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Habitat Destruction and Biodiversity Loss Due to Sugarcane Expansion

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Abstract This study explores the environmental and ecological impacts of sugarcane expansion in Brazil, India, and Australia. It highlights the significant effects of sugarcane cultivation on biodiversity, soil health, water resources, and local climates. In Brazil, the expansion into the Cerrado and Amazon regions has led to biodiversity losses, especially in soil fauna and altered hydrological cycles. In India, intensive cultivation practices have degraded local biodiversity and ecosystem services. In Australia, runoff from sugarcane fields threatens the Great Barrier Reef by causing algal blooms and coral bleaching. The study emphasizes the need for sustainable agriculture practices, robust environmental policies, community engagement, and international cooperation to mitigate the adverse effects of sugarcane cultivation. Recommendations include enforcing stricter environmental regulations, promoting sustainable farming practices, and investing in research for resilient crop varieties.
Keywords Sugarcane (*Saccharum* spp.); Sugarcane expansion; Environmental impact; Biodiversity loss; Sustainable agriculture; Soil health; Water resources; Policy; Recommendations

Sugarcane (*Saccharum* spp.) is a vital crop cultivated across more than 100 countries due to its significant role in sugar production and bioenergy. Globally, it covers approximately 27 million hectares, with Brazil being a major producer, emphasizing the crop's role in the bioeconomy. The crop's cultivation practices have evolved to meet increasing demands for sugar and ethanol, spurred by biofuel policies and the sugar trade. Sugarcane not only supports energy production but also contributes to the manufacturing of biodegradable products and animal feed (Heinrichs et al., 2017).

In regions like Brazil and India, the expansion of sugarcane is significant, driven by both local consumption and global markets. Brazil, for instance, has seen a doubling of production recently to support bioenergy needs, which impacts the sustainability of agricultural practices and land use (Bordonal et al., 2018). Furthermore, the mechanization in countries like India illustrates efforts to boost productivity amidst challenges such as labor shortages and environmental impacts (Singh et al., 2011; Ashraf et al., 2023).

Habitat destruction and biodiversity loss are critical environmental issues that occur when natural lands are converted to agricultural or other human uses, leading to a decline in native species and ecosystems. In the context of sugarcane expansion, these issues are especially pronounced as large tracts of land, often rich in biodiversity, are cleared for cultivation. The conversion impacts not only the flora and fauna but also affects soil health and water cycles, contributing to broader ecological imbalances (Watson, 2011).

The expansion of sugarcane into biodiverse regions such as the Amazon and Cerrado in Brazil, or similar habitats in Southeast Asia and Africa, often leads to significant environmental degradation. This includes the loss of habitat for endangered species and changes in local climate conditions due to deforestation and altered land use patterns. Such biodiversity loss is frequently irreversible and poses challenges to sustainability and conservation efforts (Bordonal et al., 2018). The loss of biodiversity and habitat due to sugarcane expansion represents a complex interplay of economic growth, energy production, and environmental preservation, necessitating comprehensive strategies to balance these competing interests for sustainable development.

1 Sugarcane Expansion: Scale and Locations

1.1 Key regions of the world where sugarcane production is expanding

Sugarcane production is a significant agricultural activity with a widespread presence across the globe, primarily in tropical and subtropical regions. The expansion of sugarcane cultivation is notably prominent in Brazil, India, China, Thailand, Pakistan, and several countries in southern Africa. Brazil, in particular, stands out as the largest producer, followed by India. These regions have seen extensive agricultural landscapes transformed to accommodate the growing demand for sugarcane, driven by its use in sugar production and as a bioenergy crop (Heinrichs et al., 2017).

In Brazil, the state of São Paulo is the heart of sugarcane production, accounting for about 60% of the country's total production. The expansion is not limited to traditional areas but extends to newer frontiers like the states of Goiás and Mato Grosso do Sul, where sugarcane cultivation has increased significantly over the past decade. From 2003 to 2013, sugarcane area in Goiás expanded six-fold (Spera et al., 2017).

Southern Africa is another region experiencing a surge in sugarcane production, with countries like South Africa, Swaziland, Mozambique, and Zimbabwe contributing to the growth. The potential to expand sustainable bioenergy from sugarcane in this region is significant, supported by both the climate and available arable land (Watson, 2011).

1.2 Statistics on land area converted for sugarcane cultivation over recent years

The scale of land conversion for sugarcane cultivation is vast. In Brazil alone, the cultivated area for sugarcane was estimated to have expanded from about 5 million hectares in 2000 to more than 9 million hectares by 2010, with further increases projected. Much of this expansion has replaced pasture lands and, to a lesser extent, existing croplands (Adami et al., 2011). The trend reflects a broader regional shift where sugarcane increasingly displaces other land uses, potentially impacting food security and biodiversity (Figure 1).

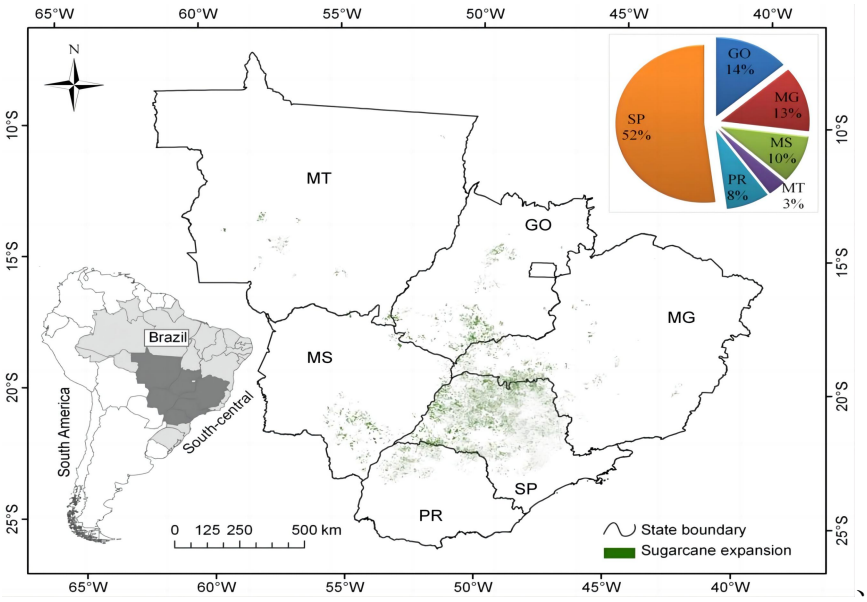

Figure 1 Study area emphasizing the expanded sugarcane area from crop year 2005/06 to 2010/11 in the South-central region of Brazil (Photo credit: Adami et al., 2011)

Image caption: The image depicts a geographical and statistical representation of sugarcane expansion in south-central Brazil, with specific focus on the states of Mato Grosso (MT), Goiás (GO), Mato Grosso do Sul (MS), Minas Gerais (MG), São Paulo (SP), and Paraná (PR). The map portion highlights areas of sugarcane expansion in green, showing that the expansion is concentrated mostly in the southeastern parts of these states. The pie chart illustrates the percentage distribution of sugarcane coverage among these states: São Paulo leads significantly with 52%, followed by Goiás (14%), Minas Gerais (13%), Mato Grosso do Sul (10%), Paraná (8%), and Mato Grosso (3%). This data suggests that São Paulo is the central hub for sugarcane agriculture in Brazil, likely due to favorable climatic and soil conditions as well as established agricultural infrastructure (Adapted from Adami et al., 2011)

In Goiás, the area under sugarcane cultivation increased from 142 000 hectares in 2003 to 847,000 hectares by 2013, demonstrating the crop's aggressive expansion into new agricultural frontiers. This expansion has been fueled by the bioethanol market and the region's favorable agricultural conditions (Spera et al., 2017).

In the context of Southern Africa, an assessment found almost 6 million hectares of suitable land available for sugarcane cultivation, suggesting considerable growth potential without immediate detrimental impacts on biodiversity or food security, contingent on sustainable management practices (Watson, 2011).

These figures illustrate the dynamic nature of land use changes associated with sugarcane, driven by its economic value and growing global demand for renewable energy sources. The continued expansion of sugarcane cultivation poses challenges and opportunities for sustainable agricultural practices and regional economic development.

2 Impacts on Habitat

2.1 Description of natural habitats displaced by sugarcane cultivation

Sugarcane cultivation often requires the conversion of natural habitats into agricultural fields. This conversion leads to significant changes in the landscape and has profound impacts on local ecosystems. The natural habitats most commonly affected by sugarcane expansion include tropical rainforests, savannahs, and wetlands.

Tropical rainforests, such as those in Brazil and Southeast Asia, are particularly vulnerable. These ecosystems are rich in biodiversity, containing a vast array of plant and animal species. The conversion of rainforests into sugarcane fields typically results in the loss of this biodiversity and disrupts crucial ecological functions such as carbon storage, water cycle regulation, and soil conservation. The case of the Atlantic Forest in Brazil is a notable example, where large areas have been converted for sugarcane production, leading to habitat fragmentation and species loss (Degefa and Saito, 2017).

Wetlands are also commonly affected by sugarcane cultivation, especially in regions like southern Africa and parts of Asia. These areas provide critical services such as flood mitigation, water purification, and habitat for water-dependent species. Sugarcane expansion into these areas often leads to altered hydrological conditions, which can reduce the ability of these ecosystems to provide these essential services. In Zambia, for instance, the expansion of sugarcane into wetland areas has significantly altered the hydrological dynamics of the Kafue River, affecting water availability and quality for downstream ecosystems and human use (German et al., 2020).

2.2 Case studies of specific ecosystems affected

2.2.1 The Brazilian Atlantic Forest

The Atlantic Forest in Brazil has been dramatically impacted by sugarcane cultivation. This region, once lush with diverse flora and fauna, has seen significant portions of its area cleared for agriculture. The sugarcane industry, in particular, has been a major driver of deforestation in this area, leading to habitat loss and fragmentation. This has had a dire impact on local biodiversity, including numerous species of birds, mammals, and insects, many of which are endemic to the region. The destruction of this habitat also affects local communities that rely on the forest for resources and ecological services (Degefa and Saito, 2017).

2.2.2 Wetlands in Southern Africa

In southern Africa, sugarcane cultivation has expanded into areas that were once wetlands. This has implications for biodiversity and the ecological health of the region. Wetlands are critical for maintaining regional water cycles, supporting aquatic life, and providing resources for local human populations. The conversion of these areas into sugarcane fields has led to a decrease in water quality and availability, changes in sedimentation patterns, and a loss of habitat for waterfowl and other wetland-specific species. German et al. (2020) study from Zambia provides a detailed look at how sugarcane expansion is altering the landscape and impacting the ecological functions of wetlands.

The displacement of natural habitats due to sugarcane cultivation highlights the need for more sustainable agricultural practices that consider the conservation of biodiversity and ecosystem services. Strategies such as the integration of biodiversity conservation into agricultural planning, the restoration of degraded lands, and the adoption of more sustainable agricultural techniques could help mitigate some of these impacts.

3 Consequences for Biodiversity

3.1 Overview of species endangered by sugarcane expansion

Sugarcane expansion, particularly in biodiversity-rich areas like the Brazilian Cerrado and Atlantic Forest, Southeast Asia, and parts of Africa, has led to significant biodiversity loss. This agriculture practice often replaces complex forest ecosystems, which are rich in species, with monocultures that offer very limited habitat variety. The alteration of natural landscapes to sugarcane fields not only reduces habitat areas but also affects the ecological balance, pushing many species towards endangerment.

For instance, studies have shown significant reductions in soil macrofauna such as ants, earthworms, and beetles due to the conversion from native vegetation or pastures to sugarcane fields. These species are crucial for soil health, influencing everything from nutrient cycling to soil structure and fertility. In Brazil, changes from pasture to sugarcane have resulted in a 90% reduction in soil macrofauna abundance and a 40% loss in biodiversity. The diversity of above-ground fauna, including mammals and birds, also diminishes as these species lose their natural habitats and food sources (Franco et al., 2016).

3.2 Specific examples of flora and fauna impacted

Flora: In regions like Ethiopia, where sugarcane is cultivated extensively, native woody vegetation has suffered greatly. A study comparing the remnant patches of woodlands to those converted to sugarcane fields found a dramatic reduction in native tree species diversity, with a higher proportion of non-native species in sugarcane zones. The loss of native flora fundamentally alters the ecological fabric of the area, reducing habitat quality for endemic and native species (Degefa and Saito, 2017).

Fauna: The impact on fauna is similarly severe. In Brazil, sugarcane expansion has been linked to declines in populations of large mammals, including the jaguar and the giant anteater, as well as numerous bird species. The displacement caused by sugarcane cultivation disrupts migration patterns, breeding habits, and food availability, leading to reduced population viability (Verdade et al., 2012).

3.3 Long-term effects on genetic diversity in the region

The long-term effects of sugarcane expansion on genetic diversity are profound and worrying. Genetic diversity within both plant and animal populations is crucial for resilience to disease and environmental changes. However, the simplification of ecosystems and the reduction of species caused by sugarcane cultivation can lead to a significant decrease in genetic diversity. This, in turn, decreases overall ecosystem resilience, making it harder for the system to recover from environmental stresses.

In areas of sugarcane expansion, the genetic diversity of the soil biota has also been impacted. The soil communities, which are vital for the health of any terrestrial ecosystem, become less diverse and abundant, which impacts plant health and productivity. This reduction in genetic diversity can alter the nutrient cycling processes and even the ability of ecosystems to sequester carbon, exacerbating the impact of climate change (Bartz et al., 2016).

The loss of biodiversity due to sugarcane expansion not only impacts the immediate area but also has a cascading effect on the surrounding environments. This loss affects food security, local climates, and disease prevalence, which can have direct and indirect effects on human populations. Therefore, balancing sugarcane production with biodiversity conservation is essential to maintain the health of the planet and the well-being of all its inhabitants.

4 Drivers Behind Sugarcane Expansion

4.1 Economic factors promoting the growth of sugarcane agriculture

Sugarcane agriculture has expanded significantly due to several key economic factors. The crop's versatility, high productivity per hectare, and ability to generate multiple products including sugar, ethanol, and bioelectricity make it economically attractive. This has led to increased investments from both domestic and international stakeholders. Brazil, for instance, has seen a surge in foreign capital inflows, new mills, and more efficient agricultural practices, contributing to its status as a leading sugar and ethanol producer (Chagas, 2014).

Additionally, the growing global demand for biofuels as cleaner energy sources has further promoted sugarcane's cultivation. Countries with suitable climates for sugarcane have found this crop to be a lucrative agricultural option, offering significant returns on investment. The introduction of mechanization and advanced agronomical practices has also increased yields, reducing costs and enhancing the competitiveness of sugarcane-based products in the global market (Martinelli and Filoso, 2008).

4.2 Role of biofuel demand in sugarcane expansion

The demand for biofuels is one of the most significant drivers of sugarcane expansion, particularly in Brazil, which has leveraged its ethanol industry to meet both domestic and international markets. The global push towards renewable energy sources has positioned sugarcane ethanol as a viable alternative to fossil fuels, thereby increasing the crop's cultivation area. This demand is not only due to the environmental benefits of biofuels but also due to their role in enhancing energy security and reducing oil dependency (Khatiwada et al., 2016).

Brazil's national policies, such as the RenovaBio program, have been instrumental in promoting biofuel production. These policies aim to incentivize biofuel production through financial mechanisms and sustainability criteria, ensuring that bioenergy remains a key component of Brazil's energy matrix while also committing to carbon reduction targets (Klein et al., 2019).

4.3 Policy and market dynamics influencing land use changes

Government policies play a crucial role in shaping land use dynamics related to sugarcane expansion. In Brazil, the government has enacted various regulations and subsidies to support the ethanol industry, which in turn influences land use decisions at the farm level. These policies often favor the conversion of other agricultural lands or pastures to sugarcane fields to meet the growing demand for ethanol (Novo et al., 2010).

Market dynamics also influence sugarcane expansion. The fluctuations in sugar and ethanol prices can make sugarcane more or less attractive compared to other crops. Additionally, the international demand for biofuels affects how much land is dedicated to sugarcane cultivation. The global trade policies, such as tariffs and trade agreements, further impact this dynamic, making sugarcane a highly responsive crop to both policy and market changes (Babcock and Moreira, 2013).

These drivers demonstrate the complex interplay between economic viability, policy frameworks, and global market demands, which collectively influence the expansion of sugarcane agriculture. The challenge lies in balancing these growth drivers with sustainability concerns to ensure that sugarcane expansion does not adversely affect the environment or social equity.

5 Mitigation Strategies

5.1 Sustainable agriculture practices in sugarcane farming

Sustainable agriculture practices are essential in mitigating the environmental impacts of sugarcane farming. One key practice is the adoption of non-burn harvesting techniques, which reduce air pollution and enhance the organic matter content of the soil. This practice not only improves soil health but also reduces greenhouse gas emissions. Additionally, integrated pest management (IPM) strategies help minimize the use of harmful pesticides, preserving biodiversity within and around sugarcane fields (Bordonal et al., 2018).

Another significant sustainable practice is the efficient use of water resources through drip irrigation systems, which optimize water use and reduce wastage. Crop rotation and intercropping are also vital for maintaining soil fertility and controlling pests and diseases, which can be particularly challenging in monoculture systems like those typically used for sugarcane (Prasara-A and Gheewala, 2016).

5.2 Conservation efforts and legal protections for vulnerable ecosystems

Conservation efforts are crucial in protecting ecosystems from the negative impacts of sugarcane expansion. Legal protections, such as the Brazilian Forest Code, play a critical role in regulating land use and ensuring that sugarcane plantations do not encroach on protected areas and vulnerable ecosystems. These regulations help maintain biodiversity and ecosystem services by setting legal boundaries and conservation zones (Martinelli and Filoso, 2008).

Additionally, the restoration of degraded lands and the creation of ecological corridors between sugarcane fields can help mitigate the effects of habitat fragmentation. These corridors facilitate the movement of species across the landscape, enhancing ecological connectivity and supporting biodiversity (Cherubin et al., 2021).

5.3 Role of international cooperation and agreements in managing environmental impacts

International cooperation is vital for addressing the global challenges of sugarcane production. Agreements such as the Paris Agreement on climate change include commitments to sustainable agricultural practices that can be applied to sugarcane farming. These international agreements encourage countries to adopt best practices in agriculture that not only improve productivity but also reduce environmental impacts.

Collaborative research and development projects between countries can lead to the adoption of new technologies and farming methods that are more sustainable. Moreover, trade agreements can include environmental standards that require the sustainable production of agricultural commodities, including sugarcane, thus influencing global practices (Filoso et al., 2015).

The integration of sustainable practices, conservation efforts, and international cooperation forms a comprehensive approach to mitigating the environmental impacts of sugarcane production. By adopting these strategies, the sugarcane industry can move towards more sustainable and environmentally friendly production methods that ensure long-term productivity and ecological balance.

6 Case Studies

6.1 Brazil: impact of sugarcane on the Amazon and Cerrado

In Brazil, the expansion of sugarcane cultivation has significantly impacted the Cerrado and the Amazon, two of the country's most important ecological regions. The Cerrado, often referred to as Brazil's savannah, hosts about 5% of the world's biodiversity. However, the rapid expansion of agriculture, particularly sugarcane, has transformed its landscape and ecosystem. The Amazon, known for its vast rainforests, has also seen sugarcane encroachment, although to a lesser extent compared to other agricultural activities like soybean cultivation and cattle ranching.

Environmental impacts on the Cerrado: The conversion from native Cerrado vegetation to sugarcane has led to significant biodiversity losses and alterations in the soil's chemical and biological properties. Studies indicate a sharp decline in soil macrofauna, which is crucial for nutrient cycling and soil structure maintenance. The abundance and diversity of soil organisms like earthworms, ants, and beetles significantly decrease when pasturelands are converted to sugarcane fields. This change results in poorer soil health, which can reduce agricultural productivity over time and increase the vulnerability of the land to erosion and degradation (Franco et al., 2016).

Impacts on water resources and local climate: Expanding sugarcane plantations in the Cerrado has also impacted water resources and local climate conditions. The alteration of land cover changes the region's hydrology, affecting water availability for local communities and other ecological uses. Moreover, studies have shown that sugarcane plantations can alter local microclimates, which can impact surrounding natural vegetation and agricultural practices (Loarie et al., 2011).

6.2 India: effects on local biodiversity in sugarcane leading states

In India, sugarcane is a major crop, particularly in states like Uttar Pradesh, Maharashtra, and Karnataka. While the crop significantly contributes to the local economy, it has considerable environmental impacts, especially on local biodiversity.

Impact on Local Flora and Fauna: The intensive cultivation practices associated with sugarcane, including heavy water usage and pesticide application, have led to habitat degradation and loss. The monoculture nature of sugarcane fields displaces local flora, reducing habitat diversity and affecting the fauna dependent on these habitats for survival. The reduction in biodiversity is not only a loss of plant and animal life but also diminishes the ecosystem services they provide, such as pollination, which is vital for many other crops (Degefa and Saito, 2017).

Soil and Water Impacts: The heavy use of fertilizers and pesticides in sugarcane cultivation has also led to soil degradation and water pollution. These chemicals can leach into local water bodies, affecting both water quality and aquatic life. Furthermore, the high water demand for sugarcane irrigation often leads to over-extraction of groundwater, which can exacerbate water scarcity issues in already water-stressed areas.

6.3 Australia: conflict between sugarcane cultivation and great barrier reef preservation

In Australia, the state of Queensland is a major sugarcane producer. The proximity of sugarcane fields to the Great Barrier Reef has led to significant environmental conflicts, primarily due to the runoff of nutrients, pesticides, and sediments into the reef.

Impact on the Reef: Runoff from sugarcane fields carries nutrients and pesticides into the Great Barrier Reef's waters. These substances can promote the growth of algae, which competes with coral for light and space, leading to coral bleaching and degradation of reef health. Sediment runoff can also smother coral and reduce water quality, further stressing the reef ecosystem.

Conservation Efforts: Efforts to mitigate these impacts include the implementation of best management practices among sugarcane farmers, such as improved irrigation techniques, controlled use of fertilizers and pesticides, and maintaining buffer zones to reduce runoff. Additionally, government and non-governmental organizations are working to enhance awareness and compliance with sustainable practices to protect this vital natural resource.

The case studies from Brazil, India, and Australia highlight the complex interplay between agricultural expansion, particularly sugarcane cultivation, and environmental sustainability.

7 Concluding Remarks

The expansion of sugarcane cultivation has profound impacts on the environment, biodiversity, and local communities across different regions of the world. This essay has explored various dimensions of these impacts through detailed case studies and a broad review of academic literature.

Brazil: In Brazil, the Cerrado and Amazon regions have experienced significant environmental changes due to sugarcane expansion. The conversion of native vegetation to sugarcane fields has led to losses in biodiversity, particularly in soil fauna, which are crucial for nutrient cycling and soil structure. Additionally, changes in land use have altered water resources and local climate conditions, impacting both ecological and human communities.

India: The ecological impacts in India are marked by reduced local biodiversity and environmental degradation due to intensive agricultural practices. The widespread use of water for irrigation and chemicals for pest control has led to habitat degradation, soil health decline, and pollution of water bodies, thereby affecting the broader ecosystem services essential for agriculture and human well-being.

Australia: In Australia, particularly in Queensland, sugarcane cultivation poses a threat to the Great Barrier Reef due to runoff containing nutrients and pesticides. This runoff leads to algal blooms and coral bleaching, thereby compromising the reef's ecological health and its capacity to support marine life.

The review has underscored the critical need for sustainable agricultural practices and robust environmental policies to mitigate the adverse impacts of sugarcane cultivation. To address the challenges posed by sugarcane expansion, it is essential to adopt a multi-faceted approach involving policy intervention, community engagement, and scientific research. The following recommendations are proposed:

1) Enhance Sustainable Agricultural Practices: Promote and incentivize the adoption of sustainable farming practices among sugarcane producers. These practices include precision agriculture, use of organic fertilizers, integrated pest management, and water-efficient irrigation systems that can help reduce the environmental footprint of sugarcane cultivation.

2) Strengthen Environmental Legislation and Compliance: Governments should enforce stricter environmental regulations concerning land use changes, water quality, and chemical usage in sugarcane cultivation. Moreover, compliance with these regulations should be strictly monitored and non-compliance penalized to ensure adherence.

3) Promote Research and Development: Invest in research to develop more resilient sugarcane varieties that require fewer water and chemical inputs. Research should also focus on improving soil health and developing advanced technologies for monitoring and managing environmental impacts.

4) Community Engagement and Education: Engage local communities in the planning and decision-making processes related to sugarcane cultivation. Educational programs about sustainable practices and their benefits should be implemented to foster community support and participation.

5) International Collaboration: Encourage international cooperation to share knowledge, technologies, and strategies for sustainable sugarcane cultivation. This can be facilitated through global agricultural forums and bilateral agreements focused on sustainable development and environmental protection.

6) Long-term Monitoring and Impact Assessment: Establish long-term monitoring systems to assess the ecological and socio-economic impacts of sugarcane expansion. These assessments can inform adaptive management strategies and policy adjustments as needed.

By implementing these recommendations, it is possible to balance the economic benefits of sugarcane cultivation with the imperative of environmental sustainability and social responsibility. Future policies should be designed to ensure that sugarcane production contributes positively to sustainable development goals without compromising the health of ecosystems and the well-being of local communities.

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References

Adami M., Rudorff B., Freitas R., Aguiar D., Sugawara L., and Mello M., 2011, Remote sensing time series to evaluate direct land use change of recent expanded sugarcane crop in Brazil.
https://doi.org/10.3390/wsf-00576

Babcock B., Moreira M., and Peng Y., 2013, Biofuel taxes, subsidies, and mandates: impacts on US and Brazilian Markets, American Journal of Agricultural Economics.

Chagas A., 2014, Socio-economic and ambient impacts of sugarcane expansion in Brazil: effects of the second generation ethanol production, 69-83.
https://doi.org/10.1007/978-3-319-05020-1_4

Degefa S., and Saito O., 2017, Assessing the impacts of large-scale agro-industrial sugarcane production on biodiversity: a case study of Wonji Shoa Sugar Estate, Ethiopia, Agriculture, 7: 1-15.
https://doi.org/10.3390/agriculture7120099

Franco A., Bartz M., Cherubin M., Baretta D., Cerri C., Feigl B., Wall D., Davies C., and Cerri C., 2016, Loss of soil (macro) fauna due to the expansion of Brazilian sugarcane acreage, The Science of the total environment, 563-564.
https://doi.org/10.1016/j.scitotenv.2016.04.116
PMid:27135579

German L., Hepinstall-Cymerman, J., Biggs T., Parker L., and Salinas M., 2020, The environmental effects of sugarcane expansion: a case study of changes in land and water use in southern Africa, Applied Geography, 121: 102240.
https://doi.org/10.1016/j.apgeog.2020.102240

Heinrichs R., Otto R., Magalhães A., and Meirelles G., 2017, Importance of sugarcane in Brazilian and world bioeconomy, 205-217.
https://doi.org/10.1007/978-3-319-58374-7_11

Khatiwada D., Leduc S., Silveira S., and Mccallum I., 2016, Optimizing ethanol and bioelectricity production in sugarcane biorefineries in Brazil, Renewable Energy, 85: 371-386.
https://doi.org/10.1016/j.renene.2015.06.009

Klein B., Chagas M., Watanabe M., Bonomi A., and Filho R., 2019, Low carbon biofuels and the New Brazilian National Biofuel Policy (RenovaBio): a case study for sugarcane mills and integrated sugarcane-microalgae biorefineries, Renewable and Sustainable Energy Reviews.
https://doi.org/10.1016/j.rser.2019.109365

Loarie S., Lobell D., Asner G., Mu Q., and Field C,. 2011, Direct impacts on local climate of sugar-cane expansion in Brazil. Nature Climate Change, 1: 105-109.
https://doi.org/10.1038/nclimate1067

Martinelli L., and Filoso S., 2008, Expansion of sugarcane ethanol production in Brazil: environmental and social challenges, Ecological Applications: a publication of the Ecological Society of America, 18(4): 885-898.
https://doi.org/10.1890/07-1813.1
PMid:18536250

Novo A., Jansen K., Slingerland M., and Giller K., 2010, Biofuel, dairy production and beef in Brazil: competing claims on land use in São Paulo state, The Journal of Peasant Studies, 37: 769-792.
https://doi.org/10.1080/03066150.2010.512458
PMid:21125724

Singh J., Singh A., Sharma M., Singh P., and Srivastava A., 2011, Mechanization of sugarcane cultivation in India, Sugar Tech., 13: 310-314.
https://doi.org/10.1007/s12355-011-0101-5

Spera S., VanWey L., and Mustard J., 2017, The drivers of sugarcane expansion in Goiás, Brazil, Land Use Policy, 66: 111-119.
https://doi.org/10.1016/j.landusepol.2017.03.037

Verdade L., Gheler-Costa C., Penteado M., and Dotta G., 2012, The impacts of sugarcane expansion on wildlife in the state of São Paulo, Brazil, Journal of Sustainable Bioenergy Systems, 2, 138-144.
https://doi.org/10.4236/jsbs.2012.24020

Watson H., 2011, Potential to expand sustainable bioenergy from sugarcane in southern Africa, Energy Policy, 39, 5746-5750.
https://doi.org/10.1016/j.enpol.2010.07.035