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Uso agropecuário da terra, frequência de cultivo e área de segunda safra no Brasil: estatísticas da FAOSTAT e novas estimativas

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Resumo - Uma representação acurada do território é crucial para uma avaliação adequada da sustentabilidade da produção de alimentos e bioenergia. No Brasil, três culturas com ambos os usos (soja, milho e cana) ocupam 3/4 da área agrícola do país. A área de uso agropecuário da terra, a frequência de cultivo e a área de cultivo na segunda safra são parâmetros essenciais para um grande número de modelos de uso da terra. Entretanto, os autores detectaram inconsistências nas estimativas da FAOSTAT e da literatura quanto a esses parâmetros. O objetivo deste trabalho é apresentar os resultados de uma iniciativa conjunta entre a Embrapa e a FAO para atualizar esses parâmetros com base em estatísticas oficiais. A atualização dos dados da FAOSTAT levou a uma mudança na área de agricultura e pastagem do Brasil para 63 e 172 Mha em 2016, respectivamente, 28% e 12% menores do que os valores anteriores. Considerando isso, a frequência de cultivo (área colhida sobre área de uso da terra) no Brasil é maior que 1.2, que resulta 30% superior às estimativas atualmente presentes na literatura e à média global. A área de segunda safra em 2017 pode ter alcançado 16 Mha, um aumento de 92% desde 2006. Em 2017, isso representava 21% da área total colhida no país, sendo composta principalmente de milho (68%), trigo (13%) e feijão (6%). Os novos dados têm importantes repercussões para modelos de uso da terra e políticas públicas para a promoção de uma agricultura e bioenergia sustentáveis.

Palavras-chave: sucessão de culturas, dupla safra, safrinha, entressafra, milho, mudança de uso da terra.

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Brazil’s agricultural land, cropping frequency and second crop area: FAOSTAT statistics and new estimates

Abstract - Accurate territory representation plays crucial role in proper food and crop-based bioenergy sustainability evaluation processes. Three crops used for both purposes (soybean, corn and sugarcane) account for 3/4 of croplands in Brazil. Agricultural land, cropping frequency and second crop area are essential parameters for a variety of land-use models. However, the authors of the current study have identified inconsistencies in FAOSTAT and in literature estimates on them. The aim of the current study is to present the results of a joint effort carried out by Embrapa and FAO in order to update those parameters with verified official records. FAOSTAT’s updated estimates show that cropland and pasture areas in Brazil back in 2016 covered 63 Mha and 172 Mha, respectively, and these numbers were 28% and 12% lower than previous figures for the same year. Accordingly, cropping frequency (i.e., ratio of harvested area / cropland) in Brazil is higher than 1.2, which is 30% higher than both the currently available estimates and the global average. Second crop area in 2017 may have reached 16 Mha, a 92% increase since 2006. In 2017, it accounted for 21% of total harvested area in the country, which mostly comprised corn (68%), wheat (13%) and bean (6%). The new data presented herein have important repercussions on land-use models and policy design to promote sustainable agriculture and bioenergy production.

Key-words: cropping intensity, multi-cropping, double cropping, off-season, maize, land-use change.

Introduction

Accurate territory representations play crucial role in proper food and crop-based bioenergy sustainability evaluations, as well as in guiding actions towards its development (Wicke et al., 2015; Woods et al., 2015; Hilst et al., 2018; Shukla et al., 2019). Brazil is a major player in global agriculture, since it is one of the largest bioenergy, food and fiber producers and exporters (OECD-FAO…, 2017; Silva et al., 2020). Simultaneously, the country holds one of the largest portions of natural areas and one of the highest biodiversity levels on the globe (Brasil, 2015, 2016). Nowadays, three crops that are used both for food and bioenergy production purposes (soybean, corn, and sugarcane) account for more than 3/4 of the cropland and harvested area in the country (Woods et al., 2015; IBGE, 2019a, 2019b). Given the growing relevance, complexity and dynamics of territories such as Brazil (OECD-FAO…, 2017), maintaining updated and accurate databases is a challenging task and an essential activity to help supporting sustainability measures (FAO, 2014; FAO, 2020).

The patterns and efficiency of land-use for agricultural purposes are major points of concern among those addressing food and bioenergy sustainability (Wicke et al., 2015; Albanito et al., 2016; Shukla et al., 2019). Agricultural area and cropping frequency are important parameters in this context, since they are in the basis of a whole range of land-use and impact-assessment studies based on international statistics (You et al., 2014; Woods et al., 2015; Shukla et al., 2019; Donke et al., 2020; Zhao et al., 2020; Cherubin et al., 2021). Equilibrium and integrated models, such as GTAP, GLOBIOM and IMAGE, for example, depend on these parameters to simulate future bioenergy and associated indirect land-use change scenarios (You; Wood, 2006; Taheripour et al., 2017; Doelman, et al., 2018; Havlik et al., 2018).

FAOSTAT is the main international database available for agricultural statistics. It is maintained by the Food and Agriculture Organization (FAO), and is built upon both national information provided by countries and estimates performed by FAO staff (FAOSTAT, 2020). While investigating data available from different sources, inconsistencies were identified in FAOSTAT database regarding information about agricultural areas (cropland and pasture) in Brazil. The aforementioned information was derived from a mix of scattered data such as an isolated 1994 internal report, extrapolations of outdated preliminary Census (IBGE, 2006) results and completed with estimates on the current harvested area. Given the current availability of more consistent data and the relevance of these parameters, the authors of the current study decided to revise and update the FAOSTAT database.

Global-wide ‘cropping frequency’ (CF) studies have mainly relied on country-level FAOSTAT statistics (e.g., Siebert et al., 2010; Ray; Foley, 2013; Taheripour et al., 2017), whereas detailed second crop area estimates remain unavailable. Because of outdated FAOSTAT data, most studies have pointed out that Brazil makes low intensive use of its agricultural land and presents low CF (e.g., Ray; Foley, 2013; Taheripour et al., 2017; Yu et al., 2019). However, it is well-documented by Brazilian national institutions (Brazilian Institute of Geography and Statistics - IBGE and National Supply Company - CONAB), as well as by the scientific literature, that a large and growing double-cropping area has been established in the country, mainly based on the soybean-corn combination (Arvor et al., 2012; Spera et al., 2014; Picoli et al., 2018). This finding allowed questioning the reliability of CF estimates available for Brazil. Moreover, although some data on second crop area are available for Brazil, comprehensive, countrywide and long-term estimates are still lacking. The viability of discriminating crops and harvest areas, based on seasons through geographic information systems (GIS) is evolving quickly (e.g., Chen et al., 2018; Picoli et al., 2018). However, data available either focus on specific regions and/or crops, and a consistent treatment to be applied to all commercial crops and regions in Brazil remains unavailable.

Therefore, the aims of the current study are to present the results of a joint effort by the Brazilian Agricultural Research Corporation (Embrapa) and FAO aimed at updating FAOSTAT database on cropland and pasture areas in Brazil, as well as to propose new and more consistent estimates on the Brazilian cropping frequency and second crop area, based on agricultural statistics for as many commercial crops and regions in the country as possible. The new data presented herein have important repercussions on national and global land-use models, on impact and life cycle assessments, and on policy design to promote sustainable agriculture and bioenergy development.

Materials and Methods

Methodological procedures were carried out at three different stages. The first stage consisted in reviewing and updating FAOSTAT's agricultural statistics recorded for Brazil, based on official national data. The second and third stages consisted in estimating CF and second crop area in Brazil, respectively.

Review and update of FAOSTAT agricultural statistics

FAOSTAT data on land use are mainly collected from countries through FAO's questionnaires on 'Land Use, Irrigation and Agricultural Practices' (FAOSTAT, 2020). Whenever countries fail to provide their data, FAO staff performs gap filling and imputations based on published information made available by governments or on sectoral studies and reports (FAOSTAT, 2020). The latest questionnaire on land use provided by the Brazilian government was handed in back in 1994, as an isolated country report by FAO's representation in Brazil; it reported 65.5 million ha of cropland area. Since then, no other official report was sent by the country to FAO. The outdated historical series was completed by FAO staff, combining data extracted from preliminary results of the 2006 Brazilian Agricultural Census (IBGE, 2006, Table 1.1), information about harvested area available in FAO database, as well as extrapolations and imputations based on these sources. After the 2017 Census (IBGE, 2019a) was released, Embrapa scientists contacted FAO colleagues and together they noticed inconsistencies in the outdated data with both the Census and other sources. Based on this finding, they proceeded with the revision and update of these data by taking into consideration the available Census data and by following current FAO's statistics good practices (FAO, 2014).

The Brazilian Agricultural Census is carried out by the Brazilian Institute of Geography and Statistics (IBGE) since 1920; it follows the international standards set by the World Program for the Census of Agriculture (IBGE, 2019a). The Census is carried out through surveys conducted at the landholding level countrywide; the latest eight surveys correspond to 1960, 1970, 1975, 1980, 1985, 1995, 2006 and 2017 (IBGE, 2019a). In order to integrate Census data into FAOSTAT, it was first necessary to create a correspondence table of land-use categories (Table 1). Next, the obtained areas were compared to other data sources in order to check their congruence, mainly with independent GIS data and with harvested area data derived from agricultural surveys (Table 2 and subtopic 2.3). Once the Census areas were shown to be more consistent over time, their final national-level consolidated data from 1995, 2006 and 2017 (IBGE, 2019a) were used to update FAOSTAT 'cropland' and 'land under permanent meadows and pastures', and, consequently, 'agricultural land' areas in Brazil in 1995, 2006 and 2017. Then, the years between them were estimated through linear interpolation; subsequently, the older historical series was revised accordingly.

Cropping frequency estimates

To estimate CF for Brazil and its states, we adopted the broad concepts proposed by Boserup (1965) and reviewed by Erb et al. (2013). Many other terms associated with this concept are available in the literature, such as cropping intensity (Siebert et al., 2010; Wu et al., 2018), cropland harvest frequency (Ray; Foley, 2013), vertical intensification (Brown et al., 2013), and intensification factor (Taheripour et al., 2017). We avoided using the term 'intensity' due to significant ambiguity observed in its use (e.g., Dietrich et al., 2012). We operationalized CF by dividing harvested area within a year by the cropland area presumably used to grow it, based on Turner and Doolittle (1978), Siebert et al. (2010) and Ray and Foley (2013). For instance, an area harvested once every two years was given CF factor of 0.5, but a factor of 2.0 if harvested twice a year, and so forth (Turner; Doolittle, 1978). We only computed commercial crops, thus disregarding cover and fodder ones (see Supplementary Material S1 for details).

Then, CF for Brazil was estimated based on the approach adopted by the main studies available in the literature (e.g., Ray; Foley, 2013). It consisted in dividing the total harvested area by the total cropland area reported by FAOSTAT (2020). In the case of Brazil, FAO's information on harvested area is derived from IBGE's Municipal Agricultural Production (PAM) survey (2019b) plus supplementations based on published data. FAO's harvested area was divided by FAOSTAT's 2019 (outdated) and 2020 (updated) cropland area versions recorded for Brazil in order to obtain national-level CFs.

Second crop area estimates

To estimate second crop area in Brazil we segregated first (spring-summer) versus second crop (fall-winter) harvested areas in Brazil, in a 12-month period, similarly to that adopted by Novaes et al. (2017). The first-season often meets the rainiest period in Brazil, whereas the second crop is often cultivated after that – details are in Supplementary Material S1. Second crop can also be referred to as 'off-season' and as composing double-cropping systems (Battisti et al., 2020; Moreira et al., 2020).

Estimates were mainly based on IBGE's PAM survey at municipal level (IBGE, 2019b), complemented with information deriving from CONAB, as well as from the Agricultural Climate Risk Zoning (Brasil, 2019a) for the definition of first and second crop areas. The segregation of total harvested area based on harvest/sowing time has been long practiced by Brazilian institutions at the time to compute agricultural statistics. Harvest/sowing seasons/times often meet climate seasons in most Brazilian regions, a fact that, in most cases, enables adopting the institutional classification. However, some crops and regions deviate from such a correspondence and were subject to different treatments depending on their specific features. Supplementary Material S1 show how each crop and data source was treated to obtain these estimates.

Both CONAB (2019a) and IBGE (2019b) provide official estimates on harvested areas segregated by first, second and third growing seasons. CONAB has been doing so for corn, common bean and peanut at state level since 1976, whereas IBGE has been listing these very same crops, in addition to potato at municipal level, since 2003. Crop or season (safra in Portuguese) for statistical purposes is defined by IBGE (2018), based on the order the crop is harvested in the civil year; and by CONAB (2019b, 2019c; Vasconcellos, F. B. personal communication[1]), based on the order the crop is sowed in the seasonal year (from September to August). These criteria are overall consistent in most of the Brazilian territory. According to IBGE, the first crop harvested in the civil year, often from January to March, is the first crop; whereas the second and third harvests are the subsequent ones, often from May to July and from August to November, respectively (IBGE, 2018). According to CONAB, crops sowed from September to December are the first crops, those sowed from January to April are the second crops, whereas the ones sowed from May on are the third-season ones. The Agricultural

[1] Information shared by e-mail by Fabiano Vasconcellos, Analyst of CONAB, in January, 30th, 2020.

Climate Risk Zoning (Brasil, 2019a) indicates the times of the year when crops present less than 20%, 30% and 40% risk of failure due to climate conditions. Periods posing lower risks for summer crops, such as soybean, are highly associated with the rainy season and with the first crop defined by IBGE and CONAB. These sources of information were combined to estimate harvested area based on season. The classification obtained herein was confirmed by experts in specific crops (Supplementary Material S1). Aggregate data were generated through an excel spreadsheet, adapted from Novaes et al. (2017; Supplementary Material S3). Three-year averages were computed to avoid inter-annual variability effect.

The first crop area obtained herein was also used to crosscheck consistency in cropland area data recorded for 2006 and 2017, since it exclusively relied on independent statistical data on harvested area. Then, a factor similar to CF was obtained by diving the obtained total harvested area by the first crop area. For example, if in a certain region presenting 100 ha of cropland, wherein 100 ha of soybean were harvested in the first crop and 50 ha of corn were harvested in the second crop, it would have a CF of 150/100 = 1.5. This calculation also was used to validate the aforementioned traditional CF estimates.

Results

FAOSTAT agricultural statistics

FAOSTAT cropland area recorded for Brazil was updated to 50.1, 60.6 and 63.5 Mha, for 1995, 2006 and 2016, respectively (Table 1; FAOSTAT, 2020), based on IBGE's Agricultural Census data (IBGE, 2019a). The aforementioned update represented reduction by 24%, 21% and 28% in cropland area size in comparison to previously published data, respectively (Table 2). Area for 'Land under permanent meadows and pastures' was updated to 178, 168 and 173 Mha, for 1995, 2006 and 2016, respectively (Table 1; FAOSTAT, 2020); these updates represent reductions by 8%, 14% and 12% in this parameter, respectively. Consequently, total agricultural area was updated to 228, 229 and 237 Mha, which correspond to reductions of 12%, 16% and 17% in these parameters, respectively.

Table 1. Correspondence of agricultural area statistics between Brazil's Agricultural Census and FAO's land-use classification.

Year	Land-use type*	FAO correspondence	Area (ha)
1995	Lavouras permanentes	6650 - Land under permanent crops	7,541,626
	Lavouras temporárias	6630 - Land under temporary crops	34,252,829
	Lavouras temporárias em descanso	6640 - Land with temporary fallow	8,310,029
	Pastagens naturais	6659 - Perm. meadows & pastures - Nat. Growing	78,048,463
	Pastagens plantadas	6656 - Perm. meadows & pastures - Cultivated	99,652,009
	Total cropland	**Sum items 6650, 6630, 6640**	**50,104,483**
	Total pasture	**Sum items 6659 and 6656**	**177,700,472**
2006	Lavouras permanentes	6650 - Land under permanent crops	11,679,151
	Lavouras temporárias	6630 - Land under temporary crops	44,609,043
	Lavouras - área plantada com forrageiras para corte	6633 - Land under temp. meadows and pastures	4,203,772
	Pastagens - naturais	6659 - Perm. meadows & pastures - Nat. Growing	57,633,188
	Pastagens (plantadas em boas condições e degradadas)	6656 - Perm. meadows & pastures - Cultivated	102,408,876
	Área para cultivo de flores	6774 - Cropland area under protective cover	100,607
	Sistemas agroflorestais	6655 - Land under permanent meadows and pastures (Agroforestry systems)	8,316,122
	Total cropland	Sum items 6650, 6630, 6633, 6774	60,592,573
	Total pasture	Sum items 6659, 6656, 6655	168,358,186
2017	Lavouras permanentes	6650 - Land under permanent crops	7,755,815
	Lavouras temporárias (in 2017, includes 6633 - Land under temp. meadows and pastures)	6630 - Land under temporary crops	55,642,059
	Lavouras - área para cultivo de flores	6774 - Cropland area under protective cover	119,927
	Pastagens - naturais	6659 - Perm. meadows & pastures - Nat. Growing	47,323,399
	Pastagens (plantadas em boas condições' e más condições)	6656 - Perm. meadows & pastures - Cultivated	112,174,148
	Sistemas agroflorestais	6655 - Land under permanent meadows and pastures (Agroforestry systems)	13,863,254
	Total cropland	**Sum items 6650, 6630, 6633, 6774**	**63,517,801**
	Total pasture	**Sum items 6659, 6656, 6655**	**173,360,801**

* Original terms used by IBGE only available in Portuguese

These updated cropland and pasture areas are congruent with other three independent, GIS-based analyses carried out by two different Brazilian Institutions and by the United States Geological Survey (USGS) (Table 2). Estimates based on the national greenhouse gas (GHG) inventory (Brasil, 2020) and on USGS (Zhong et al., 2017) have indicated that cropland area in Brazil covered 69 Mha, in 2016, and 64 Mha, in 2015, respectively; whereas estimates based on the national inventory have indicated that the pasture area covered 189 Mha, in 2016. According to MapBiomas, which is an internationally-funded open-access non-governmental initiative (MapBiomas, 2019; Souza et al., 2020), categories such as 'Agriculture' and 'Pasture' accounted for 59 and 175 Mha in 2017, which, summed with a proportion of category 'Mosaic of agriculture and pasture' (the agriculture: pasture ratio given by IBGE's Census at municipal level) led to 68 and 183 Mha, in 2017.

Table 2. Comparison of different estimates of agricultural areas in Brazil (Mha).

Item	Source*	Data origin	Retrieving date	Years**							
				94	95	02	06	10	15	16	17
Cropland	FAOSTAT, 2019	Census+ interp.	Feb 19	60	66	69	77	78	88	88	NA
	FAOSTAT, 2020		Mar 20	51	50	57	61	62	63	63	63
Agriculture‡	MapBiomas 4.0	GIS	Sep 19	-	40	-	52	-	-	-	68
Net Cropland Area	US Geological Survey	GIS	NA	-	-	-	-	-	64	-	-
Agriculture	III BR GHG Inventory	GIS	NA	52	-	56	-	69	-	-	-
Agriculture	IV BR GHG Inventory	GIS	NA	44	-	50	-	58	-	69	-
First season area	This study	Surveys	NA	-	-	-	54	-	-	-	61
Land under perm. m. and pastures	FAOSTAT, 2019	Census + interp.	Feb 19	191	193	197	196	196	196	196	NA
	FAOSTAT, 2020		Mar 20	178	178	172	168	170	172	172	173
Pasture‡	MapBiomas 4.0	GIS	Sep 19	-	166	-	186	-	-	-	183
Pasture	III BR GHG Inventory	GIS	NA	148	-	174	-	173	-	-	-
Pasture	IV BR GHG Inventory	GIS	NA	156	-	180	-	185	-	189	-

to be continued...

Table 2. Continuation.

Item	Source*	Data origin	Retrieving date	Years**							
				94	95	02	06	10	15	16	17
Agricultural area (cropland + pasture)	FAOSTAT, 2019	Census + interp.	Feb 19	251	259	266	273	274	284	284	NA
	FAOSTAT, 2020		Mar 20	229	228	229	229	232	235	235	236
	MapBiomas 4.0	GIS	Sep 19	-	206	-	237	-	-	-	251
	III BR GHG Inventory	GIS	NA	200	-	230	-	241	-	-	-
	IV BR GHG Inventory	GIS	NA	200	-	230	-	243	-	258	-

* FAOSTAT, 2019 and 2020 refer to outdated and updated data, respectively. The remaining sources are Brazil's Third (2016) and Forth (2020) National GHG Inventory, MapBiomas collection 4.0 (2019; Souza et al., 2020) and USGS' GFSAD30SACE available in Zhong et al. (2017).

**Years with Census data available are 1995, 2006 and 2017. The values for the years between these are interpolations from that by FAO staff. Years shown in the table were selected to allow comparisons among different sources.

‡ 'Agriculture' and 'Pasture' categories plus 'Mosaic of agriculture and pasture' multiplied by the agriculture-to-pasture ratio given by IBGE's Census (own calculations; see Supplementary Material S2).

NA - not applicable; just dynamic databases have retrieving dates.

Cropping frequency

Based on these new FAOSTAT cropland areas and on the FAOSTAT harvested area, CF estimated for Brazil was 1.03, 1.03 and 1.24 in 1995, 2006 and 2017, respectively (Table 3). These new estimates are considerably different from, and higher than, other estimates available in the literature, mainly because the latter ones were largely based on outdated FAOSTAT cropland statistics (e.g., Ray; Foley, 2013; Taheripour et al., 2017). In fact, the new data point towards CF higher than 1.0 for Brazil in the past 20 years and to CF more than 30% higher than the global mean estimates recorded for the last 10 years (Table 3). Brazil also accounts for figures higher than those of many other important agricultural countries and regions, such as South America, the EU and the US. The same increasing trend reported herein had been previously observed in other studies (Ray; Foley, 2013; Taheripour et al., 2017); it is also consistent with the sixfold increase in second crop area of corn from 1995 to 2017 and with the twofold increase in it from 2006 to 2017 (IBGE, 2019b, Table 4).

Furthermore, the CF level is highly heterogeneous across the Brazilian territory (Fig 1; Supplementary Material S2). According to IBGE data, CF levels vary from 0.5 to 1.7 among Brazilian states (threefold difference). The highest CF levels were observed in the Central-Southern states, which presented high superposition to the *Cerrado* and Southern Atlantic Forest biomes, whereas the lowest levels were observed in the Northern and Northeastern states, which overall correspond to the Amazon and Semiarid regions.

Table 3. Cropping frequency estimates in Brazil in comparison to other regions and to the global average.

Country	Source	Parameter	Years*								
			95	00	03	06	11	13	14	16	**17**
Brazil	Taheripour et al., 2017**	HOL	-	-	0.8	0.8	0.9	0.9	-	-	-
	Ray e Foley, 2013**	CHF	-	0.8	0.8	0.8	0.9	-	-	-	-
	Portmann, 2011**	Cropping intensity including fallow	-	0.9	-	-	-	-	-	-	-
	FAOSTAT, 2020	FAO harvested / 2019 crop. area	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	-
		FAO harvested / 2020 crop. area	1.0	0.9	1.0	1.03	1.1	1.1	1.2	1.2	1.24
	This study	FAO harvested / First season harvested area	-	-	-	1.15	-	-	-	-	1.26
Global	Taheripour et al., 2017**	HOL	-	-	0.9	0.9	0.9	0.9	-	-	-
	Ray and Foley, 2013**	CHF	-	-	-	-	0.9	-	-	-	-
	Siebert et al., 2010	Cropping intensity including fallow	-	0.8	-	-	-	-	-	-	-
	FAOSTAT, 2020	FAO harvested / crop. area	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9
South America	Taheripour et al., 2017**	HOL	-	-	0.9	0.9	0.9	0.9	-	-	-
	FAOSTAT, 2020	FAO harvested / cropland area	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.1

to be continued...

Table 3. Continuation.

Country	Source	Parameter	Years*								
			95	00	03	06	11	13	14	16	**17**
China	Taheripour et al., 2017**	HOL	-	-	1.3	1.3	1.4	1.5	-	-	-
	Qiu et al., 2017	China - Cropping intensity	-	-	-	-	-	1.4	-	-	-
	Ray and Foley, 2013**	CHF	-	1.2	1.2	1.3	1.4	-	-	-	-
	FAOSTAT, 2020	FAO harvested / cropland area	1.2	1.2	1.3	1.3	1.4	1.4	1.4	1.4	1.4
EU	Taheripour et al., 2017**	HOL	-	-	0.9	0.9	0.9	1.0	-	-	-
	FAOSTAT, 2020	FAO harvested / cropland area	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8
US	Taheripour et al., 2017**	HOL	-	-	0.7	0.7	0.7	0.7	-	-	-
	Ray and Foley, 2013**	CHF	-	0.7	0.7	0.7	0.7	-	-	-	-
	FAOSTAT, 2020	FAO harvested / cropland area	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.6

*Years shown in the table were selected to allow comparisons among sources.

**Own calculations based on published data (see details in Supplementary Material S2; pastures were not included).

HOL Ratio of the harvested area over available land

CHF Cropping harvest frequency

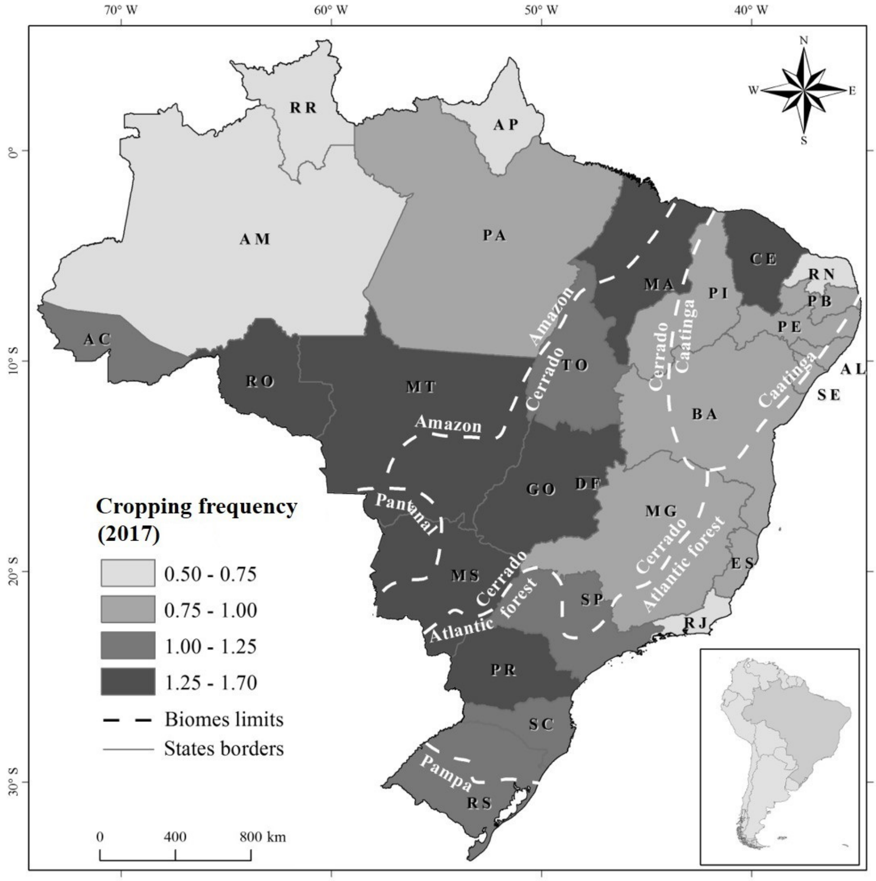

Figure 1. Cropping frequency variation across Brazilian states, based on IBGE data recorded for 2017. See Supplementary Material S2: https://cloud.sede.embrapa.br/owncloud/s/idnTZgDxjF32TiB for further details and full states' names.

Second crop area

The 13 crops considered partly or fully harvested in the second harvest season led to a commercial agricultural area harvested in the second crop in Brazil of 8.3 and 15.9 Mha in 2006 and 2017, respectively (Table 4). These numbers correspond to 13% and 21% of the total area harvested in these years, respectively. Corn accounts to roughly 2/3 of this value, with approximately 11 Mha harvested in the 2016/2017 second crop season (CONAB 2019a; IBGE, 2019b). The other two largest contributors were wheat and common bean, which accounted for roughly 13% and 6% of total second crop area, respectively; they were followed by sorghum, cotton and oat (Table 4).

Second crop harvested area has increased by 92% from 2006 to 2017, whereas total harvested area increased by 25% (Table 4). Among the 13 analyzed crops, corn recorded the largest area increase, 7.5 Mha or an increase of 227% (Table 4); this number is much higher than the reduction observed for some crops. The largest reductions observed in the current study were recorded for winter crops such as oat and triticale (approximately 0.1 Mha, each). Among the Brazilian states, 'Mato Grosso' (MT) and 'Paraná' (PR) accounted for 32% and 23% of total second crop area in 2017; they were followed by 'Mato Grosso do Sul' (MS), 'Goiás' (GO) and 'Rio Grande do Sul' (RS) states (Supplementary Material S2).

The size of the first crop area was estimated at 53.6 and 61.3 Mha in 2006 and 2017, respectively (Table 4). These estimates, which were based on harvested data, were very close to those of the Census cropland area, mainly in 2017 (Table 2). By dividing the estimates of total harvested area by first crop areas, an index similar to CF factor, results were very close to those estimates based on standing cropland area – 1.15 and 1.26 in 2006 and 2017, respectively (Tables 3 and 4). These results were considered indicative of consistency in FAOSTAT updated data.

Table 4. Estimates of second crop area in Brazil (Mha).

Year		2006	2017	Evolution	Share in second crop
Total harvested area (IBGE)		61.9	77.2	25%	
Second crop area*		8.3	15.9	92%	100%
	Barley	0.11	0.10	-4%	1%
	Bean	0.98	1.02	4%	6%
	Cotton	0.65	0.61	-6%	4%
	Linen	0.02	0.01	-56%	0%
	Corn	3.33	10.87	227%	68%
	Oat	0.28	0.38	37%	2%
	Peanut	0.02	0.01	-73%	0%
	Potato	0.07	0.06	-3%	0%
	Rye	0.004	0.005	23%	0%
	Sorghum	0.72	0.70	-3%	4%
	Sunflower	0.06	0.07	9%	0%
	Triticale	0.11	0.02	-85%	0%
	Wheat	1.92	2.05	7%	13%
First season area (total – 2^{nd})		53.6	61.3	14%	
Cropping frequency (total / first)		1.15	1.26	10%	

* See Supplementary Material S1 and S2 for more details.

Discussion

The data presented herein points towards significant reduction by 25%-30% in estimated cropland area and by 8%-14% in pasture area in Brazil, based on the FAOSTAT database, in comparison to previously published information. Updated CF estimates for Brazil resulted in figures 30% higher than previous records, showing a large variation in CF across Brazilian states. The current study is the first to provide estimates on second crop area in Brazil, as well as information about the main crops contributing to it, which can be used as proxies for double-cropping area. Agricultural land, CF and double-cropping estimates are adopted in several models and in studies focused on investigating land-use issues associated with bioenergy (e.g., Taheripour et al., 2017; Doelman, et al., 2018; Hilst et al., 2018; Cherubin et al., 2021). These new data offer an updated representation of Brazilian agriculture and, if adopted, can help better addressing agricultural land-use sustainability in Brazil. Production projections for 2028/2029 point towards continuous growth of second crop areas of corn and wheat, whereas common bean is expected to have its area stabilized (Brasil, 2019b; Moreira et al., 2020). These trends point towards total increase in the second crop area in Brazil, in the next few years, and it would contribute to enhance cropping frequency and yield, as well as to reduce the demand for land (Wu et al., 2018).

The estimates presented in the current study should also be considered as starting points for further refinements based on broader and different data sources. We only accounted for Census and statistical data on commercial crops available in IBGE and FAO databases. Thus, the final values present intrinsic uncertainty associated with data sampling and collection methods adopted by the aforementioned institutions. In addition, the definition of crops and regionalized season patterns was based on general and state-level simplifications. Further detailing these definitions and using GIS-derived data could help refining and further validating such estimates in the future. Finally, the conceptual definition of second crop area, its systematic accounting by agricultural statistics institutions, as well as its scope, can be improved. A number of different terms associated with its concept are available in the literature, leading to confusion and neither Brazilian nor international institutions systematically account for this parameter in a comprehensive manner. With respect to its scope, current results disregarded other important second crop agricultural land uses adopted in Brazil, such as cover crops, roughage fodder and pastures in Integrated Crop-Livestock-Forestry systems (Gil et al., 2015; IBGE, 2019a). We believe that further improvement in data and metrics could help better representing land-use systems in Brazil and abroad, as well as enable more effective measures focused on reaching agricultural and bioenergy sustainability.

Additional Information

Supplementary material to this article may be found online at **bit.ly/33Ob9Pu.**

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References

ALBANITO, F.; BERINGER, T.; CORSTANJE, R.; POULTER, B.; STEPHENSON, A.; ZAWADZKA, J.; SMITH, P. Carbon implications of converting cropland to bioenergy crops or forest for climate mitigation: a global assessment. **GCB Bioenergy,** v. 8, n. 1, p. 81-95, 2016.

ARVOR, D.; MEIRELLES, M.; DUBREUIL, V.; BEGUE, A.; SHIMABUKURO, Y. E. Analyzing the agricultural transition in Mato Grosso, Brazil, using satellite-derived indices. **Applied Geography,** v. 32, n. 2, p. 702-713, 2012.

BATTISTI, R.; FERREIRA, M. D. P.; TAVARES, É. B.; KNAPP, F. M.; BENDER, F. D.; CASAROLI, D.; JÚNIOR, J. A. Rules for grown soybean-maize cropping system in Midwestern Brazil: Food production and economic profits. **Agricultural Systems,** v. 182, article 102850, 2020.

BOSERUP, E. **The conditions of agricultural growth: The economics of agrarian change under population pressure**. London: George Allen & Unwin, 1965. 124 p.

BRASIL. **Zoneamento Agrícola de Risco Climático**. 2019a. Disponível em: http://indicadores.agricultura.gov.br/zarc/index.htm. Acesso em: 12 dez. 2021.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. **Projeções do agronegócio**: Brasil 2018/19 a 2028/29 projeções de longo prazo. Brasília, DF, 2019b. 126 p.

BRASIL. Ministério da Ciência e Tecnologia e Inovações. **Quarto Inventário Nacional de Emissões e Remoções Antrópicas de Gases de Efeito Estufa**: relatório de referência. Brasília, DF, 2020.

BRASIL. Ministry of the Environment. **Fifth Report to the Convention on Biological Diversity**: Brazil. Brasília, DF, 2015.

BRASIL. Ministry of Science, Technology and Innovation. **Third national communication of Brazil to the United Nations Framework Convention on Climate Change**. Brasília, 2016.

BROWN, J. C.; KASTENS, J. H.; COUTINHO, A. C.; VICTORIA, D. D. C.; BISHOP, C. R. Classifying multiyear agricultural land use data from Mato Grosso using time-series MODIS vegetation index data. **Remote Sensing of Environment**, v. 130, p. 39-50, 2013.

CONAB. **Acompanhamento da safra brasileira de grãos**: v. 7 safra 2019/20: terceiro levantamento. Brasília, DF, 2019a. Disponível em: https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos/item/download/29855_6663a5da9d6f1b4af9616d6df23357cb. Acesso em: 12 dez. 2021.

CONAB. **Calendário de plantio e colheita de grãos no Brasil 2019**. Brasília, DF, 2019b. Disponível em: https://www.conab.gov.br/institucional/publicacoes/outras-publicacoes/item/download/28424_34d371f808b23d9bd37b9101c8ed5094. Acesso em: 10 dez 2021.

CONAB. **Série histórica das safras.** Brasília, DF, 2019c. Disponível em: https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras. Acesso em: 10 dez. 2021.

CHEN, Y.; LU, D.; MORAN, E.; BATISTELLA, M.; DUTRA, L. V.; SANCHES, I. D. A.; OLIVEIRA, M. A. F. Mapping croplands, cropping patterns, and crop types using MODIS time-series data. **International Journal of Applied Earth Observation and Geoinformation,** v. 69, p. 133-147, 2018.

CHERUBIN, M. R.; CARVALHO, J. L. N.; CERRI, C. E. P.; NOGUEIRA, L. A. H.; SOUZA, G. M.; CANTARELLA, H. Land use and management effects on sustainable sugarcane-derived bioenergy. **Land,** v. 10, n. 1, article 72, 2021.

DIETRICH, J. P.; SCHMITZ, C.; MÜLLER, C.; FADER, M.; LOTZE-CAMPEN, H.; POPP, A. Measuring agricultural land-use intensity: a global analysis using a model-assisted approach. **Ecological Modelling**, v. 232, p. 109-118, 2012.

DOELMAN, J. C.; STEHFEST, E.; TABEAU, A.; MEIJL, H.; LASSALETTA, L.; GERNAAT, D. E.; SLUIS, S. Exploring SSP land-use dynamics using the IMAGE model: regional and gridded scenarios of land-use change and land-based climate change mitigation. **Global Environmental Change,** v. 48, p. 119-135, 2018.

DONKE, A. C. G.; NOVAES, R. M. L.; PAZIANOTTO, R. A. A. Integrating regionalized Brazilian land use change datasets into the ecoinvent database: new data, premises and uncertainties have large effects in the results. **The International Journal of Life Cycle Assessment**, v. 25, n. 6, p. 1027-1042, 2020.

ERB, K. H.; HABERL, H.; JEPSEN, M. R.; KUEMMERLE, T.; LINDNER, M.; MÜLLER, D.; VERBURG, P. H.; REENBERG, A. A conceptual framework for analysing and measuring land-use intensity. **Current Opinion in Environmental Sustainability,** v. 5, n. 5, p. 464-470, 2013.

FAO. **The FAO statistics quality assurance framework**. Rome, 2014.

FAO. **FAO Statistical Programme of Work 2020-2021**. Rome, 2020.

FAOSTAT. **Inputs/land use domain, previous version**. Rome, 2019.

FAOSTAT. **FAOSTAT inputs/land use domain**. Rome, 2020.

GIL, J.; SIEBOLD, M.; BERGER, T. Adoption and development of integrated crop-livestock-forestry systems in Mato Grosso, Brazil. **Agriculture, Ecosystems & Environment,** v. 199, p. 394-406, 2015.

HAVLIK, P.; VALIN, H.; MOSNIER, A.; FRANK, S.; LAURI, P.; LECLERE, D.; OBERSTEINER, M. **GLOBIOM documentation**: draft 4. Laxenburg: International Institute for Applied Systems, 2018. 38 p.

HILST, F. van der; VERSTEGEN, J. A.; WOLTJER, G.; SMEETS, E. M.; FAAIJ, A. P. Mapping land use changes resulting from biofuel production and the effect of mitigation measures. **GCB Bioenergy,** v. 10, n. 11, p. 804-824, 2018.

IBGE. **Censo Agropecuário 2006**: resultados preliminares. Rio de Janeiro, 2006.

IBGE. **Série Relatórios Metodológicos**. 3a. Rio de Janeiro, 2018.

IBGE. **Censo Agropecuário 2017**: resultados definitivos. Rio de Janeiro, 2019a.

IBGE. **Produção Agrícola Municipal**. Rio de Janeiro, 2019b.

MAPBIOMAS: coleção 4.0: estatísticas. 2019. Disponível em: https://mapbiomas.org/. Acesso em: 12 dez. 2021.

MOREIRA, M. M. R.; SEABRA, J. E. A.; LYND, L. R.; ARANTES, S. M.; CUNHA, M. P.; GUILHOTO, J. J. M. Socio-environmental and land-use impacts of double-cropped maize ethanol in Brazil. **Nature Sustainability**, V. 3, P. 209-2016, 2020.

NOVAES, R. M. L.; PAZIANOTTO, R. A. A.; BRANDÃO, M.; ALVES, B. J. R.; MAY, A.; FOLEGATTI-MATSUURA, M. I. S. Estimating 20-year land-use change and derived CO2 emissions associated with crops, pasture and forestry in Brazil and each of its 27 states. **Global Change Biology,** v. 23, n. 9, p. 3716-3728, 2017.

OECD-FAO Agricultural Outlook 2017-2026. Paris: OECD; Rome: FAO,2017.

PICOLI, M. C. A.; CAMARA, G.; SANCHES, I.; SIMÕES, R.; CARVALHO, A.; MACIEL, A.; ARVOR, D. Big earth observation time series analysis for monitoring Brazilian agriculture. **ISPRS Journal of Photogrammetry and Remote Sensing,** v. 145, p. 328-339, 2018.

PORTMANN, F. T. **Global estimation of monthly irrigated and rainfed crop areas on a 5 arc-minute grid**. Frankfurt: Institut für Physische Geographie, 2011. (Frankfurt Hydrology Paper, 9).

QIU, B.; LU, D.; TANG, Z.; SONG, D.; ZENG, Y.; WANG, Z.; XU, W. Mapping cropping intensity trends in China during 1982-2013. **Applied Geography,** v. 79, p. 212-222, 2017.

RAY, D. K.; FOLEY, J. A. Increasing global crop harvest frequency: recent trends and future directions. **Environmental Research Letters,** v. 8, n. 4, article 044041, 2013.

SHUKLA, P. R.; SKEA, J.; CALVO BUENDIA, E.; MASSON-DELMOTTE, V.; PÖRTNER, H. O.; ROBERTS, D. C.; ZHAI, P.; SLADE, R.; CONNORS, S.; DIEMEN, R. van; FERRAT, M.; HAUGHEY, E.; LUZ, S.; NEOGI, S.; PATHAK, M.; PETZOLD, J.; PEREIRA, J. P.; VYAS, P.; HUNTLEY, E.; KISSICK, K.; BELKACEMI, M.; MALLEY, J. (ed.). **Climate Change and land**: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Genebra: IPCC, 2019.

SIEBERT, S.; PORTMANN, F. T.; DÖLL, P. Global patterns of cropland use intensity. **Remote Sensing**, v. 2, n. 7, p. 1625-1643, 2010.

SILVA, R. F.B. da; BATISTELLA, M.; MILLINGTON, J. D.; MORAN, E.; MARTINELLI, L. A.; DOU, Y.; LIU, J. Three decades of changes in Brazilian municipalities and their food production systems. **Land**, v. 9, n. 11, article 422, 2020.

SOUZA, C. M.; SHIMBO, Z.; ROSA, J.; M., R.; PARENTE, L. L.; ALENCAR, A.; RUDORFF, A.; B., F.; OLIVEIRA, S. W. Reconstructing three decades of land use and land cover changes in Brazilian biomes with landsat archive and earth engine. **Remote Sensing,** v. 12, n. 17, article 2735, 2020.

SPERA, S. A.; COHN, A. S.; VANWEY, L. K.; MUSTARD, J. F.; RUDORFF, B. F.; RISSO, J.; ADAMI, M. Recent cropping frequency, expansion, and abandonment in Mato Grosso, Brazil had selective land characteristics. **Environmental Research Letters,** v. 9, n. 6, article 064010, 2014.

TAHERIPOUR, F.; CUI, H.; TYNER, W. E. An exploration of agricultural land use change at the intensive and extensive margins: implications for biofuels induced land use change. In: QUIN, Z.; MISHRA, U.; HASTINGS, A. (ed.). **Bioenergy and land use change**. Hoboken: Wiley; Washington, DC: American Geophysical Union, 2017.

TURNER, B. L.; DOOLITTLE, W. E. The concept and measure of agricultural intensity. **Professional Geographer,** v. 30, n. 3, p. 297-301, 1978.

WICKE, B.; HILST, V. D. van der; BANSE, M.; BERINGER, T.; GERSSEN-GONDELACH, S.; HEIJNEN, S.; KARSSENBERG, D.; LABORDE, D. LIPPE, M.; NASSAR, A.; POWELL, J.; PRINS, A. G.; ROSE, S. N. K.; SMEETS, E. M. W.; STEHFEST, E.; TYNER, W. E.; VERSTEGEN, J. A.; VALIN, H.; VAN VUUREN, D. P.; YEH, S.; FAAIJ, A. P. C. Model collaboration for the improved assessment of biomass supply, demand, and impacts. **GCB Bioenergy**, v. 7, n. 3, p. 422-437, 2015.

WOODS, J.; LYND, L. R.; LASER, M.; BATISTELLA, M.; CASTRO, V. D.; KLINE, K.; FAAIJ, A. Land and bioenergy. In: SOUZA, G. M.; VICTORIA, R. L.; JOLY, C. A.; VERDADE, L. M. (Ed.). **Bioenergy & sustainability**: bridging the gaps. Paris: Scope; São Paulo: Fapesp, 2015. p. 258-301. (Scope, 72).

WU, W.; YU, Q.; YOU, L.; CHEN, K.; TANG, H.; LIU, J. Global cropping intensity gaps: Increasing food production without cropland expansion. **Land Use Policy,** v. 76, p. 515-525, 2018.

YOU, L.; WOOD, S. An entropy approach to spatial disaggregation of agricultural production. **Agricultural Systems,** v. 90, n. 1-3, p. 329-347, 2006.

YOU, L.; WOOD, S.; WOOD-SICHRA, U.; WU, W. Generating global crop distribution maps: From census to grid. **Agricultural Systems,** v. 127, p. 53-60, 2014.

YU, Q.; XIANG, M.; WU, W.; TANG, H. Changes in global cropland area and cereal production: An inter-country comparison. **Agriculture, Ecosystems & Environment,** v. 269, p. 140-147, 2019.

ZHAO, X.; MENSBRUGGHE, D. Y.; KEENEY, R. M.; TYNER, W. E. Improving the way land use change is handled in economic models. **Economic Modelling,** v. 84, p. 13-26, 2020.

ZHONG, Y.; GIRI, C.; THENKABAIL, P. S.; TELUGUNTLA, P.; CONGALTON, G.; YADAV, R.; OLIPHANT, K.; A., J.; XIONG, J.; POEHNELT, J.; SMITH; C. **NASA making earth system data records for use in research environments (MEaSUREs) Global Food Security-support Analysis Data (GFSAD)**: cropland extent 2015 South America 30 m V001. Sioux Falls: Nasa, 2017. 29 p.