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2023-02-10

Maeda , E E , Aragao , L E O C , Baker , J C A , Balbino , L C , de Moura , Y M , Nobre , A D , Nunes , M H , Silva Junior , C H L & dos Reis , J C 2023 , ' Land use still matters after deforestation ' , Communications earth & environment , vol. 4 , no. 1 . https://doi.org/10.1038/s43247-023-00692-x

http://hdl.handle.net/10138/356259
https://doi.org/10.1038/s43247-023-00692-x

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earth & environment

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https://doi.org/10.1038/s43247-023-00692-x OPEN

Land use still matters after deforestation

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Careful management of deforested Amazonian land cannot replace, but must complement, efforts to preserve the rainforest. Sustainable agricultural practices that promote diverse uses can help minimise climate and environmental impacts.

Different land uses in deforested regions of Amazonia can have very different impacts on the climate and environment. Although different sectors of society are engaged in efforts to curb Amazonian deforestation, the consequences of land use in deforested areas have not received enough attention. After deforestation, the remaining forest fragments continue to be affected by ecosystem disturbances in the surrounding areas. These disturbances have profound effects not only on the biodiversity and functioning of remaining forests but also on agribusiness. We argue that we need a land-use revolution toward the management of deforested lands that takes an environmental, social and economic perspective.

Rapidly changing land use

The uses of deforested areas in the Amazon region are under constant change. After the 1970s, a combination of technological advances, including plant breeding and soil acidity correction (i.e., liming), led to the expansion of soybean plantations into Brazil's Savannas—the Cerrado—and the Southern Amazon frontier. Together, these advances marked a turning point for agricultural production in the Southern Amazon. Higher productivity and increasing profits created fertile ground for corporate farming and led to a rapid expansion of extensive monocultures[1]. From 2000 to 2019, the area of soybean cultivation in the Amazon region increased more than 10-fold (Fig. 1), from 0.4 to 4.6 Mha[2].

Not all deforestation is the same

Environmental changes within remaining forest fragments often mirror changes in their surroundings[3]. The climatic impacts that arise from forest loss depend on the size of deforested patches, on land use, and on the land management in those areas. Small-scale deforestation of patches below 10 km^2 in size leads to more shallow clouds as there is more convective energy in the system, and promotes higher volumes of rainfall[4]. However, as deforested areas increase in size, convective lifting mechanisms lose force, which reduces the appearance of shallow clouds, and thereby evapotranspiration and rainfall[5]. This shift is already taking place in many areas of Amazon[6].

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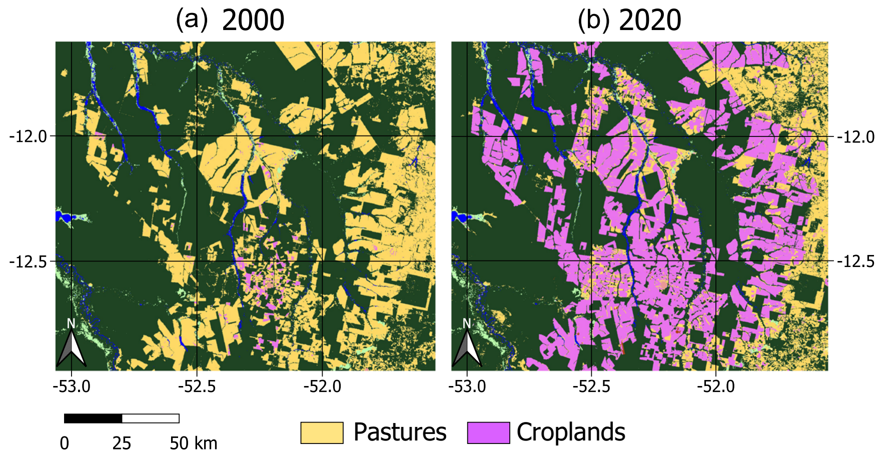

Fig. 1 Cropland expansion from the year 2000 to 2020 in Southern Amazonia. **a** Land use in 2000. **b** Land use in 2020. Source: Mapbiomas[19].

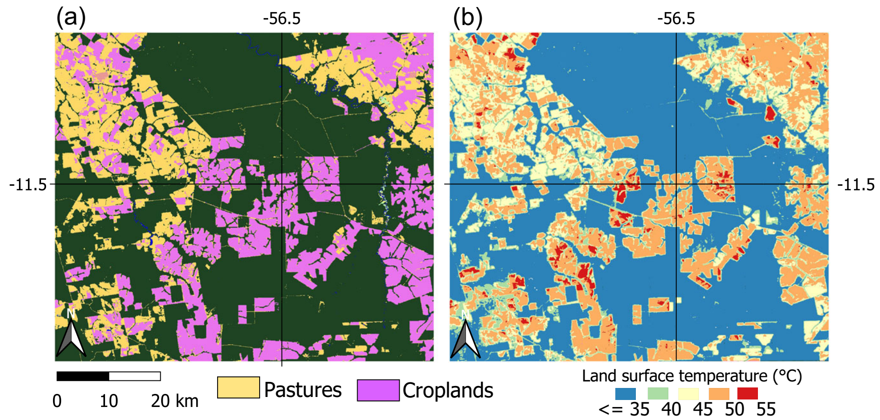

Fig. 2 Land surface temperature over areas with different land use during September 2017. **a** Land use classification according to the Mapbiomas project[19]. **b** Landsat 8 Collection 2 level-2 surface temperature image.

Pastures in previously forested land have a distinct climatic impact, compared to croplands: conversion to commodity croplands can cause surface temperature increases up to three times higher than conversion to pastures over small rural settlements (Fig. 2)[6]. The difference is particularly evident in large-scale commodity farms. The harvesting and seeding of commodity crops lead to abrupt changes in the land surface properties, due to the reduction of vegetation cover[7]. This pattern is further magnified in some parts of the Southern Amazon where the long growing season allows multiple crop production cycles. Intensive management of the land reduces plant transpiration and causes shifts in the surface energy balance. If we are to minimize deforestation-related climate risks, it is a critical first step to establish climate-friendly land use strategies for the deforested areas.

Solutions through diversification

Alternative agricultural systems that can better sustain flora and fauna diversity and maintain ecosystem functioning, have been studied for decades. For instance, syntropic farming, a branch of agroecology that aims to use plant and animal life to improve natural conditions, and thereby enhance biodiversity, emerges as an innovative approach to sustainable farming. Syntropic farming promotes a diverse vertical stratification of plants through a combination of forest and agricultural plants that ultimately maximizes the conservation of energy in the system[8]. Critics argue that these approaches lack scalability and may reduce economical outcomes. Nevertheless, successful cases have been reported at larger scales, such as for farms of more than 1000 ha[9].

Other alternatives to traditional crop farming, such as Integrated Crop–Livestock–Forestry systems, may hold a better chance at larger scales. These agricultural systems aim to improve production through the integration of various types of agricultural production, such as crops, livestock and forestry, in the same area, using intercropping, or rotations, to obtain synergies among agroecosystem components[10]. Integrated systems have been increasingly studied due to the potential of offsetting carbon emissions associated with beef production[11]. Integrated Crop–Livestock–Forestry can also increase canopy cover, the main factor that supports non-radiative cooling by evapotranspiration.

Integrated Crop–Livestock–Forestry systems cannot be expected to fully replace monoculture farming. In particular, soybean plants grown under integrated systems had lower yields because of reduced solar incidence[12]. However, land-use diversification does not need to follow a single prescription for all cases. The concept of using integrated systems needs to be expanded to consider not only the combination of plants in the same space but also in distinct but interconnected spaces[13]. In such a setting of regional agroforestry, commercially viable perennial species, such as cacao trees (*Theobroma cacao*) and rubber trees (*Hevea brasiliensis*) could be planted in between monocultures. Such a planting strategy could reduce the size of homogeneous deforested patches and promoting regional cooling (Fig. 3). The land use revolution we propose should aim to improve productivity without an expansion of deforested areas.

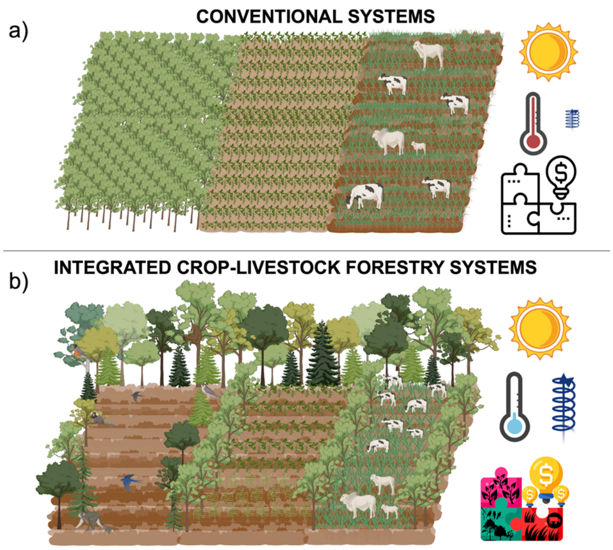

Fig. 3 Environment and economic aspects of conventional agricultural systems and Integrated Crop–Livestock–Forestry. The conventional system **a** is characterized by large areas of monoculture production with intensive management of the land, whereas the integrated system **b** offers more diversity.

Finally, where possible the ecosystem functions of unused lands should be restored. Deforested areas are poorly used, as evidenced by the vast extent of abandoned lands[14]. Secondary forests are currently regrowing on approximately 20% of previously deforested areas in Brazil[15].

Pathways for change

Brazil is an agricultural superpower. Farmers are skilled and adaptable. The agricultural sector is usually open to technological innovations that can reduce environmental impacts and boost productivity. Examples of this flexibility include the widespread adoption of biological nitrogen fixation in soybean plantations around the 1990s, which significantly reduced the use of fertilizer, and the introduction of no-till agriculture during the same period, which contributed to reducing soil erosion (although the use of herbicides increased as a result).

Effective strategies to mitigate the climatic impacts of deforestation will have to be constructed in cooperation with the agricultural sector, and not against it. Finger-pointing is unlikely to yield progress, instead, it may lead to polarized and unfruitful debates. The political path is also a complicated and volatile one. Recent history has demonstrated that land change dynamics in the Amazon can rapidly shift depending on who is in power[16].

Sustained changes will depend on modifications throughout the supply chain, including consumer preferences. Producers are often quick to sense changes in the market and consumers' behavior. If producers wish to offer products to environmentally conscientious buyers, they will have to implement techniques that protect ecosystem functioning.

More importantly, however, it is imperative to educate farmers about the fact that the viability of agricultural production in the Amazon is at great risk if current trends continue. The expansion of croplands and the establishment of large continuous deforested areas can substantially reduce rainfall[6,17], the cornerstone of the high yields observed in the Southern Amazon. Rising temperatures and aridity have already pushed approximately 30% of the rainfed production in the Southern Amazon beyond optimum climatic limits. It is expected that by 2030, over 50% of agricultural land will fall outside of these limits[18].

Halting deforestation has the potential to prevent agricultural losses associated with rainfall reduction by up to US$ 1 billion annually[17]. We argue that careful management of land that is already deforested can also provide substantial benefits to the environmental and climatic health of the Amazon region. We firmly expect the agricultural sector to benefit from a new green revolution in the long run, with a production system inspired by natural ecological processes, where food production is harmoniously integrated into the local ecosystem.

Received: 22 November 2022; Accepted: 27 January 2023;
Published online: 10 February 2023

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Author contributions

E.E.M.: Proposed the manuscript, conceptualized the first draft, and created figures. Y.M.M. and J.C.R.: contributed to manuscript writing, creating figures, and revision. L.E.O.C.A., J.C.A.B., L.C.B., A.D.N., M.H.N., and C.H.L.S.J. contributed to manuscript writing and revision.

Competing interests
The authors declare no competing interests.

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