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Ecosystem Services and Agricultural Production in Latin America and Caribbean

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Acronyms

LAC	Latin America and the Caribbean
MA	Millennium Ecosystem Assessment
GNI	Gross National Income

1. Background

Latin America and the Caribbean (LAC) is facing a daunting challenge: produce food, fiber, and fuel and preserve its mega biodiversity and associated ecosystem services.[1] It is important to remember that this is one of the few regions in the world that due to its area and relatively low population density may balance food production and preservation. It is also important that agriculture as an ecosystem service has an important impact on the LAC economy.[2] Agriculture and livestock are vigorously expanding in LAC due to a series of political and economic changes initiated in the 1990s.[3] As a consequence, this region became an important food producer on a global level. For instance, LAC is a leading producer and exporter of soybean, sugar, coffee, fruits, poultry, beef, and—more recently—ethanol.

The growth in agriculture has unfortunately been followed by deterioration of the environment. Today LAC leads the world in biomass burning, jeopardizing a myriad of important biomes and its mega biodiversity. On the other hand, with some adjustments, agriculture in LAC has the ability to promote not only economic growth but also economic development.[4] But agriculture, while being one of the most precious ecosystem services, depends on the services provided by healthy and resilient ecosystems.

2. Overview of LAC Agriculture

Expansion

LAC has experienced an unprecedented growth of its agriculture in recent decades.[5] In 1961, arable land in LAC represented only 7 percent of the world total; in 2009 this proportion increased to 11 percent. In other areas of the world, only Africa showed an equivalent increase in arable land. Europe and North America decreased their proportions in relation to the world's total, and Asia and Oceania had small increases, less than 2 percentage points in the same period of time (1961–2009). Livestock showed the same trend. The number of chicken heads increased

[1] Franko 2007; Grau and Mitchell 2008.
[2] David et al. 2000; Barbier 2004.
[3] Barbier 2004; CEPAL 2005.
[4] World Bank 2008; Martinelli et al. 2010.
[5] David et al. 2000; Barbier 2004; CEPAL 2005.

exponentially in the last five decades; and although it was not exponential, cattle growth was also very sharp in LAC.

Latin America and the Caribbean, especially Central America and the Andes-Amazon region,[6] were important centers of vegetal species domestication and one of the cradles of agriculture in the world.[7] More than 15 crops used today were domesticated in LAC.[8] Among them are some staple crops for several populations of the globe: cassava, common beans, and maize.[9] Additionally, at the household and local levels, huge varieties of plants are cultivated for food, fiber, and medicinal purposes,[10] which characterize LAC as also having a high agro-biodiversity.

At the regional level, however, the trend is totally diverse; pastures alone dominate almost 80 percent of agricultural lands, and it seems that livestock will continue to be the main land use in the future.[11] Eight crops dominate 80 percent of the harvested arable land area. Among these, cassava, beans, and maize, which were originally domesticated in the region, are still present. On the other hand, soybean, which was practically nonexistent here 50 years ago, occupied one-third of the harvested arable land and, together with maize, more than half of the arable land area in 2009. Other important crops, in decreasing order of harvested area, are sugarcane, wheat, rice, and coffee. (See Table 1.) Beans, cassava, and rice are important staple crops for people in this region. Yet, curiously, the harvested area of cassava has been approximately constant for a long period and, more important, the harvested area of beans and rice has been decreasing since the 1990s. Three crops are increasing in harvested areas in LAC: maize, sugarcane, and soybean.

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6 Piperno et al. 2000.
7 Diamond 2002; Purugganan and Fuller 2009.
8 Simpson and Ogorzaly 2001.
9 Duputié et al. 2011; Martínez-Romero 2003; Matsuoka et al. 2002.
10 Clement 1999; Fraser et al. 2011.
11 Wassenaar et al. 2007.

Table 1

Land use area and livestock production in LAC and its relative contribution to world's land use and livestock production

Crops	Area (million ha)	Production (million tonnes)	World (percent)
Agricultural area[1]	722		15
Pasture[1]	550		15
Arable land[1]	150		11
Soybean	43	95	42
Maize	27	100	12
Sugar cane	11	900	54
Wheat	9	21	3
Beans	7	6	29
Coffee	5	0.5	58
Cassava	2.5	33	15
Livestock	**Head (million)**	**Production (million tonnes)**	**World (percent)**
Chicken	2700	15	18
Cattle	400	14	22
Pig	80	6	6

The spatial distribution of these crops is really important in terms of loss of habitats and the mega biodiversity that LAC holds. Highly insightful maps produced by the Global Landscapes Initiative project (Institute on Environment, University of Minnesota) have been used to consider the distribution; they show the land cover intensity of the main crops globally.[12] Considering the four major crops in terms of harvested area (see Table 1), there is a tendency of a high concentration between the southeast region of Brazil and the northeast region of Argentina, including Uruguay and Paraguay. (See .) Besides this core area, soybean has expanded in Brazil, first to the center-west region, and more recently toward the Amazon basin, reaching the city of Santarém in the state of Pará. Outside of this core area, soybean is also

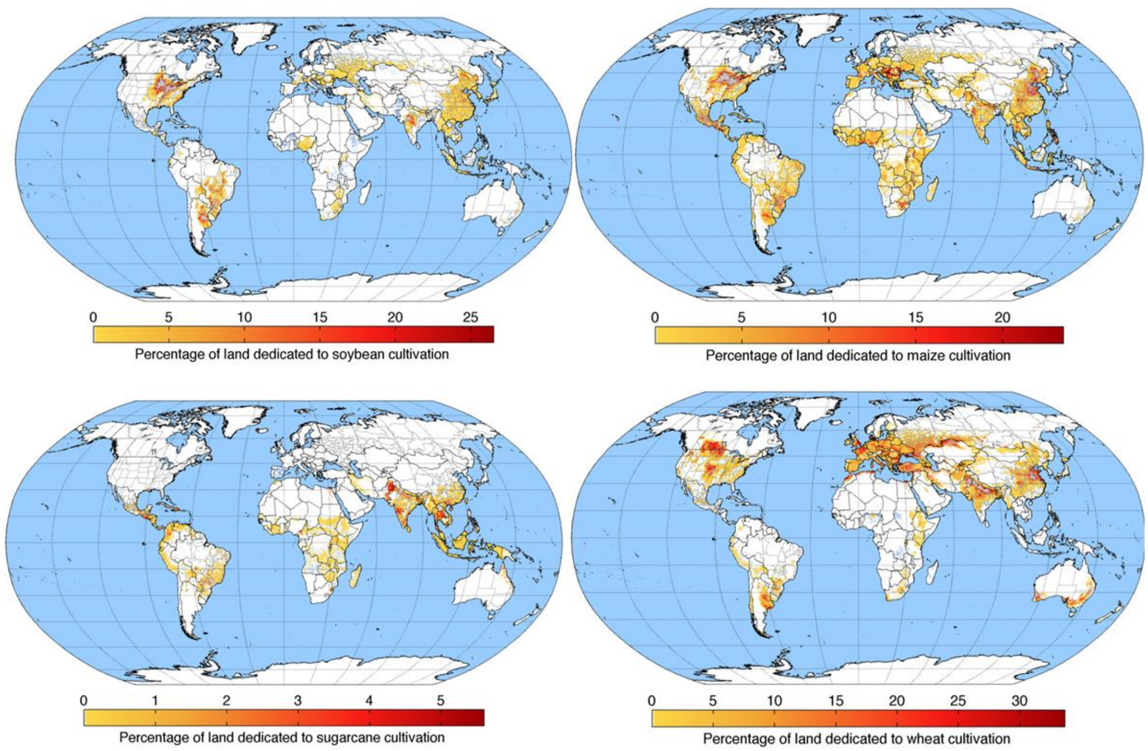
[12] Ramankutty et al. 2008.

present in Bolivia, Mexico, Ecuador, Venezuela, and Colombia. Maize is spread throughout LAC, with the exception of northern Chile, the southern tip of South America, and the Amazon basin. In terms of harvested area, however, Brazil and Mexico alone are responsible for 70 percent of the total; if Argentina, Colombia, Guatemala, Paraguay, and Venezuela are included, 90 percent of the harvested area is accounted for. Sugarcane is also present in several countries, but Brazil on its own has more than 70 percent of the harvested area. Wheat is more restricted to the southern regions of South America, since is a temperate crop. Argentine harvests almost half of that total area; adding in Brazil, both countries harvest more than 70 percent of the wheat.

Figure 1.

Land cover intensity of four major crops in LAC

Source: Global Landscape Initiative Project – Institute of Environment, University of Minnesota (http://environment.umn.edu/atlas/).



Intensification

The extensification of agriculture in Latin America was followed by intensification.[13] One effect of this was the increase of productivity of several crops. All major crops in the region have experienced significant productivity increases; one exception to this was cassava, which is a staple crop for several countries and indigenous people but which had the lowest increase in productivity.

The general increase in productivity has several causes. One is the development of a tropical agriculture to replace traditional techniques used in temperate industrial countries coupled with the development of varieties adapted to tropical conditions.[14] Fertilizer consumption also increased in total consumption as well as per area. Use of nitrogen fertilizer increased in the last 50 years from 5 kg/ha to almost 45 kg/ha; use of phosphorus and potassium in the same period increased from less than 5 kg/ha to approximately 35 kg/ha. Data on agrochemicals like insecticides and herbicides are more sparse and difficult to access. Data available for Brazil from 1990 to 2001 showed a constant and sharp increase in the consumption of these compounds.[15] Brazil has more than 400 registered pesticide formulas for soybean use in the field, and for sugarcane, at least more than 200—more than in any country worldwide.[16] Approximately 40 percent of these formulas are considered “extremely toxic” or “highly toxic” to humans, and approximately half of them are considered “highly dangerous” or “very dangerous” to the environment.[17] According to the consultant company the Kleffmann Group, in 2008 Brazil became the leader in agrochemical consumption in the world, a market worth US$7 billion.[18] LAC, with 11 percent of the world’s arable land, is responsible for 20 percent of the agrochemical world’s market. Additionally, the highest increase in agrochemical sales is expected in this region.[19]

[13] Green et al. 2005.
[14] Martinelli et al. 2010.
[15] Martinelli and Filoso 2009.
[16] Schiesari and Grillitsch 2011.
[17] Ibid.
[18] Pacheco 2009.
[19] Mcdougall 2008.

Environmental Impacts of Expansion and Intensification

The initial impact of the agricultural process occurs at the point of replacing original vegetation with a crop. Probably this is the most important impact of agriculture in LAC because, in contrast to regions where agriculture has been practiced in areas converted many years ago, LAC still has a vast area occupied by original vegetation that can be converted to agriculture. In 2010, LAC had approximately 670 million ha of primary forests—equivalent to approximately 30 percent of its land area and almost 60 percent of the primary forest areas on Earth.[20] Between 1990 and 2010, however, this region lost almost 90 million ha of forests.[21] Losses of primary vegetation were higher in tropical forests, mainly in the Amazon and Atlantic Forest; it was not restricted to these types of forest, however, as it also affected other types of vegetation, including the savannas of the Brazilian Cerrado, the dry forests of Chaco, the mountain forests of Ecuador, and the grasslands of the Pampas.[22]

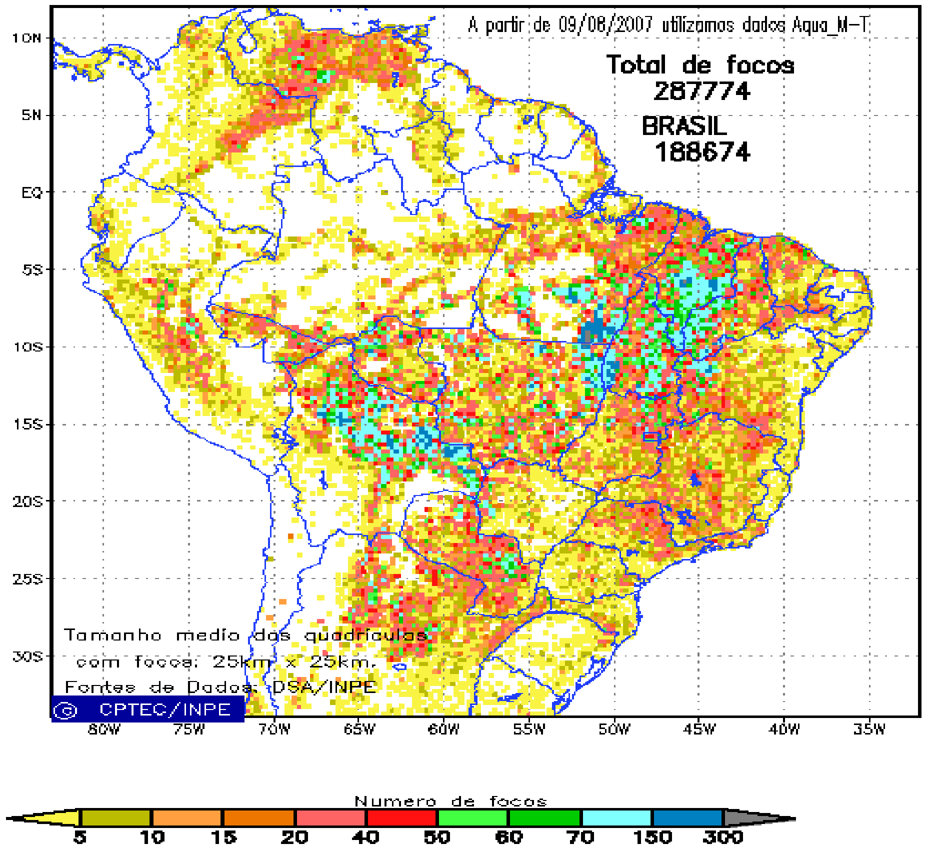
Most of the original vegetation is burned prior to soil cultivation in LAC. Chuvieco et al. estimated that in 2004, a total of 15 million ha were burned, but Lauk and Erb estimated the figure to be twice as high.[23] Yevich and Logan estimated that approximately 350 million tons of wood for fuel are burned per year in LAC, with half this amount in Brazil alone.[24] Additionally, Lauk and Erb found that human-induced vegetation fires consumed approximately 800 million tons of biomass.[25] The extent of fires can be viewed from satellite-composed images for 2010 made by the Brazilian Institute of Spatial Research. It is clear from these images that with the exception of parts of the western Amazon and the northern region of Chile, there were several fire zones throughout all countries of South America. (See Figure 2.)

[20] FAO 2011.
[21] Ibid.
[22] Klink and Machado 2005; Grau and Mitchell 2008.
[23] Chuvieco et al. 2008; Lauk and Erb 2009.
[24] Yevich and Logan 2003.
[25] Lauk and Erb 2009.

Figure 2

Cumulative number of focus of heat in 2010 for the central part of South America

Source: CEPTEC-INPE (http://sigma.cptec.inpe.br/queimadas/).



These extensive fires in LAC have several major consequences on ecosystems, the atmosphere, and public health. In terrestrial ecosystems, the increase of soil temperature due to vegetation burning has several deleterious effects, including decreased soil water content and increased bulk density, which in turn leads to soil compaction and potentially increased soil erosion.[26] Nutrients stocked in the burned vegetation are transferred to the atmosphere or the soil.[27] In the soil these nutrients are in part lost to aquatic systems;[28] subsequently, nutrients are exported via deep leaching, erosion, and agricultural products, culminating in nutrient impoverishment of the original system if the nutrients are not constantly replaced by organic or mineral fertilizer.

Nitrogen, which is a limiting nutrient, is transferred from the vegetation to the atmosphere as NO_x and NH_3, as well as particulate nitrate and ammonium.[29] Part of the nitrogen emitted to the atmosphere returns to the ecosystem via wet and dry deposition. Dentener et al. modeled total N deposition in LAC and found two regions where deposition is similar to the highest amounts found in the rest of the world.[30] One area overlaps with the area of major agricultural development, which encompasses southeast Brazil, Uruguay, Paraguay, and the northern portion of Argentina. At the same time the model indicated a high N deposition area in the northern part of South America, including Colombia, Venezuela and Ecuador. One of the consequences of this extra N in the atmosphere is the formation of HNO_3 and consequently acid rain events.[31] In turn, acid rain may lead to further cation impoverishment of the already cation-poor tropical soils.[32] More interesting yet is the fact that such impoverishment may occur far from the burning zone, as is the case in the Andean montane forests of northern Ecuador, which receives the biomass plume from the Amazon lowlands.[33] Another consequence is that the increase in N deposition to values higher than the natural deposition interferes with the local biodiversity.[34]

Aerosols emitted to the atmosphere due to vegetation burnings are another source of concern due to the extent of fires in LAC. In the Amazon basin fires emit an enormous amount

[26] Dourado-Neto et al. 1999; Oliveira et al. 2000.
[27] Martinelli 2003.
[28] Neill et al. 2001; Thomas et al. 2004.
[29] Mace et al. 2003; Rocha et al. 2005; Trebs et al. 2006.
[30] Dentener et al. 2006.
[31] Lara et al. 2005.
[32] Krusche et al. 2003.
[33] Boy et al. 2008.
[34] Bobbink et al. 2010.

of particles to the atmosphere;[35] the same is true for sugarcane areas of southeastern Brazil.[36] Aerosols may alter several aspects of the atmosphere and related climatological process. Among them, high emissions of aerosols decreases the climate radiative forcing; as a consequence, less radiant energy reaches the ground.[37] Aerosols also act as cloud condensation nuclei, which in turn, according to their size, will determine the intensity of rainfall.[38] By controlling the intensity of rainfall, aerosols are influencing the hydrological cycle, which in turn will affect ecosystem functioning.[39]

Nitrogen fertilizers are another source of reactive nitrogen in LAC ecosystems.[40] The mean N fertilizer consumption per area basis in LAC in the last three years varied from 40 to 46 kg N/ha/yr. These values are well below the world average of approximately 75 kg N/ha/yr. However, the use of N fertilizer in LAC has been the largest proportional increase in the world in the last decades.[41] Additionally, it is well known that crops cannot absorb all fertilizer applied on the ground even in low nitrogen input agrosystems.[42] The N that is not taken up by plants has the potential to cause pollution problems in different areas of the ecosystem.[43] As the use of N fertilizer tends to grow in LAC, environmental pollution problems are also likely to occur.[44]

One way that fertilizer may reach an aquatic ecosystem is through soil erosion and surface runoff. Soil erosion is considered the main cause of soil degradation.[45] There are numerous papers showing that soil erosion–related problems are widespread in the region (see Metternicht et al. for a compilation of several papers).[46] However, an estimate for the whole area is difficult due to several factors. The only work available was conducted by the Global Assessment of Human-induced Soil Degradation.[47] Although this survey had limitations,[48] it is useful to point to critical areas that soil conservationists should be aware of. For LAC, the total soil erosion (water plus wind) was estimated at approximately 200 million ha, which is equivalent to 30 percent of the agricultural land of LAC.

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[35] Artaxo et al. 1998, 2002; Andreae et al. 2002; Martin et al. 2010.
[36] Lara et al. 2005.
[37] Hobbs et al. 1997.
[38] Rosenfeld et al. 2008.
[39] Barth et al. 2005; Martin et al. 2010.
[40] Martinelli et al. 2006.
[41] Ibid.
[42] Balasubramanian et al. 2004.
[43] Goulding 2004; Galloway et al. 2008.
[44] Martinelli et al. 2006.
[45] Lal 2001.
[46] Metternicht et al. 2010.
[47] Oldeman et al. 1991.
[48] Bai et al. 2008.

Soil erosion affects not only the soil itself but also the area that receives the erosion products, especially water bodies.[49] Soil cultivation tends to increase soil nutrients and carbon losses;[50] erosion exposes this soil carbon to future chemical and physical reactions. Eroded soil particles also transport pesticides used in agricultural fields to aquatic ecosystems, where they may affect aquatic life and human health.[51]

3. Agriculture and Ecosystems Services in LAC

The Millennium Ecosystem Assessment (MA) was the most comprehensive study of ecosystem services. According to the MA definition, "ecosystem services are the benefits people obtain from ecosystems."[52] The authors grouped ecosystem services into three broad categories: *provisioning, regulating*, and *cultural*. *Provisioning* encompasses, among others, food, wood and fiber, fuel, and fresh water. *Regulating* refers to climate, diseases, wastes, flood, and water quality. *Cultural* involves aesthetic, spiritual, educational, and recreational services. The *provisioning* and the *regulating* services depend on basic *supporting* services, such as soil formation, photosynthesis process, and nutrient cycling. The MA understood that human well-being includes multiple needs: *basic material for a good life*, *health, security, good social relations,* and *freedom of choice and action*.[53]

This section discusses how changes due to agriculture affect *regulating* and *provisioning* services in Latin America and the Caribbean. This does not mean that *cultural* services are less important, but they are beyond the scope of this paper.

Regulating Services

Regulating services are those that are essential to meet basic needs like food and water. Examples of these are regulation of climate, diseases, and water quality.[54] Climate encompasses several different aspects, such as physical attributes, that interfere directly with ecosystem functions, such as precipitation and air temperature. Global changes in climate are expected to affect the capacity of ecosystems to meet basic human needs. According to Marengo et al.,

[49] Starr et al. 2000.
[50] Guo and Gifford 2002.
[51] Gilden et al. 2010.
[52] MA 2005.
[53] Ibid.
[54] Ibid.

consistent warming throughout the year for South America (Central America and Caribbean were not included in the study) is expected for the end of this century.[55] Although changes in precipitation patterns are more variable, it seems most likely that there will be a reduction of rainfall in eastern Amazonia and northeast Brazil, as well as an increase in rainfall in the northwest coast of Peru and Ecuador and in the southern region of Argentina.[56] Also, it is likely that, although annual rainfall will not change drastically, the breadbasket region of LAC between southern Brazil and northern Argentina will face extreme precipitation events, with possible deleterious consequences to agriculture.[57]

Climate-regulating services also provide one of the clearest linkages between biodiversity and ecosystem services. The Amazon basin is the origin of the moisture that is transported by a corridor linking the basin to the breadbasket region.[58] Moisture from the Amazon also contributes to the center-west region of Brazil, where most of the soybean of the country is produced. This is the same water vapor source that may cause extreme precipitation events under a global change scenario at the end of this century. The key role that trees play in the Amazon has been already shown in the local water cycle, in which they pump water back from the soil to the atmosphere.[59] More recently it was shown that besides evapotranspiration, trees also contribute to rain by emitting to the atmosphere isoprene that is transformed in particles of 2-methilthertion, a hygroscopic particle that helps to form rain droplets.[60] Recently, Ekström et al. preliminarily demonstrated a third mechanism through which microorganisms, by releasing biological surfactants to the atmosphere, may help to form rain droplets by acting like particles of 2-methilthertion.[61] Therefore, all these mechanisms indicate that biodiversity plays a key role even in the water cycle, which is primarily driven by physical factors.

Provisioning

Perhaps the most important ecosystem service in LAC is agriculture itself—the provision of food, fiber, and fuel. The food supply in the region, with the exception of the Caribbean, has steadily increased in recent decades, reaching values similar to or larger than the world average

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[55] Marengo et al. 2009.
[56] Ibid.
[57] Ibid.
[58] Ibid.
[59] Salati et al. 1979.
[60] Claeys et al. 2004.
[61] Ekström et al. 2010.

food supply. Another important feature of the food economy is the proportion of food from animal origin, which is increasing in Central and especially in South America, reaching proportions significantly higher than the world average. It is also important that agriculture as an ecosystem service has an important impact on the LAC economy.[62] Although the relative participation of agriculture in the gross national income (GNI) per capita has been decreasing steadily since the 1980s, in absolute terms there has been an increase in the GNI linked to agriculture since 2001. An important aspect of agriculture in LAC is that several countries became net exporters of agricultural commodities, and this has helped a net positive trade balance.[63] For instance, in 2007 agriculture accounted for 40 percent of Brazil's trade surplus.[64]

Although agriculture is so important for LAC countries, it is no longer possible to promote an unsustainable agriculture that has deleterious environmental consequences. Accordingly, it is necessary to change the agricultural paradigm of investing only in crop production by expanding agricultural areas or by intensifying existing crop fields. Countries have to develop and promote what is called sustainable agriculture.[65] In this kind of agriculture it is paramount to maximize agricultural productivity on one side while promoting environmental services at the same time. In addition to providing food, fiber, and fuel, agricultural fields that are managed properly may provide a series of other environmental services—a win-win situation.[66] Carbon sequestration by agricultural soils, for instance, is one of these services.

Agro-ecosystems are indeed a simplification of more complex natural ecosystems. The main goals of sustainable agriculture are to mimic natural ecosystems, adding to agro-ecosystems' layers of complexity, and to increase functional diversity.[67] Additionally, sustainable agriculture recognizes the role of neighboring landscapes in providing key services to agriculture.[68] The most recognizable of these services are pollination and biological pest control.[69]

Most staple crops do not depends on pollinators, but several fruits, vegetables, nuts, and stimulant crops like coffee are highly dependent on them.[70] It is important to remember that LAC

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[62] David et al. 2000; Barbier 2004.
[63] CEPAL 2005
[64] Martinelli et al. 2010.
[65] Pretty et al. 2003, 2006; Pretty 2008; Keating et al. 2010; Godfray et al. 2010; Phalan et al. 2011.
[66] Swinton et al. 2007; Power 2010.
[67] Scherr and McNeely 2008; Tilman 1997.
[68] De Marco and Coelho 2004; Ricketts 2004.
[69] Power 2010.
[70] Ghazoul 2005; Klein et al. 2007.

is an important fruit and vegetable producer and the largest coffee exporter of the world. Gallai et al. estimated that the insect pollination economic value for LAC would be worth approximately €12 trillion, and most losses would be felt due to losses in coffee production.[71]

The few studies of pollination in LAC are concentrated on coffee, passion fruit, and grapefruit.[72] These studies and others have concluded that the number of pollinators and other useful insects decreases proportionally to the distance of agricultural fields from natural ecosystems.[73] Therefore, it is fundamental that agricultural fields are embedded in a landscape where natural fields may provide shelter for pollinators and other insects that are enemies of crop pests.[74] The two major threats to pollinators are deforestation (loss of habitat) and the use of insecticides that kill not only agricultural pests but also other insects.[75] As noted earlier, the use of insecticides is increasing without precedent in this region.

Agricultural sustainability also includes a series of field management activities in order to add layers of complexity to agricultural fields. These techniques include no till, cover crops, and nutrient management. No till or reduced till means letting crop residues from the last harvest cover the soil with minimum soil disturbance. This would mimic natural ecosystems where bare soil is rarely exposed; it was inspired by ancient techniques adopted in the *roçados* of Brazilian indians and in the *chinampas* of the Aztecas in Mexico.[76] Today this kind of cultivation practice is widespread in LAC, especially in Brazil, Uruguay, Paraguay, and Argentina.[77] In Brazil alone more than 27 million hectares have adopted this kind of cropping system.[78] No till has several advantages over conventional till: building up soil organic matter, increasing soil fertility, enhancing biological nitrogen fixation, and preventing soil erosion.[79] In the first case it was estimated that in the southern region of Brazil the average rate of carbon gain in the soil under no till was of almost 0.50 Mg/ha/yr, decreasing in the Cerrado region to 0.35 Mg/ha/yr.[80] A negative side of no till is that the area of gliphosate-resistant soybean is increasing in LAC, and more

[71] Gallai et al. 2009.
[72] De Marco and Coelho 2004; Ricketts 2004; Yamamoto et al. 2010; Chacoff and Aizen 2006.
[73] Philpott et al. 2008; Maués et al. 2010; Garibaldi et al. 2011; Teodoro et al. 2011.
[74] Scherr and McNeely 2008; Priess et al. 2007; Gardiner et al. 2009.
[75] Imperatriz-Fonseca et al. 2007; Freitas et al. 2009.
[76] Patiño-Zúñiga et al. 2008.
[77] Díaz-Zorita et al. 2002; García-Préhac et al. 2004; Pinheiro et al 2010.
[78] Boddey et al. 2010.
[79] Diekow et al. 2005; Hungria and Vargas 2000; García-Préhac et al. 2004; Bernoux et al. 2006.
[80] Bayer et al. 2006.

weeds are becoming gliphosate-resistant, which calls for the replacement of gliphosate, which has a low environment impact, with less environmentally friendly herbicides.[81]

Crop rotation is also important in terms of a strategy to keep soil covered all year around and maintain a closer nutrient cycle in agro-ecoystems, increasing soil organic matter content.[82] Crop rotation is usually done with a cash crop and a cover crop that is normally an N-fixing legume.[83] Part of this fixed nitrogen is used by the next crop.[84] This extra nitrogen from biological nitrogen fixation also decreases the N-fertilizer use that can have diverse deleterious effects on the environment, as described. One important unintended consequence of the use of legumes as cover crops is an increase in the emission of N_2O, a potent greenhouse gas.[85] Therefore, it is important to maximize N uptake by plants as soon as N is available through the mineralization-nitrification process.[86]

Crop-livestock systems are the ultimate layer of complexity that can be add to sustainable agriculture; these systems consist of adding animals to no till and crop rotation systems. In these systems animals act like recyclers of nutrients, taking them from vegetation and returning them to the soil via animal excreta. The expected result is improved soil fertility and an accumulation of carbon in the soil. In order for this system to work properly, it is paramount to choose the right stocking rates of animals, ensuring that the nutrient uptake by animals would not be excessive and that vegetation biomass of forage crops would be enough to act as mulch for the next crop.

Crop-livestock systems were initially used in LAC to establish pasture, where rice was first cultivated in order to be used as a cash crop and also to use nutrients available in the soil due to the original biomass burning.[87] In Uruguay since the 1960s crop-livestock integration has been the predominant management system.[88] According to Díaz-Zorita, since the 1990s this system has been used in part of the pampas in Argentina.[89] In other areas, like the Amazon region and the Brazilian cerrado, this system was used to improve soil fertility of degraded pastures, and a grain crop was used again as a cash crop to finance improvements of these degraded pastures.[90]

[81] Valverde 2007; Cerdeira et al. 2011.
[82] Zanatta et al. 2007; Vieira e al. 2009.
[83] Hungria and Vargas 2000.
[84] Rosolem et al. 2004.
[85] Jantalia et al. 2008.
[86] Gomes et al. 2009.
[87] Carvalho et al. 2010a.
[88] García-Préhac et al. 2004.
[89] Díaz-Zorita et al. 2002
[90] Carvalho et al. 2010a.

More recently, areas of the Amazon and cerrado have been adopting crop-livestock systems as a long-term management practice.[91] This system is particularly developed in the south region of Brazil, where there are several crop-livestock systems. For instance, in larger properties, mechanized soybean are cropped in the summer and forages for cattle for beef are cultivated in the winter; in smaller properties, maize, rice, beans, and other crops are combined with cattle for dairy or sheep and goats.[92] The main advantages of the crop-livestock systems are a better economic return to the farmer, improvement of the physical, biological, and chemical soil properties, and an improvement in the productivity of the following crop.[93]

All the systems that characterize conservation or sustainable agriculture just described have the potential to mitigate greenhouse gas emissions. Under conventional agriculture it has been demonstrated that in most cases there is a reduction in the carbon stocks of the soil, probably because there is an increase in the soil organic matter mineralization and also erosion carbon losses.[94] Agricultural practices like no till, crop rotation, and crop-livestock systems seem to revert these losses and in several cases promote carbon accumulation in the soil.[95] This is an important agro-ecosystem service because the increase of organic matter influences several soil properties, leading to an increase in crop productivity.[96] However, no till management and the use of cover crops like legumes may increase N_2O emissions, which would offset the carbon accumulation in the soil.[97] There are still few studies to fully evaluate the role of N_2O emissions under different cropping systems in LAC. Under tropical and subtropical conditions, N_2O emissions under no till cropping system were low, not offsetting the benefits in mitigating GHG emissions of this system.[98] However, in order to avoid any nitrogen losses to the atmosphere or for deep leaching, it is advisable to synchronize N-availability with plant uptake, as discussed.[99]

In summary, agriculture, depending on how it is conducted, can produce not only food, fiber, and fuel but also a series of ecosystem services. But for that to happen, agricultural fields have to be integrated in the landscape, and a mosaic of natural vegetation and crop fields has to co-exist. This implies that most of the deforestation has to end in LAC and that an increase in

[91] Carvalho et al. 2010b.
[92] Balbinot et al. 2009.
[93] Ibid.; Carvalho et al. 2010a.
[94] Don et al. 2011.
[95] Bernoux et al. 2006; Pinheiro et al. 2010; Govaertz et al. 2009; Powlson et al. 2011.
[96] Powlson et al. 2011.
[97] Patiño-Zúñiga et al. 2008; Jantalia et al. 2008; Gomes et al. 2009.
[98] Jantalia et al. 2008; Gomes et al. 2009.
[99] Gomes et al. 2009.

agricultural production has to come from sustainable intensification, which in turn implies the adoption of a series of certain sustainable management practices.

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