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Estimation of greenhouse gas emissions from agricultural activities in the Aburra valley Metropolitan Area - Colombia

Estimación de las emisiones de gases de efecto de invernadero generados por actividades agrícolas en el Área Metropolitana del Valle De Aburrá – Colombia

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ABSTRACT

Key words:
Agricultural production
Gases emissions
Fertilization
Global warming
Greenhouse effect
Uncertainty estimation

The aim of this study was to estimate emissions of greenhouse gases (GHG) generated by the agricultural activities carried out in the Metropolitan Area of the Aburrá Valley (AMVA), located in Medellin - Colombia. A TIER 1 approach of the methodology of the Intergovernmental Panel on Climate Change, IPCC was followed. Emissions of GHG from cropland, aggregate sources and non-CO_2 emissions from land were estimated and analysis of the uncertainty of activity data and emission factors were made. The estimated total emission was 63.1 and 66 Gg CO_2 eq for 2009 and 2011, respectively. The greatest contribution to greenhouse gases in agricultural production was the application of nitrogen to soils in the form of synthetic and organic fertilizers, which was associated with direct and indirect N_2O emissions. The main sources of uncertainty were those derived from the activity data.

RESUMEN

Palabras claves:
Producción agrícola
Emisiones de gases
Fertilización
Calentamiento global
Incertidumbre

El objetivo de este estudio fue estimar las emisiones de gases de efecto invernadero (GEI) generados en la producción agrícola del Área Metropolitana del Valle de Aburrá (AMVA), Medellín – Colombia. Para esto, se usó la metodología del Panel Intergubernamental de Expertos sobre el Cambio Climático, IPCC siguiendo una aproximación TIER 1. Se estimaron las emisiones de GEI en tierras de cultivo, fuentes agregadas y emisiones de gases diferentes a CO_2 a partir de tierras, y se hizo análisis de la incertidumbre a los datos de actividad y factores de emisión. La emisión total estimada fue de 63,1 y 66 Gg CO_2 eq para 2009 y 2011, respectivamente. El mayor aporte a los GEI en la producción agrícola fue la aplicación de nitrógeno a los suelos en la forma de fertilizantes sintéticos y orgánicos, que estuvo asociada con emisiones directas e indirectas de N_2O. Las principales fuentes de incertidumbre fueron aquellas derivadas de los datos de actividad.

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In 1992, the UN Framework Convention on Climate Change (UNFCCC) recognized that human activities have contributed to the substantial increase in atmospheric concentrations of greenhouse gases, intensifying the natural greenhouse effect and contributing to an additional warming of the Earth, which may adversely affect natural ecosystems and human welfare (UN, 1992). Today, scientific reports of increased ocean temperature and air worldwide, melting glaciers, declining ice caps and rising sea levels are becoming more frequent. Between 1900 and 2005, there has been increased precipitation in eastern North and South America, Northern Europe and Northern and Central Asia, while it has decreased in South Africa, the Mediterranean and South Asia. Despite efforts to reduce emissions, the Fourth Assessment Report Climate Change (AR4; IPCC, 2007) reported that the total annual emissions of greenhouse gases (GHGs) have continued to grow. In 2010, these emissions totaled 49.5 Gt of carbon dioxide equivalent (CO_2 eq), a value never observed before (Working Group II, IPCC, 2014).

Although not high, emissions from Colombia and Latin America contribute to the global pool of GHG emissions. In 2004, Colombia emitted 0.18 Gt of CO_2 eq, whereas US and EU emissions were 6.2 and 3.9 Gt of CO_2 eq, respectively (IDEAM, 2009). In 2002, Mexico had emissions of 0.5 Gt of CO_2 eq (Instituto Nacional de Ecología, 2004) and in 2000, Argentina emitted 0.2 Gt of CO_2 eq, (Secretaría de Ambiente y Desarrollo Sustentable, 2007). Thus, it is necessary to implement measures to reduce GHG emissions, increase mitigation and allow adaptation to climate change, which must come from policies and actions at the local, regional and national level. Together with the generation of new technologies, a change must occur in human behavior and consumption patterns (Working Group II, IPCC, 2014).

Although Colombia has conducted two National Greenhouse Gas Inventories, there have been few instances of initiatives at the regional level to determine the contribution of these regions to national GHG emissions (Echeverri, 2006; Pulido, 2012). In 2009, it was estimated that the Metropolitan Area of the Aburrá Valley, located in the department of Antioquia (Colombia), with 3,306,490 inhabitants (DANE, 2007) and 10 municipalities; had emissions of 3,694,374.7 t of CO_2 eq, from stationary and mobile sources, mainly vehicles and industry (Grupo de Investigaciones Ambientales, 2014). This has drawn attention to the relevance of these emissions to human health and environmental quality of the Aburrá Valley.

In 2009 and 2011, approximately 25% of the land in the Aburrá Valley was used in agricultural production, either as managed crops or as pastures (SIMAP, 2007-2012). Most of the crop production in this area comes from smallholders, which differs from the most important livestock production activities that take place in the region, of which a significant portion is at the hands of big producers and/or commercial companies. In order to identify the most effective mitigation actions, GEI inventories from the agricultural sector in this region, must be carried out separating emissions from crops and those directly generated in animal agriculture, as this will allow identification of actions with the greatest probability of adoption among different producers. In consequence, the aim of this study was to estimate GHG emissions from crop-only activities as a contribution to the analysis of mitigation and adaptation strategies to climate change that can be carried out in the region.

MATERIALS AND METHODS

Localization

The study took place in the Aburrá Valley, Antioquia department, northwestern Colombia, which is shaped by the geography of the Aburrá River (and its tributaries) basin, and has a length of 60 k. This valley is framed by an uneven and sloping topography with altitudes ranging between 1,300 and 2,800 m (Área Metropolitana del Valle de Aburrá, 2010) and has an area of 1,152 km^2 of which 340 km^2 correspond to urban land and 812 km^2 to rural land. This geographical area is home to 58% of the departmental population and 7.7% of the Colombian population (Área Metropolitana del Valle de Aburrá, 2007). The study area corresponds to the 10 municipalities of the Valle de Aburrá, which are Barbosa, Girardota, Copacabana, Bello, Medellín, Itagüí, Envigado, Sabaneta, La Estrella and Caldas.

Activity data and emission factors

Emissions of CO_2, CO and N_2O due to changes in land use and fertilization were estimated. This estimate consisted in combining activity data (AD, information on the extent of human activity) with emission factors (EF, coefficients that quantify the emissions or removals by human activity), using Equation 1 recommended by the IPCC (2006):

$$Emissions = AD * EF$$

In this inventory, an approach (TIER) 1 was used for each component of the inventory and depending on the case, the equations presented in Chapters 2, 5 and 11 of Volume 4 of the Guidelines (IPCC, 2006) were used. Activity Data and Emission Factors were determined from a macro to a micro scale (Top-Down), based on data from studies and statistics at the departmental level, down to the level of municipality, township or village, subject to availability of the information. Shortly, emissions were determined in CO_2 equivalent for each subcategory, adding the emissions of all subcategories and then calculating the uncertainty of the results.

To estimate the changes in land use, two sources of information were used: 1) land cover information of 2007, as a result of the "Metropolitan System of Protected Areas" (SIMAP) project, which provided information from that year; 2) The information on land cover in 2012, generated the "Green Belt" project. The maps of land cover, for 2007 and 2012 were used for linear interpolation and to estimate land cover data for the years 2009 and 2011, defined in the inventory as the initial and current year, respectively. These data were analyzed with respect to all land uses in AFOLU to the Aburrá Valley in order to determine changes in land use in the study years. This information did not include specific data for each type of crop.

To quantify emissions from the use of organic and synthetic fertilizers, lime and urea application to soils in the Aburrá Valley, information from areas in permanent and temporary crops recorded in Antioquia Statistical Yearbooks for 2009 (Gobernación de Antioquia, 2010) and 2011 (Gobernación de Antioquia, 2012) was used for each category of crops in the region. The percentage contribution from each municipality to the total area of permanent and temporary crops are shown in Table 1.

Table 1. Percentage of area for permanent and temporary crops in the municipalities of study, years 2009 and 2011.

	Permanent		Transitory		Total	
Municipality	**2009**	**2011**	**2009**	**2011**	**2009**	**2011**
Barbosa	40	38	36	27	39	37
Girardota	21	22	0	0	19	19
Copacabana	4	4	0	0	4	4
Bello	4	4	10	22	5	7
Medellín	20	21	48	47	24	24
Itagüí	0	0	0	0	0	0
Envigado	1	1	0	0	1	1
Sabaneta	3	2	0	0	2	2
La estrella	2	2	3	1	2	2
Caldas	5	5	3	2	5	5

The area planted as specific permanent crops in the two years of study at the Aburrá Valley is shown in Figure 1a, while the corresponding area of temporary crops is shown in Figure 1b. A total of nineteen different crops were included within the category of permanent crops, while another twenty were classified as temporary crops.

The contributions of urea were also included in managed pastures, which were estimated to be 13,738 ha in 2009 and 12,224 ha in 2011. Being a TIER 1 inventory, the emission factors used were those supplied by default in the IPCC Guidelines (IPCC, 2006), and those are presented in Table 2.

After evaluating the reliability of the information, this was inputted in both the IPCC software (WMO, UNEP, IPCC, SPIRIT, 2013), as in the worksheets developed based on the IPCC guidelines (IPCC, 2006), with the aim of having supports in the verification of results.

Uncertainty estimation

The uncertainty estimate constitutes good practice and it is an essential element in an exhaustive inventory of emissions and removal of gases. In this study, the uncertainty analysis was carried out by the method of error propagation, which is based on measuring the propagation of uncertainty in emissions or removals based on combining the uncertainties in activity data, emission factors and other estimation parameters using the following equation:

$$U_{Total} = \sqrt{U_1^2 + U_2^2 + ... + U_n^2}$$

Where U_{total} is the uncertainty percentage of the product of the quantities (half the 95 percent confidence interval, divided by the total and expressed as a percentage) and U_i is the uncertainty percentage associated with each of the quantities.

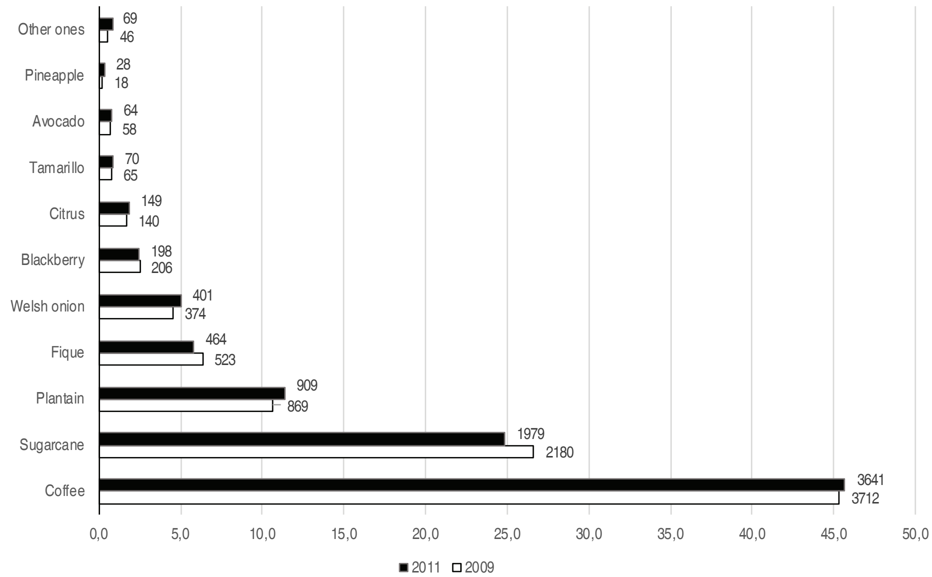

Figure 1a. Total area (ha) planted as permanent crops in the Aburrá Valley during 2009 and 2011.

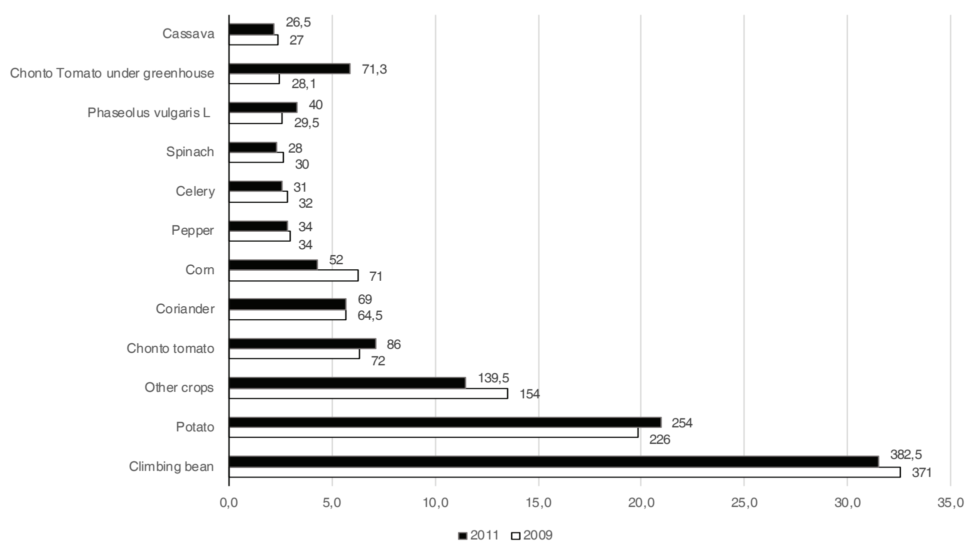

Figure 1b. Total area (ha) planted as temporary crops in the Aburrá Valley during 2009 and 2011.

Table 2. Emission factors (IPCC, 2006) used for quantification of GHG emissions from different agricultural activities in the Aburrá Valley.

	Emission Factor	Unit	Value
Biomass	Biomass accumulation rate (G)	t ha^{-1} C per year	2.6
	Loss of Carbon from Biomass (L)	t ha^{-1} C per year	21
	Biomass permanent crops	t ha^{-1}	70.5
	Biomass transitory crops	t ha^{-1}	10
	Harvest cycle/Maturity	Year	8
	Existence of carbon in biomass After a year (ΔCG) Annual crops	t ha^{-1} C	5
	Existence of carbon in Biomass after a year (ΔCG) Perennial crops	t ha^{-1} C	2.6
Carbon in soil	Land use(FLU)	Dimensionless	1
	Tillage (FMG)	Dimensionless	1.09
	Input (FI)	Dimensionless	1
N_2O emissions	EF1 (N inputs of synthetic and organic fertilizers , agricultural residues and N mineralized)	kg N_2O–N /kg N	0.01
	EF3 PRP (N deposited on soils for cattle grazing)	kg N_2O –N /kg N	0.02
	EF4 (volatilization and re- deposition of N)	kg N_2O –N / (kg NH_3–N + NO_X–N volatilized)	0.01
	EF5 (leaching and runoff)	kg N_2O –N / (kg N leaching/runoff)	0.0075
	FracGASF (Volatilization of synthetic fertilizer)	(kg NH_3–N +NOx–N)/ (kg N applied)	0.1
	FracGASM (Volatilization organic fertilizers, manure and urine from grazing animals)	(kg NH_3–N +NOx–N) / (kg N applied or deposited)	0.2
	FracLEACHING-(H) (N loss due to leaching and runoff)	kg N	0.3
Lime	EF dolomite lime	Dimensionless	0.13
Urea	EF urea	Dimensionless	0.2

RESULTS AND DISCUSSION

Changes in land use and estimated soil area used for different crops

By using the information available from the “SIMAP” and “Green Belt” maps to identify crop areas in the Aburrá Valley, a total of 13,514.3 ha was obtained, for the year 2009 and 14.102 ha for 2011. It was not possible to account for the type of crops represented in these areas, only to quantify the changes in areas under permanent and temporary crops. From the second source of information used, the Statistical Yearbook of Antioquia, more detailed information was obtained on the areas for each crop by municipality (Table 3). The major permanent crops in the study area are coffee and sugarcane, with an approximate combined share of 72% of the total area of the permanent crops for 2009 and 71% for 2011 (Figure 1a). In turn, as

Table 3. Area of permanent and transitory crops in the study region in 2009 and 2011. Sources: SIMAP and Green Belt projects and Statistical Yearbook of Antioquia.

	Cultivated area (ha)				Weighed difference (%)	
	Maps coverage		Statistical yearbook			
Crops	2009	2011	2009	2011	2009	2011
Permanent	11509.1	11834.2	8189.0	7971.0	33.71	39.01
Temporary	2005.2	2267.8	1139.1	1213.8	55.09	60.55
Total	13514.3	14102.0	9328.1	9184.8	36.65	42.23

shown in Figure 1b, the transitional cultivation with greater crop area is arbustive bean, which occupied 32.6% of the total area in 2009 and 31.5% in 2011, followed by potatoes and other seasonal crops (including beans, beets, cabbage, lettuce, carrot and onion), with minor contributions of 20 and 13.5% of the total area, respectively. The area destined for managed pastures was of 13,739 and 12,225 ha for the years 2009 and 2011, respectively.

There was a difference of 4,186 ha between both sources of information (maps vs. yearbook) in 2009. For 2011, that difference was 4,917 ha. These differences depict the sum of several inaccuracies, which include those associated with the collection of data on maps and the inability to access information of detail on the differentiation of vegetation cover with greater certainty. It should be noted that statistical yearbooks are made "by consensus" in the Municipal Agricultural Technical Assistance Units (UMATA) and this would explain much of the observed discrepancy between these two estimates.

In terms of use of land for crops, the municipality with the greatest contributions to total crop area is Barbosa, which represented 39% of the total crop area in 2009 and 37% of total crop area in 2011 (Table 1). The municipality of Medellín contributes 24% of total crop area in the Aburrá Valley. This corresponds mainly to the contribution of the rural areas of San Antonio de Prado, San Sebastián de Palmitas and San Cristóbal (Alcaldía de Medellín y Universidad Nacional de Colombia, 2009).

Table 4. Dose (kg ha^{-1} per year) of synthetic fertilizer nitrogen applied to crops and pastures.

	Activity data	Value	Reference
Permanent	Sugarcane	62.5	(FAO and CORPOICA, 2007)
	Plantain	220	(CORPOICA, 2006)
	Pineapple	355	(CORPOICA and SENA, undated)
	Welsh Onion	480	(Castellanos, 1999)
	Avocado	102	(CORPOICA, 2008)
	Coffee	250	(CENICAFE, 2012)
	Cabbage	80	(Seminario Consorcio Lechero)
	Strawberry	60	(Molina *et al*., 1993)
	Blackberry	120	(CORPOICA, 1986)
	Valencia Orange	150	(Molina, 2000)
	Tamarillo	300	(Universidad Técnica del Norte, 2011)
Temporary	Potato	275	(Ramírez, 2012)
	Chonto Tomato	300	(Centro Nacional de Tecnología Agropecuaria y Forestal - CENTA, undated)
	Chonto Tomato under greenhouse	900	(CORPOICA, 2006)
	Pepper	228	(Nuez, 2003)
	Celery	468	(Monómeros Colombovenezolanos S.A., 1998)
	Cassava	60	(Centro Internacional de Agricultura Tropical - CIAT, 2008)
	Corn	100	(Bonilla, 2009)
	Climbing bean	97	(FAO and CORPOICA, 2007)
	Phaseolus vulgaris L	53	(Hernández, 2009)
	Coriander	70,5	(Universidad Nacional de Colombia, 2010)
	Cabbage	150	(Monómeros Colombo Venezolanos S.A., 1998)
	Garlic	300	(Monómeros Colombo Venezolanos S.A., 1998)
	Cauliflower	300	(Monómeros Colombo Venezolanos S.A., 1998)
	Lettuce	80	(Monómeros Colombo Venezolanos S.A., 1998)
	Carrot	100	(Monómeros Colombo Venezolanos S.A., 1998)
	Beet	100	(Monómeros Colombo Venezolanos S.A., 1998)
Grasslands	Managed pastures	161	(Asociación Internacional de la Industria de los Fertilizantes, 1992; International Plant Nutrition Institute (IPNI), 2003)

The rate of N applied to soils was determined through review of the literature regarding crop nutrient requirements and the recommended dose of nitrogen fertilizer application, for the main permanent and temporary crops and pastures in the Aburrá Valley (Table 4).

Quantification of emissions

It was estimated that total emissions (Gg CO_2 eq) were 63.1 in 2009 and 66.0 in 2011. These corresponded to around 30% of emissions from AFOLU in the Aburrá Valley in 2009 and 32% of AFOLU emissions in 2011. The main source of GHG emissions in agricultural activities is the application of N to the soil in the form of synthetic and organic fertilizers. Thus, direct N_2O emissions corresponded to 54 and 49% of total emissions for 2009 and 2011, respectively, whereas indirect N_2O emissions were 31% for 2009 and 37% by the year 2011. According to Stehfest and Bouwman (2006), the increase in atmospheric N_2O concentration is primarily due to increased use of nitrogenous fertilizers in agriculture, and this is denoted in other reports in the literature. In 2008, in the module of agriculture of the GHG Inventory of Cundinamarca, Colombia, Pulido (2012) reported that 49% of contributions to GHG from agricultural land came from the use of nitrogenous fertilizers, both organic and synthetic, which is consistent with the findings in this study.

The agricultural practice that generates the lowest annual GHG emissions to the atmosphere is the application of lime, which contributed approximately 1.8 Gg CO2 eq in both years, corresponding to 3% of total emissions from agricultural activities, as shown in Figure 2. This is due both to the lower frequency of this practice as well as the low emission factor associated with this activity (Table 2).

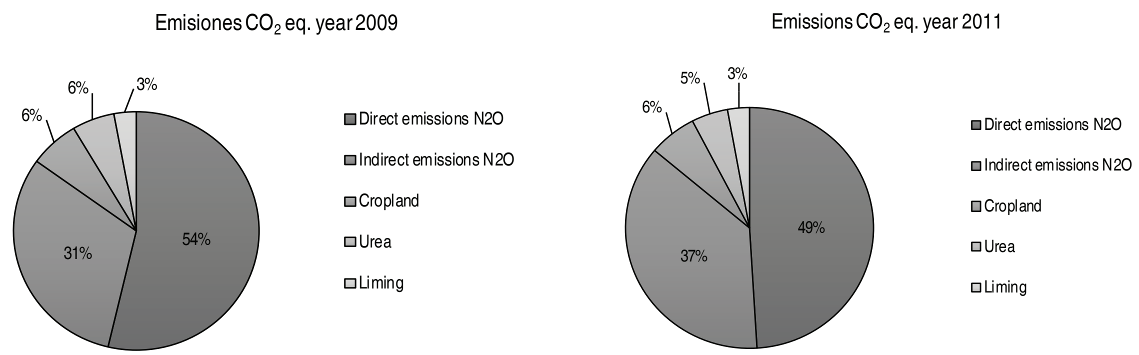

Figure 2. Emissions of CO_2 eq in agricultural production as a percentage of the total issued.

In 2009 and 2011, the application of synthetic fertilizers produced 56% of total direct emissions of N_2O in the Aburrá Valley, while the contribution of N by deposition of urine and manure in the pasture by grazing cattle, produced about 41%. Tubiello *et al.* (2014) reported that 2011, global emissions resulting from the application of synthetic fertilizers were about 14% of total emissions from agriculture. During the period 2001-2011, annual emissions from this activity increased by 37%. Emissions estimated in this study for the Valley of Aburrá do not differ from these estimates.

Most indirect N_2O emissions, were generated by volatilization and leaching of N from manure applied to the soil as organic fertilizer or deposited directly by grazing (68% in 2009 and 76% in 2011). In extensive grazing, type of cultural practices and inadequate application of synthetic nitrogen fertilizers are major sources of emissions due to great losses of N in nitrification and denitrification (Van Der Hoek, *et al*., 2007; Popp *et al*, 2010). In addition, high rainfall accentuate leaching processes (Eckard and Cullen, 2011). Tubiello *et al.* (2014) reported that global annual N_2O emissions from application of manure as fertilizer increased by more than 12% between 2001 and 2011, with N supply mainly coming from cattle (45%) and pigs (18%) manure; while emissions from manure and urine deposited on pastures increased by 16% over the same period.

Emissions of N_2O arising from residues of beans, corn, potatoes, carrots and cassava crops contributed approximately 0.8% to total GHG emissions in this period.

This small contribution can be attributed to little production of these crops in the region and the emission factor used. In this study, the contribution to emissions from the burning of crop residues, were estimated to be zero, since there are no official figures on this practice for the ten municipalities included in the study. In 2011, the global contribution of this practice was estimated to be only 0.5% of total emissions from agriculture and originated from burning corn, wheat, rice and sugarcane crop residues (Tubiello *et al*., 2014).

The emissions associated with land use changes were 4.13 Gg CO_2 eq for both years, of which 100% was due to CO_2 emissions, mainly by the passage of forest lands, pastures and stubble, to farmland as the agricultural frontier advanced (Dawson and Smith, 2007; Sierra *et al*, 2007). It was estimated that 689.5 ha in pasture and forestry became agricultural crops in 2009 and 2011. The IPCC (2013) suggested that logging activities disturb the carbon stored in soil and biomass, resulting in average annual net emissions of CO_2 of 0.9 [0.1 to 1.7] Gt C per year over the period of 2002 to 2011. As this is a new measurement, and countries have not yet based their national communications on the 2006 IPCC guidelines, it is not possible to compare the results obtained in this study with those of previous national communications.

Uncertainty in the estimation of emissions

Several sources of uncertainty were identified, including the estimation of activity data and the appropriateness of the emission factors, which may not be applicable to the conditions of production systems evaluated (Milne *et al*., 2014). To verify doses of fertilizers used by producers in the area, the concept of experts and producers of major crops in the study area were included. The uncertainties of crop areas from the two sources of information were estimated as well as those originated by organic fertilizer, urea and lime application to the soils, and those derived from the use of unspecific emission factors for calculating emissions of CO_2 and N_2O. The combined uncertainties obtained for each category using the error propagation method are shown in Table 5.

Table 5. Estimation of uncertainty for GHG emissions from agricultural production in the Aburrá Valley in 2009 and 2011.

Categories	Gas	Emissions 2009 (Gg CO_2eq)	Emissions 2011 (Gg CO_2eq)	Activity data uncertainty (%)	Emission factor uncertainty (%)	Combined uncertainty (%)
Cropland	CO_2	4.1	4.1	46	50	68
Direct emissions	N_2O	33.9	32.4	57	50	76
Indirect emissions	N_2O	19.7	24.5	57	50	76
Liming	CO_2	1.9	1.9	41	50	65
Urea application	CO_2	3.5	3.1	46	50	68

The magnitude of the uncertainties encountered was due to the difficulties in identifying reliable and detailed information sources, corresponding to the characteristics of the study of the area. Additionally, the lack of precise, updated and reliable geographic information, represented an obstacle to determine land use and its evolution over time, increasing the uncertainty of the inventory. The default emission factors used can be further sources of uncertainty, as they may not be representative of the GHG emissions associated with agricultural production at the Aburrá Valley (Flynn *et al*., 2005). Uncertainty can change depending on the quality of activity data and emission factors used, and according to the IPCC uncertainties of up to 100% can be qualified as acceptable for a TIER 1 inventory, yet there is not any doubt that the completeness and quality of information needs to be improved (Rypdal and Winiwarte, 2001).

CONCLUSIONS

The GHG emissions from agricultural production in the Aburrá Valley for the years 2009 and 2011 were 63.1 and 66.0 Gg CO_2 eq, respectively. These emissions correspond approximately to 1.3% of total GHG emissions in the Aburrá Valley for 2009 and 2011. Nitrogen fertilization is the main source of N_2O emissions in the Aburrá Valley, with a contribution of 85% in emissions in 2009 and 86% in 2011. Of these, the contribution of synthetic nitrogen and organic nitrogen fertilization by pig and poultry manure act as the main source.

The change in the use of forest and pasture soils towards crops was an important source to CO_2 emissions, contributing 6% of total emissions. Despite the low emissions as a result of land use, this should be highlighted as it involves the felling of natural and planted forests, loss of high and low shrubby areas, reducing the capture of CO_2 from not only in agricultural production by soil disturbance and use of lime and urea, but in other sectors such as the industry. This also means the loss of ecosystem services that forests provide, such as biodiversity, protection of water sources, control of erosion and landscape services, among others.

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