,360	-
67	Matupa	-	-	-	-	0	-
70	Nortelandia	-	0	-	-	-	-
74	Nova Lacerda	-	0	-	-	-	-
82	Novo Mundo	-	-	0	-	-	0
83	Novo Horizonte do Norte	-	-	-	0	-	-
85	Paranaita	-	-	-	-	0	-
88	Pedra Preta	0	-	-	-	-	-
101	Querencia	-	-	-	-	0	-
107	Santa Carmem	-	-	-	-	-	0
109	Sao Jose do Povo	0	-	-	-	-	-
114	Rondonopolis	-	-	-	-	17,326,795	-
123	Sapezal	-	0	2,536,657	-	-	30,000
126	Sorriso	-	76,210,646	-	0	288,923	-
(b) The municipal district associated with increase in DAA							
19	Brasnorte	-	0	-	0	661,646	-
24	Campos de Julio	0	113,918,312	0	0	0	0
45	Gaucha do Norte	-	-	0	0	-	0
61	Juscimeira	-	-	0	-	-	-
84	Novo Sao Joaquim	-	-	-	-	0	-
94	Pontes e Lacerda	-	-	0	-	0	-
98	Porto Estrela	-	-	0	-	-	-
100	Primavera do Leste	-	-	0	-	-	-
131	Tesouro	-	-	0	-	-	-
139	Nova Marilandia	-	-	0	-	-	-
141	Nova Monte Verde	-	-	-	-	-	0

In the same manner as Table A2, Table A3 shows the total export volume of each agro-pastoral product in the municipal districts which are subject to deforestation and the increase in *DAA* due to agro-pastoral activity. However, the data collection period is from 2002 to 2020. The changes in land use are exactly the same as in Table A2. In other words, land use after 2002 is not taken into account. Export volumes of soybeans, corn, and cotton were increased, as well as the number of municipal districts exporting these crops.

Table A3. Total net weight for exports during 2002–2020 for each agro-pastoral product in the municipal districts which are (a) subject to deforestation and (b) the increase in *DAA*, expressed in kilograms. '-' means that there are no related to deforestation and increase in *DAA*.

No	Name	Cattle	Soybean	Corn	Sugarcane	Cotton	Rice
(a) The municipal district associated with deforestation							
14	Aripuana	0	-	0	-	-	0
32	Colier	-	0	-	0	-	-
37	Cotriguacu	-	-	0	-	-	-
40	Denise	216,622	-	-	-	-	-
41	Diamantino	-	-	-	-	-	0
59	Juina	0	-	-	-	-	-
60	Juruena	-	-	-	-	0	-
63	Lucas do Rio Verde	-	-	-	0	417,360	-
67	Matupa	-	-	-	-	0	-
70	Nortelandia	-	12,681,520	-	-	-	-
74	Nova Lacerda	-	0	-	-	-	-
82	Novo Mundo	-	-	0	-	-	0
83	Novo Horizonte do Norte	-	-	-	0	-	-
85	Paranaita	-	-	-	-	0	-
88	Pedra Preta	0	-	-	-	-	-
101	Querencia	-	-	-	-	0	-
107	Santa Carmem	-	-	-	-	-	0
109	Sao Jose do Povo	0	-	-	-	-	-
114	Rondonopolis	-	-	-	-	17,326,795	-
123	Sapezal	-	0	2,536,657	-	-	30,000
126	Sorriso	-	76,210,646	-	0	288,923	-
(b) The municipal district associated with increase in *DAA*							
19	Brasnorte	-	2,358,929,385	-	0	14,123,373	-
24	Campos de Julio	0	5,002,378,807	3,454,018,932	0	28,235,846	0
45	Gaucha do Norte	-	-	54,691,618	0	-	0
61	Juscimeira	-	-	0	-	-	-
84	Novo Sao Joaquim	-	-	-	-	0	-
94	Pontes e Lacerda	-	-	0	-	0	-
98	Porto Estrela	-	-	0	-	-	-
100	Primavera do Leste	-	-	0	-	-	-
131	Tesouro	-	-	0	-	-	-
139	Nova Marilandia	-	-	0	-	-	-
141	Nova Monte Verde	-	-	-	-	-	0

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