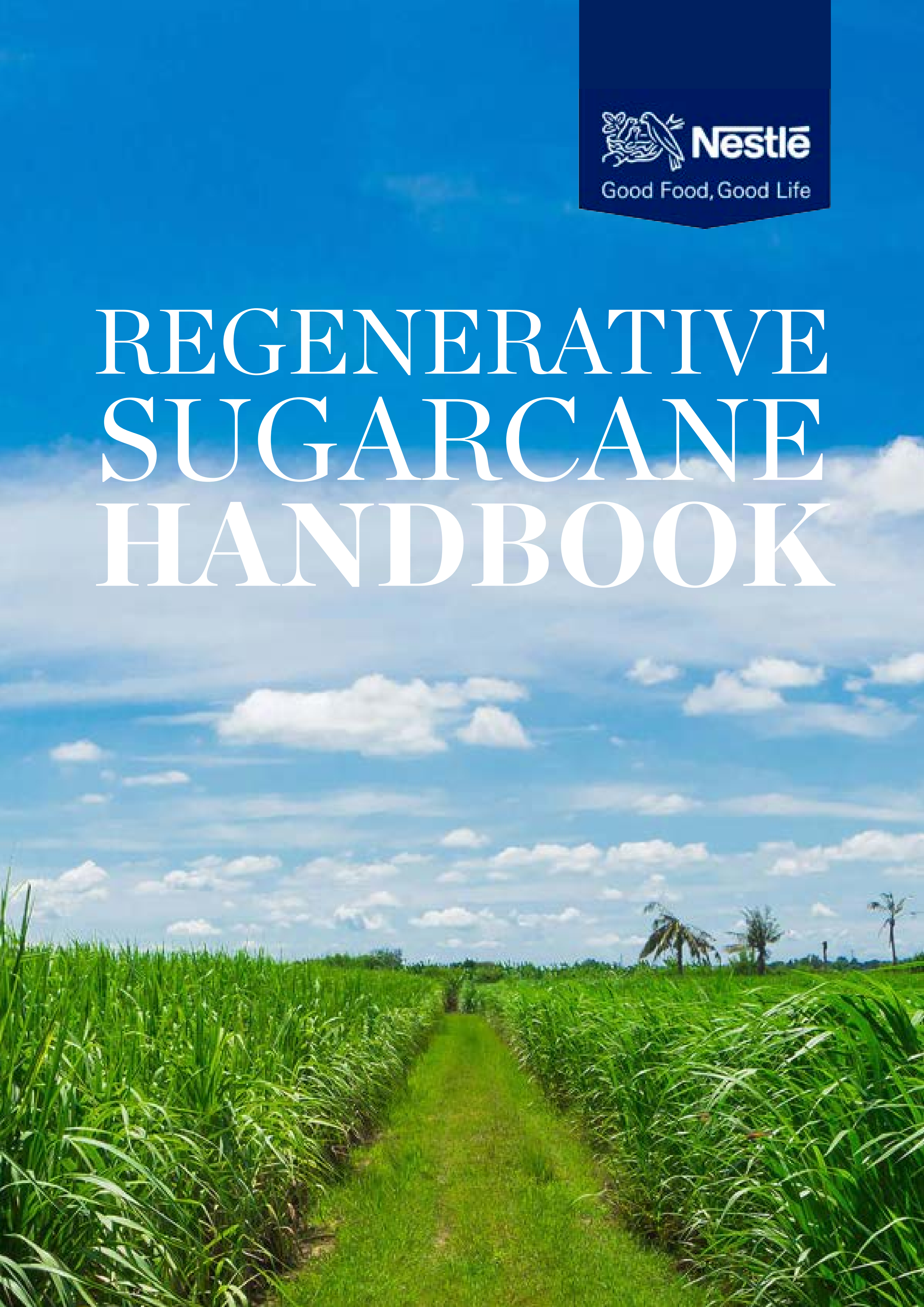


Good Food, Good Life

REGENERATIVE SUGARCANE HANDBOOK

Cover: Sugarcane cultivation, Thailand. Photo credit: © subinpumsom.

Pp 5-6: Regenerative sugarcane cultivation in El Hatico Nature Reserve, Colombia
Photo credit: © Álvaro Zapata.

Pp 14-15, 160-161, 174-175, 182-183, 186-187 :
Saccharum officinarum - Jardín Botánico de Berlín, Germany - CC BY-SA.
https://www.europeana.eu/item/11630/SCHWEINFURTHBOTANICALDRAWINGSXBGBMXGERMANYXBXSZX0000365

Design & illustration © Lina Rada

REGENERATIVE SUGARCANE HANDBOOK

5 REFERENCES

6 ANNEXES

7 ADDITIONAL RESOURCES

8 GLOSSARY

List of Acronyms

AFOLU: Agriculture, Forestry and Other Land Uses

C/N: Carbon to Nitrogen Ratio.

CATIE: Tropical Agricultural Research and Higher Education Center

CBD: Convention of Biological Diversity

CEC: cation exchange capacity

CENGICAÑA: Guatemalan Center for Sugarcane Research and Training

CENICAÑA: Sugarcane Research Center

CEPAL: Economic Commission for Latin America (ECLA)

CIPAV: Center for Research on Sustainable Agricultural Production Systems

CONADESUCA: National Committee for Sustainable Sugarcane Development

COP: Conventions of the Parties for Climate Change

EPA: U.S. Environmental Protection Agency

FAO: Food and Agriculture Organization of the United Nations

FEDEARROZ: National Rice Growers Federation

FFS: Farmer Field School

FUNDEMAS: Foundation for Business Development of El Salvador

GHG: Greenhouse Gases

GPS: Global Positioning System

HHRR: Human Health Risk Resources

HR: Human Resources

ILO: International Labour Organization (United Nations)

IPM: Integrated Pest Management

ISTA: Salvadoran Institute for Agrarian Transformation

NDC: Nationally Determined Contribution

NGO: Non-governmental organization

OECD: The Organisation for Economic Co-operation and Development

OHCHR: United Nations Human Rights Office of the High Commissioner

PAH: Polycyclic Aromatic Hydrocarbon

Pb: Bulk density

PPE: Personal Protection Elements

PVS: Participatory Varietal Selection

ResCA: Resilient Central America project

SIB: Sugar Industry Control Board in Belize

SIRDI: Sugar Industry Research and Development Institute

SOC: Soil organic carbon

SOM: Soil organic matter

TNC: The Nature Conservancy

USDA: United States Department of Agriculture

WTO: World Tourism Organization

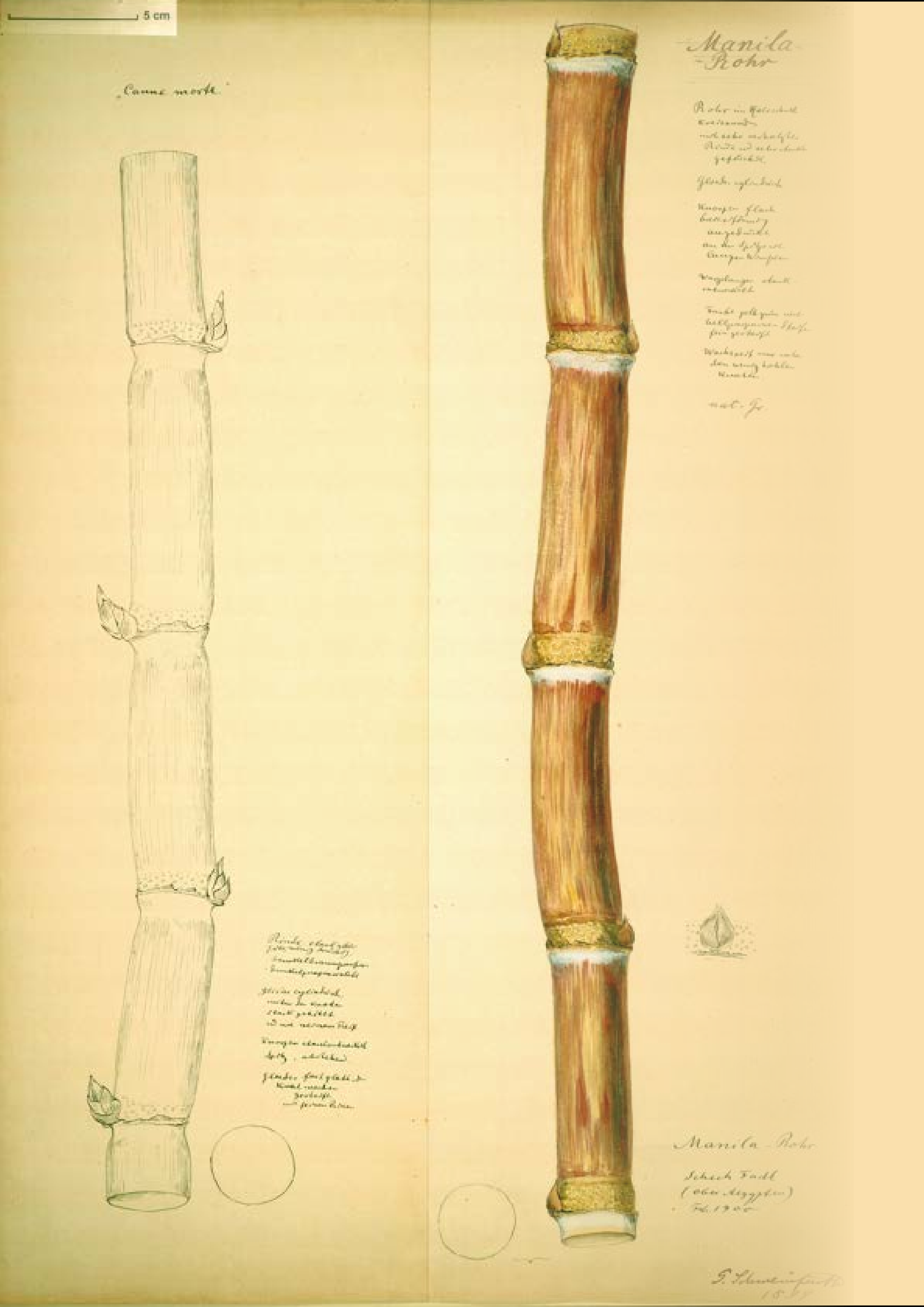
WWF: World Wildlife Fund

Handbook for Regenerative Sugarcane Practices

Nestlé´s Handbook for Regenerative Sugarcane Practices aims to promote the uptake of improved practices among sugarcane producers across different landscapes, based on the understanding that there is a common destination but no single pathway. The main goal of the handbook is to provide sugarcane producers with the **basic understanding and evidence to support their transition towards regenerative agriculture**, helping them reap the benefits of a healthier, more sustainable production. A second goal is to **contribute to improve human health and well-being** by helping farmers grow and harvest better ingredients to produce food products. The third goal is to deliver **broader societal benefits** through improved agricultural practices that contribute to climate change mitigation and adaptation and to the protection of ecosystem services. By making this handbook available to sugarcane producers, extension workers, producer associations, mills, local governments, and other companies, Nestlé's vision is to engage all stakeholders in the gradual transformation of the global sugarcane production system.

This handbook describes the general practices recommended for the transition to regenerative sugarcane production as well as the agroecological principles underlying these practices. However, it does not provide specific agronomic recommendations because each producer will need to interpret and adapt the information based on an assessment of their agroclimatic conditions, needs, challenges, and available resources.

While the handbook is intended for all types of sugarcane producers, it was developed specifically for small and medium-scale producers who may have limited access to information and technical support needed for the implementation of regenerative practices. However, the principles discussed here are universal and can therefore be applied to large-scale production as well. Whenever possible, the handbook mentions specific practices for large producers. It also provides a case study section with examples that illustrate the different forms that regenerative practices can take in different contexts. We hope that this handbook will be useful to diverse sugarcane producers around the world who are committed to producing better in a way that benefits both present and future generations. This handbook is part of Nestlé's series of materials designed to provide guidance on how to improve production systems in key value chains, including dairy, coffee, vegetables, among others.



5 cm
„Canne morte"
Manila-Rohr
Manila Rohr
Scheich Fadl
(Ober Aegypten)
Feb. 1900
nat. Gr.
G. Schweinfurth

1 | INTRODUCTION

Saccharum officinarum - Berlin Botanical Garden, Germany CC BY-SA.

1.1 Global Context for Sugarcane Production

1.1.1 Looking ahead to 2030

Companies from all sectors have recognized the importance of improving their production practices to face the environmental, social, and economic challenges expected for the first half of this century. Agri- and other businesses whose value chains largely depend on agricultural commodities have started to shift their production paradigms in response to both internal changes in priorities, and to external demands for greater transparency and responsibility in their sourcing. The impacts of a sprawling industrial agriculture on biodiversity, climate change, soil and water health, and human communities are undeniable (Nestlé, 2022a). As a result, the Conventions of the Parties for Climate Change (COPs) and Biological Biodiversity (CBDs) have highlighted the Agriculture, Forestry and Other Land Use sector (AFOLU) as critical to tackle in the upcoming decades. Similarly, 90% of the 190 countries that submitted NDCs for the next 5 years have targeted agriculture as a priority sector for interventions to curb emissions and strengthening climate resilience (CEPAL et al., 2021).

1.1.2 Mainstream agricultural production and its challenges

Following the green revolution and the liberalization of international trade, the world has experienced undeniable improvements in agricultural productivity and the flow of commodities across many regions. While many social benefits also materialized as a result, the global scale impacts of modern agriculture are undeniable: up to 37% of the total GHG released into the atmosphere (Latam Climate Summit, 2022), more than 400 Mha of forests and natural ecosystems cleared for agricultural expansion (Campari, 2021), unprecedented biodiversity loss inside and outside of agroecosystems, and disruptions to different global element cycles including the climate system (Dudley & Alexander, 2017; Joseph & Anilkumar, 2018; Joshi & Upadhya, 2019). Intensive crop management strategies such as burning and tilling, extensive irrigation, and the intensive use of agrochemical inputs are taking a toll on the health of humans and ecosystems alike. These widespread agricultural practices, with their focus on maximizing yields and revenue, cannot be perpetuated into the future without further aggravating the environmental and social crises.

1.1.3 Agriculture and planetary boundaries: the need for systemic change

Agriculture depends directly on ecosystem services for its sustained functioning and efficiency, but it is harming natural resources and contributing to the transgression of planetary boundaries. Ninety five percent of our food and fiber supply depends on viable soils, and yet at our current use rate the arable fertile soil layer will be exhausted within 60 years (CEPAL et al., 2021; Nestlé, 2022a). Agriculture uses about 70% of global freshwater withdrawals, contributing to excess consumption and issues such as eutrophication (Smil, 2000). Meanwhile, as populations have grown and diets have shifted to globalized production, demand for commodities has increased to the point where only four products –sugarcane, maize, wheat, and rice– account for half the global primary crop production (FAO, 2022c). As the demands of our current production model continue to exhaust the planet´s productive potential and exceed its resilience, the need for systemic transformation becomes more pressing if we want to reduce risk for human societies and maintain the stability of the earth systems (Campbell et al., 2017).

1.1.4 Sugarcane production, advantages, and challenges

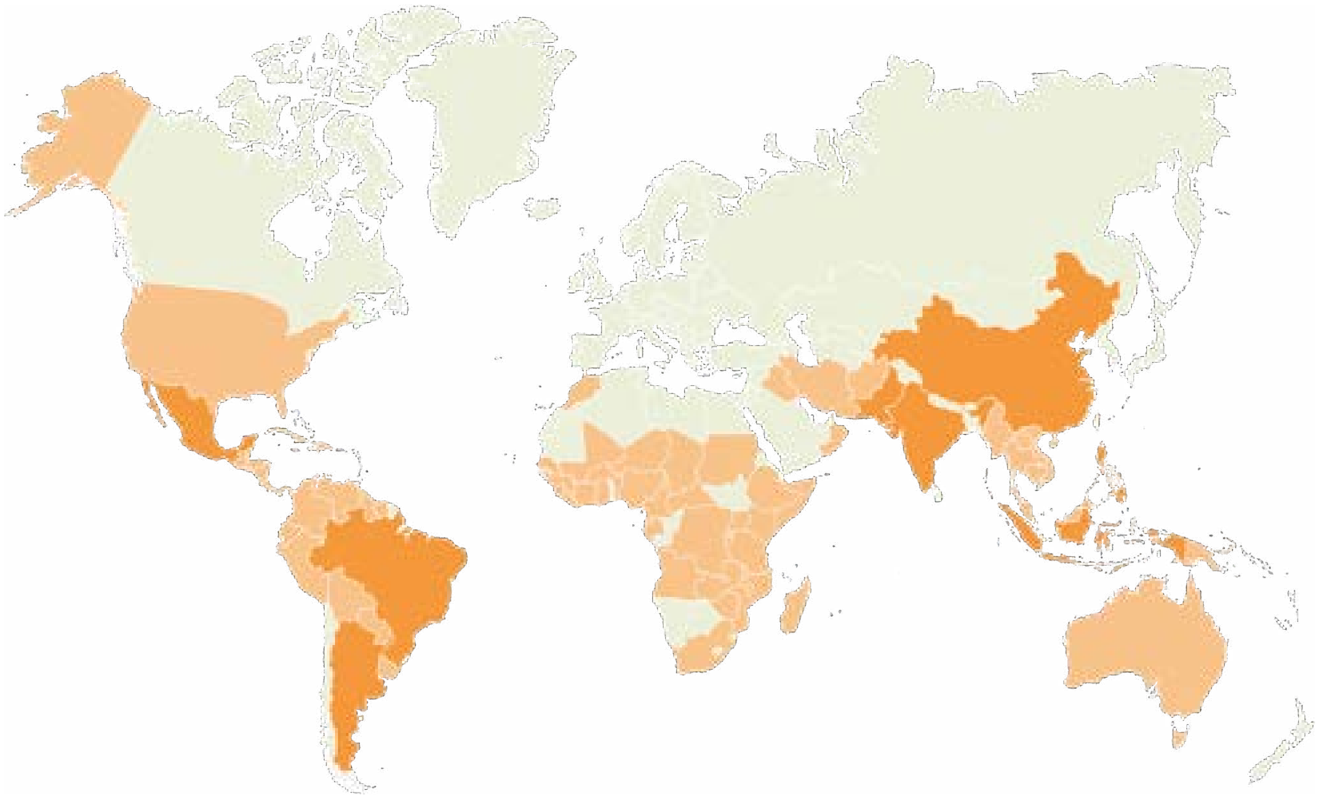
Sugarcane is a perennial grass native to India, Southeast Asia, and New Guinea (Figure 1). The plant, which belongs to the genus *Saccharum,* has a remarkable photosynthetic capacity which allows it to transform sunlight into biomass more efficiently than any other crop. When sufficient water and sunlight are available, its rapid growth rate leads to high absorption of carbon dioxide (CO_2). As a crop, sugarcane is incredibly versatile: the stalks are pressed to produce food products such as sugar, molasses, and vinegar; the leaves and crop residues are used as livestock feed, mulch, and source for bioenergy production; and the liquid and solid by-products can be transformed into a wide range of products including ethanol and alcohol, pharmaceuticals, organic compost, bioplastics, paper and cardboards, and biogas. And because most by-products in sugarcane cultivation and processing can be recircled –for example, effluents from sugar processing can be recycled for irrigation– the crop has the potential to work as a closed-system (Wang et al., 2020).

Sugarcane cultivation dates as far back as 4 B.C., but it has expanded globally to become **one of the world's major commodities**. Today, sugarcane is cultivated in 24.4 Mha across many tropical and subtropical regions with production averaging 1756 Mt (OECD & FAO, 2021). Latin America and Asia are the leading sugarcane producing regions, with Brazil and India providing 642.5 Mt and 296.9 Mt respectively between 2017 and 2019. Sugarcane is grown for different purposes in different countries; in India 99% of the crop is used for sugar, while in Brazil 58% is processed as biofuels (OECD & FAO, 2020). Global production is projected to continue to increase, especially in developing countries which are expected to eventually supply an estimated 78% of global sugar (OECD & FAO, 2021).

Given its global growth and reach, sugarcane cultivation has a high social impact. The crop provides legal rural employment in over 100 countries, supporting an estimated 100 million people worldwide (ILO, 2017; Sugarcane Org, 2022). Smallholders account for 40% of the global production, while the remaining 60% comes from vertically integrated operations in which mostly medium and large-size farmers supply the mills (ILO, 2017). However, the exact proportion of smallholders is difficult to establish because of varying definitions: while in Asian countries small growers usually own less than 2 ha of cropland, in Brazil the law defines smallholders as those who own up to 480 ha and earn 70% of more of their income from the farm mostly with family labor (Jonkman, 2015). For each direct job in sugarcane cultivation, related industries are estimated to provide three additional indirect jobs. For example, in Brazil, the average income for a sugar sector employee is 92% higher than the national minimum wage (Sugarcane Org, 2022).

To reach the current production levels, most top global suppliers employ mainstream cultivation practices which are linked to environmental and social impacts that pose serious challenges to sustainability. **Monocropping**, the common approach to sugarcane production, is associated with severe multiscale biodiversity loss. At the landscape scale, sugarcane fields are often planted with no regard for conserving native vegetation or connectivity, which often eliminates most animal species. At the field level, the use of a handful of sugarcane varieties results in the loss of genetic crop diversity (Fairagora Asia, 2022; Martinelli & Filoso, 2008; Plaisier et al., 2017). Both losses reduce the crop's natural resilience to pests and diseases and increase reliance on synthetic inputs.

SUGARCANE PRODUCING COUNTRIES



TOP COUNTRIES

Brazil
India
Thailand
China
Pakistan
Mexico
Argentina
Indonesia
Philippines

OTHER COUNTRIES

USA
Colombia
Australia
Cuba
South Africa
Guatemala
Viet Nam
Bolivia
Myanmar
Ecuador
Cameroon
Egypt
Dominican Republic
Paraguay
Madagascar
Cambodia
Iran
Kenya
Nigeria
Bangladesh
Peru
El Salvador
Uganda
Nicaragua
Sudan
Nepal
Honduras
Eswatini
Costa Rica
United Republic of Tanzania
Venezuela
Mozambique
Zimbabwe
Zambia
Congo
Mauritius
Belize
Fiji
Panama
Ethiopia
Malawi
Liberia
Côte d'Ivoire
Haiti
Lao Republic
Central African Republic
Japan
Angola
Guyana
Congo
Sri Lanka
Papua New Guinea
Senegal
Morocco
Jamaica
Niger
Rwanda
Taiwan
Uruguay
Ghana
Somalia
Guinea
Burkina Faso
Mali
Gabon
Chad
Cabo Verde
Suriname
Burundi
Bahamas
Barbados
Afghanistan
Malaysia
Sierra Leone
Benin
Guinea-Bissau
Dominica
Grenada
Oman
French Polynesia
Bhutan
Antigua and Barbuda
Iraq
Lebanon
Puerto Rico
Russian Federation
Saint Kitts and Nevis
Saint Lucia
Samoa
Singapore
South Sudan
Syrian Arab Republic
Trinidad and Tobago
Ukraine
Yemen

Source: FAOSTAT, 2022

Figure 1. Map of total sugarcane production in the world

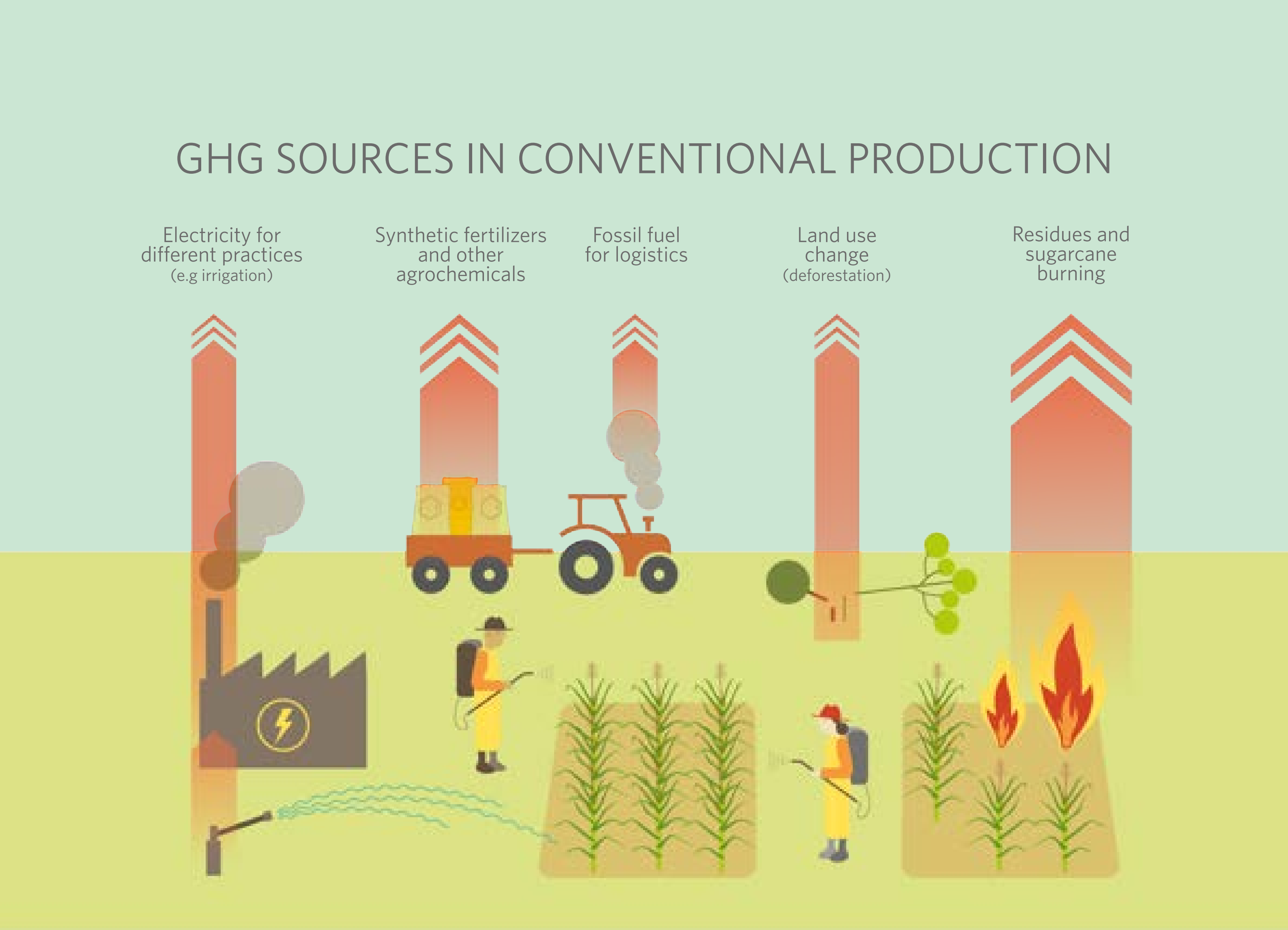


Figure 2. Sources of GHG emissions in conventional sugarcane production compared to potential sources of GHG reductions in regenerative production. Arrow sizes will vary depending on the practices used.

Another common practice is frequent **soil tillage**, which disturbs the soil creating opportunities for weed growth while damaging soil structure and depleting soil fertility. This often promotes the use of both herbicides and fertilizers at different stages of production, which is linked to further soil degradation, loss of ecosystem services and direct risks for human health (Fairagora Asia, 2022; Kasambala Donga & Eklo, 2018; Raza et al., 2019). Tillage and the use of synthetic inputs also contribute to the high levels of GHG emissions associated to sugarcane (Figure 2). Frequent tillage is needed in conventional production because sugarcane is treated as a temporary rather than a perennial crop. By contrast, regenerative management tends to extend the lifespan of the crop, extending the period between crop renewals from the average 5-6 years (Bordonal et al., 2018) to over 15 years, which significantly reduces the need to tillage and therefore, its damaging impacts.

Additional concerns about sugarcane arise from the high level of GHG emitted during cultivation and processing. At the field level, emissions can be mitigated by replacing mainstream practices such

as residue burning, tillage, and overuse of synthetic inputs, with regenerative low-carbon practices. During the processing stage, emissions can also be reduced through more efficient and circular industrial processes. Finally, while claims about the positive impacts of sugarcane on GHG emissions are common in countries that transform most of the crop into bioethanol to replace fossil fuels, the issue remains unresolved.

Mainstream sugarcane production is also linked to serious social concerns. In several countries, highly toxic pesticides that affect terrestrial and aquatic life are commonly used. In Malawi and Punjab, over two thirds of the assessed sugarcane farmers reported skin irritation, headaches, and other symptoms during and after pesticide handling (Kasambala Donga & Eklo, 2018; Raza et al., 2019). Lack of fair pay, appropriate living and working conditions, and safe work practices remain an issue in many places (ILO, 2017; Nestlé, 2022). In Asia, Latin America and Africa, concerns have been raised about harsh labor conditions with reports of child labor and, in some cases, forced labor (Schwarzbach & Richardson, 2015; Tabriz et al., 2021; ILO,

Sugar cane root system. Photo credit: ©alfribeiro.

2017). Finally, sugarcane expansion has been linked to social conflicts over water and land, including threats to food security when sugarcane takes over lands used for local food crops. These challenges raise local and global concerns about sugar, a key ingredient in many consumer goods, and highlight the need for improvements and transparency in the sugarcane supply chain.

Despite the challenges described, transformative changes in sugarcane cultivation that deliver significant benefits to both the communities involved and the environments where it is grown, are possible. For example, if projected sugarcane expansion can be directed to degraded lands and away from native ecosystems or other productive croplands, forest clearing, competition with other food crops, and other land use issues can be avoided. In Brazil the integration of sugarcane with livestock is showing promise as an efficient strategy to increase food production on previously degraded lands (Bordonal et al., 2018). This handbook is a first step in explaining the impacts of the current practices and some of the alternatives that will enable us to leverage the many advantages of this unique crop.

1.2 Regenerative Agriculture: its Importance for Sugarcane and Nestlé

1.2.1 Nestlé's model for regenerative agriculture

As one of the largest global food processors, Nestlé recognizes the many sustainability challenges in its supply chains and the need for a more responsible sourcing of its main ingredients. Consequently, the company has embarked on a long-term effort to promote a more holistic agricultural approach that delivers positive change. Nestlé is committed to sourcing 20% of its key ingredients from regenerative agriculture by 2025, and 50% by 2030. In doing so, Nestlé aims to promote the large-scale transition from conventional to regenerative practices.

There is currently no consensus definition of regenerative agriculture, with some definitions emphasizing the agricultural practices used, others the outcomes achieved, and others focusing on a combination of both (Newton et al., 2020). For Nestlé, regenerative agriculture is about **farming responsibly in a way that protects and restores key natural resources –soil, water, and biodiversity– to secure our present and future food and fiber supplies, while also building climate resilience, decreasing reliance on chemical inputs, and ultimately improving livelihoods** (Fairagora Asia, 2022;

Nestlé, 2022a). This approach must go beyond environmental concerns by also considering the health and wellbeing of the people who work the land, and therefore promoting fair and reciprocal relationships among all stakeholders (Montagnini, 2022).

Nestlé has identified three main challenges that regenerative agriculture can address. First is the **degradation of natural resources** resulting from the mainstream agricultural model that dominates global production of key commodities. Second is **climate change** and the undeniable role that the current agricultural model plays in exacerbating climate variability and the related risks. And third is **massive habitat loss** and the need for a production system that halts the expansion of the agricultural frontier.

Rising to these challenges, Nestlé´s Regenerative Agriculture Model takes a holistic approach based on five pillars: **soils, biodiversity, water, livestock,** and **farmers** (Nestlé, 2022b). The goal of the model is to support the scaling-up of farming practices that protect soil health and increase soil organic matter (SOM); reduce the use of chemical inputs and optimize organic fertilization, biological pest control and efficient irrigation; promote plant and animal biodiversity above and below ground; and integrate livestock and optimized grazing into agroecosystems, whenever possible (Nestlé, 2022b). At the core of this model are the farmers, who must be fully engaged in this transformation as both actors of change and direct recipients of the benefits. Together, the pillars and practices (Table 1) provide a clear vision for regenerative agriculture in Nestle´s sugarcane supply chain.

To facilitate progress towards regenerative supply chains, Nestlé has established additional support strategies. For example, Nestlé is working with local partners to develop pilot farms where the feasibility of the regenerative approach is showcased and communicated to a broader audience through evidence-based and producer-to-producer learning, and capacity-development programs.

The final component is monitoring, which is critical to assess progress and impact. Monitoring consists of mapping the baseline farm conditions to identify challenges and prioritize actions and defining performance indicators to measure results and maximize impacts. By tracking both implementation of desirable practices and their impacts under real farming conditions, we ensure that the right interventions are taking place. Nestlé calls on the scientific community, national agriculture research organizations and expert third parties to be partners in this endeavor (Nestlé, 2022a, 2022b).

REGENERATIVE PRACTICES FOR SUGARCANE PRODUCTION AND THE PILLARS THEY SUPPORT

PRACTICES	PILLARS: SOIL	WATER	BIODIVERSITY	GHG
Green harvesting and the elimination of residue burning	●		●	●
Natural ripening	●	●	●	
Integrated weed management (without herbicides)	●	●	●	
Decreased use of chemical synthesis inputs	●	●	●	●
Increased use of organic fertilizers, compost, manure, green manures	●	●	●	●
Post-harvest crop residue management (mulching)	●	●	●	
Crop integration (intercropping and crop rotation)	●		●	
Efficient water use and irrigation	●	●		
Biological insect control	●		●	
Biodiversity protection	●	●	●	●
Soil management practices (rational tillage and minimum disturbance)	●	●	●	●
Multi-variety cultivation			●	

Table 1. Regenerative practices for sugarcane production and the pillars they support.

1.2.2 Regenerative agriculture applied to sugarcane cultivation

In conventional production, sugarcane systems are oversimplified monocultures that rely heavily on external inputs. As the sustainability challenges of this model come under scrutiny, there have been some attempts to address the problems in the model. In recent years, some large producers in Brazil and elsewhere have embraced organic sugarcane production mainly in response to the rising demand for raw organic food ingredients. Under organic standards, producers focus mainly on reducing use of agrochemical and other harmful inputs (Fairagora Asia, 2022) and implementing practices such as no burning, reduced tillage, and the protection of forest patches (Miranda & Ariedi, 2015). Still, organic sugarcane production which is located mostly in Brazil, Paraguay, Colombia, and Argentina (Willerton, 2019), only accounts for about 1% of total global yield (Beroe, 2022).

Beyond best practices and organic certifications, sugarcane production requires a more profound transformation. Rather than simply replacing a few mainstream practices, the idea behind the regenerative approach is to introduce incremental changes that strengthen and harness the ecosystems' natural processes until the system achieves a dynamic of its own. Nevertheless, the elimination of two specific mainstream practices –**pre- and post-harvest burning and the massive use of synthetic inputs**– is critical to this transformation. From there, efforts should turn to improving the physical, chemical, and biological conditions of soils, water, and biodiversity, first at the farm level and then across the landscape. As ecological complexity recovers, a regenerative system will consolidate adding value to the crop and improving producers' livelihoods.

Given the diversity of ecological and social conditions under which sugarcane is produced globally, implementation of a regenerative approach will vary by context. In all cases, the process will require time, scientific evidence, and economic investment. Producers' efforts to transform their agricultural systems must be recognized and supported through a combination of proper economic incentives, adequate public policies, improved access to technologies, knowledge exchange opportunities, differentiated markets, and novel funding and financial mechanisms. Corporate buyers and individual consumers can play a key role in supporting farmers' appetite for change by making purchasing decisions that recognize these efforts. Tilting the market scale in favor of producers is key, as they will need the financial backing to choose regenerative over conventional practices.

Use of animal traction for manual sugarcane harvesting. Photo credit: Depositphotos.
Pp 28-29: Woman in the middle of sugarcane field. Photo credit: Depositphotos.

2 | THE SOCIAL COMPONENT IN REGENERATIVE SUGARCANE

Women working in the sugarcane harvest. Photo credit: Depositphotos.

Nestlé's aim in promoting regenerative agriculture is to help conserve and restore farmland, its ecosystems, and its key resources, while also delivering benefits to farmers, the environment, and society. At the center of this model are the farmers, who manage the resources and make decisions about which practices they adopt, and therefore should be the direct beneficiaries of this approach (Nestlé, 2022). However, farmers operate within a nested system, and therefore are constrained by the interaction of social and ecological variables within that system. Farmers need to understand these interactions, because their engagement is required to achieve progress, and their success is essential for scaling-up the process (Haggard and Mang 2016; Soloviev and Landua 2016, Gordon 2022). Other stakeholders in the agroecosystem and agribusinesses must also understand these interrelations if they are to successfully support the transition to regenerative production systems.

Nestlé promotes the uptake of regenerative practices among producers across different landscapes, with the understanding the transition has **a common destination, but no single pathway**. In other words, regenerative agriculture is based on a series of agroecological principles that underpin a variety of practices. While the principles are universal, they can be applied as a range of practices whose relevance and suitability will vary depending on the specific socioecological context. For example, diversifying cropping systems is a basic agroecological principle that can take shape as different practices: intercropping, crop rotation, livestock integration or a combination of these. Which practices are relevant and appropriate depends on the social and ecological conditions of the specific locality.

Agriculture is a social and cultural activity that both shapes and is shaped by landscapes (McIntyre et al. 2009). Given the diversity of ecological and social conditions under which agriculture occurs globally, **implementation of a regenerative approach will take different forms in different contexts**. Each producer's situation is different and context-specific and therefore, the implications – positive and negative– of introducing changes to the current practices will vary. This is the case for sugarcane, which is currently grown in over 100 countries and under wildly different circumstances. It is therefore critical that interventions begin with a situational analysis that assesses both the opportunities and risks at the local level as the basis to design a successful and sustainable implementation pathway.

A common misconception about regenerative agriculture is that, by correctly implementing a series of best agronomic practices, benefits will inevitably reach to the people involved.

But the reality is far more complex. While regenerative practices in general can be considered beneficial, their implementation entails efforts and trade-offs, and both the efforts, the benefits and the trade-offs are highly context specific (Table 2). Any changes in the way food and agricultural raw materials are produced will potentially have both positive and negative implications, not only on the crop and the environment but also on the people involved in farming. If the benefits fail to materialize for the people, regenerative practices will not take hold. Consequently, the first step of a successful transition to regenerative agriculture is to fully map and understand the local context, constraints, and opportunities, both in terms of the natural and human resources, and analyze the potential benefits, trade-offs and investment needed for the proposed changes. Only then can you identify the practices and sequence that best address the key challenges and deliver the most benefits with the least harm. After all, agriculture cannot be truly regenerative if the people who participate in it are not better off.

In the process of selecting the appropriate regenerative practices, it is critical to consider whether their implementation in a particular social context may create new, or exacerbate existing, risks or have unintended social consequences. For example, the shift to labor intensive practices such as cover crops, incorporation of crop residues, or manual weeding may be highly beneficial in regions where qualified labor is available and rural jobs are needed. But where labor is already scarce, implementing such practices may mean that the tasks are passed on to women increasing their workload, to children interfering with their school time, or to migrants enabling abusive practices where labor regulations are not in place. Thus, increased need for labor means different things in different contexts and anticipating factors such as who is available to supply this labor and whether responsible recruitment policies are in place, is critical.

Another example is the replacement of chemical inputs, which for a large producer with access to technical assistance and alternative nutrient sources may lead to optimized use of inputs and significant cost cuts. But for a small producer working on poor soils and with no access to alternative nutrients, reducing the use of already limited chemical fertilizers may lead to productive losses from which they may not recover. Similarly, the implementation of native vegetation strips may effectively reduce runoff and provide habitat for beneficial insects, but in some cases, it may prevent worker families from growing food on field margins, thereby exacerbating food insecurity. Table 2 provides a general overview of some social benefits and trade-offs to consider when selecting the route to transition from a conventional to a regenerative sugarcane production system.

WHAT ARE HUMAN RIGHTS?

> Rights we have simply because we exist as human beings –they are not granted by any state. These universal rights are inherent to us all, regardless of nationality, sex, national or ethnic origin, color, religion, language, or any other status. They range from the most fundamental - the right to life - to those that make life worth living, such as the rights to food, education, work, health, and liberty

United Nations Human Rights Office of the High Commissioner (OHCHR)

Regenerative agriculture represents a departure from the simplified agricultural systems that have severely impacted the health of people and landscapes globally (Gordon, 2022). But because these mainstream practices are deeply engrained, regenerative agriculture must aim to transform peoples' mindsets by targeting deep and sustained systemic change in social processes (Gordon, 2022). Regenerative agriculture involves both the material systems and the intangible socio-cultural structures. Therefore, it must address how producers and the broader agricultural systems perceive and construct technologies, institutions, and practices. The successful transformation of agroecosystems and agrobusinesses thus **requires a cultural shift at different levels.**

Nestlé acknowledges that transitioning to regenerative farming is a knowledge-intensive journey that generates added risks and costs, and that ultimately, the final decisions about which practices to adopt, and how, are up to the farmer. Farmers, especially smallholders, have much to gain from this transition in terms of resilience, economic stability, and profitability, but they need support and collaboration to achieve a just transition (Nestlé, 2021).

That is why Nestlé has developed the Regenerative Agriculture Framework and is producing handbooks like this one, intended as knowledge- and evidence-based tools to support the transition process. And it is why the guiding principles are aimed at fostering collaborations with farmers' associations, NGOs, and research institutions to help farmers adapt the approach to their local conditions. These tools consider social and cultural aspects as critical for promoting behavioral change at multiple scales.

REGENERATIVE AGRICULTURE MUST ADHERE TO THE HIGHEST STANDARDS OF ETHICS, FAIRNESS, AND EQUITY

Agroecosystems are spaces where both broad topics –human rights, human health, food security, and diversity and gender inclusion– and more specific ones –generational change, agricultural livelihoods, climate risks, and land tenure– converge. Agricultural practices are closely interlinked with farmers' livelihoods, workers' health and safety, and the physical and financial health of the local farming communities (Figure 3). Hence, the transition to regenerative agricultural systems must deliver wellbeing and improved opportunities on all these aspects to all those involved, from workers to producers of all sizes. If achieving **social benefits is an explicit goal rather than a collateral effect of regenerative agriculture** (Proforest, 2022), companies claiming to practice this approach should promote fair and reciprocal relationships between all the system's stakeholders (Montagnini, 2022) by following practices related to responsible hiring (i.e., decent wages, working and living conditions), health and safety (i.e., provision and use of PPE, work safety and health frameworks), community-building and governance, and fair trade business practices. And of course, regenerative agriculture must adhere to the highest standards of ethics, fairness, and equity by following a set of universal principles and rights that apply to all economic activities (Annex 1).

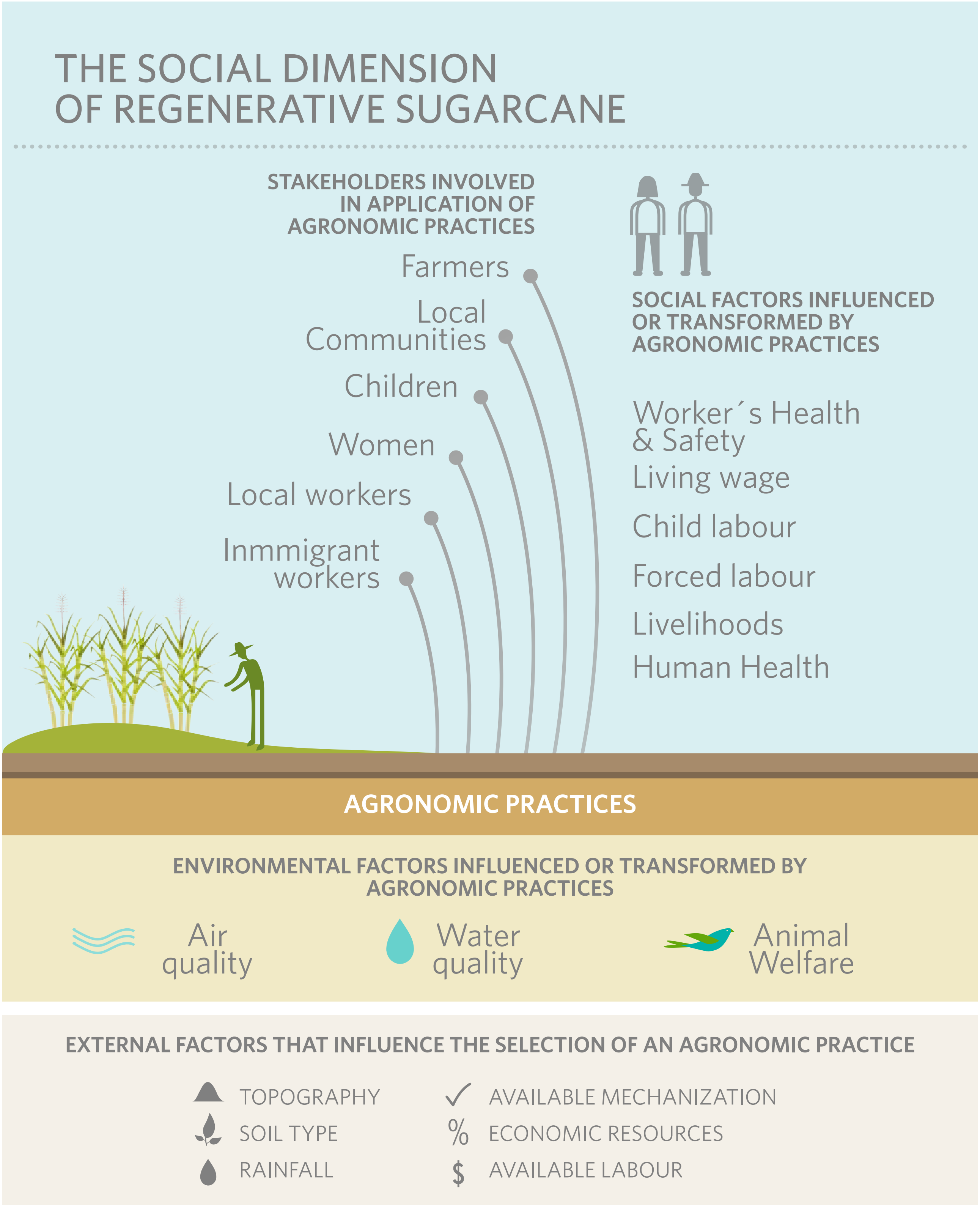


Figure 3. Connections between the agronomic practices in a production system and the environmental and socioeconomic welfare they produce.

GREEN HARVESTING OR THE ELIMINATION OF PRE-HARVEST BURNING

CONVENTIONAL AGRONOMIC PRACTICE	NEGATIVE SOCIAL IMPACTS OF CONVENTIONAL PRACTICE
 Manual harvesting of burnt cane	• High temperature due to fire causes dehydration • Respiratory diseases from particulate matter and gas emissions • Lower crop quality due to soil quality loss • Reduced soil fertility leading to negative impacts on productivity and livelihoods • Consumption of SOM by high intensity burning • Loss of soil macro and microorganism populations decrease biological interactions and its ecosystems services • Child labour often used for manual harvesting (specially in some geographies where manual labour is scarce, or family farming is common)

REGENERATIVE AGRONOMIC PRACTICE	POSITIVE SOCIAL IMPACTS	NEGATIVE SOCIAL IMPACTS
 Manual harvesting of green cane (of standing sugarcane)	• Manual harvesting of green cane (of standing sugarcane) -Reduced incidence of dehydration from high temperature burning • Improved air quality and reduced impact of respiratory diseases due to inhalation of particles • Improved soil health leading to long-term productivity and improved livelihoods • Improved level of productivity and livelihoods • Reduces risk of fire expansion that might harm workers or surrounding communities • Less particulate matter and GHG emissions reducing contributions to climate risks and phenomenon such as acid rain	• More labour intensive/ physically demanding than harvesting burnt cane • Reduced harvest during transition period leading to lower earnings for workers • Increased demand for labour may result in hiring of migrant workers under poor working and housing conditions • Labour shortages (e.g., Mexico, Colombia, China, and Philippines) • Increased risk of encounters with dangerous wildlife (e.g., reptiles and snakes)
 Mechanical harvesting (of cut sugarcane)	• Reduced incidence of dehydration from high temperature burning • Improved air quality and reduced impact of respiratory diseases due to inhalation of particles • Improved soil health leading to long-term productivity and improved livelihoods • Reduces risk of fire expansion that might harm workers or surrounding communities	• Reduced need for manual labour due to mechanization may impact livelihoods • Loss of cane cutting jobs can increase poverty in the communities of origin • Reduced labour force may lead to provision of poor or inadequate shelter/ shade in the field

Table 2. Social impacts of conventional and regenerative agronomic practices for sugarcane cultivation.

INTEGRATED WEED MANAGEMENT (WEED CONTROL)

CONVENTIONAL AGRONOMIC PRACTICE

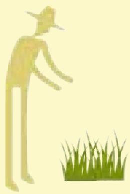
NEGATIVE SOCIAL IMPACTS OF CONVENTIONAL PRACTICE

Chemical Weed Control

- Increased risk of pollution of surface and ground water sources due to run-off and infiltration of excess chemical inputs
- Health impacts on agricultural workers, including women and children
- Possible soil contamination due to long-term retention of certain chemical compounds
- Loss of biodiversity (plants and animals) on the farm and their associated ecosystem services

REGENERATIVE AGRONOMIC PRACTICE

Manual weed control



Manual weed control

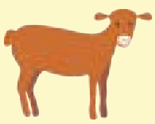
POSITIVE SOCIAL IMPACTS

- Increased demand for labour creates new job opportunities
- Reduced use of chemical inputs leads to improvements in the health of humans, water, soils, and biodiversity

NEGATIVE SOCIAL IMPACTS

- Increased use of child labour for weeding tasks
- Manual labour can have harsh working conditions and cause physical strain
- Potential to cause issues if health & safety work condition are not implemented
- Loss of jobs/supply chain relationships from reducing chemical weed control

Livestock grazing



Livestock grazing

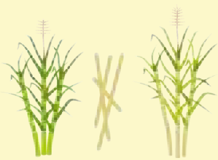
POSITIVE SOCIAL IMPACTS

- Income diversification for small and medium holders
- Improved food security for smallholders
- Improved soil health and soil fertility resulting in improved livelihoods
- Improved yields from animal crop integration
- Cost optimization due to reduced use of herbicides

NEGATIVE SOCIAL IMPACTS

- Social conflict between herders and farmers
- Crop loss due to consumption by cattle
- Increased labour from risk of cattle getting stuck
- Loss of jobs/supply chain relationships from reducing chemical weed control

Cover crops



Cover crops

POSITIVE SOCIAL IMPACTS

- Reduced use of chemical inputs leads to improvements the health of humans, water, soils, and biodiversity
- Cost optimization due to reduced use of herbicides
- Gradual recovery of soil fertility

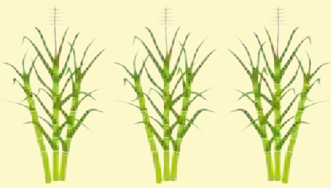
NEGATIVE SOCIAL IMPACTS

- Loss of jobs/supply chain relationships from reducing chemical weed control

INTEGRATED CROPS

CONVENTIONAL AGRONOMIC PRACTICE

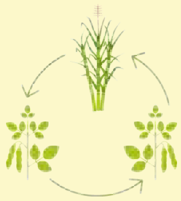
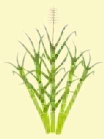
NEGATIVE SOCIAL IMPACTS OF CONVENTIONAL PRACTICE



Monoculture

- Deplete soil nutrients
- Favour pest attacks and risks livelihoods
- Reduce biodiversity
- May increase insecurity if all land is devoted to commodity crop
- High input need causing high production costs and less profitable margins for the producer
- Not reaching full productive potential when using a single variety

REGENERATIVE AGRONOMIC PRACTICE

REGENERATIVE AGRONOMIC PRACTICE	POSITIVE SOCIAL IMPACTS	NEGATIVE SOCIAL IMPACTS
 Crop rotations	• May help smallholders to diversify income (via cash crops) increasing economic resilience over time • Allows some soil replenishment • Reduce soil erosion • Reduce need for fertilizers • Reduce recurrent pest attacks • mproved water quality in water bodies	• May require more land area leading to clearing of new lands and possible land conflicts • Risk of rotating crop becoming invasive • Need for technical assistance and guidance that might not be available
 Associated crops	• Potential for increased earnings via other crops • May contribute to food security	• Competition for land for lower priced cash crops • Need for technical assistance and guidance that might not be available
 Use of High Yield or other select varieties	• For high yield varieties, improved livelihoods due to increased productivity • For drought tolerant varieties, improved resilience, and better climate risk management	• Cost limits access to many farmers • Requires access to knowledge
 Multiple Variety Crops	• For high yield varieties, improved livelihoods due to increased productivity • For drought tolerant varieties, improved resilience, and better climate risk management	• Cost limits access to many farmers • Requires access to knowledge

INTEGRATED PEST MANAGEMENT

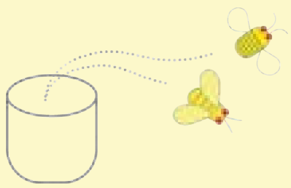
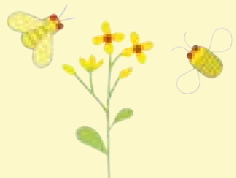
CONVENTIONAL AGRONOMIC PRACTICE

NEGATIVE SOCIAL IMPACTS OF CONVENTIONAL PRACTICE

Chemical pest management

- Use of synthetic inputs
- Risk of overapplication when spraying
- Schedule is not based on monitoring of pest populations
- Cause of human illnesses and aspiration of potentially toxic elements
- Chemical aerosols and particulate matter

REGENERATIVE AGRONOMIC PRACTICE

	POSITIVE SOCIAL IMPACTS	NEGATIVE SOCIAL IMPACTS
 Control by release	• May create local employment opportunity from insect rearing and release • Improved personal and environmental health due to less agrochemicals • Reduced water and air pollution	• Correct use requires knowledge • May entail additional costs • Limited access, especially for smallholders • Creates dependency on external input (insect for release)
 Control by conservation	• Reduced use of synthetic inputs • Reduced water and air pollution • Improved natural pest control, reducing costs to producers for population management • Contributes to overall biodiversity with benefits for all crops	• High opportunity cost: land devoted for conservation is no longer used for production • May create leakage: displacing agriculture to other lands
Other Specific Practices  1 Use of microorganisms (fungi and entomopathogenic nematodes)	• Reduced use of synthetic inputs • Improve biodiversity which is positive for cane and other crops • Reduced water and air pollution	• Correct use requires knowledge -May require additional equipment to deal with live organisms • Access may be limited, especially for smallholders • Additional costs may limit access
2  Other pest control methods (Insecticides/repellents from botanical extracts; organic compounds)	• May create local employment opportunity • Improved personal and environmental health due to reduced use of synthetic inputs • Reduced water and air pollution	• Correct use requires knowledge • Additional costs may limit access • May require additional equipment

CROP RESIDUE MANAGEMENT

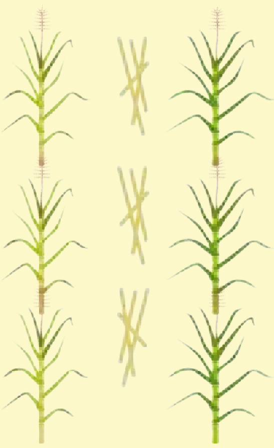
CONVENTIONAL AGRONOMIC PRACTICE

NEGATIVE SOCIAL IMPACTS OF CONVENTIONAL PRACTICE

Burning of crop residues

- Respiratory diseases and other health impacts on local communities
- Air pollution
- Destruction of soil biota and SOM from high temperatures
- Loss of soil fertility from repeated burning
- Loss of valuable nutrients that could be used to replenish the soil
- Increase soil erosion in bare soils

REGENERATIVE AGRONOMIC PRACTICE



Distribution of crop residues

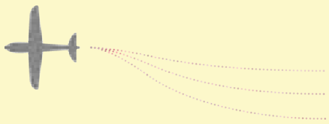
POSITIVE SOCIAL IMPACTS

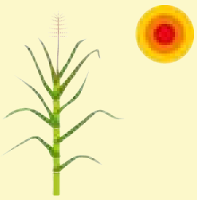
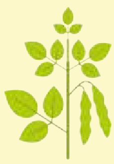
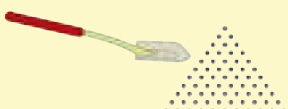
- Reduced air pollution and impacts on human health
- Increase need for labour may create new job opportunities
- Over time, builds organic matter into the soil improving fertility and maintaining productivity
- Soil Organic Matter improves moisture retention reducing irrigation needs over time
- May reduce need for fertilisers, lowering costs for farmers

NEGATIVE SOCIAL IMPACTS

- If labour is scarce, may entail additional work for women, children and elderly, or unfair working conditions for migrants
- Increased cost of removing excess residues from the field
- Health and Safety issues related to manual labour for crop residue management
- Increased use of fossil fuels or risk of soil compaction if distribution is mechanical

REDUCED RELIANCE ON CHEMICAL INPUTS

CONVENTIONAL AGRONOMIC PRACTICE	NEGATIVE SOCIAL IMPACTS OF CONVENTIONAL PRACTICE
 Application of synthetic ripeners	• Air pollution • Respiratory diseases and other health impacts on local communities • Negative impacts of ripener drift on other crops
 Synthetic fertilizers	• Increased and variable production costs • Creates dependency on external inputs with trend for incremental use to maintain productivity • Contributes to degrade soil structure over time, with impacts on yield and water retention • Pollution of water sources

REGENERATIVE AGRONOMIC PRACTICE	POSITIVE SOCIAL IMPACTS	NEGATIVE SOCIAL IMPACTS
 Natural sugarcane ripening	• Reduced expenses from purchase of chemical inputs • Reduced cost from labour to apply ripeners • Reduced health risk from non-exposure to chemicals	• Impacts in delivery to mills due to lock of control in ripening process • Extended harvesting times that may interfere with crop rotation • Reduced demand for labour • May influence sugar content and therefore price received at mill gate
 Green manure	• Reduce need for synthetic fertilisers • Alternative to improve soil fertility for those who cannot afford fertilizers • Help build soil health and fertility over time • Help with weed suppression and erosion control. • Can lead to livelihood improvements over time via increased productivity.	• May increase labour costs for larger operations • May increase need for use of machinery in larger operations
 Organic fertilizers	• May provide local employment opportunities from production of composts and others • Improved human and environmental health due to less exposure to agrochemicals	• Correct use may require specialized knowledge not available to all farmers. • May entail higher costs.

PROMOTING BIODIVERSITY PROTECTION

CONVENTIONAL AGRONOMIC PRACTICE

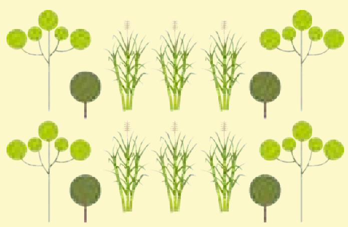
NEGATIVE SOCIAL IMPACTS OF CONVENTIONAL PRACTICE

Elimination of vegetation in/around cultivation areas

- Contribute to biodiversity loss with affects natural pest control
- Contributes to degrade soil structure over time, with impacts on yield and water retention
- Increase risk of erosion and run-off
- Contribute to changes in water and carbon cycling which impact water sources and climate

REGENERATIVE AGRONOMIC PRACTICE

POSITIVE SOCIAL IMPACTS / **NEGATIVE SOCIAL IMPACTS**



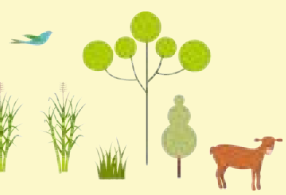
Vegetation strips on crop margins

Positive social impacts:

- Reduced runoff after rain events reduces erosion and improved nutrients retention
- Improved habitat for beneficial insects potentializes agriculture via biological pest control, pollinizing etc.
- Can improve habitability and beauty perception of farms

Negative social impacts:

- Some opportunity cost: land used for strips is not available for production
- Impacts on food security due to competition for land



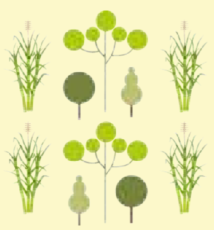
Regenerating forest areas and conservation of natural ecosystems

Positive social impacts:

- May create opportunities for tourism that improve livelihoods
- Can improve habitability and beauty perception
- Reduced runoff after rain events reduces erosion and improved nutrient retention
- May improved access to water
- Improved habitat for beneficial insects potentializes agriculture via biological pest control, pollinizing etc.

Negative social impacts:

- High opportunity cost: land devoted to conservation is no longer available for production
- Impacts on food security due to competition for land
- Loss of aesthetic value in the landscape



Incorporating tree lines

Positive social impacts:

- Higher productivity due to nutrients retention in the soil and erosion prevention
- Shade for workers during breaks
- Opportunity for additional income from specialty trees wood

Negative social impacts:

- Some opportunity cost: land used for strips is not available for production
- Impacts on food security due to competition for land
- Interference with mechanized tasks
- Shade over crops or land reducing productivity

SOIL PREPARATION

CONVENTIONAL AGRONOMIC PRACTICE

NEGATIVE SOCIAL IMPACTS OF CONVENTIONAL PRACTICE

Soil Levelling

- Loss of organic matter in soils reducing productivity and increasing need for synthetic inputs
- Particulate matter releases and changes in natural run-off slopes

REGENERATIVE AGRONOMIC PRACTICE

Topography analysis and other practices prior to crop cultivation

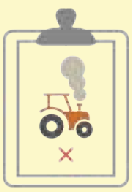
POSITIVE SOCIAL IMPACTS	NEGATIVE SOCIAL IMPACTS
• Reduced water use, which improves human access to water • Reduced soil erosion	• High-cost limits access to many farmers • Requires access to knowledge and equipment
• Productivity gains • Improved soil infiltration results in more water available for other uses	• High-cost limits access to many farmers • Requires access to knowledge and equipment

PRECISION AGRICULTURAL TECHNIQUES

CONVENTIONAL AGRONOMIC PRACTICE

NEGATIVE SOCIAL IMPACTS OF CONVENTIONAL PRACTICE

Homogenous agronomic practices



- Less efficient use of available resources (water, soil)
- Higher costs when higher user of inputs exists.

REGENERATIVE AGRONOMIC PRACTICE

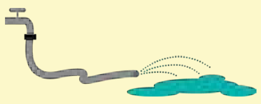
Precision agriculture techniques

POSITIVE SOCIAL IMPACTS	NEGATIVE SOCIAL IMPACTS
• Makes more rational use of inputs • Reduce production costs and increase productivity • Increased need for qualified labour	• Adapted for extensive systems • Not highly applicable to small scale farmers due to cost and knowledge barriers

IRRIGATION SYSTEMS AND WATER USE EFFICIENCY TOOLS

CONVENTIONAL AGRONOMIC PRACTICE

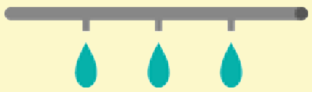
NEGATIVE SOCIAL IMPACTS OF CONVENTIONAL PRACTICE



Irrigation at will

- May lead to inefficient use of water when not based on soil moisture measurements
- Excess ground water extraction competes with water for human use
- May cause salinization issues
- Uneven water application
- Water logging

REGENERATIVE AGRONOMIC PRACTICE



Rational need-based irrigation

POSITIVE SOCIAL IMPACTS

- Need-based irrigation conserves water
- Avoids depletion of ground water resources, increasing human access to water
- Prevent soil salination from excess irrigation, improving productivity
- Decreased use of agrochemicals as only required input are added in the irrigation streams
- Reduced water use, which improves human access to water
- Reduced soil erosion (topography analysis)

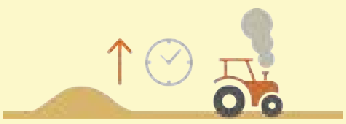
NEGATIVE SOCIAL IMPACTS

- High cost of investment to set up efficient irrigation system
- Irrigation systems
- High-cost limits access to many farmers
- Requires access to knowledge and equipment

REDUCED TILLAGE

CONVENTIONAL AGRONOMIC PRACTICE

NEGATIVE SOCIAL IMPACTS OF CONVENTIONAL PRACTICE



Regular tillage

- Damages soil structure over time
- Increases risk of erosion
- Increases production costs
- High GHG emissions from soil carbon

REGENERATIVE AGRONOMIC PRACTICE

Reduced tillage

POSITIVE SOCIAL IMPACTS

- Decreases soil run-off which may reduce water pollution
- Reduces damage to soil structure and risk of erosion
- Maintained yields in the long run
- Reduces costs from labour or machinery operation
- Reduces production costs

NEGATIVE SOCIAL IMPACTS

- Requires access to knowledge and equipment

Pp 46-47: Weeds conservation along the margins of sugarcane field, Colombia.
2022.08 Cali Kickoff ©TNC - Federico Gomez.

3 | MAIN REGENERATIVE PRACTICES FOR SUGARCANE PRODUCTION

Pre-harvest sugarcane burning, Thailand. Photo credit: © kampee_p.

3.1 Green harvesting and the elimination of post-harvest burning

In many parts of the world, the practice of burning sugarcane –both the standing crop pre-harvest and the leftover residues post-harvest– has been banned or regulated due to its many negative impacts. Nevertheless, burning remains a widespread practice and one of the main sustainability challenges in sugarcane production.

Several reasons explain why burning has persisted. When the harvest is done manually, producers burn to facilitate a physically demanding labor that is often paid by weight harvested rather than by time invested. Pre-harvest burning is also done to protect workers by killing or scaring off snakes, scorpions, and other animals. If the harvest is mechanized, burning helps to reduce the amount of leftover crop residues and optimize the operation of the machinery, reducing production costs.

In some regions, producers use burning as a strategy to make up for lack of planning in the supply chain. For example, mills in Thailand often set short deadlines for delivery of the harvested cane, forcing producers to burn so they can reduce their harvest times and deliver on time (Fairagora Asia, 2022).

Finally, some producers burn because they are unaware of alternative ways to harvest, because they have limited access to the technology needed for green harvesting, because they are unaware of the multiple benefits of mulching with crop residues, or simply because mills do not require the elimination of burning.

> WHEN THE HARVEST IS DONE MANUALLY, PRODUCERS BURN TO FACILITATE A PHYSICALLY DEMANDING LABOR THAT IS OFTEN PAID BY WEIGHT HARVESTED RATHER THAN BY TIME INVESTED. PRE-HARVEST BURNING IS ALSO DONE TO PROTECT WORKERS BY KILLING OR SCARING OFF SNAKES, SCORPIONS, AND OTHER ANIMALS.

1. Compounds that cause genetic damage to the DNA.

3.1.1 Impacts of sugarcane burning

Although burning can improve harvest efficiency, this practice has a variety of negative impacts that need to be considered.

Impacts on human health

Burning has lasting effects on air quality that may severely impact human health. When sugarcane is burned, incomplete combustion of the biomass emits black smoke, particulate matter and pollutants that impact the respiratory health of people exposed to the fires, both directly in the field and indirectly in distant areas. Workers are directly exposed to high levels of particulate matter and various compounds[1] including PAHs.

In Brazil, hospital admissions for asthma increase during the sugarcane harvest season due to increased exposure to particulate matter (Arbex et al., 2007 & Mazzoli-Rocha et al. 2008 cited by Silveira et al., 2013). Also, PAHs from sugarcane burning have been found on food products such as sugarcane juice, and in the atmosphere (Tfouni & Toledo, 2007, Tfouni et al 2009, de Andrade et al., 2010). In Thailand, where air circulation is slow and smoke is not easily dispersed, extensive sugarcane burning has led to periods of persistent haze that interfere with air traffic and other economic activities[2].

GHG emissions

Burning emits large amounts of GHG from the biomass and releases the carbon stored in the soil, contributing to exacerbate climate change (Kumar et al., 2020 cited by Fairagora Asia, 2022). In Brazil, burning is responsible for up to 48% of GHG emissions during the planting and processing of cane for ethanol and sugar (Pinto, 2019).

Impacts on ecosystem resources

Burning deteriorates soil health, which over time compromises crop productivity. Recurrent use of high intensity fire eliminates soil biota, the micro- and macro-organisms in the topsoil that are critical for nutrient cycling and replenishing soil fertility.

3.1.2 What is the regenerative alternative to burning?

In regenerative production, the alternative to pre-harvest burning is **green harvesting**, which means harvesting the standing cane without previously burning, and the

Image right: Opposite: Mechanized green harvest. Photo credit: Depositphotos.

2. Read The Tangled Problem of Sugarcane Burning in Thailand.

alternative to residue burning is to use the crop residues as mulch to enhance the soils. These practices can be adapted for both manual and mechanized harvest to eliminate the many problems linked to burning.

In small growing areas, harvesting is the most commonly done manually by cutting each stem individually with a machete or similar hand-held tool. In larger cultivation areas, green harvest is mostly mechanized with agricultural machinery that cuts multiple stalks at a time, leading to savings in harvesting time.

MANUAL GREEN HARVEST REQUIRES TWO CUTS: A LOW CUT AT GROUND LEVEL FOLLOWED BY A SECOND CUT THAT REMOVES THE TIP LEAVING ONLY THE STALK.

3.1.3 Recommendations for implementation

For manual green harvesting:

- The first cut should be done as low as possible to improve resprouting of the cuttings left in the field for the next cropping cycle. Proper cutting of the stems prevents the proliferation of pests which in turn reduces the need for spraying chemicals.
- Manual harvesting is particularly suitable for smaller plots with irregular topography or difficult terrain (e.g., steep slopes, water-logged soils), where mechanization can damage the soils.

For mechanized green harvesting:

- The agronomic requirements for the effective operation of the harvesting machinery should be considered during the planting design.
- An additional pass of manual cutting may be required after the mechanical cut to homogenize the remaining stalks. Not doing so may increase the risk of failed resprouts and fermentation in the field, which can encourage pest attacks.

3. Mainly related to lower costs of irrigation labors and use of agrochemical inputs.

3.1.4 Benefits of green harvesting and residue management

- Green harvesting improves air quality, public health and working and living conditions by eliminating smoke and soot from crop burning (Ortiz Laurel et al., 2012). It also reduces the risk of accidental fires and accidents due to reduced visibility from persistent smoke.
- Green harvesting eliminates the damaging impacts of burning on both the biological and physical components of the soil. This preserves and strengthens soil health over time, allowing for the gradual decrease in the use of external inputs and the associated costs[3].
- Crop residues spared from burning can be redistributed in the field as mulch, providing nutrients and organic matter that contribute to the gradual recovery of soil fertility and the accumulation of soil organic carbon (SOC).
- Green harvesting extends the life span of sugarcane plant thereby reducing the frequency of crop renewal. In Colombia, crop renewal has been extended from 5-6 years in conventional management to 15+ years in regenerative systems.

3.1.5 Limitations

- Whereas not burning can increase soil carbon storage, some of the carbon will eventually be released when fields are eventually ploughed for replanting (De Figueiredo et al. 2015 cited by Bordonal et al., 2018). A better understanding of the potential impact of regenerative management on the life span of the crop is therefore crucial to estimate the real carbon benefits.
- As with all innovations, producers' natural reluctance to changes in longstanding practices can pose a challenge for the implementation of green harvesting. Evidence-based guidance and examples of success are key to demonstrate the viability and benefits of the practice.
- Relative to burned harvesting, green harvesting usually requires more labor and time which leads to higher production costs. However, these costs can often be offset through savings from other regenerative practices and reduced environmental impacts.

Aircraft used for herbicide spraying in sugarcane. Photo credit: ©Tomás Castro.

Mechanized green harvest. Photo credit: ©Enrique Murgueitio.

3.2 Induced ripening

3.2.1 Why is sugarcane ripened?

The ideal time to harvest sugarcane is at physiological ripening when the stems reach their maximum potential for sucrose accumulation (Cenicaña, 1995). The maximum sucrose content achieved through natural ripening will vary depending on the sugarcane variety, the availability of water and nutrients, temperature, and luminosity. So, when agroclimatic conditions do not favor natural ripening, industrial sugarcane production often turns to applying chemical ripeners.

Globally, the use of ripeners and other chemically synthesized inputs, such as growth regulators and biostimulators, before harvesting is a common practice. These substances accelerate the physiological ripening of sugarcane, to stimulate and increase sucrose concentration, and to inhibit flowering. Producers also use ripening agents when they need to deliver the crop to the mills on a tight deadline and cannot wait for natural maturation.

In most cases, producers apply chemical ripeners to increase the sucrose concentration in their sugarcane rapidly and get a higher economic return; in other cases, ripener use is required by the sugar mill purchasing the sugarcane. In Brazil, Colombia, and other countries, producers may be paid not by the amount of biomass delivered but by the sugar yield obtained during the milling process.

3.2.2 Ripeners, biostimulants and growth regulators

Ripeners are chemically synthesized substances applied to sugarcane to achieve uniform maturation of the crop within a shorter period, and to accelerate physiological processes such as root development, bud sprouting and germination, among others (Cenicaña, 2015). Biostimulants[4] are liquid fertilizers

> IN TROPICAL REGIONS, SUGARCANE REACHES OPTIMAL MATURATION BETWEEN 12.5-13.5 MONTHS ON AVERAGE. HOWEVER, THE TIME WILL VARY DEPENDING ON THE LOCAL CLIMATIC CONDITIONS, AGRONOMIC MANAGEMENT, AND SUGARCANE VARIETY.

4. Bioticon and Foliar potassium are among the most used biostimulants in Colombia's sugarcane industry (Cenicaña, 2015).

applied to promote physiological functions; most are foliar fertilizers that need to be applied in high quatities to achieve sufficient coverage (Cenicaña, 2015). Growth regulators[5] are also synthetic products that, unlike ripeners and biostimulants, can be applied in low volumes without affecting their maturing action (Cenicaña, 2015). The sucrose content obtained with biostimulants is generally lower than with other substances like growth regulators (Villegas T & Arcila A, 2003).

Although many producers still view ripener application as beneficial for sugarcane production, the practice has environmental and social impacts worth mentioning:

- Chemical ripeners can contaminate both the soils and the surface and ground water sources, especially if used recurrently and in excess.

- Ripeners can affect the health of people exposed either via direct contact, when applied without the use of adequate personal protective gear, or indirectly, for example by consuming contaminated water.

- Some ripening agents can accumulate and concentrate in the soil, eventually reaching levels that interfere with the optimal development of sugarcane and other crops.

- Some ripeners are non-selective herbicides that can drift causing damage to broadleaf crops (Villegas T & Arcila A, 2003). Damage to non-target crops such as sunflower, coffee, cotton, eucalyptus, passion fruit, and corn has been documented from drift of ripeners like glyphosate or sulfometuron-methyl (Souza Rodrigues & Aguiar Alves, 2020).

- Glyphosate is one of the most widely used foliar herbicides worldwide. Although there is no conclusive evidence of widespread sugar contamination, mass spraying in other crops has led to water contamination via runoff, and trace components have been found in some agricultural products (Jean Dodds, 2020).

3.2.3 How are ripeners used in regenerative production?

Regenerative production should aim for the gradual elimination of all chemical ripening agents. The recommended alternative is to allow for the crop to ripen naturally. Discontinuing the use of these substances leads to an almost immediate cessation of impacts, and eventually to improvements

5. Glyphosate Fluazifop-p-Butyl y trinexapac-ethyl are among the most used growth regulators in Colombia's sugarcane industry (Cenicaña, 2015).

Mature sugarcane crop. Photo credit: ©Enrique Murgueitio

in the health of the soil, the water, and the neighboring populations. Reduced production costs are an additional benefit of eliminating the use of these chemicals.

In the absence of synthetic ripening agents, one option is to plant cane varieties known for their high potential to accumulate sucrose under natural conditions (Villegas T & Arcila A, 2003). Another alternative is the use of organic ripeners, also known as sucrose concentrators or promoters. These mineral-based inputs provide the plant with elements such as boron (B), zinc (Zn), and phosphorus (P), that improve the transportation of sucrose from the leaves to the stem.

Trials in regenerative production in Colombia show that natural maturation can increase the total sugar yield after processing, promote better ratoon germination, and reduce the frequency of crop renovation.

3.2.4 Recommendations

- Sugarcane should be allowed to ripen naturally and harvested when it has reached its maximum physiological ripening. Peak maturation can be detected with handheld refractometer, which provides a maturation index based on a comparison between the sugar concentration in the upper and lower internodes of the stem[6]. Additional methods are also available[7].

- In irrigated systems, suppressing irrigation ten months after the crop is planted can induce natural exhaustion, which forces the plant to shift from producing biomass to translocating sucrose from the leaves to the stalk (Villegas T & Arcila A, 2003).

- To maximize the amount of sucrose produced and avoid losses during processing, farmers should minimize the amount of non-sugarcane biomass in the harvested mix and limit the time between cutting and milling to under 24 hours (Villegas T & Arcila A, 2003).

3.2.5 Limitations

- Natural ripening depends mainly on the local agroclimatic conditions – temperatures, luminosity, high water tables, irrigation management, soil drainage– and other factors that are not always under the producers' control.

6. Brix is the unit of measurement that indicates the sucrose content (Bharathi et al., 2017).
7. Another method is pre-harvest sampling, which is based on repeated measures collected over time which are used to develop a "ripening curve" that is used to estimate the best time to harvest the cane. However, this method is expensive and requires trained staff and access to laboratory and field equipment, so it is not viable for all producers unless the sugar mill provides it.

Use of precision drone in sugarcane cultivation, Brazil. Photo credit: © 1974 jrslompo71.yahoo.com.br

Manual application of chemical pesticides. Photo credit: Depositphotos.

3.3 Weed Management

Weeds are plants that grow spontaneously in cultivated fields and may compete with the cultivated species for resources such as water, light, nutrients, and physical space, disturbing or impeding the normal development of the crop, decreasing its yield or quality, and generating economic losses to the producer. In conventional agriculture, all weeds are considered a nuisance that must be eradicated, and significant economic and human resources are allocated to this end. Regenerative agriculture takes a more nuanced approach, distinguishing between harmless and harmful weeds and focusing on managing the latter.

> IN REGENERATIVE MANAGEMENT THERE ARE NO GUIDELINES FOR THE USE OF SPECIFIC INPUTS. HOWEVER, ONE OF THE UNDERLYING PRINCIPLES IS REDUCING THE USE OF EXTERNAL INPUTS, ESPECIALLY CHEMICALLY SYNTHESIZED ONES.

- **Aggressive or high interference weeds** are generally tall and fast-growing plants that effectively compete for light aboveground, and deep roots that compete for water and nutrients underground; some are climbers that may smother the crop. They often set seed early on, which explains their invasive potential and the need to control them.

- **Noble or low interference weeds** are usually short in stature, have superficial roots, and produce a limited number of seed. Their presence in the cultivated field can be beneficial because they can help maintain soil cover and support populations of beneficial insects.

A wide variety of weeds grow among the sugarcane crop, and they vary by geographic and agroclimatic conditions. To control weeds and release the crop from competition, conventional production relies on two types of control methods: mechanical and chemical.

Mechanical control refers to cutting the weeds by hand or using agricultural machinery. The goal is to destroy the aerial part of the plant to stop its development. Manual weed control is mainly used around the cultivated fields, in small areas, and

Harmless weeds growing with sugarcane in agroecological production, Colombia. Photo credit: ©Alicia Calle.

where machinery access is restricted due to the topography and soil conditions. In larger cultivated areas, agricultural machinery is commonly used to eliminate weeds while simultaneously preparing the soil for planting.

Chemical control refers to the application of chemical herbicides, the most widespread method for weed control by both small and large sugarcane producers. The type of product, the dosage, and the frequency of control events varies depending on the types of weeds present in the field.

Although herbicide application is widespread in sugarcane production, like other agrochemicals these substances can have adverse impacts on both human and agroecosystem health, especially when excessive dosages are applied. Herbicide application significantly reduces the presence of other plant species in the field, including beneficial ones; herbicide drift can cause harm to different crops in neighboring fields; herbicides can contaminate surface and groundwater sources[8]; and they gradually erode soil health due to the harmful effects on micro and macro-organisms.

8. Overuse of herbicides and other agrochemicals in sugarcane production increases the risk of runoff into groundwater, rivers, and local ecosystems (Fairagora Asia, 2022). When applied repeatedly or directly to the soil, herbicides may have residual effects that last beyond the current crop cycle.

Harmless weeds growing with sugarcane in agroecological production, Colombia. Photo credit: ©Enrique Murgueitio.

In regenerative sugarcane production, the goal is to strengthen the agroecosystem to allow for the eventual **elimination of herbicides for weed control**. Mechanical control, which can be done manually or with the help of machinery or livestock, is the alternative.

Manual control consists of pulling the weeds from the field by hand during the early months of sugarcane development[9]. This practice requires more manual labor and is less efficient than mechanized removal, which makes it more expensive[10]. However, properly trained workers can become very effective in selectively pulling out only the harmful weeds and leaving the beneficial plants in place.

Mechanized weed control consists of using some type of agricultural machinery[11] to eliminate weeds from the field. This method is only effective during the early stages of crop development, as in later stages the machinery may damage the crop. This option is best suited for large cultivation areas because it saves time and therefore reduces weeding costs.

9. Manual weeding can be done with a machete, hoe, or any local tool. Eliminating weeds in the early stages of crop development is crucial to ensure the correct growth of sugarcane. After a certain height, sugarcane will shade out most weeds, and any additional control must be done by hand as machine access to the field is limited by crop density.
10. In a context of increasing input costs and raw material shortages, the real cost of herbicide application must be reevaluated.
11. Usually, a tractor adapted with different weed control attachments.

Other strategies related to weed control include:

- Certain livestock species that are selective herbivores have been effectively used to support weed control activities. Species such as sheep or ducks, when allowed onto the sugarcane field, will consume the weeds while ignoring the crop[12], which makes them especially useful to control weeds during advanced stages of cultivation when access to the field becomes difficult. As a bonus, these animals contribute nutrients and organic matter to the soil through their feces and transform weed biomass into animal protein that provides supplementary income for the producer.

- Weed control efforts should focus exclusively on high interference species known to compete with the sugarcane; low interference weeds can be left in the field and harnessed for other uses. For example, leaving permanent strips of weedy vegetation along field margins and in crop alleys provides habitat for beneficial insects that contribute to pest control[13]. Weeds can also be used as green manure[14] by incorporating them into the soil before they go to seed, recycling their nutrients in favor of the crop.

- Cover crops[15] not only help to replenish the soils but they can be an effective weed control strategy. Many nitrogen-fixing cover crop species can be grown during the fallow or crop renewal stage where because of their fast growth, they tend to rapidly occupy physical space that would otherwise be taken up by weeds. Once they cover the field, cover crops help to physically protect the soil from erosion. After they mature, cover crops with commercial value (e.g., soybean *Glycine max* or sunflower *Helianthus annuus*) can be harvested for sale, while others can be incorporated as green manure to provide nutrients for the new crop.

- Increasing the width of the crop furrows and reducing the planting distance between sugarcane plants is another way to limit the space and light available for weed development. In wider furrows, field closure can happen up to 60 days earlier than in regular furrows (Rodriguez Tassé et al., 2020), reducing the number of weed control events and increasing total crop yield. However, this strategy is only applicable in farms that are not fully mechanized.

12. When using herbivores to support weed control tasks, there is the risk that the animals may damage the crop. To minimize this risk, producers should avoid the use of livestock during the first 3 months of sugarcane development, and control animal access into the crop with the help of a herder or a mobile electric fence.
13. See Biological insect control chapter.
14. See Fertilization of the sugarcane crop chapter for more information on green manures.
15. See Post-harvest crop residue management chapter.

Sheep used for selective weed control in sugarcane, Colombia. Photo credit: 2022.08 Cali Kickoff ©Alejandra Pinzon.

3.3.2 Benefits of non-chemical weed control

Replacing chemical herbicides with non-chemical weed control alternatives should be a gradual process. Over time, the elimination of chemical weed control renders a range of benefits, including:

- Many of the negative impacts associated with chemical inputs, such as water contamination, biodiversity loss, and damage to soil health, are mitigated.
- Phasing out chemical herbicides can create additional employment opportunities in mechanical or manual weeding.
- The permanent conservation of weeds in crop-adjacent areas provides adequate conditions to support populations of beneficial insects that control crop pests, improving the natural balance of insect populations.

3.3.3 Limitations

- The implementation of regenerative alternatives for weed control may increase production costs initially as the demand for labor increases. As operators become more efficient and weed persistence decreases, these additional costs may be recovered via reduced purchase of chemical inputs, especially in a context of high prices and input shortages.
- While weed management is one of the costliest management tasks in regenerative production, this cost must be considered relative to its multiple benefits, including reduced water and input use, and higher overall crop productivity.
- The use of livestock for weed control may require a stricter management and entail higher costs, for example, to hire trained personnel to manage the herd. However, the herd itself can be an additional source of food and income for the farm.
- In non-chemical weed management, the number of labor hours per unit area depends on the type and density of weeds in the cropping area. The best way to keep the costs down is to perform weed control at the early stages of crop development. This is especially true during the rainy season, when weeds grow faster, and more labor is required to accomplish the task.

THE TRANSITION TO REGENERATIVE SUGARCANE PRODUCTION

The transition to regenerative sugarcane production can lead to an increase in the abundance and diversity of weeds growing in the cropping area. However, this increase tends to be temporary, and its effects are not always negative. Therefore, weeds can be managed differently to promote a balanced species composition that does not affect crop yield. Desirable impacts of maintaining low-density populations of beneficial weeds include (Guzmán Casado & Alonso Mielgo, 2009):

- Help conserve soil moisture.
- Maintain soil coverage reducing losses to leaching of key nutrients such as N.
- Protect the soil from erosion .
- Improve soil structure and stimulate biological activity.
- Can be used as green manures to enrich the soil with nutrients and organic matter.
- Improve the microclimate in favor of the crop.
- Promote functional biodiversity by harboring beneficial pollinators and natural enemies of pests.
- Serve as traps by attracting crop damaging insects.
- Promote a healthy soil microbiome. For example, microorganisms associated with the roots of some weeds in alfalfa (*Medicago sativa*) inhibit the growth of pathogenic fungi.

Fertilizers application using machinery. Photo credit: ©fotokostic.

3.4 Fertilization of the sugarcane crop

Fertilization is one of the most important agronomic and cultural activities in agriculture. It aims to ensure that the necessary nutrients are available in the soil for uptake by crop, enabling maximum vegetative growth and plant productivity. Various products are used to meet a crop's nutritional requirements, most of which are chemical blends that are added to the soil, and to a lesser extent, directly to the plant. Despite the benefits of these products, their over-application may result in significant contamination of both the soil and water, as well as GHG emissions. In 2019, global GHG emissions due to synthetic fertilizer application were estimated at more than 6,000 GT CO_2eq (FAOSTAT, 2022).

Sugarcane has a long development cycle and a high nutrient demand, so fertilization is essential. Although the use of chemical fertilizers has visible short-term effects on plant growth, over time the recurrent use of high fertilization rates leads to soil degradation, among other impacts (Shamsul Arefin et al., 2022).

In general, the excessive use of chemical fertilizers can lead to a vicious cycle of misuse and degradation. In this cycle, the producer typically applies the fertilizer and soon observes a positive response by the crop; meanwhile, negative impacts such as weed proliferation due to excess N availability in the soils, go unnoticed. Over time, the gradual accumulation of these negative impacts may diminish the crops' initial response to fertilization, and the producer may be tempted to increase the dosage to replicate the original result. This application of chemical inputs in increasing doses leads to higher production costs, cumulative effects on soil and water sources, impacts on human health, and higher GHG emissions (Carmo et al., 2013; Echeverri Sánchez et al., 2020; Soto Estrada et al., 2020).

Nitrogen (N), potassium (K), and phosphorus (P) are the three most important macronutrients[16] for sugarcane cultivation. N is directly related to a plant's vegetative development, such as internode growth and plant leaf area, which improve photosynthetic efficiency and benefit crop productivity (Stacciarini et al., 2021). K is linked to physiological processes like photosynthesis, plant enzyme activation and root development (Fernandes Carlos da Costa et al., 2016), and in sugarcane, resistance to disease (Romero et al., 2018). P facilitates sprouting, root development and stem elongation, and its adequate availability influences the plant's ability to uptake N from the soil solution and move

16. Nineteen nutrients are considered essential for sugarcane development: non-mineral elements such as C, Hydrogen (H) and Oxygen (O); macro-elements such as N, P, K, Ca, Mg, Sulfur (S) and Silicon (Si); and micronutrients such as Iron (Fe), Zn, B, Copper (Cu), Chlorine (Cl), Manganese (Mn), Nickel (Ni), Sodium (Na) and Molybdenum (Mo). (Romero et al., 2018).

Sugarcane bagasse for organic fertilization. Photo credit: Depositphotos.

it to the roots and shoots, improving crop productivity (Arroyo et al., 2020).

As in many other crops, increasing soil N availability is a key goal[17] in sugarcane production. The most common method to make N available is to apply fertilizer directly to the soil. However, only 20-50% of N applied in this way is effectively used by the crop (Romero et al., 2018), while the rest is lost to percolation through the soil profile, leaching into surface water and aquifers, runoff after rainfall or irrigation, and ammonia (NH_3) volatilization when temperatures are high. N leaching is particularly problematic because it may result in eutrophication which diminishes water quality, affecting the health of freshwater ecosystems and human populations (Fairagora Asia, 2022). These N losses also affect crop growth because plants cannot secure an adequate supply. On the other hand, excess N in the soil is also problematic as it may inhibit the plants' ability to uptake the nutrient (Fairagora Asia, 2022).

17. N uptake in sugarcane cultivation depends on crop development stage, soil condition, agroclimatic conditions and expected yields (Romero et al., 2018).

Early stage of sugarcane development. Photo credit: ©Álvaro Zapata.

Increased rates of chemical fertilizer use lead to higher GHG emissions related to the energy involved in their manufacturing, distribution, and application.

Increased risk of soil acidification of changes in soil pH from continuous use of fertilizers with acid residual effects. Salinization and toxicity problems that negatively impact crop productivity are also possible (Jaramillo J, 2022).

Disruption of biological processes and natural chemical cycles, such as the N-cycle (Echeverri et al., 2020).

Increased crop susceptibility to fungal and microbial attacks. Overfertilization can lead to sugarcane stalks with high water and low sucrose and fiber content witch break easily, and are more vulnerable to pest and disease attacks (Fairagora Asia, 2022; Romero et al., 2018).

3.4.1 Fertilization in regenerative sugarcane

In regenerative production, the main goal is to recover soil health to a point where chemical fertilization can be reduced or even eliminated. This approach aims to promote biological activity by progressively replacing synthetic fertilizers with alternative organic sources of nutrition that provide the crop with sufficient nutrients for its development. A variety of products can be used to replace chemical fertilizers, including many by-products of the sugar industry. Replacement of chemical with organic sources implies logistical, managerial, cultural, and financial adjustments, and therefore it should be done gradually to avoid shocks to the production system.

As the replacement of chemical fertilizers with other nutritional alternatives progresses, the soil's biological processes and its physical and chemical properties will improve, allowing for a gradual reduction of chemical inputs. Ultimately, the goal of regenerative management is to recover the soil's natural capacity to recycle and supply the nutrients required by the crop.

To progressively reduce reliance on synthetic fertilizers and encourage the use of organic sources, producers can guide their fertilization planning by following the 4Rs principles. The **4Rs –the right source, at the right rate, with the right timing and with right placement**[18]– mean that the best fertilization is provided when the type of fertilizer and the amount used match the crop's needs, and the timing and location of fertilizer application ensure optimal uptake by the crop. Although the principles are global, how they are applied will vary depending on context-specific factors. For example, the sugarcane variety, the specific soil parameters, the local agroclimatic conditions, or the availability of alternative nutrient sources nearby, all influence the fertilization plan.

Keep in mind that complementary regenerative practices that improve soil health, such as mulching with crop residues, will gradually impact fertilization needs (Ghube, 2017; Shamsul, 2022; Volverás-Mambuscay, 2020). For example, healthy soils with abundant organic matter can provide an estimated 50% or more of the N required by sugarcane, so in the long term these practices will reduce the need for fertilization (Romero et al., 2018).

The process of adjusting fertilization can be aided by tools that optimize the rate, timing, and placement of delivery. **Precision agriculture** is a set of GPS-based tools used to conduct various crop-related tasks in a differentiated and precise manner. Its main goal is to tailor input application based on

18. See 4 Nutrient Stewardship for more information on the 4Rs.

On-farm organic fertilizer production for sugarcane crop nutrition, Colombia. Photo credit: ©Alicia Calle.

site-specific information about the crop or the soil, enabling farmers to apply the precise amount of fertilizer to each part of the field, reducing the amount and costs of inputs applied and the risk of contamination (Nestlé, 2022).

In Australia, where keeping production costs low is the main strategy to remain competitive, many producers rely on precision agriculture. Drones, GPS-enabled machinery, rigorous data collection and other tools are used to ensure optimal application of agricultural inputs and meet the stringent environmental regulations. For example, sugarcane fertilization is based on georeferenced soil sampling, and precise dosages are applied with the use of high-tech machinery. The goal is to ensure that 'what goes in the field, stays in the field', preventing nutrient contamination in key water bodies such as the Great Barrier Reef. These tools help farmers optimize costs and provide buyers with a highly traceable product (Canegrowers, 2017b, 2017a).

> SOIL MOISTURE IS ESSENTIAL TO ACTIVATE THE MICROORGANISM POPULATIONS THAT MINERALIZE ELEMENTS AND MAKE THEM AVAILABLE TO PLANTS. ORGANIC MATTER, TEMPERATURE AND PH ARE ALSO CRITICAL TO ENSURE SOIL BIOLOGICAL ACTIVITY.

3.4.2 By-products of the livestock industry

Animal waste is one of the most valuable nutrients sources for crop nutrition and its use as an organic fertilizer for sugarcane has multiple advantages. Chicken litter and pig manure are among the most widely available sources. In general, the animal by-products are those readily available at a low cost and a short distance from the cultivation area. However, a key consideration is that animal by-products are only as safe as the practices used to rear the animals, so it is important to understand the potential risks.

Poultry litter is a by-product of raising hens and chickens for egg and meat production, which consists of a mix of animal excreta with food residues and other components. It is a phosphorus-rich[19] organic fertilizer that can be applied manually or mechanically. As a crop fertilizer, it increases the content of SOM, which in turn enhances soil properties that benefit agricultural production such as water infiltration and water holding capacity, cation exchange capacity (CEC), and structural stability (Moore et al., 1995). When applied along with sugarcane and cabbage residues, important substrate properties can be optimized, including moisture content, pH[20], C/N ratio[21] and substrate porosity (Saleem et al., 2017).

Poultry litter can entirely replace chemical fertilization in sugarcane (several authors, cited by Guimarães et al., 2016). However, over-application of poultry litter may also lead to P accumulation in the soil, increasing the risk of water source contamination. Therefore, care must be taken to avoid applying litter on soils with high levels of P, and a specific plan may be required to avoid P buildup that may affect crop growth and productivity as well as water quality (Saleem et al., 2017).

In Colombia, *El Hatico Nature Reserve* has been using poultry litter to replace chemical fertilization for over 30 years. Every year, 4 tons ha^{-1} (including 80 kg of N) are applied 45-60 days after the harvest. To minimize losses from N volatilization, the poultry litter is immediately incorporated into the soil to a depth of 30-75 cm (Rodríguez Hurtado & Valencia Montenegro, 2015; (Zapata et al., 2022).

---

19. Composition of poultry litter should be analyzed every 6- 12 month to determine its nutritional contribution and adjust the fertilization plan accordingly (Zapata & Uribe, 2021).
20. Soils with a neutral pH have better rates of organic matter decomposition (Jaramillo J, 2022).
21. Carbon-N ratio (C/N) is linked to the rate of organic matter decomposition (Jaramillo J, 2022).

3.4.3 By-products of the sugarcane industry

Manufacturing of the main products in sugarcane mills –sugar and ethanol– renders a variety of by-products that can be used for crop fertilization.

Vinasse is a concentrated liquid obtained as a by-product during ethanol distillation. In the past, vinasse was often discharged directly into water sources without treatment[22], leading to adverse impacts in waterbodies (Sarria & Preston, 1992). Nowadays sugar mills often use it as a complement to chemical fertilization (Cenicaña, 2015a). As a biofertilizer, vinasse has high N, P, K, and S content (Conadesuca, 2016) so it promotes plant development and improves soil structure by increasing soil aggregate stability (Showler, 2015). It can also replace costly potassium chloride (KCl). Vinasse can be applied to sugarcane via surface irrigation or sprinkler, and it is currently the most widely used input for sugarcane fertigation worldwide (Conadesuca, 2016).

The proper use of vinasse as a biofertilizer requires an understanding of its nutritional composition to guide decisions about its proper application and the extent to which it can substitute chemical fertilizers depending on expected yields and soil nutrient status (Sarria & Preston, 1992). Due to its low pH (4.9-5.4), above-optimum application rates can exacerbate soil acidity problems (Conadesuca, 2016). High application rates can also lead to N leaching or P and N runoff that contaminate surface and ground waters (Fairagora asia, 2022).

Filter cake, also known as cachaça, is the residue of the sugarcane juice clarification process during the production of raw sugar. As a biofertilizer, it provides organic matter, calcium (Ca), P, N, K, and other nutrients such as magnesium (Mg) (Gonçalves et al., 2021). Over time, its decomposition in the soil increases the Fe and Cu content and supports microbial activity (Cenicaña, 1995).

> ANY MATERIAL USED FOR SOIL NUTRITION, ESPECIALLY IF IT CONTAINS ANIMAL MANURE, MUST BE PREVIOUSLY COMPOSTED TO ENSURE THE ELIMINATION OF PATHOGENS THAT MAY AFFECT THE SOIL, THE CROP, OR THE HEALTH OF CONSUMERS.

22. Disposing of vinasse was a challenge for a long time util its potential as a fertilizer was recognized due to its nutritional load, especially its high potassium content (Sarria & Preston, 1992).

Organic fertilization application in regenerative sugarcane, Colombia. Photo credit: ©Enrique Murgueitio.

3.4.4 Additional fertilization inputs

- **Biofertilizers, including N-fixing bacteria, plant-promoting bacteria, and P- and K- solubilizing bacteria.** These products are based on one or more non-pathogenic microorganisms that, through their biological activity, enhance nutrient bioavailability and accelerate SOM mineralization. Overall, they contribute to enhance plant growth and development, soil conservation and other agroecosystem resources (Velasco-Velasco, 2014).

- **Organic fertilizers** are obtained from composting, which is the decomposition of organic matter under controlled temperature, humidity, and pH conditions with the help of microorganisms, to obtain nutrients and minerals for crop nutrition. These fertilizers provide readily available nutrients for plant uptake (Sandoval Legazpi et al., 2012) and have the potential to improve other aspects of soil quality including soil porosity, aggregate stability, water retention capacity and microbial activity (Medina Giménez et al., 2011). Compost can be produced locally, which reduces the amount of GHG released during production and transportation (Fairagora Asia, 2022).

Cowpea planted as green manure in regenerative sugarcane. Photo credit: ©Enrique Murgueitio.

- **Green manures** are fast-growing plants, generally leguminous species that fix atmospheric N in the soil and sometimes provide cash crops. Grasses and cruciferous plants also have a potential as green manures due to their ability to cover the soil quickly and fix carbon (Córdova-Gamas et al., 2016). Green manures are generally accepted as a low-cost fertilization alternative with no negative impacts on soil or water resources.

  Green manures can be established in two ways. When **intercropped**, they are sown alongside sugarcane to improve soil fertility and enhance crop growth and productivity.

  When used as **rotational crops or cover crops**, they are planted before crop renewal to improve soil fertility and maintain soil coverage; prior to the next planting, they are cut and incorporated into the soil as biomass amendment to boost SOM and nutrient content (Zapata et al., 2022).

  Alternatively, green manures can be cut and left in the field as mulch to protect the soil from solar radiation, reduce evaporation, enhance moisture retention, limit weed growth, and create a supporting microclimate for soil biological activity (Zapata et al., 2022).

Cowpea (*Vigna unguiculata*) is a legume commonly used as a green manure. Aside from contributing biomass, cowpea can reduce weed germination, especially when incorporated with the 2X1 method which consists of alternating two rows without residues and one row with residues across the entire crop area[23]. This reduces the use of chemical fertilizers and herbicides (Sanclemente Reyes et al., 2015). Other common green manures used in sugarcane cultivation include soybean (*Glycine max*), jack bean (*Canavalia ensiformis*), monkey bean (*Mucuna deeringianum*), sunn hemp (*Crotalaria juncea*), peanut (*Arachis hypogea*), common bean (*Phaseolus vulgaris*) and alfalfa (*Medicago sativa*) (Zapata et al., 2022).

Weeds that establish easily can also be used as green manures[24] and incorporated into the soil to provide significant N. Unlike legumes, beneficial weeds do not require strict agronomic management for their appropriate development. Spiny starwort *(Pallenis spinosa)* and Brazilian ginseng (*Pfaffia glomerata)* are examples of beneficial weeds.

3.4.5 Recommendations for the use of green manures

- The development cycle of the green manure should be synchronized to that of the sugarcane. This prevents interference with the crop and facilitates machinery access to the field at the proper time.
- Legumes can be planted up to 45 days after harvesting the sugarcane and distributing the residues, either manually or with the help of machinery.
- If green manures are sown during the dry season, irrigation is recommended to encourage germination and development of the sugarcane. During the rainy season, green manures should be cut manually to avoid the use of machinery on wet soils, which can lead to soil compaction (Zapata et al., 2022). In rainfed systems, both crops must be synchronized to the local rainy seasons.

23. The method for planting green manures depends on planting arrangement of the sugarcane and the space available for a secondary crop, as well as the resources and needs of each producer.
24. In regenerative production, weeds can be established in the crop alleys to facilitate harvesting with the use of machinery and then be used as green manure.

3.4.6 Benefits of reducing or eliminating chemical fertilization

- Reduces reliance on external inputs, and when replaced with local alternatives, may reduce total production costs.
- Reduces multiple risks related to excessive fertilization, including soil and water contamination, emissions from anaerobic biological processes, and accumulation of elements that cause soil acidity, toxicity, or salinization.
- Reduces GHG emissions associated with the production, transportation, and application of chemical fertilizers.
- Reduces the risk of harmful chemical residues reaching food products.
- Reduces health risks related to mishandling or wrong application of fertilizers, or to missing or defective PPE.

Benefits of green manures

- Provide soil cover minimizing the effects of erosion and suppressing weed growth
- Contribute to soil decompaction and improved soil porosity through their root growth
- Improve the root N-fixing bacteria associations in the soil
- Provide high quality organic matter that can be readily incorporated
- Provide temporary resources for beneficial insect populations

3.4.7 Recommendations for fertilization

- Whenever possible, producers should rely on soil tests and production records to guide the fertilization plan, optimizing the selection and dosage of nutrient application in different cultivation sites (Romero et al., 2018). Complete soil analyses every 5 years and basic soil analysis every year are recommended.
- Understanding the nutritional composition of different biofertilizers and organic fertilizers is key to avoid harmful accumulations of elements in the soil, and to identify the optimal mix of inputs needed to adequately nourish the crop.
- The best alternatives to gradually replace chemical fertilizers will depend on the producer's needs, capacity, and available resources. Ongoing technical assistance is recommended to help producers address any challenges that may arise during the transition in a timely manner.
- In regenerative production, the gradual recovery of soil fertility may lead to accelerated weed growth. Incorporating the weeds into the soil as green manure is an additional practice recommended to take advantage of their nutrients and avoid the use of herbicides.

3.4.8 Limitations

- Whereas soil analyses are useful to guide fertilization, many producers have limited access to a soil laboratory, to an individual who can interpret the results, or to the resources to pay for either (Fairagora Asia, 2022).
- The transition from chemical fertilization to other alternatives is complex and requires knowledge, patience, and ongoing support, as it may generate temporary reductions in crop productivity. Lack of knowledge and technical support can therefore be serious impediments.
- During the early transition, replacing chemical fertilization may entail additional production costs. However, as soil health recovers, permanent savings in the purchase of chemical inputs are expected in the medium and long term.
- GHG emissions may initially be comparable to conventional sugarcane because different alternatives may need to be tested to replace synthetic fertilizers. In Brazil, total nitrous oxide (N_2O) and CO_2 emissions were found to vary by fertilization method, with the highest emissions in the combination of ethanol by-products and mineral fertilizer (Carmo et al., 2013).

3.5 Post-harvest crop residue management

In conventional sugarcane cultivation, crop residues left in the field are considered waste material and burning or removing them are common practices intended to facilitate land management and preparation for the next cycle. However, burning crop residues has multiple negative consequences: it emits GHG, it impacts soil biodiversity, it affects human health (Avilez et al., 2021; Fairagora Asia, 2022), and perhaps most importantly, it wastes what could be a valuable resource for the crop itself.

In regenerative production, sugarcane is harvested green, and the residues left in the field become immediately available. Residues can be used as livestock feed, as biomass for energy generation in the case of industrial producers, and perhaps more importantly, as biomass to maintain soil cover and increase soil fertility.

After the harvest and before crop renovation, residues can be evenly distributed across the cropping area as mulch to create a buffer layer that protects the soil from impact by heavy machinery (Rodríguez Hurtado & Valencia Montenegro, 2015). As this biomass decomposes, nutrients are broken down and released back into the soil, and organic matter is added that enhances water holding capacity. Retention of 50% of the crop residues as ground cover improved sugarcane yields during the dry periods in the state of Paraná, Brazil (Gisele et al., 2016). The thick residue layer also controls weed development, regulates temperature, and protects soil from erosion.

The amount of crop residues used for mulching in cultivated areas depends on the local agroecological conditions, the sugarcane variety and productivity, the harvest season, and the harvest efficiency (Ortiz Laurel et al., 2012).

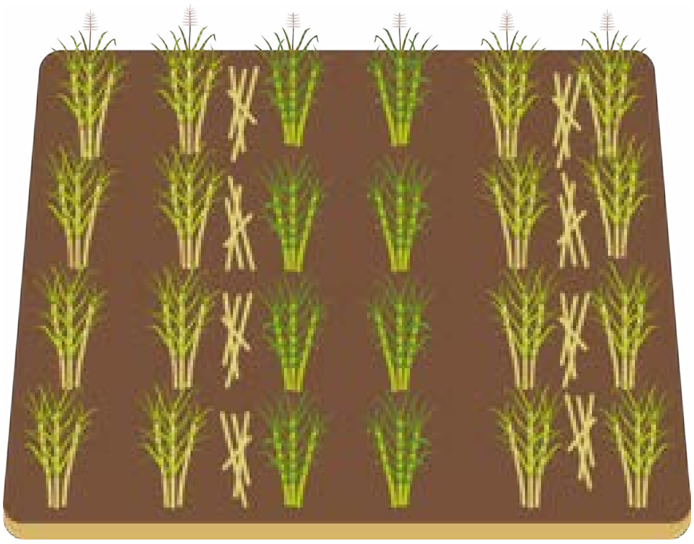
> WHILE SOILS SHOULD ALWAYS BE COVERED WITH CROP RESIDUES, COVER IS ESPECIALLY IMPORTANT DURING THE FIRST FOUR MONTHS OF CROP DEVELOPMENT WHEN THE SOIL IS MORE EXPOSED TO DIRECT SUNLIGHT AND EROSION CAUSED BY PRECIPITATION AND IRRIGATION.

CROP RESIDUES DISTRIBUTION METHODS ON SUGARCANE PLANTATION

0X1
METHOD

Harvest residues are distributed evenly across the field, clearing the stumps and shoots to ensure better regrowth.

2X1
METHOD



Harvest residues are distributed alternating two residue-free rows with one residue-laden row across the entire cropping area.

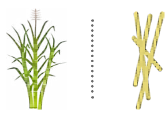
Sugarcane  Harvest residues

Figure 4. Residue distribution methods in sugarcane crop area.

Use of crop residue for soil protection. Photo credit © Ikf.

3.5.1 How are crop residues distributed?

Post-harvest crop residues can be distributed in two different ways. One is piling crop residues at specific intervals between crop rows, as in the **2X1 method** which alternates two residue-free rows with one residue-laden row across the entire cropping area. The other is clearing the residues, as in the **0X1 method** which consists of distributing residues evenly across the field, leaving the stumps and shoots uncovered to ensure better regrowth (Figure 4). This technique is used immediately after green harvesting[25]. Both techniques are best done with the use of machinery, so they are mainly used by medium and large-scale growers and sugar mill contractors (Zapata et al., 2022). Mechanical residue distribution requires tractors with special implements that can enter the crop area without causing damage. On wet soils, however, it should be done manually to prevent soil compaction.

25. Regrowth of the sugarcane stock begins as soon as five days after the harvest, so residue distribution should be done as soon as possible.

3.5.2 Recommendations

- The 2X1 method is recommended to distribute the residues on top of the soil. The residue-free rows can be used for mechanized tasks, such as soil decompaction and fertilization (Zapata et al., 2022).
- Residue-free rows should be alternated periodically so the entire cropping area gets the additional organic matter inputs from the mulch (Chacón, 2019).
- After clearing, hand removal of leftover biomass from the sugarcane stumps may be needed to prevent problems during regrowth.

CLEARING IS THE OPTIMAL METHOD OF DISTRIBUTION BECAUSE IT LEAVES RESIDUES COVERING ALL CROP ALLEYS AND ELIMINATES THOSE COVERING THE SUGARCANE STUMPS[26]

3.5.3 Benefits

- Mulching with crop residues protects the soil from erosion caused by the impact of raindrops during heavy rain or hailstorms, and from surface runoff which may wash away the topsoil and nutrients[27].
- A permanent mulch layer helps preserve soil structure by reducing the risk of physical compaction and protecting biota[28]. In Colombia, mulching with sugarcane has resulted in increased levels of stable organic matter, reduced bulk density, higher total porosity, and better soil aggregation and structural stability (Sadeghian KH & Madriñan M, 2000).
- Mulching reduces water losses to direct evaporation, and increases soil moisture via added soil organic matter. In rainfed systems where rainfall is scarce during part of the growing cycle, increased moisture retention is critical for maintaining yields (Ortiz Laurel et al., 2012). In irrigated systems, it helps to curb the need for irrigation.

26. Sugarcane stumps should not be covered by crop residues because this can affect regrowth in the next crop cycle. Similarly, they should not be covered in heavy or clay soils because excess moisture can cause them to rot.
27. Reducing runoff limits the amount of sediment that is washed into the crop irrigation channels and reduces maintenance costs.
28. Key attributes of soil structure include soil porosity, texture, infiltration capacity, and moisture retention.

- Used in conjunction with organic fertilizers and green manures, mulching contributes significant amounts of N, K, Ca and Mg, which reduces fertilization costs (Chacón, 2019). In Colombia the incorporation of 22 t ha^{-1} of residue dry matter contributes 590 Kg ha^{-1} of nutrients to the soil[29], with estimated savings of $550 USD in input and labor costs (Molina et al., 2022).

- Mulching effectively controls weeds because the residues block the sunlight preventing weed seed germination and growth. Weed control efforts may be reduced by up to 80% (Zapata et al., 2022), lowering herbicide and labor requirements (Avilez et al., 2021; Digonzelli et al., 2009).

3.5.4 Limitations

- In sites with excess moisture due to poor drainage or high water-tables, mulching may reduce direct evaporation limiting the elimination of residual moisture. In such cases, residues can be incorporated into the soil to a depth of 30 cm or removed from the field in extreme cases (Digonzelli et al., 2009). Burning residues, however, should be avoided.

- Too much mulch can lead to excess moisture retention during the rainy seasons causing phytosanitary problems in the crop and inhibiting the resprouting of the sugarcane stumps (Cenicaña, 1995).

- Whereas mulching can initially limit weed development, the pulse of additional nutrients and organic matter from its decomposition can accelerate the growth of weeds that do emerge. Timely non-chemical weed control is therefore critical.

- Other potential impacts include higher costs of mechanized residue management, increased risk of accidental fires, and higher proportion of residue in the harvested crop (Cengicaña, 2017). However, most of these risks can be mitigated with proper management.

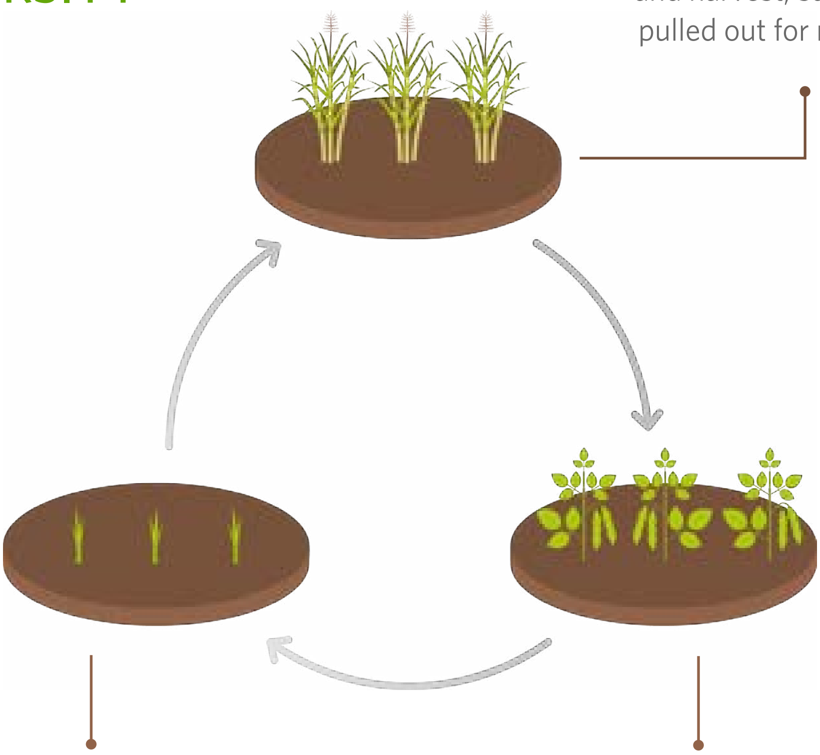
29. 590 Kg ha^{-1} distributed as follows: 179 Kg of N, 22 Kg of P; 162 Kg of K; 137 Kg of Ca, and 90 Kg of Mg (Molina Durán et al., 2022).

PROMOTING CROP DIVERSITY IN SUGARCANE: INTERCROPPING AND CROP ROTATION

Figure 5.
Distribution of secondary crops in a sugarcane plantation (intercropping).

PROMOTING CROP DIVERSITY

After several cycles of growth and harvest, sugarcane is pulled out for replanting.



The secondary crop is harvested for commercial use, subsistence or incorporation as a green manure. Sugarcane seed is replanted, and the cycle starts again.

After the sugarcane harvest, the secondary crop, usually a N-fixer, is planted to replenish the soil and protect it from erosion.

Figure 6. Crop rotation dynamics in sugarcane production.

3.6 Crop integration

Monoculture, the common system for sugarcane production, has been associated with biodiversity loss at multiple scales. At the landscape level, extensive areas of sugarcane are often planted at the expense of natural habitats such as riparian forests, impeding species movement, and diminishing their populations[30]. At the farm level, emphasis on a single crop leads to the loss of biodiversity above and belowground. Both losses reduce the crop's natural capacity to respond to pathogen attacks, increasing reliance on synthetic inputs and other harmful practices.

Over time, monoculture productivity declines creating the need to transform new lands for production. Sugarcane expansion has been a key driver of deforestation in some of the world's most threatened ecosystems, such as Brazil's Atlantic Forest. Unless the current agricultural lands can be kept productive, by 2050 we will need 50% more land to meet the projected global sugarcane demand (WWF, 2015).

Regenerative sugarcane production aims to improve crop yields in established agricultural areas and prevent its further expansion by improving soil fertility and promoting crop diversity. This can be achieved through **intercropping** and through **crop rotation**.

30. See the Protecting Biodiversity chapter.

3.6.1 Intercropping

Intercropping, or mixed cropping, consists of growing two or more plant species simultaneously in the same area (Mohammadi & Pankhaniya, 2017), for cash, subsistence, or both (Figure 5). Globally, intercropping is considered one of the most sustainable agricultural practices (Tang et al., 2021 cited by Pang et al., 2022). In the case of sugarcane, intercropping is best done with crops that contribute to soil fertility either through incorporation of biomass or N-fixation.

In regions of China and Africa, legumes are among the preferred crops to intercrop with sugarcane due to the benefits they provide for soil fertility and pest and disease control (Pang et al., 2022). In mixed sugarcane-peanuts (Arachis hypogaea) systems, better vegetative development of the sugarcaneand

REGENERATIVE MANAGEMENT IS A HOLISTIC APPROACH, AND THEREFORE, A REGENERATIVE SUGARCANE PRODUCER MUST APPLY THESE SAME PRINCIPLES TO MANAGE SECONDARY CROPS.

improvements in edaphic factors[31] like pH, P content, available N, and bacterial and fungal richness in the rhizosphere have been observed (Lian et al., 2018). Similarly, intercropping of sugarcane with soybean (*Glycine max*) can improve N availability, organic carbon, pH, and fungal growth in the soil, which benefits nutrient and carbon recycling and accelerates sugarcane development (Lian et al., 2018).

3.6.2 Crop rotation

Crop rotation consists of planting fast-growing secondary crops during the fallow periods, for example between harvesting and replanting of sugarcane, or during the early stage of sugarcane development (Figure 6). During these periods, the bare soil is exposed to the sun, rain, wind, and the impact of machinery, all of which affect its physical properties (Singh et al., 2018).

Rotation crops are planted after the sugarcane harvest and allowed to grow until they reach peak N-fixation. Then they are cut and incorporated into the soil to supplement fertilization and support crop growth. In Australia, where sugarcane production is completely mechanized, intercropping is a regular practice to recover soil health. Sugarcane is grown in 5-year cropping cycles, followed by a 6–12-month fallow period in which farmers plant soybeans or other N-fixers. Farmers fallow 20% of their land every year, so the soils are replenished every 5 five years. In smallholder systems, farmers often select food or cash crops for intercropping.

Legumes are widely used in rotation due to their ability to increase SOC and N, reduce soil erosion and degradation, and control weeds without the use of herbicides (Dabney, S.M. et al, 2001 cited by White et al., 2020). Soybean, cowpea, and sunn hemp are legumes commonly used in rotations to provide biomass, fix N and improve sugarcane yields(White et al., 2020). In addition, these crops produce seed that growers can use time and again (White et al., 2020).

> IN SUGARCANE PRODUCTION, CROPS SUCH AS SOYBEAN (*GLYCINE MAX*), SUNFLOWER (*HELIANTHUS ANNUUS*) AND SORGHUM (SORGHUM SPP.) CAN BE INTERCROPPED IN THE INTER-ROWS AS AN ALTERNATIVE TO FEED THE CROP.

31. Compared to monoculture, intercropping sugarcane and peanut significantly improved P (20.1%), N (65.3%) and available organic matter (56.0%) in the soil rhizosphere (Pang et al., 2022).

3.6.3 Benefits

- Intercropping legumes in sugarcane systems improves soil fertility and promotes soil biota boosting biological activity and reducing the need for costly fertilization (Luo et al., 2016; Singh et al., 2018). In Belize and India, sugarcane intercropping systems have reached similar or higher yields than monoculture systems (Avilez et al., 2021).
- Crop rotation helps to maintain permanent soil cover and reduce erosion, control weed growth, increase nutrient availability, improve soil physicochemical properties, stimulate microorganisms, and increase SOM (Fairagora Asia, 2022; Orgeron et al., 2020).
- Many species commonly used for intercropping and rotations have a high nutritional value, so they are key in smallholders' systems to supplement family diets without sacrificing sugarcane production (Rehman et al., 2014; Singh et al., 2018).
- In medium-sized production, intercropping with commercial spices and short cycle vegetables can increase sugarcane productivity while providing additional income[32].
- Intercropping systems are more effective at suppressing weed growth and therefore reduce the effort invested in weed control (Kaur et al., 2016).

29. In Punjab, India, sugarcane farmers tripled their profits after starting to intercrop their sugarcane with garlic, potato, and turmeric.

CATEGORY	CROPS
Cereals	Wheat
Legumes	Pea French vean Chickpea Lentil
Oilseeds	Mustard Toria Linseed Sunflower Sesame
Flowers	Gladiolus Marigold
Spices	Chillies Onion Garlic Coriander Fennel Cumin Fenugreek Nigella Turmeric
Vegetables	Potato Tomato Carrot Turnip Cauliflower Cabbage Knoll Kohl Lettuce Radish Lady's Finger Cucurbits
Medicinal and aromatics	Mentha Ginger

Table 3. Short cycle crops such as cereals, pulses, vegetables, and spices that can be incorporated as intercrops for sugarcane production. Potato cultivation has been promising in countries such as India. Cauliflower, cabbage, turnip, carrot, and radish are also suitable for intercropping (Singh et al., 2018).

3.6.4 Recommendations

- The best time to intercrop short-cycle crops is during the first 90-120 days of development, when sugarcane growth is slow and soil resources are available for the complementary crop (Rehman et al., 2014; Singh et al., 2018).

- To minimize competition for nutrients, water, and sunlight, intercropping species should have low stature, a compact canopy[33] and a short life cycle (Singh et al., 2018; Tang et al., 2021) (Table 3).

- When intercropping, sugarcane should be planted with a wider spacing between rows[34] to facilitate the use of machinery and other cultivation tasks (Nadeem et al., 2020; Singh et al., 2018).

- The optimal species for intercropping with sugarcane will vary depending on the local conditions and species available (Table 3); their management will be influenced by the local production practices and the resources available to the producer.

33. Plants with an extended canopy can limit sugarcane growth.
34. The optimum recommended row spacing for intercropping in autumn planted sugarcane in India is 90 cm, a practice widely followed in subtropical India.

3.6.5 Limitations

- Intercropping may not be feasible in regions where labor is scarce, as it entails additional labor for the manual or mechanized tasks required to ensure proper development of all crops (Nadeem et al., 2020).

- Understanding the specific water use requirements of each crop in the intercropping mix is critical as some crops may compete with sugarcane for this critical resource.

- Understanding the effects of the companion crop on soil pH is also critical. Some species can modify soil pH, requiring the addition of K and P compound fertilizers or organic manure to return the soil to the optimum pH for sugarcane development (Luo et al., 2016).

- When soil pH requires correction, the use of mineral amendments (e.g., K sulfate, agricultural lime), preferably from natural sources and without chemical processes, may be required.

- The agronomic characteristics, management requirements, and additional costs of all crops involved should be considered before planting a new intercropping system.

Soil moisture conservation from using crop residue as soil cover. Photo credit: ©Álvaro Zapata.

Pipe with windows used for sugarcane irrigation. Photo credit: ©Álvaro Zapata.

3.7 Irrigation for sugarcane cultivation

The agricultural sector is one of the world's largest water users, accounting for 70% of the global freshwater withdrawals and more than 90% of its consumption. Water remains a key input along the entire food supply chain, well beyond the field production phase; as such, the agri-food sector is one of the most vulnerable to water scarcity (FAO, 2022). Much of the agricultural water consumption is linked to irrigation, the practice of providing water directly to the crop to meet its requirements for optimal growth[35]. Irrigated agriculture represents 20% of the total cultivated land and provides 40% of the total food produced worldwide (FAO, 2022b).

3.7.1 Sugarcane irrigation

Sugarcane is a thirsty crop that requires large volumes of water for its development, especially during its rapid growth stage (4-10 months) when water deficit can seriously impact crop productivity. Sugarcane can consume 12,000-15,000 m3ha-1 of water every year, although the specific requirement varies by geography, soil type and sugarcane variety (Cenicaña, 2018; Solidaridad, 2020). In subtropical areas with more intense and prolonged dry seasons, the requirement may be higher (Cruz Valderrama, 2015).

Most of the global sugarcane production comes from systems that are exclusively rainfed. However, in regions where rainfall distribution is highly variable or insufficient, irrigation is needed to supply water to the crop at critical times. Irrigation water can come from either surface or underground sources (Cenicaña, 2018). Globally, approximately 31% of sugarcane is cultivated in regions with extreme water stress where irrigation involves competition with other users –other crops, human settlements, and industry– for an increasingly scarce resource. In many parts of Asia, Australia and tropical Africa, sugarcane production depends on irrigation and is therefore vulnerable to water stress (Solidaridad, 2020).

Aside from satisfying the crop's water needs, irrigation also benefits sugarcane in different ways.

- Enhances the effects of soil amendments and fertilizers because soil moisture content, along with temperature, are key factors for the activation of the

35. The amount of water a crop needs to develop its biomass and meet the water balance of its vital physiological processes (Cruz Valderrama, 2015).
36. Globally, groundwater provides about 43% of all agricultural irrigation water (FAO, 2022b).
37. Operating machinery on water saturated soils may also cause problems such soil compaction.

Use of sprinkler for sugarcane irrigation. Photo credit: ©Álvaro Zapata.

microorganisms that solubilize nutrients.

- On excessively dry soils[37], it protects soil structure from damage caused by mechanization.
- Facilitates germination of sugarcane from seed, and development of sprouts following the harvest.
- Encourages the germination of complementary crops such as intercropped legumes.

3.7.2 Benefits of irrigation

- Supplies the crop with the right amount of water, reducing the risks of moisture saturation in the soil and fluctuations in nutrient availability[38] .
- Contributes to a more efficient water use and therefore helps reduce production costs and ensure water availability for other users.

38. N is one of the most important macronutrients for the development of sugarcane. When the moisture is adequate, the plant acquires N from the soil as ammonium (NH_4+) or nitrate (NO_3-); when the soil is saturated, absorption by the plant may be limited (Cruz Valderrama, 2015).

Channel for gravity irrigation in sugarcane, Colombia. Photo credit: 2022.08 Cali. Kickoff ©Alejandra Pinzón.

3.7.3 How are irrigation systems implemented for sugarcane?

Several irrigation systems are used in sugarcane production (Table 4), the goal of which is to provide water to the crop at the right time in the most efficient way. The best irrigation system is the one that fits the producer's needs and capacity to install and operate it. To design an efficient irrigation system, the producer must:

- Determine how much precipitation water is available in the production system.
- Consider the soil type, the agronomic characteristics of the field (e.g., slope, water source), and the tools needed when selecting the irrigation system.
- Understand the local water balance –the difference between the water available and the water required by the crop. This determines the optimal amount of water to apply per irrigation event, and the number and timing of those events per crop cycle. Additional factors such as soil storage capacity and crop root depth must also be considered (Cenicaña, 2018).

IRRIGATION SYSTEM	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Gravity irrigation	Channels are dug directly into the ground to move water from the surface catchment source to the head of the crop area. From there, water is distributed by gravity through furrows between each row to the other end of the field	• Low investment • Low maintenance	• Low water use efficiency from losses to evaporation, percolation, and surface runoff, leading to higher consumption per irrigation event • Surface runoff may generate erosion between crop rows • Uneven water distribution over the crop area due to variations in slope • If surface water is not available, additional equipment and infrastructure are required to pump groundwater, increasing costs
Piped irrigation with openings	Like gravity irrigation but uses pipes to carry water from the catchment to the head of the cultivated plots. Pipes have openings or 'windows' that let the water flow into the furrows. Recommended for sandy soils where water losses are higher due to percolation.	• Higher water use efficiency relative to open canals (Zapata et al., 2022) • Lower irrigation costs resulting from higher efficiency • Low maintenance	• Higher implementation costs from input purchase and installation • Requires specialized tools (pipelines, pumps, conduction structures) to transport water from source to cropping area • If no surface water is available, additional equipment and infrastructure are required to pump groundwater, which increases costs.
Reduced-flow irrigation	A variation on gravity irrigation where a set volume of water is supplied to the crop mor frequently. Used in clay soils with smaller pores and in regions with water scarcity (Cenicaña, 2015b).	• Low implementation cost • Low maintenance • Less topsoil loss from surface runoff relative to gravity irrigation.	• Low water use efficiency due to evaporation, percolation, and surface runoff losses • Possible uneven distribution of water over the crop area due to variations in soil slope • If no surface water is available, additional equipment and infrastructure are required to pump groundwater, which increases costs
Alternating furrow irrigation	Similar to gravity irrigation, but water is not distributed along all the furrows in the cropping area. When doing green harvest, water is distributed through the inter-rows or furrows free of crop residue.	• More efficient than the gravity irrigation method • Lower costs due to lower volume usage • Low maintenance • Low implementation costs	• Low water use efficiency due to evaporation, percolation, and surface runoff losses • Possible uneven distribution of water over the crop area due to variations in soil slope • If no surface water is available, additional equipment and infrastructure are required to pump groundwater, which increases costs
Sprinkler irrigation (center pivot or cannon)	System that broadcasts water homogeneously over the cropping area, with the range of distribution varying based on the size and power of the sprinkler. A pump is required to ensure adequate pressure in the conduction and distribution pipes, and to channel water from catchment point to field.	• Higher application efficiency (80 -85%) compared to gravity irrigation (Cruz Valderrama, 2015) • Can be used for fertigation – application of fertilizers with irrigation water • Suitable for medium and large producers with larger cultivation areas	• High cost of implementation • Require continual maintenance • If no surface water is available, additional equipment and infrastructure are required to pump groundwater, which increases costs
Drip irrigation	Water is applied to the plant with greater precision: more frequently, in small volumes and directly. Avoids excess soil moisture by applying the amount of water required during each event. Suitable for soils of any texture or type (clay to sand) and for regions where access to water is limited.	• Application efficiency greater than 90% (Cruz Valderrama, 2015). • Uses up to 50% less water than gravity irrigation (Cruz Valderrama, 2015). • Limits weed development because water is applied directly to the sugarcane.	• High upfront costs from purchase of specialized inputs for installation and operation. • Requires continual maintenance • Requires good quality water because high concentrations of sediment or salts tend to clog drippers. • If no surface water is available, additional equipment and infrastructure are required to pump groundwater, which increases costs

Table 4. Types of irrigation systems for sugarcane. Adapted from (Cruz Valderrama, 2015)

40. Root systems anchor plants to the soil and absorb water and nutrients necessary for optimal development. In sugarcane, 85-92% of the roots are in the top 40 cm of soil (Cruz Valderrama, 2015).
41. Also known as gravity flow, flood irrigation or gravity fed irrigation.
42. In Colombia, this method has reduced water loss by up to 56%, with each irrigation event using less than 1,400 m3ha-1 (Zapata et al., 2022).

3.7.4 Additional recommendations to improve irrigation efficiency

Soil moisture sensors that provide precise data on moisture levels can help optimize water use by identifying the best time for irrigation. They can be installed temporarily or permanently in the field, and measurements can be done manually or automatically (Cenicaña, 2018). In Colombia, the use of sensors in sugarcane has allowed for the elimination of up to two irrigation events per crop cycle (Zapata et al., 2022). Nestlé has supported the use of moisture sensors to improve water management in other supply chains including livestock in Africa and Pakistan, tomato cultivation in Spain (Nestlé, 2022c) and sugarcane in Brazil, India, and Australia.

- In sites with extreme dry seasons or limited water availability, planting sugarcane varieties adapted to drier conditions contributes to a more efficient water use.

3.7.5 Irrigation in regenerative production

In regenerative sugarcane production, the number of irrigation events required is expected to decrease as soil health recovers, leading to a more efficient use of the resource (Bordonal et al., 2018) (Table 5).

CONVENTIONAL PRODUCTION	REGENERATIVE PRODUCTION
• Intensive mechanization damages soil structure, reducing pore size and leading to soil compaction. Compacts soils have lower water infiltration and holding capacity. • Recurrent burning damages soil structure and eliminates soil biota, reducing the soils' water holding capacity. • Burning residues eaves topsoils exposed to runoff caused by precipitation or irrigation. • Excessive use of chemical inputs contaminates surface and ground water sources, affecting its quality and limiting its availability for other activities.	• Limited use of mechanized tillage reduces the risk of soil compaction and loss of soil structure. • The elimination of burning practices helps maintain or recover soil health, improving its infiltration and water holding capacity. • Permanent soil cover reduces runoff erosion and limits direct evaporation losses. • Eliminating chemical inputs reduces the risk of contamination of nearby water sources and minimizes residual toxic effects on the soil.

Table 5. Impacts of conventional vs. regenerative production practices on soil water retention capacity

3.7.6 Drainage

Drainage, the set of practices and tools that remove excess water from the soil after a specific event, is also critical for the optimal development of sugarcane, especially in high rainfall areas. Draining excess water not only protects the crop and the soils, but it also decreases the risk of contaminating nearby water sources with chemicals and sediments in the runoff.

There are two types of drainage. Superficial drainage removes the excess water that accumulates in the topsoil to reduce the risks of erosion and downstream flooding. Subsurface drainage lowers the water table below the root zone to prevent damage to the crop (Smartcane BMP, 2022a).

In regenerative production, natural alternatives are encouraged to ensure the proper removal and filtering of water from the cultivation areas. For example, in the tropical region of Australia, where sugarcane is grown in high precipitation coastal areas, producers take advantage of their natural wetlands to improve surface drainage and naturally filter out excess water, minimizing the amount of agricultural pollution that flows into nearby marine ecosystems. In addition, these vegetation areas promote the conservation of native species (Smartcane BMP, 2022b).

3.7.7 Benefits

- When soils recover their infiltration and water holding capacity, water remains available to the plants for longer. This allows the sugarcane to grow even when water requirements peak and reduces the number of irrigation events. This reduces costs as irrigation is among the costliest practices in sugarcane production.
- Reducing demand in irrigation water minimizes possible conflicts with other users over water access and consumption.
- As soils recover their water holding capacity, the crop's ability to use green water increases, and dependence on irrigation decreases. In some cases, when crop development is synchronized with the local dry and rainy seasons, and local temperatures favors soil moisture retention, irrigation can be eliminated.
- Efficient irrigation reduces risks related to excess moisture, such as salinization or fluctuating nutrient availability, which affect crop productivity and soil health.

3.7.8 Recommendations

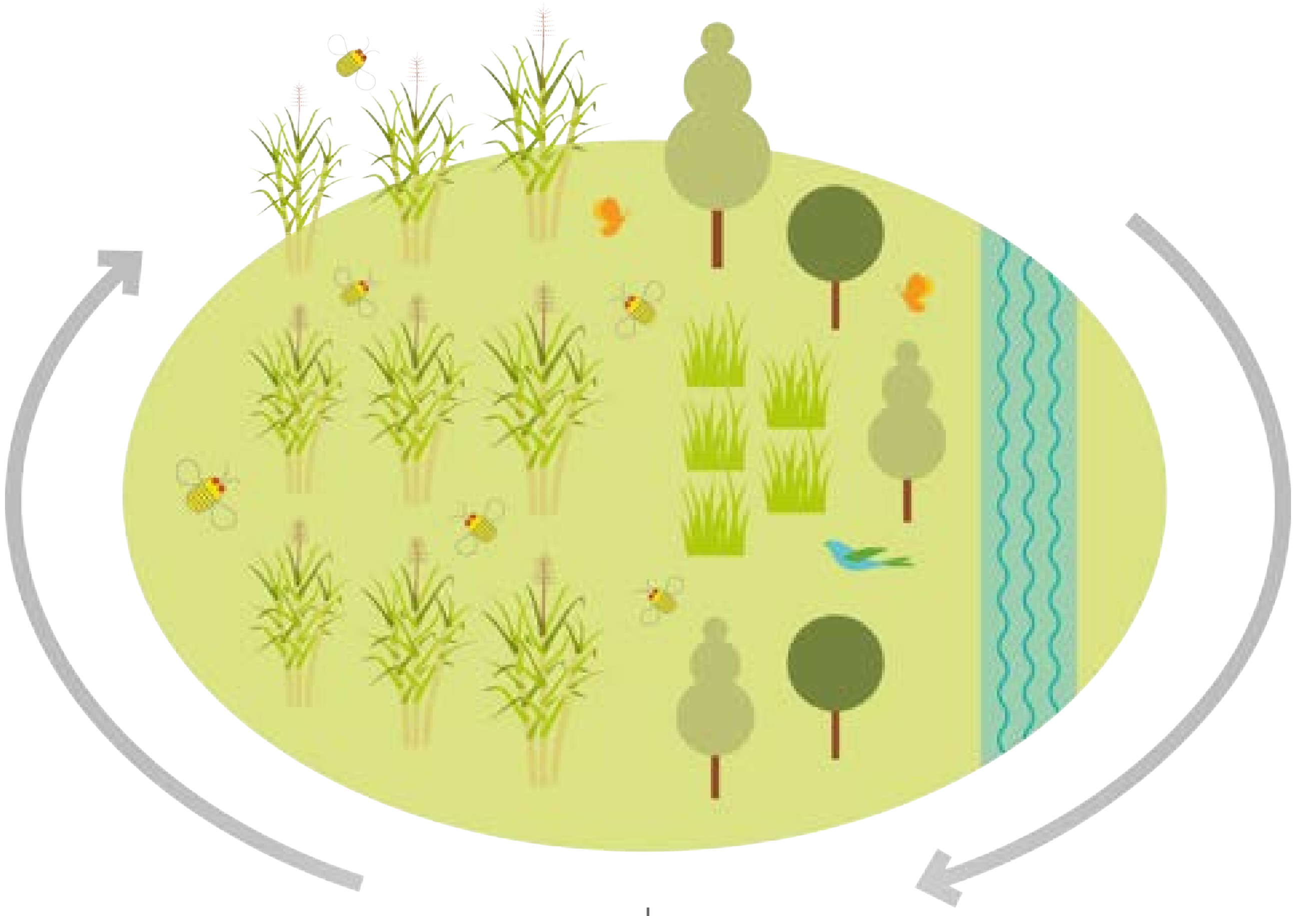
- Planning sugarcane planting according to the regional climatic cycle allows the crop to use mostly green water, reducing the need for irrigation. The crop's early development stage, when water demand peaks, should be aligned to the rainy season.
- Design and install the irrigation system that best fits the needs, resources, and conditions of the cropping area and the producers' management capacity.
- Plan irrigation events using tools such as water levels or moisture sensors[43]. This will help identify the best times to supply water to the crop based on its development stage and optimize water usage.

3.7.9 Limitations

- Installing an irrigation system can be costly as it entails designing a tailored system, purchasing inputs, and paying for installation, operation, and maintenance. However, in the long term, an irrigation system can lead to significant savings.
- Whereas moisture sensors are an effective water-saving tool, the high cost of operating and monitoring the equipment may limit access by many smallholders.
- Soil regeneration is a gradual and long-term process, so the benefits associated with water savings are not immediate. Simultaneously implementing multiple regenerative practices that contribute to improve soil health will help accelerate the process and maximize the water saving benefits.

43. See Tensiometers and Using the GDot: Soil moisture sensors in sugarcane information sheets for more information.

DYNAMICS OF BIOLOGICAL CONTROL BY CONSERVATION IN SUGARCANE CULTIVATION



Incorporating and conserving other forms of permanent vegetation in sugarcane production systems promotes the natural balance of insect populations.

Figure 7. Biological control by conservation.

3.8 Biological insect control

In a diverse agroecosystem, there is a natural balance between the harmful insects or pests –those that feed on the crops– and the beneficial insects –those that feed on, and naturally control, pest populations. However, in a homogeneous sugarcane monoculture, where the focus is on maximizing crop density by eliminating natural habitats, most insect species are lost. Beneficial insect populations tend to be especially affected because the conditions that enable their permanence and reproduction are not met. This destabilizes the natural balance between insects, enabling the harmful species to multiply rapidly, and leaving the crop exposed to attack. If harmful insect populations are not adequately controlled, crop development can be affected leading to economic losses for the producer.

3.8.1 Pest control methods in conventional sugarcane

In conventional sugarcane cultivation, the main strategy to control pest outbreaks that may affect optimum crop development and decrease crop productivity is the application of chemical insecticides. These substances are seen as a convenient and low-cost solution that is suitable for manual application on the ground in small areas or via aerial dusting in larger areas.

However, insecticides may be problematic when used incorrectly[44], for example at the first signs of insect attack or when applied in excess. This type of use can have the same negative impacts as chemical fertilizers and herbicides[45], especially when products are designed to have residual effect to avoid reinfestation. It can also lead to pests developing insecticide resistance[46] and the need to increase dosages to achieve the same effect. Non-selective insecticides may also inadvertently eliminate beneficial insect species that help stabilize of pest populations.

Another method still used in many countries to control pest outbreaks is to burn the sugarcane residues before the next planting cycle. While burning may help interrupt the insects' life cycle, the negative impacts of fire on the cropping system far outweigh the benefits[47] (Tabriz et al., 2021).

3.8.2 Pest control methods in regenerative production

The recommended approach for controlling harmful insects in regenerative production

44. Incorrect use of chemical insecticides refers applying them at will, with no previous evaluation of insect populations or level of crop damage, or in dosages not based on the insects' specific development stage.
45. See Weed Management chapter.
46. A heritable change in the susceptibility of a pest population to a particular insecticide or insecticide group that results from the selective pressure of repeated pesticide application.
47. See Green Harvesting or elimination of burning chapter.

is **Integrated Pest Management (IPM)**, which relies on a combination of information and common-sense practices to keep pest populations under control. IPM uses information about the pest´s life cycle in a specific environment paired with constant monitoring of the populations as the basis to select among the available control methods (Nestlé, 2022d). These may include biological insect control, the use of pest-resistant sugarcane varieties, mechanical control, and in some cases, targeted pesticide application (Smeets et al. 2008 cited by Bordonal et al., 2018). IPM is intended to reduce crop damage by controlling pest outbreaks in a timely manner while minimizing the impacts of insecticide use on the health of people and the environment.

IPM is an iterative approach to pest control that follows four basic steps:

- **Set action thresholds:** The threshold should consider environmental conditions, the insect population present, and the level of crop damage in the crop. Once the threshold is met, the decision to use insect control methods is triggered.

- **Monitor and identify insects[48]:** Not all insects require control, so before acting, it is important to correctly identify which insects pose a real risk. Monitoring and identification of the insects present, along with action thresholds, allow producers to use the best control alternative only as needed, and avoid using unnecessary or costly methods.

- **Prevention:** IPM emphasizes risk prevention methods such as planting pest-resistant varieties, rational crop nutrition, and protecting natural habitats to support healthy insect populations.

- **Control:** Priority is given to lower risk control methods such as biological control or crop renewal. Insecticide applications should be used only when strictly needed.

The following are some of the insect control methods considered under IPM.

- **Insect-resistant sugarcane varieties:** Some sugarcane varieties have been identified as more resistant to attack by certain insects. Using these varieties, alone or in a mix, can effectively reduce and/or progressively eliminate pest populations from the cropping area, reducing the need for insecticide use (Bustillo Pardey, 2013). For example, control of the destructive sugarcane borer is the main pest control task in many regions. Borer-resistant varieties have already been developed that are typically hardier (i.e., tougher stalks), which makes perforation by the insects and subsequent rotting less likely.

48. For examples of material for monitoring insects for sugarcane production (available in Spanish) see Identification, evaluation, and control of Diatrea spp. and Insect pests and beneficial organisms of sugarcane cultivation in Colombia

- **Biological control:** This method takes advantage of the array of beneficial insects that attack unwanted insects when present in the crop. Beneficial insects such as the *Genea jaynesi* fly and the *Trichogramma exiguum* wasp, which parasite the sugarcane borer, can help growers control common pests and minimize risks to crop productivity. There are two methods to get these beneficial insects in the cropping system.

- **Control by release:** Beneficial insects are reared in a laboratory and released into production systems when an outbreak is detected. The main benefits are the convenience of releasing the insects as needed and the reduced need for insecticides. This method is a standard of sustainability for sugarcane production (Zapata et al., 2022).

- **Control by conservation:** The method relies on supporting permanent populations of beneficial insects in and around the cultivation area so they can prevent any future outbreaks. This requires that natural vegetation areas be restored or conserved to provide beneficial insects with long-term habitat, breeding sites, shelter during periods of dormancy, permanent food sources and corridors for movement (Figure 7) (CATIE, 1990). These patches also serve as barriers for the movement of harmful insects.

Natural vegetation areas can be incorporated in different ways: in crop alleys, field borders, and living fences, or as riparian strips or forest fragments. They must be maintained for extended periods of time so they can consolidate as permanent habitat for beneficial organisms and foster biological interactions (Blanco & Leyva, 2007). In the long term, building diverse resident insect communities helps reduce the costs linked to pest control.

Benefits of biological pest control in sugarcane

- Reduces biodiversity loss.
- Reduces soil and water contamination associated with overuse of agrochemicals.
- Supports diverse biological interactions that increase the crop's resistance to pests.
- Reduces human exposure to chemicals that pose risks to human health.
- Reduces economic losses to crop damage and costs related to insect control.

Ladybird beetle of the species Cycloneda sanguinea (Coleoptera: Coccinellidae) feeding on aphids in the Cauca River Valley, Colombia. Photo credit: © Leonardo Rivera, Cenicaña.

Pathogenic agents: Some entomopathogenic fungi can be effectively used to attack specific crop-damaging insects without harming other plant or insect species. For example, the *Nomuraea rileyi* fungus controls larval populations of the cane borer.

Whereas this method is effective, it is not widely used in sugarcane mainly because of the costs of the technology and the fact that it requires specialized knowledge not available to all farmers, for example about the organism's reproductive cycles.

Ethological control: Feeding and sexual pheromones are natural chemicals that can be used alone or in mixtures to attract specific insects. Sticky traps with pheromones and other attractants can be set out to monitor and control populations of harmful insects present in the sugarcane crop. For example, the black palm weevil (*Rhynchophorus palmarum L.*), a coleopteran that attacks sugarcane at all stages, can be controlled with pheromone traps.

Targeted insecticide application: Although minimizing the use of chemical inputs is a goal in regenerative production, sometimes pesticide application can be the only option to prevent significant crop losses. In those cases, the pests' developmental stage and the minimum effective dosage are key elements to consider.

In addition to IPM, regenerative methods for insect control should always focus on strengthening natural biological interactions within the agroecosystem by encouraging a diverse mix of plant species in and around the cultivated area.

3.8.3 Recommendations

- Access to technical support and ongoing training is critical to help producers correctly implement IPM, both to monitor and identify harmful insects and to decide which control methods are best. In India, lack of knowledge and technical capacity are known barriers to the adoption of IPM (Raza et al., 2019).
- Encouraging permanent forest areas, riparian strips, and patches of native flowering plants in and around sugarcane fields, and shrubby vegetation inside the cultivated area, is the best way to support natural enemy populations and guarantee year-round pest control.
- Vegetation areas of any size –even narrow strips of native vegetation along field margins or between sugarcane allies– can contribute to enhance natural insect control.
- Mexican sunflower (*Tithonia diversifolia*), cobblers peg (*Bidens pilosa*) and other flowering plants in the daisy family (Asteraceae) are especially well-suited to attract and support insect populations[49] and should be incorporated into permanent vegetation strips as much as possible.

3.8.4 Limitations

- Whereas biological control by release can be highly effective, the benefits are limited in time because laboratory-reared insects tend to dwindle in the field as the prey population is eliminated. This results in additional costs for every new release and creates a different type of input dependency.
- Biological control by conservation requires time for the vegetation areas establish and become sufficiently complex to support beneficial insects. However, over time these vegetation areas will become increasingly diverse and effective.
- Biological pest control requires knowledge of both the prevention and control measures and the identification of problem species. If technical assistance is not available, producers may fail in its implementation and revert to the use of chemical control.

49. Broadleaf plants in the Amaranthaceae and Malvaceae families are also recommended (Bustillo Pardey, 2013).

Fragment of tropical dry forest in El Hatico Nature Reserve, Colombia. Photo credit: 2022.08 Cali Kickoff ©TNC - Federico Gomez.

3.9 Protecting biodiversity

Biodiversity refers to the range of organisms – plants, animals, microorganisms, fungi – that interact within an ecosystem. There are three levels of biodiversity: genetic diversity refers to the variety of genes within the same species, for example, varieties of potato; species diversity refers to all organisms that inhabit a region; and ecosystem diversity is the variety of habitats found in a geographical region, for example, deserts, humid forests, and wetlands.

In a healthy agroecosystem, different species have different roles, and this is known as **functional biodiversity**. Many of these functions contribute to biological processes such as nutrient recycling, which are critical because they ensure the proper functioning of the whole system, and therefore underpin its economic and ecological sustainability (Altieri, 1999).

In an agricultural system, biodiversity can be classified into two types. **Planned biodiversity** refers to the species of plants and animals that a producer introduces and manages to fulfill a productive role. **Associated biodiversity** is the set of species, from soil microorganisms to animals, that come from the surrounding landscape to settle in the cultivated area, fulfilling different roles.

In traditional agricultural systems, planned and associated biodiversity are high, and therefore able to fulfill many regulating functions. But in highly simplified monocultures, where associated biodiversity is minimal, these functions are disrupted, and the producer must constantly intervene to substitute their roles with external inputs and management practices.

3.9.1 Conventional practices in sugarcane production

In recent years, sugarcane cultivation has expanded across parts of Southeast Asia, South America, and Australia, often transforming vast areas of natural ecosystems, and homogenizing the landscape with practices that impact biodiversity at multiple scales (Table 6). Species loss affects the provision of vital ecosystem services, such as pollination, and therefore also affects agricultural productivity (Cheesman, 2004; Millennium Ecosystem Assessment, 2007). This leaves crops increasingly vulnerable to environmental changes such as extended droughts, and to biological changes such as pest attacks.

CONVENTIONAL MANAGEMENT PRACTICE	OBJECTIVE OF IMPLEMENTATION	IMPACTS ON BIODIVERSITY
TRANSFORMATION OF NATURAL ECOSYSTEMS	• Natural ecosystems (e.g., forests, wetlands) are transformed or eliminated to expand cropping areas.	• Massive loss of species at the regional level, either because they are eliminated in the process or because they are gradually lost due to lack of connectivity in the landscape.
BURNING OF CROP AND HARVEST RESIDUES	• Pre-harvest (standing) burning facilitates the harvest, increases harvesting efficiency, and eliminates plant residues from the final product. • Post-harvest burning reduces the volume of residues and avoids possible phytosanitary risks.	• Pre-harvest burning eliminates microorganism populations in the soil's surface layer, affecting soil fertility and structure. Residue burning removes a resource that could serve as a habitat for beneficial insects that control populations of pest species.
APPLICATION OF CHEMICAL INPUTS: HERBICIDES, INSECTICIDES, RIPENERS AND FERTILIZERS	• Chemical inputs are used to nourish the crop, control weeds and harmful insects, and accelerate ripening, always with the goal of increasing productivity.	• Chemical inputs eliminate associated biodiversity that perform functions that directly and indirectly benefit the crop, such as the mineralization of key elements in the soil by microorganisms. Burning contributes to direct and diffuse contamination of air and water sources.
MONOCULTURE SYSTEM	• Monocultures are used to maximize both cultivation and productivity.	• Reduces the genetic diversity of sugarcane. Homogenizes the production landscape, reducing the variety of plant and animal species. Increases crop vulnerability to extreme climate events or attacks by pathogenic agents.

Table 6. Common practices in conventional sugarcane production and their impacts on biodiversity

3.9.2 The importance of biodiversity in regenerative production

Unlike conventional agriculture, which simplifies systems leaving only a few variables to control, regenerative agriculture aims to reintroduce complexity by integrating more species and encouraging ecological interactions. The goal is to recover critical ecological processes that support crop development, such as natural pest control or nutrient recycling. Management practices such as intercropping are therefore used to simulate natural processes and harness available resources –green water, luminosity, or atmospheric N – to improve crop productivity. These practices set in motion endogenous processes that gradually reduce dependence on external inputs and some harmful practices.

3.9.3 Alternative practices to promote biodiverse sugarcane landscapes

In highly transformed monoculture landscapes, reestablishing biodiversity can seem like a daunting task. However, with adequate **landscape planning** that considers both cultivation areas and the surrounding land and water bodies, it can be achieved (Rivera et al., 2020). In the cultivation areas, regenerative practices contribute gradually recovery and maintain biodiversity levels that support production. At the landscape level, connectivity between cultivated areas and the surrounding lands must be strengthened by conserving permanent or semi-permanent vegetation areas.

Biodiversity islands are areas of vegetation within a modified or degraded landscape, that serve as refuge for species, supporting their survival in an otherwise hostile environment. Their defining characteristic is permanence in a context of constant disturbance, which enables some ecological functions that are important for cultivation. For example, the presence of birds, which tends to be low in sugarcane, increases when patches of natural forest or tree lines are maintained on field edges (Cheesman, 2004). Raptors and herons, which use these vegetation edges, effectively help to control rodents in the crop and larvae and worms that emerge when the crop soil is turned over.

Biodiversity islands can be natural or created ecosystems and can vary in scale and configuration. Table 7 summarizes best practices that help promote biodiversity conservation in sugarcane cultivation areas, and some of the benefits and trade-offs.

The practices in Table 7 promote biodiversity in different ways and at different scales. For example, **maintaining non-aggressive weeds in the field** is a local level practice that helps prevent erosion, improve soil structure, and recycle nutrients. Promoting the growth of plants of the umbellifer, legume and daisy

IMPACTS OF CONVENTIONAL PRODUCTION VS. REGENERATIVE PRODUCTION

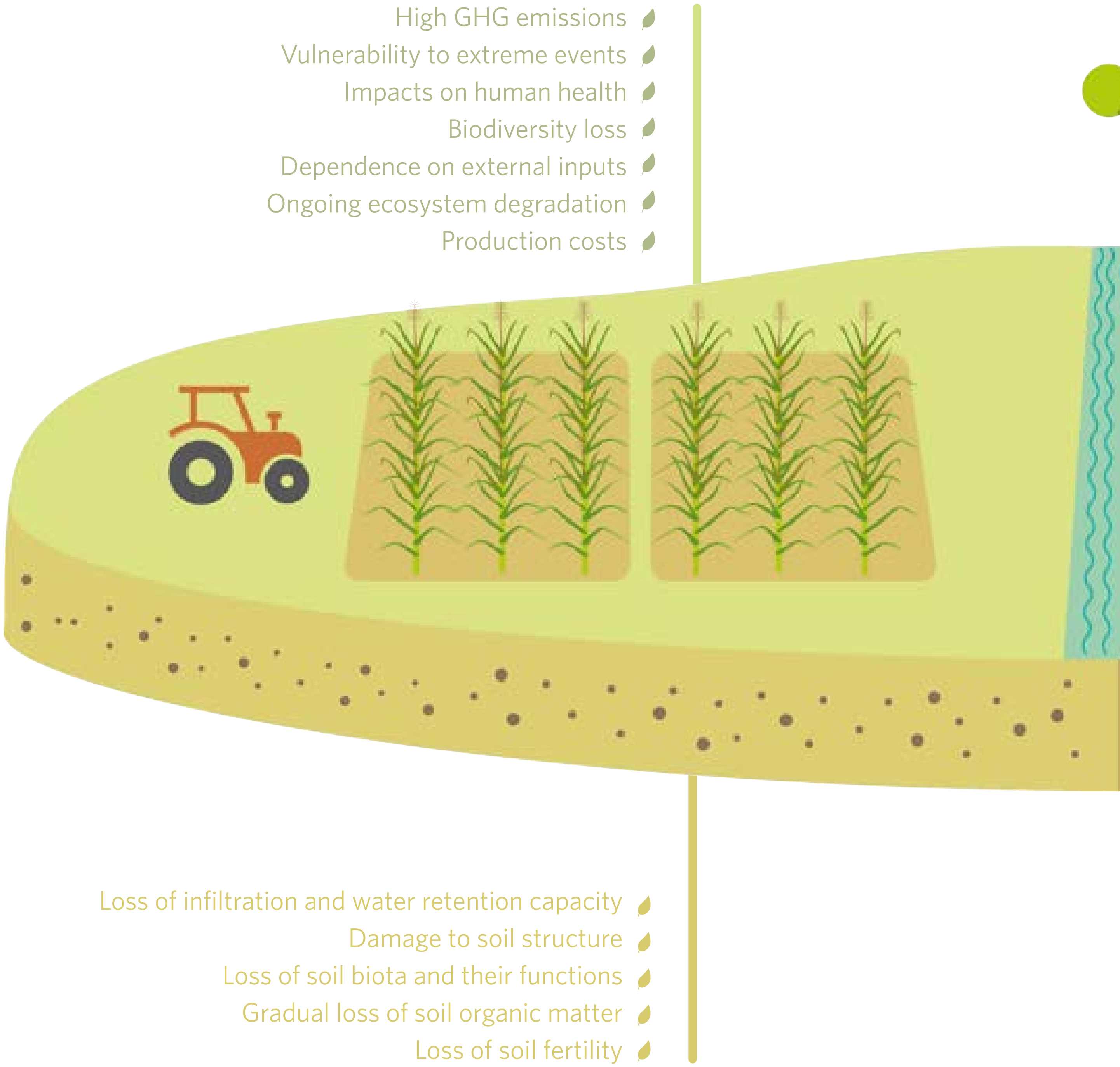
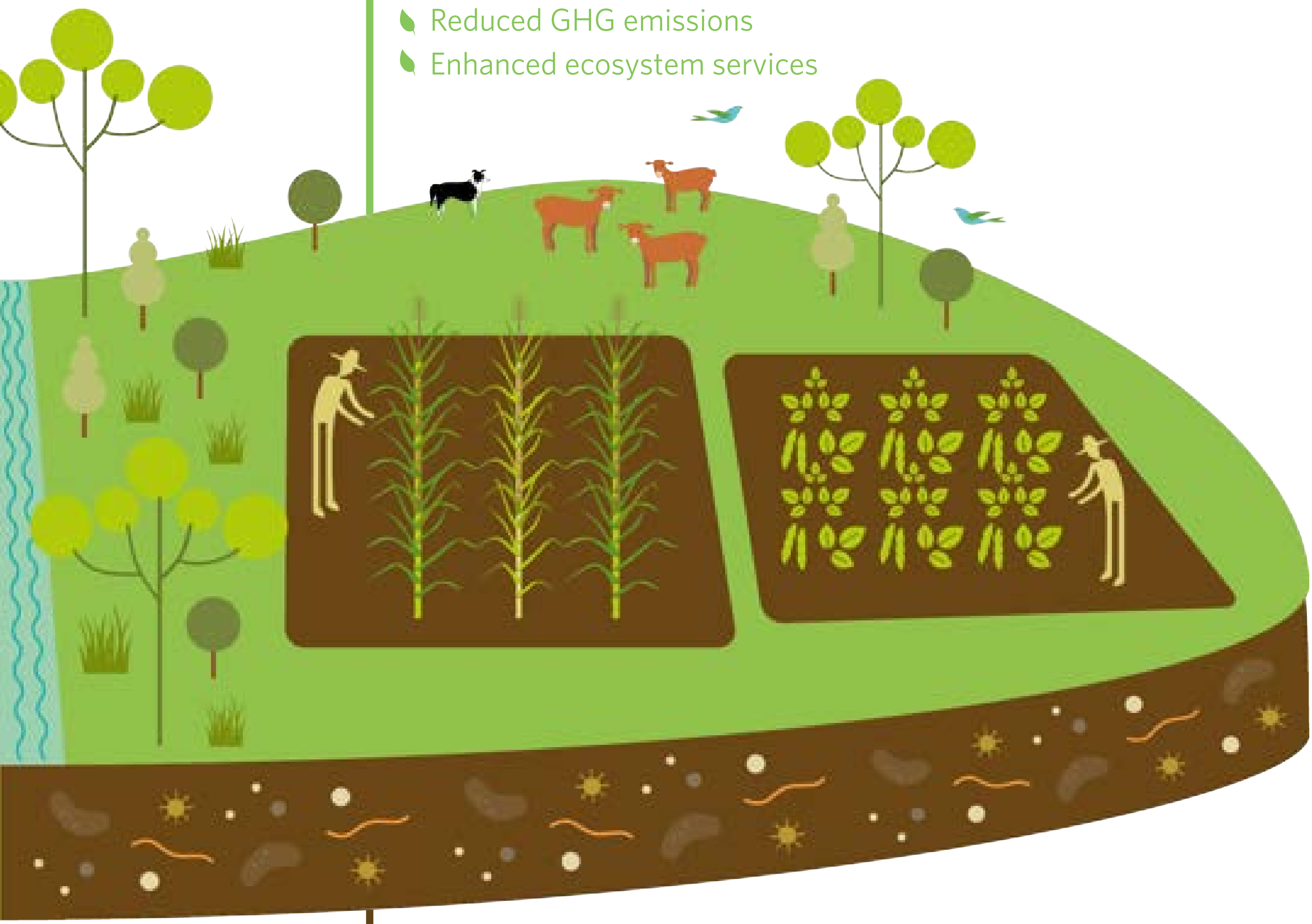


Figure 8. Positive impacts of regenerative production practices on soil and sugarcane production system.

- Crop, animal and human health
- Crop diversity, balanced diet and higher economic income
- Improved crop productivity and yield stability
- Resilience to climate variability
- Biological control
- Biodiversity conservation across the landscape
- Reduced GHG emissions
- Enhanced ecosystem services



- Increased soil organic carbon
- Nutrient recycling and element mineralization
- Improved soil structure
- Natural control of pathogen populations
- Water infiltration and retention
- Enhanced biological activity
- Biological N fixation

Living fences or windbreaks in sugarcane cultivation. Photo credit © Alicia Calle.

families on the field margins can help sustain populations of beneficial insects that control crop pests (Altieri, 1999). For example, allowing the common weed *Bidens pilosa* to grow in crop alleys and field margins contributes to natural pest control (Arévalo et al., 2021; Chauhan et al., 2019).

On the other hand, **protecting riparian forests** has impacts at the broader landscape level. Riparian forests are vegetation areas adjacent to water bodies that, although often protected by law, are commonly cleared for cultivation. Protecting them when they exist, or restoring them if they have been destroyed, has multiple benefits because these areas provide habitat for beneficial insects and other organisms that prey on sugarcane pests (Cheesman, 2004). Riparian forests also act as filters of sediments and chemicals carried in runoff water, reducing pollution of water sources (Nestlé, 2022d). Finally, many species use these linear forests as corridors to move across the landscape, so the areas contribute to strengthen connectivity (Altieri, 1999).

REGENERATIVE PRACTICE	BENEFITS	TRADE-OFFS
Conservation of forest patches	• Host native fauna and flora of the landscape, including some rare or endangered species. • Provide organic matter which protects the soil and contributes to crop nutrition. • Larger patches can act as sponges that retain and release water for the benefit of both crops and human populations.	• Conserving them involves an opportunity cost if viewed as land that remains uncultivated.
Riparian corridors[50]	• Protect water sources from contamination by sediment and agrochemicals • Protect watercourses from runoff erosion. • Increase landscape connectivity facilitating movement of organisms. • Host beneficial insects and other species	• Conserving them involves an opportunity cost if viewed as land that remains uncultivated.
Living fences or windbreaks	• Protect crops and soils from the effects of the wind and other elements, improving the microclimate in the field. • Protect the crop from agrochemical drift. • Increase landscape connectivity facilitating movement of organisms. • Host beneficial insects and other biodiversity. • Contribute organic matter to the crop soil. • Provide wood and other products.	• Conserving them involves an opportunity cost if viewed as land that remains uncultivated.
Vegetation strips along crop edges	• Host beneficial insects, birds, and ants, contributing to biological control in the crop. • Protect crops and soils from the effects of the wind and other elements, improving the microclimate in the field.	• Implementing and maintaining them generates additional costs for the grower.
Establishment and conservation of non-aggressive weeds	• Provide food sources and refuge for beneficial insects that control crop pests. • Improve soil porosity. • Reduce direct soil exposure to sun, wind, and rain. • Can be used as green manures to improve soil fertility.	• Can be easily affected by herbicides use. • Their management requires knowledge of plant species to carry out selective control in the crop and its surroundings.
Multi-varietal cultivation (a mix of sugarcane varieties)	• Increases the genetic diversity of the crop. • Increases crop's resilience to specific factors (drought, pests). • Specific variety traits can meet different market needs (higher biomass or sucrose concentration).	• Implementation requires knowledge and monitoring to identify benefits and challenges of each variety.
Crop rotation	• Enables soils to recover by switching to a crop with different soil nutrient needs • Helps eradicate insect and pathogen infestations. • Improves soil fertility if rotation has N-fixing species. • Generates potential new income streams or nutritional benefits commercial or food crop are included.	• Requires knowledge of regenerative management of the additional crop(s). • Not always feasible in areas of extensive cultivation or highly specialized sugarcane production. • Not suitable for all types of producers.
Intercropping	• Improves soil fertility if intercropped with a N-fixing species • Generates potential new income streams or nutritional benefits commercial or food crop are included. • Increases diversity in the production system.	• Requires knowledge of regenerative management of the additional crop(s) • Not always feasible in areas of extensive cultivation or highly specialized sugarcane production. • Not suitable for all types of producers

Table 7. Recommended practices to foster and conserve biodiversity in sugarcane cultivation

50. Also called riparian corridors or riparian buffer zones.

3.9.4 Benefits of conserving or restoring vegetation areas

Practices that foster diversity in agricultural landscapes are related to vegetation management and conservation at different scales. Implementing several practices concurrently is recommended to generate heterogeneous and high-quality habitats with the following benefits:

- **Biodiversity conservation.** Just as the presence of vegetation in and around crops benefits many wildlife species, animal species also contribute to the conservation of these areas by pollinating plants and dispersing their seeds.

- **Species interactions within the crop.** Permanent vegetation cover fosters greater species diversity and more abundant interactions. Over time, populations reach a natural biological balance that reduces the need to manage pest and disease. For example, birds and ants living in forest patches are critical to control the sugarcane borer (Rivera et al., 2020).

- **Landscape connectivity.** Forests, living fences, tree lines and other vegetation features facilitate species movement across cultivated areas, helping them survive in these landscapes.

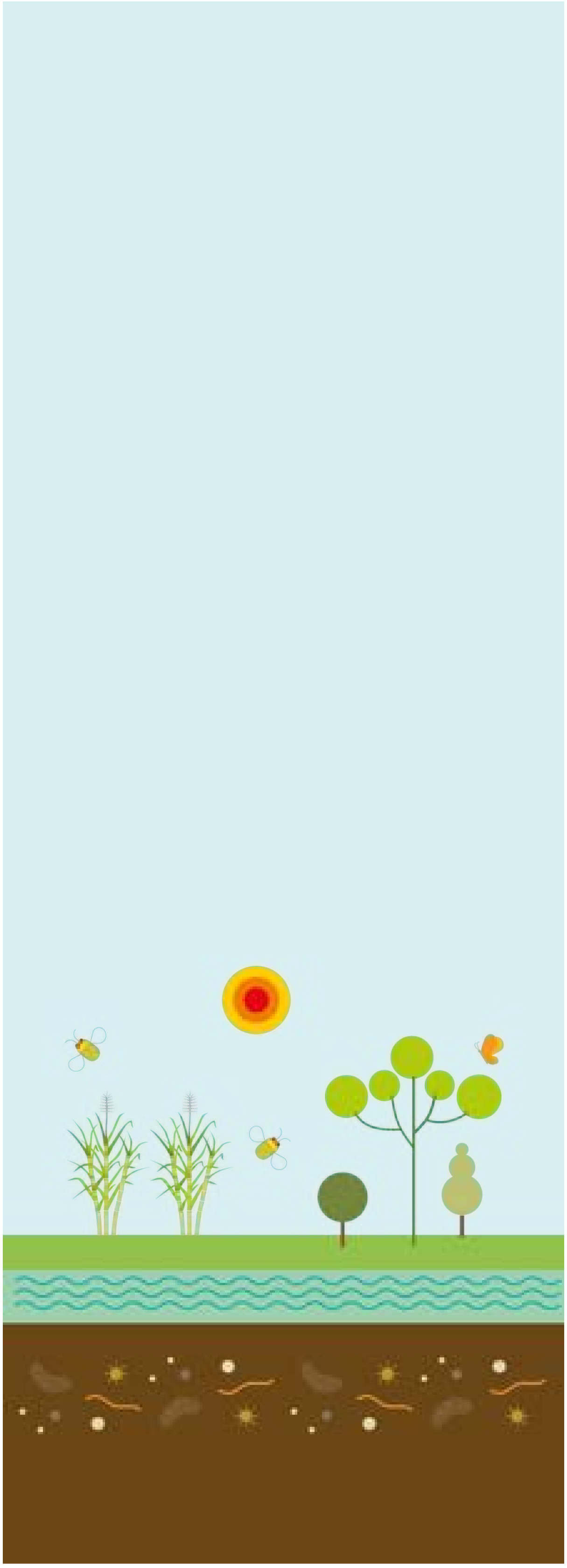
- **Soil health.** Areas of permanent vegetation support soil biological activity by regulating temperatures and humidity, and depositing leaf litter that keeps soils covered. In turn, soil biological activity supports crop productivity.

3.9.5 Limitations

- Implementation of forest patches, riparian corridors and other permanent vegetation areas may imply giving up land that could otherwise be cultivated, an opportunity cost that may be too high relative to the potential economic return. However, the intangible long-term benefits of these conservation areas must be considered.

- Establishing permanent vegetation areas for biodiversity requires financial and human resources, and the benefits may be delayed when the lands are degraded and need to be restored. However, as the areas are consolidated and maintained, the benefits will increase gradually and remain for the long term.

- Many producers are unaware of productive and economic benefits of biodiversity conservation practices. Developing a comprehensive valuation of ecosystem services with an inbuilt mechanism to incentivize their adoption, for example through payments for ecosystem services, is worthwhile (Montagnini, 2022).



Decomposition of crop residue by microorganisms and fungi in regenerative sugarcane production, Colombia.
Photo credit: ©Álvaro Zapata.

3.10 Soils in sugarcane production

Soil is a living and dynamic component of natural ecosystems. It is the foremost resource for agriculture because it provides the substrate, nutrients, water, and gas exchange essential for plant development. Soil is made up of solid particles bound together into aggregates, minerals, organic matter, pore space, gases and liquids, and a diversity of macro- and microorganisms responsible for the biological activity that makes soil productive.

For thousands of years, agriculture has harnessed the vast richness of soils to meet human demands for food and raw materials. But conventional agricultural production, with its intensive practices, has led to widespread soil degradation. An estimated 33% of the world's soils are currently moderately to severely degraded, and it is usually the smallholders who are relegated to degraded lands (FAO, 2021).

The extent and nature of conventional agricultural production makes soil a significant source of CO_2 and other GHG emissions[51]. By 2019, 31% of the world's CO_2 equivalent emissions originated from agri-food systems[52], with almost 7 billion tons coming directly from agriculture. However, healthy soils can play an important role in the fight against climate change thanks to their capacity to store significant amounts of organic carbon (FAO, 2021). The implementation of regenerative practices can restore health to soils previously degraded by conventional practices (Nava-López et al., 2017).

3.10.1 Soil management in conventional sugarcane production

Most management practices used in conventional sugarcane production are used to minimize risks that may compromise crop development, and to ensure maximum yield and returns. However, many of those practices also impact the physical, chemical and/or biological properties of the soil and contribute to progressively diminish soil health and quality (Table 8).

3.10.2 Soil management in regenerative sugarcane cultivation

All regenerative management practices are related, directly or indirectly, to soil health (Table 9) as one of the pillars of agricultural production that ensures crop and animal productivity and supports the provision of other ecosystem services (Montagnini, 2022; USDA, 2022).

51. Soils emit N2O when fertilizers are applied or N-fixing crops; flooded crops such as rice emit methane (CH4) (FAO, 2021).
52. Of these, 21% were from CO2, 53% of CH4 and 78% of N2O emissions (FAO, 2021).

CONVENTIONAL PRACTICE	IMPACTS ON SOIL
PREPARING THE GROUND (LEVELLING AND TILLING THE SOIL AND CROP RENOVATION)	**Levelling:** Smooths the soil surface removing irregularities so the land is flat and optimal for the operation of irrigation systems. May affect the soil physical structure, damaging aggregates and altering pore space. **Tilling:** Mixes and distributes the soil to form the furrows where the crop is planted and to achieve optimum texture for seed germination and plant anchorage. May destroy soil structure and increases the loss of water, carbon, and nutrients. **Crop renovation:** Shakes and mixes the soil to achieve an optimal texture for plant development before establishing a new crop. Over time destroys soil structure and increases soil carbon release. Physical disturbance of the soil directly impacts the habitat of microbial which reduces their populations, slows down nutrient cycling, increases organic matter decomposition, and affects crop development (Altieri, 1999). The heavy machinery used in these tasks can compact the soil also affecting microbial populations.
APPLYING CHEMICALLY SYNTHESIZED INPUTS (PESTICIDES AND FERTILIZERS)	Liberal application of chemical inputs reduces soil microorganism populations affecting processes like mineralization, and destabilizing nutrient cycles due to the addition of excess nutrients. Chemical inputs also affect mycorrhizal and N-fixation. Some pesticides have residual effects, meaning their components remain active to kill weeds and insects between crop cycles.
PRE- AND POST-HARVEST BURNING IN CULTIVATED AREAS	Burning of standing cane or crop residues affects microbial life in the topsoil, directly impacting soil fertility. Removing crop residues post-harvest leaves the soil vulnerable to erosion from rainfall, wind, or direct sunlight. Irrigation can also lead to loss of topsoil through surface runoff.
LAND USE CHANGE FOR AGRICULTURAL EXPANSION	Forest and grassland clearing reduces the number of plant species diminishing habitat and food for soil organisms and severely changes the soil environment (Ruíz et al., 2008).

Table 8. Impacts on the soil generated by conventional sugarcane management practices

REGENERATIVE PRACTICES FOR SUGARCANE PRODUCTION AND THE PILLARS THEY SUPPORT

	SOIL HEALTH FACTORS				
PRACTICES	SOIL STRUCTURE	SOIL CHEMISTRY	ORGANIC MATTER CONTENT	SOIL BIOLOGICAL ACTIVITY	WATER INFILTRATION AND RETENTION CAPACITY
Green harvesting			●	●	
Reduced or not use of agrochemicals		●	●	●	
Use of organic fertilizers	●	●	●	●	
Crop residue distribution on soil	●		●	●	●
Rational Tillage	●			●	●
Rational crop renewal	●		●	●	●
Crop replanting	●			●	
Erosion control practices	●			●	●
Crop integration (rotation + intercropping)	●	●	●	●	

Table 9. Impacts of some regenerative practices for sugarcane production on soil health.

SOIL HEALTH

SOIL STRUCTURE	Ideal structure in agricultural soils allows plant root growth and stability; stable aggregates and sufficient porosity to allow gas and water movement, required for soil organisms and plants livelihoods.	Regenerative practices protect soil's structure and restore other characteristics that promote it, such as accumulation of SOM.
SOIL CHEMISTRY	The chemical reactions and processes between soil's components are essential for plant growth and the health of the environment.	Regenerative practices maintain the chemical balance in the soil through promoting these natural processes and reduce the use of chemical inputs.
ORGANIC MATTER CONTENT	SOM is the portion of the soil comprised of partially or well-decomposed organisms that makes soil fertile, improves its structure, buffers its pH, and improves its water holding capacity.	Regenerative practices focus on reducing soil disturbance and enhancing biological activity to replenish SOM (Parikh & James, 2012).
SOIL BIOLOGICAL ACTIVITY	Activity and variety of processes that the ensemble of macro- and microorganisms, that live in and work the soil, are key for soil health and agricultural productivity.	Regenerative practices restore proper conditions for conservation and reproduction of biota in the soil.
WATER INFILTRATION AND RETENTION CAPACITY	Infiltration is the soil's ability to allow vertical water movement through its pores, while retention is its ability to hold on to water and make it available to crops and organisms.	Regenerative practices focus on replenishing SOM to enhance the soil's structure and its ability to filter water, making it available to plants during dry periods.

Figure 9. Soil health factors.

What is soil health?

Soil health is the soil's capacity to function and sustain plants, animals, and humans as part of the ecosystem. Soil health is determined by a combination of five factors: soil structure, soil chemistry, organic matter content, water infiltration and retention capacity, and soil biological activity (Figure 9). Problems in one these aspects can have cascading effects on the others. Regenerative practices such as mulching with crop residues to maintain soil coverage, allow producers to healthy soils –soils with good structure, high nutrient availability, diverse microbiological communities, high organic matter, and the capacity to sequester carbon[53] (USDA, 2022).

Although soil health is the focus of regenerative production, measuring it can be difficult. Indicators such as the health of crops and animals, water quality, or some physical, chemical, and biological soil parameters can provide insights into the additional measures needed to address specific concerns.

Soil analyses

In large-scale conventional production, periodic soil analyses are conducted as a basis to inform management practices such as crop fertilization based, for example, on the levels of available macronutrients. In regenerative production, these soil analyses serve a different purpose. A baseline analysis before starting the transition to regenerative is necessary as a benchmark to assess progress over time, and regular analyses at least every five years are recommended to observe the gradual impacts of the practices. Soil analysis should focus at least on three key parameters related to its physical, chemical, and biological properties: bulk density, organic carbon content, and abundance of organisms. When monitored periodically, changes in these three parameters allow producers to gage the impact that regenerative practices are having and make informed adjustments.

Physical property: Bulk density

Soil structure is comprised of solid mineral particles, organic matter and pores. Bulk density (*Pb*) measures total soil mass per unit of volume. A high *Pb* is indicative of intense mechanization, high compaction, and loss of organic matter. In general, soils with a higher *Pb* are less healthy because they have less pore space, which leads to limited water circulation and retention[54] and less air spaces for root development and microorganism activity.

Chemical property: Soil organic carbon

Agricultural soils are one of largest untapped carbon reserves, estimated to have twice as much potential for carbon storage as plant biomass. Therefore,

53. A comparison between green harvested sugarcane in conventional tillage vs reduced tillage systems showed significant differences in the soil carbon: 0.67 Mg C ha-1 year-1 vs 1.63 Mg C ha-1 year-1 (Bordonal et al., 2018a).

54. Soils with low porosity are slower to drain excess water following an irrigation event or heavy rainfall, which affects crop development.

improved soil management is a viable option for climate change mitigation, given that by some estimates they could store more than 10% of anthropogenic emissions over the next 25 years (FAO, 2022b, 2022a).

The amount of carbon in the soil is expressed in two ways. SOM refers to all the plant and animal components found in the soil, and it made up of 58% SOC, plus water and nutrients (Navarro-Pedreño et al., 2021). The amount of SOC is related to the thickness of the arable layer of the soil, or the topsoil where the biological processes responsible for nutrient mineralization and crop development take place (FAO, 2022d).

The stability of SOC depends largely on the type of soil management practices. Tillage breaks up soil structure and exposes SOM to aeration, promoting decomposition and releasing CO_2 into the atmosphere. Therefore, reduced tillage used in combination with other regenerative practices like mulching, can result in higher rates of soil carbon sequestration in sugarcane soils (Segnini et al., 2013).

Biological property: Abundance of soil organisms

Based on their size, soil organisms can be classified as macroorganisms (diameter >2 mm), mesoorganisms (diameter 0.1-2 mm), and microorganisms (diameter <0.1 mm). The presence of macroorganisms such as ants or millipedes in the topsoil usually indicates healthy soils. Similarly, the presence of fungal hyphae which resemble white threads, is a sign of good soil health[55]. These organisms will vary in abundance and activity by season, soil temperature and moisture content. Microorganisms, while not visible to the naked eye, can sometimes be detected as pink nodules on the roots of sugarcane stocks and other N-fixing plants such as legumes.

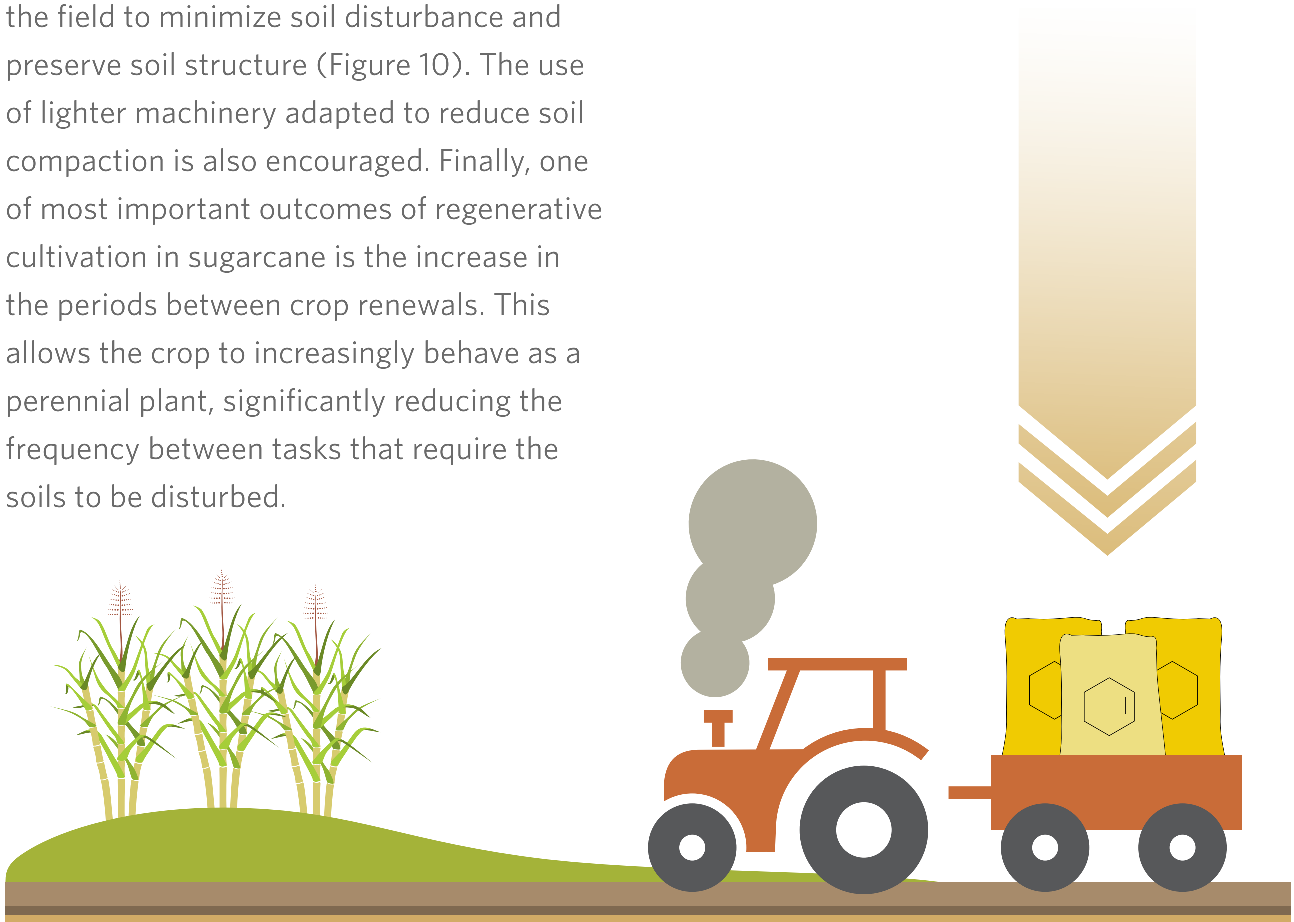
3.10.3 Soil management practices in sugarcane production

Around the world, sugarcane is often grown in large areas where most tasks are mechanized. The use of heavy machinery is an often-overlooked problem in sugarcane cultivation. However, the recurrent use of soil-disturbing practices increases the risk of damaging its structure, destroying soil aggregates, compacting the soil, and altering its infiltration and water retention capacity (Cheesman, 2004). In addition, mechanization increases GHG emissions from the use of fossil fuels.

Regenerative production does not expect to end mechanization, but it does encourage a more rational use of machinery that avoids repeated and unnecessary transit across

55. One gram of soil is estimated to contain over 1000 fungal hyphae and over 1,000,000 colonies of bacteria (Altieri, 1999).

the field to minimize soil disturbance and preserve soil structure (Figure 10). The use of lighter machinery adapted to reduce soil compaction is also encouraged. Finally, one of most important outcomes of regenerative cultivation in sugarcane is the increase in the periods between crop renewals. This allows the crop to increasingly behave as a perennial plant, significantly reducing the frequency between tasks that require the soils to be disturbed.



FACTORS THAT INFLUENCE THE DISTURBANCE OF SOIL PHYSICAL PROPERTIES

Frequency and depth of tillage practices

Type and weight of the machinery (e.g., use of more power in machinery than recommended)

Type of machinery attachments (calibration/maintenance)

Soil texture

Soil moisture

Terrain slope

Figure 10. Factors that influence the disturbance of soil physical properties.

.

Other management practices encouraged to reduce damage to soil structure are described below:

Crop renewal

Renewal is the process of pulling out old sugarcane stock and replacing it with new stock. The preparation process involves turning the arable soil layer to promote optimal conditions for the new sugarcane crop. This disturbance of the topsoil destroys soil aggregates and triggers the loss of organic matter. Renewal is done for various reasons, including to plant a newly developed variety or for phytosanitary reasons, but most often to meet targets set by the industry. In Colombia, the average time set by the mills to renew the crop is every 5-6 years.

In regenerative production, the goal is to no longer treat sugarcane as a transient crop and instead, to gradually recover its perennial nature. This means that renewal is used sparsely, and only as needed.

Replanting

The populating with seed or cuttings of areas of the field that have been left empty to maintain a homogenous planting density and a stable crop productivity. It can be done mechanically or manually. Replanting guarantees stability in crop productivity and extends crop longevity for several consecutive harvests, reducing the need for crop renewal.

Erosion control practice

Every year, 20-37,000 tons of surface soil are lost to erosion, with collateral losses of nutrients, organisms, organic matter, and other critical elements (FAO, 2021). Soil conservation practices that focus on minimizing soil disturbance can play a big role in preventing soil erosion. In sugarcane production, alternatives to minimize soil erosion caused by climatic agents include:

Windbreak

Lines of trees are established around the cultivation area to protect the crop from the impact of strong winds. Trees also protect the crop from the impact of pesticide drift, create a favorable microclimate for the crop, and provide food and shelter for local biodiversity.

Planting in contour line

The crop is planted in lines perpendicular to the natural slope of the land to reduce the amount of topsoil that is dragged in runoff due to heavy rain or irrigation.

Soil cover

Soils are kept permanently covered with crop residues to protect them from wind, precipitation, and direct sunlight, to favor moisture retention, and to provide an ideal microclimate for the action of soil organisms[56].

56. See Post-harvest crop residue management chapter.

3.10.4 Benefits

- Regenerative agriculture not only conserves soil health but it has the capacity to progressively improve it. This restoration of soil condition generates multiple benefits that positively impact productive systems, making them more resilient to climate change and more productive, providing better socioeconomic conditions for producers and communities.

3.10.5 Limitations

- Regenerative practices allow for the gradual recovery of the physical, chemical, and biological properties that define soil health. However, recovery time depends on the level of soil damage, so soils that have been under conventional management for a long time will likely take longer to recover. What makes the regenerative approach effective is not the number of practices applied, but whether those practices are designed to fit the specific context, tailored to address the existing damage, and used in combination to generate synergies among different biological processes.

- Measuring the impact of regenerative practices on soil recovery requires an assessment of the baseline conditions as a benchmark for comparison. Soil analyses are therefore a critical tool to assess progress. However, these analyses may not always be available to all producers, either due to high costs, lack of technology, or lack of access to a professional con can interpret the results.

MULTI-VARIETY SUGARCANE CULTIVATION

Multi-variety cropping combines two or more varieties in the same field, alternating rows of a single variety (as shown) or combining varieties in the same row.

Figure 11. Multi-variety sugarcane cropping.

3.11 Multi-variety sugarcane cultivation

Sugarcane breeding programs around the world are constantly working to create improved varieties, plants with a combination of genetic characteristics that makes them more productive, better adapted, and more resistant to potential risks (Table 10) (Gazaffi et al., 2014). The development of these improved varieties is, in part, what has allowed for significant productivity increases in many sugarcane producing regions, even under adverse agroclimatic conditions (Brasileiro et al., 2014). As demand for sugarcane products continues to grow, variety improvement programs will be critical to increase production without further conversion of natural areas.

Improved sugarcane varieties are used in both conventional and regenerative production, but in different ways. In conventional production, new varieties usually focus on higher productivity. Once a new variety is introduced, all fields are gradually renewed until the entire cultivation area has been replaced. This makes crop making management easier but leads to the loss of genetic diversity which may increase the risk of severe losses in case on an extreme event.

In regenerative production, the introduction of new varieties focuses on traits besides productivity, such as lower nutrient requirements or improved climate resilience. Regenerative systems also promote the simultaneous planting of two or three varieties either in separate but adjoining fields, or within the same field, a practice known as **multi-variety cropping**[57] (Figure 11). This crop configuration leverages the intrinsic characteristics of each variety to generate synergies that make an efficient use of resources, boost crop productivity, and facilitate management[58].

• Lower nutritional requirements • Lower water requirements • Increased resistance to disease and harmful insect attacks • Adaptation to special soil conditions (e.g., soil salinity, poor drainage) • Higher sucrose concentration	• Higher biomass production • Improved N-use efficiency • Tolerance to weather extremes (e.g., drought and flooding) • Shortened crop cycle (early maturity) • Improved regrowth capacity • Flowering suppression

Table 10. Criteria for the development of new sugarcane varieties.

57. Varieties in the same field are selected for high biomass production, high sucrose concentration and increased disease resistance (Zapata et al., 2022).
58- Crop management benefits include reduced frequency of pest control, weed management and irrigation.

3.11.1 Benefits

- Reduced risk of catastrophic losses in case of a severe pathogen attack or insect infestation.
- Greater resilience to climate variability from using drought- or flood-resistant varieties.
- Higher productivity per ha due to lower vulnerability to pests and diseases.

3.11.2 Limitations

- Breeding and selection of new crop varieties is a time and resource-consuming process. Because it often relies on industry funding, breeding tends to focus on productivity rather than traits valued in regenerative production, such as higher water use efficiency and lower nutrient demand.
- The goal of multi-variety cropping is to identify synergistic combinations of crop varieties that leverage genetic diversity within the cropping system. This requires experimentation, observation, and record keeping, and therefore entails risks that most farmers are not willing to take. It is therefore critical to support innovator farmers who are willing to test out these combinations.
- Variety mixing is useful when then local dominant variety does not meet production needs. However, previous experimentation is needed to identify and adequate pairing that minimizes competition.
- Combining different sugarcane varieties in the same plot adds complexity to the agronomic management as the species may behave differently. For example, adding a variety with high sucrose concentration but thin leaves may improve sugar production in the mill, but it can also facilitate weed development requiring more weed control.

Pp 130-131: 2022.08 Cali Kickoff ©Alejandra Pinzon

4 | CASE STUDIES

Riparian corridor of the Zabaleta River in the sugar cane region of the Cauca River Valley, Colombia.
Photo credit: © Leonardo Rivera, Cenicaña.

4.1 *Caña Biodiversa* Project:

Promoting Conservation and Socioeconomic Sustainability in Colombia

In the Cauca River Valley region of Colombia, historical agricultural activity has brought about gradual reductions in native tropical dry forest coverage and today, only relicts of forest and strips of riparian vegetation remain. This vegetation has the potential to provide habitat to a diversity of animal species, plants, and beneficial microorganisms that provide important services to the agroecosystem. Biological control through the natural conservation is a complementary tool to the release of biological controllers to mitigate pest attacks, a practice used in the cultivation of sugarcane in this region.

Riparian vegetation can act as biodiversity corridors, facilitating the movement of various wild species, including the natural enemies of crop-damaging insects, as well as bees and other pollinators vital to the agroecosystem, supporting them to find habitat and resources for nesting. In addition, this diversity can be harnessed for other purposes. For example, the native stingless bee can be kept by farmers, providing them with an additional income through artisanal honey production, which supports the livelihoods of rural communities while ensuring local habitat conservation.

Within this context, the Caña Biodiversa project aims to generate strategies to restore riparian corridors in sugarcane-growing areas and highlight the benefits of biodiversity for rural populations with a view to increasing sustainable development in the region while increasing the sugarcane crop's resilience to climate variability. The restoration of riparian corridors along waterways and in other uncultivated areas is carried out for three purposes:

1. to create refuge or habitats for biodiversity (flora and fauna);
2. to promote economic alternatives for the rural population; and
3. to strengthen the biological control of insects potentially harmful to sugarcane cultivation (Rivera et al., 2022).

This project is being developed in the Cauca River Valley region, an agro-landscape with a patchwork of 244,644 ha in sugarcane cultivation extending over five departments of the country (Asocaña, 2021).

The methodology for its implementation consists of three stages: 1) a diagnostic and establishment of the biodiversity baseline; 2) implementation of restoration actions; and 3) vegetation monitoring. In addition, information about the project is disseminated in the local area and environmental education spaces are created with farmers and other stakeholders in the territory in order to ensure a local sense of ownership around the project's objectives.

The diagnostic is carried out with interested producers, gathering information through interviews in five areas of interest: social context, ecosystem quality, present vegetation cover, connectivity capacity with other vegetation areas, and producers' crop management systems.

The flora inventory prioritizes the arboreal vegetation present in the riparian areas, with a total of 32 native species to date, some of which are categorized as endangered species. Similarly, some species of wild plants, commonly considered weeds, have been identified as valuable for restoration processes because they compete with other aggressive species such as grasses and grow quickly without affecting crop productivity. To learn more about the fauna, soil arthropods were sampled in farms with strips of vegetation adjacent to the sugarcane crop. Five classes of arthropods were found, including predators and regulatory parasitoids of the ecosystem. In addition, several species of wild bees were recorded, with the *Apidae* and *Megachilidae* families being observed particularly in the forest fragments, and the Halictidae family in the vegetation strips.

The restoration work is based on a site-specific design for each location, considering the flora species to be planted, the sources of plant material (e.g., nurseries, salvage of seedlings, donations), and the planting schedule.

Under the Caña Biodiversa project, more than 18 km of riparian zones belonging to 26 farms have been restored, making use of 74 tree and shrub species (6,387 specimens acquired with 85 salvaged specimens). Seventy percent of the species planted have been native, flood-tolerant species, some of which provide permanent habitats for bees.

Finally, the project has provided workshops on meliponiculture to local women from two rural localities in the region. The objective has been to train these groups of women from communities adjacent to the sugarcane fields as an activity that will both generate income for their households as well as raise awareness of the importance of conserving the region's biodiversity.

Genea jaynesi fly (Diptera: *Tachinidae*), main parasitoid of the Diatraea borer, found in natural vegetation of weeds in association with the crop. Photo credit: © Leonardo Rviera, Cenicaña.

Trees and palms planted in sugarcane field, El Hatico Nature Reserve, Colombia. Photo credit: ©Juan José Molina.

4.2 El Hatico Nature Reserve:

Pioneering Agroecological Sugarcane Production in Colombia

El Hatico Nature Reserve pioneered organic sugarcane production in Colombia and developed a model that is economically viable, environmentally friendly, and resilient to a changing climate, by applying the basic agroecological principles (Calle et al., 2022).

The transformation of El Hatico's sugarcane production system is aligned with the mission of this family business: to strengthen their legacy by integrating conservation and production. More than 30 years have gone into researching and documenting the impacts of agroecological practices on crop productivity and agroecosystem health in collaboration with the Center for Research on Sustainable Agricultural Production Systems (CIPAV), Colombian Sugarcane Research Center (Cenicaña), universities, professionals in diverse disciplines, and university students (Molina Durán et al., 2022).

In 1993, a study comparing the SOM content in different farm's land uses (sugarcane, semiannual crops, cattle, and forest) revealed that soils in the conventional sugarcane plots had much lower SOM (1.95%) than those in the farm's native forest patch (4.2%). This led to a dramatic conclusion: only two decades of conventional management practices had exhausted half of the farm's SOM (Calle et al., 2022).

These results motivated the elimination and replacement of three major conventional practices: **pre-harvest burning was replaced with green harvesting; chemical fertilizers were replaced with organic fertilization**, mainly poultry manure; and **weed control changed from chemical to integrated management** involving manual labor, sheep implementation and some mechanized practices (Calle et al., 2022). Following a three-year transition, in 1997 El Hatico obtained organic certification for their 123 ha of sugarcane and ranching. As a result of this success, in alliance with another producer and a local sugar mill, the first bag of organic sugar for

Colombia was produced in September 1999, generating a dynamic that has led local sugar mills to start implementing organic practices, with more than 20,000 hectares in transition and organic (10% of the area planted in sugarcane for the agro-industrial sugarcane sector in Colombia) (Molina Durán et al., 2022).

El Hatico Nature Reserve also implements diverse practices to make a more efficient water use: they mulch with crop residues, plant water-efficient varieties, have updated irrigation infrastructure, and use soil moisture sensors. These practices, along with the recovery of the SOM, have enabled the farm to reduce irrigation water use by 40% (Calle et al., 2022). To complement their manual weed control strategy, the farm also brought in a herd of Cuban sheep for selective weed control which has not only yielded excellent results but has reduced weeding costs by 35%. As a bonus, the sheep generate additional income from the production of high-quality meat, the sale of breeding females, and the raw material to produce organic fertilizer for the sugarcane (Calle et al., 2022).

The owners of El Hatico see soils as their most valued asset (Molina Durán et al., 2022). That is why they have focused on recovering and conserving soil health through a variety of regenerative practices, that include: **green harvesting, reduced tillage, incorporation of weed biomass, distribution of crop residues as soil cover, and integration of green manures, especially N-fixing legumes**. The results are reflected primarily in the recovery of the SOM from 2 to 4%, almost the level of native forest (Arias, 1994). Other soil properties showing significant improvement over time are biostructure, porosity, *Pb*, pH, natural P, and cation exchange capacity, all of which are key for sugarcane production (Zapata et al., 2022).

As a Nature Reserve, El Hatico also emphasizes conservation by maintaining forest fragments and native vegetation strips along crop margins, and strips of trees and weeds within the crop. These elements support populations of beneficial organisms such as ants, spiders, parasitoid wasps, and birds which contribute to an effective biological control of sugarcane pests (Calle et al., 2022).

While agroecological management has clear benefits for resource conservation, this model is only sustainable if the farm's productivity and profitability remain competitive. This is the case in El Hatico, where average productivity measured in tons of cane per hectare per month is 5 to 8% higher, outperforming the average of conventional production in the same agroclimatic zone. In addition, agroecological sugarcane has an average useful life of 20 cuts before renovation, compared to the industry's 5 cuts (Cenicaña2001–2018 Informes anuales cited by Calle et al., 2022).

Finally, the regenerative practices implemented in El Hatico also lead to reductions in total GHG emissions. Accounting for total emissions from the use of fossil fuels and electricity, N_2O emissions, use of chemical inputs and transportation, regenerative sugarcane production can reduce emissions by up to 70% compared to conventional management (Molina Durán et al., 2022; Calle et al., 2022). Sugarcane managed agroecologically generates a much higher favorable carbon footprint compared to other agricultural and forestry activities due to its status of C4 plant, which makes it the most efficient plant in carbon sequestration due to its photosynthetic process.

El Hatico Nature Reserve in numbers:

Generates 50 direct employments.

Benefits at least 200 people directly.

15% (40 ha) of the reserve's total area is used for the conservation of the tropical dry forest (the most threatened on Earth).

30% of the crop is harvested manually.

The oldest cane now has 29 cuts, without crop renewal, thus promoting one of the great benefits of sugarcane cultivation, its perennial nature.

40% reduction in irrigation water.

Recovery of 100% of SOM over 25-year period.

With agroecological management, the arrival of different forms of life is potentiated, conserving, and multiplying biodiversity of birds, ants, butterflies, spiders, among others.

4.3 Native:

Advancing Organic Sugarcane Production at Scale in Brazil

The Balbo Group is a Brazilian company that produces sugarcane in the districts of Sertãozinho, Ribeirão Preto, Jardinópolis, Dumont, Barrinha and Jaboticabal. For decades, they have been working to develop and refine a sustainable sugarcane production model that balances their economic, social, and environmental interests. Having explored ways to diversify their business lines through improved production, the company stands as an example that such sustainable production at an industrial scale is possible.

The Group's transition to a more sustainable production model was motivated by the desire to restore the natural balance of the soils and restore their fertility. They started by implementing crop management practices such as planting green manures and transitory crops and mulching with crop residues in the cultivated area. These practices resulted in increased SOM and improved soil structure, which in turn enhanced water filtration and retention capacity, and reduced losses to evaporation.

In 1986, the group shifted focus to the landscape and started implementing interventions to recover and conserve islands of biodiversity in the proximity of cultivated areas. They planted over one million native trees on hundreds of hectares in and around the cultivation areas, prioritizing lakes, wetlands, and other freshwater bodies. They also started monitoring wildlife and recoded 312 vertebrate species –26 amphibians, 230 birds, 39 mammals, and 17 reptiles– from 2002-2003.

In 1997, the company achieved organic certification for nearly 7500 ha of sugarcane; it has since expanded certified areas that supply organic sugarcane to several of its mills. By combining organic production with improvements in energy efficiency from replacing gasoline with energy from sugarcane bagasse and ethanol, the Group has significantly reduced GHG emissions relative to conventional production. In fact, Native, the group's

Organic sugarcane production. Photo credit: ©mangostock.

flagship organic brand, achieved carbon neutrality in 2006-2007.

Today, the Balbo group regularly implements a variety of practices, including:

- Biological pest control
- Restoration of native forests
- Green harvesting
- Recycling of agro-industrial organic effluents
- Use of green manures
- Biomass energy production
- Generation of carbon credits
- Biodiversity monitoring in agricultural areas
- Waste composting for biofertilizer production

Between 1998-2009, the Balbo Group's organic production reached a sugarcane productivity of 110 tons ha^{-1}, higher than the average 95 tons ha^{-1} in its conventional plots. This result is in open contradiction with the common view that organic systems are less productive and demonstrates that it is possible to produce sustainably on a large scale, while providing benefits for farmers, consumers, associates, and for biodiversity.

4.4 Mechanization and Workforce:

Improved Labor Practices in the Philippines and China

Labor Proforest has been supporting the responsible production and sourcing of agricultural and forest commodities by helping companies and their supply chains to have positive social and environmental outcomes in agricultural landscapes (Proforest, 2022). As part of this work, the non-profit group has intervened in sugarcane production in the Philippines and China. A key takeaway from the work done to date is that an increase in mechanization due to the adoption of some regenerative practices, does not necessary result in loss of job opportunities for the local workforce. Examples in both countries show that there is a severe labor shortage, especially harvesters, which gives rise to: 1) harvesting tasks being shifted to aging and female farmers, and 2) changes in the negotiation dynamics between the employer and the harvester. In this context, evidence shows that the sugarcane sector has had to rely on expensive local labor to harvest the cane. For example, in China cases were reported of seasonal workers coming from Vietnam to supply labor for the harvest. However, given the stricter border restrictions put in place due to Covid-19, it is not clear whether Vietnamese workers have returned in the same numbers. This suggests that even as mechanization is adopted, the need for labor remains and harvesters may now be in a better position to demand higher wages and better living conditions.

Where mechanization could potentially outcompete local labor, some producers choose not to mechanize and instead provide employment opportunities to local communities. Employments are mainly being offered it other farming activities such as land preparation, planting, weeding or input application. The need to retain farmers may also be driving some management decisions. For example, despite the negative effects of smoke inhalation, the decision

Crop residue distribution in sugarcane field, the Philippines. Photo credit: ©Proforest.

to maintain the practice of pre-harvest burning may be driven by other health and safety considerations, such as farm workers' concerns about exposure to insect bites, snakes, scratches, and their demand that fields are burnt prior to harvesting.

In the Philippines, large scale planters have developed a high level of social responsibility for the farmers and worker communities in their area. They are interested in seeing how regenerative agriculture can benefit these communities through 1) the transfer of knowledge and capacity regarding better/ more innovative farming practices; or 2) the potential to strengthen livelihoods indirectly through opportunities linked to regenerative practices, in particular using the quiet periods during the crop cycle for activities such as production of organic fertilizer, composting, or additional harvesting from crop rotation/intercropping, etc. Proforest is implementing its Responsible Sourcing from Smallholders (RSS) program in the Negros Occidental landscape to enhance working conditions for smallholders and improve their access to training on sustainable sugarcane production (Proforest, 2022). The program was developed under the SHARP Partnership funded by Nestlé and American Sugar Refining (ASR); so far it has reached over 4,000 farmers with training on the proper use of personal protective equipment (PPE) and the distribution of 3,000 PPE kits to sugarcane farmers.

4.5

Women and Youth in the Sugarcane Sector:

Improving Participation in Belize

According to recent data from the Sugar Industry Control Board in Belize, sugarcane farmers in the country are aging, and this poses a threat to the sustainability and continuity of the industry. In Belize, as in the rest of the world, women account for half of the population by gender, and youth for half of the population by age (SIB, 2022). However, women in the agricultural sector are typically underrepresented, paid less than men, and are limited in certain land rights, all of which leads to a lack of gender equity in the agri-food sector.

To fulfil the right to gender equality in labor issues, Belize's sugar industry started working with women and youth to empower and guide them into jobs that were previously regarded as exclusively masculine. In 2011, the Sugar Industry Research and Development Institute (SIRDI) adopted the Farmer Field School (FFS) methodology to improve support for and interaction with women, youth, and farmers, and to adapt best management practices in sugarcane production. The FFS methodology, released by FAO in 1989, has been validated in various continents showing great adaptability to different crops and cropping systems. The FFS program is based on the principles of learning through practical examples and hands-on application, with knowledge exchange and experience sharing among all participants. These exchanges are then strengthened through FFS modules which rely on field practices as the main learning methodology. Twelve training modules were delivered over a period of 20 months to groups of 25–30 leading farmers.

Students visit sugarcane fields, Belize. Photo credit: ©Luciano Chi.

The main outcome of the program were the training courses offered in Corozal and Orange Walk, two predominantly agricultural districts of Belize, with 276 students, mostly women and youth, trained in best sugarcane management practices. The women and youth that participated in the modules have been able to increase their yields, optimize the use of synthetic inputs and eliminate post-harvest burning, with significant environmental, economic, and social benefits. This type of gender and youth inclusion programs not only benefits participants but may also contribute to improving generational relay which is a big challenge for the farming sector globally.

Sugarcane cultivation in Ahuachapán, El Salvador. Photo credit: ©Tomás Castro.

4.6 Resilient Sugarcane:

Fostering Partnerships to Achieve Sustainable Transformation in El Salvador

The Nature Conservancy (TNC) and the Foundation for Business Development of El Salvador (Fundemans) partnered in the Resilient Central America (ResCA) project to promote Corporate Social Responsibility in the sugarcane and ranching sectors. The project focused on the region of Ahuachapán in the southwest of El Salvador. Activities aimed to change the business-as-usual practices through the implementation of demonstration plots where farmer-to-farmer and technical exchanges were held, resulting in increased knowledge-sharing and innovation both at farm and sector level.

Fundemas worked with Fundazucar, which promotes sustainable development in sugarcane production, and in partnership with six sugarcane mills. By partnering with key stakeholders, the ResCA Fundemas project was able to reach producers and other actors in the value chain via trusted local organizations (TNC, 2021a). Partnerships with local authorities and research centers ensured that science-based data and knowledge reached the demonstration plots, sector associations, and local producers. Building capacity across the sugarcane value chain was key in promoting the adoption of better management practices and sustainability principles at all levels, and around three main components:

- **Promoting sustainable agricultural production policies.** Best practices for sugarcane production were co-designed, consulted, validated, and launched with key allies, including mills, producers, public sector representatives and union members. An online tool was developed to monitor best practices allowing for comparison and information exchange among stakeholders. A manual for agroecological production was developed and adopted by sugar mills, producers, and cooperatives as a tool to showcase successful models and promote their replication. Staff from Fundazucar and local sugar mills were trained to promote this more sustainable productive model.

- **Strengthening alliances.** ResCA worked in collaboration with central and local governments, the private sector (entrepreneurs, large farmers, medium, small and microenterprises) and civil society. Alliances were established with the Salvadoran Institute for Agrarian Transformation (ISTA), the Ministry of Environment and Natural Resources, and Davivienda Bank to restore forest patches in sugarcane cropping landscapes in the municipality of Jujutla. This was a successful case for private-public alliances to improve sugarcane production at landscape level.

- **Building producers' capacities.** Training in agroecological models was provided to 179 sugarcane producers and local technicians. A cross country exchange of experiences between producers, technicians, and experts from research institutions took place in Colombia with the participation of key stakeholders from El Salvador. Demonstration farms were then established and received technical assistance to ensure the ongoing conservation of natural resources, soil restoration and reduction in the use of external inputs.

Fundemas and Fundazucar designed 'Observatories for Improved Agricultural Practices in the Sugarcane Sector' to establish a monitoring system that compiles results and analyzes information about the practices implemented. These observatories were intended to remain in six sugar mills of El Salvador, which account for 60% of the country's production, and to continue providing relevant information to the sector both locally and regionally through a public webpage (TNC, 2021a).

ResCA enabled sugarcane farmers to see the results of improved practices such as soil nutrition, integrated pest management, and worker health and safety measures. Coordination with the sugar mills was important to help scale sustainable practices across El Salvador. A protocol agreement with mills considered actions such as phasing-out herbicide use, eliminating pre- and post-harvest burning, and implementing practices that improve soil quality and moisture retention to achieve sustainable outcomes and reduce production costs for Salvadorian farmers.

Crop residues as soil cover in sugarcane cultivation. Photo credit: ©Tomás Castro.

4.7

Climate Change Project:

Reducing Greenhouse Gas Emissions from Nestle sugarcane production in Thailand

FairAgora Asia (FAA), a Thai registered company based in Bangkok, has a regional presence in Southeast Asian markets and provides advisory services, monitoring, data science and training in compliance and sustainability with a focus on agriculture and seafood industries. The Climate Change project (2021-2025) was initiated by Nestle and FAA to tackle climate change and promote human rights awareness under the commitment of Nestlé's responsible sourcing to the UN Guideline principles. The main objective is to reduce GHG emissions in the Thai sugarcane production at the farm level, while encouraging the adoption of sustainable farming practices and ensuring a decent livelihood for all farmers.

After conducting an extensive literature review, the FAA team has written a detailed report on the implementation of regenerative agriculture practices in Thai sugarcane farming. This background knowledge was key to orientate the choices of farming practices and the training topics to implement. Monitoring GHG emissions requires specific scientific knowledge and rigor, and the scarcity of available information on how to build a GHG emissions model for sugarcane was a challenge for this project. The Fairagora team has done extensive research on the appropriate methodologies required before computing the model to estimate GHG emissions at the farm level. The construction of the model in the R open software follows an iterative process and the current version already covers the main emission sources.

FAA is working with the mills in the Nestlé supply chain, the governmental organization 'Office of the Cane and Sugar Board' (OCSB), and the Farmers Associations to collect the data required for the project. The data collection process is a big challenge given that some stakeholders can be reluctant to share detailed information. The project also

Sugarcane cultivation, Thailand. Photo credit: ©subinpumsom.

fosters a bottom-up approach by onboarding local leaders and heads of villages to increase trust by the farmers and mills. The team has created specific surveys that will be useful to collect additional information with the farmers to crosscheck the answers with the data provided by the other stakeholders involved. Online media channels like Facebook, Youtube and Tiktok are used to support daily interactions with farmers and provide specific knowledge on social and environmental topics.

The direct next steps will be the implementation of onsite workshops to increase awareness about regenerative agriculture practices such as reducing the burning and optimizing the fertilizer input.

Training on social topics is also planned: living income wages, gender equality, child labor, access to education, responsible recruitment, data protection and better health and safety for all workers. FAA team is currently also exploring a scenario with an optimization of the sugarcane production to increase carbon sequestration, and the implementation of farming practices that would enable higher N-fixation in the soil and therefore reduce the amount of fertilizer required. The expected results of this project are, on the one hand, a clear identification of the most effective mitigation activities that can realistically be implemented and scaled in Thailand, on the other hand, a 5 % reduction of the overall GHG emissions from the sugarcane farms within Nestlé's supply chain.

Sugarcane cutter. Photo credit: ©maurotoro.

4.8

Hydration, Shade, and Rest:

Improving Welfare for Cutters in Mexico

In Mexico, chronic kidney disease (CKD) is one of the main reasons for the use of emergency services and for hospitalization. It is estimated that as much as 15-20% of the Mexican social security budget is spent on kidney disease care, which represents a significant challenge for the healthcare system (Secretaría de Salud México, 2018).

Sugarcane crop workers are one group particularly at risk from CKD, as they are subjected to long working days in the field under high temperatures, direct sun exposure, inadequate hydration, and limited access to rest areas (Ramos Sandoval et al., In review). Although these agricultural workers represent a sizeable percentage of CKD patients, there is no reliable data on the precise numbers affected.

In the field, a sugarcane cutter subjected to temperatures of up to 45°C and demanding physical exertion may lose 3-4 liters (L) of water per day. To compensate for this loss, a daily hydration of 5.5-7 L of water would be recommended. However, because areas of work are remote and access to safe drinking water is often difficult, workers usually consume only the water they can carry, which is insufficient, and often of poor quality.

Proforest has been working with various groups focused on sugarcane cultivation - Beta San Miguel, Ingenios Santos, and Grupo Azucarero México - to improve the working conditions of sugarcane cutters in the principal sugarcane growing regions of Mexico. To address the problem of dehydration, Proforest has implemented a program in which each worker is given a thermos of between 3.8-5 L capacity to ensure that they have drinking water during their working day. The cutting group leader is responsible for providing the thermoses and supplying the water, sometimes with electrolytes, for workers to refill their bottles in the field.

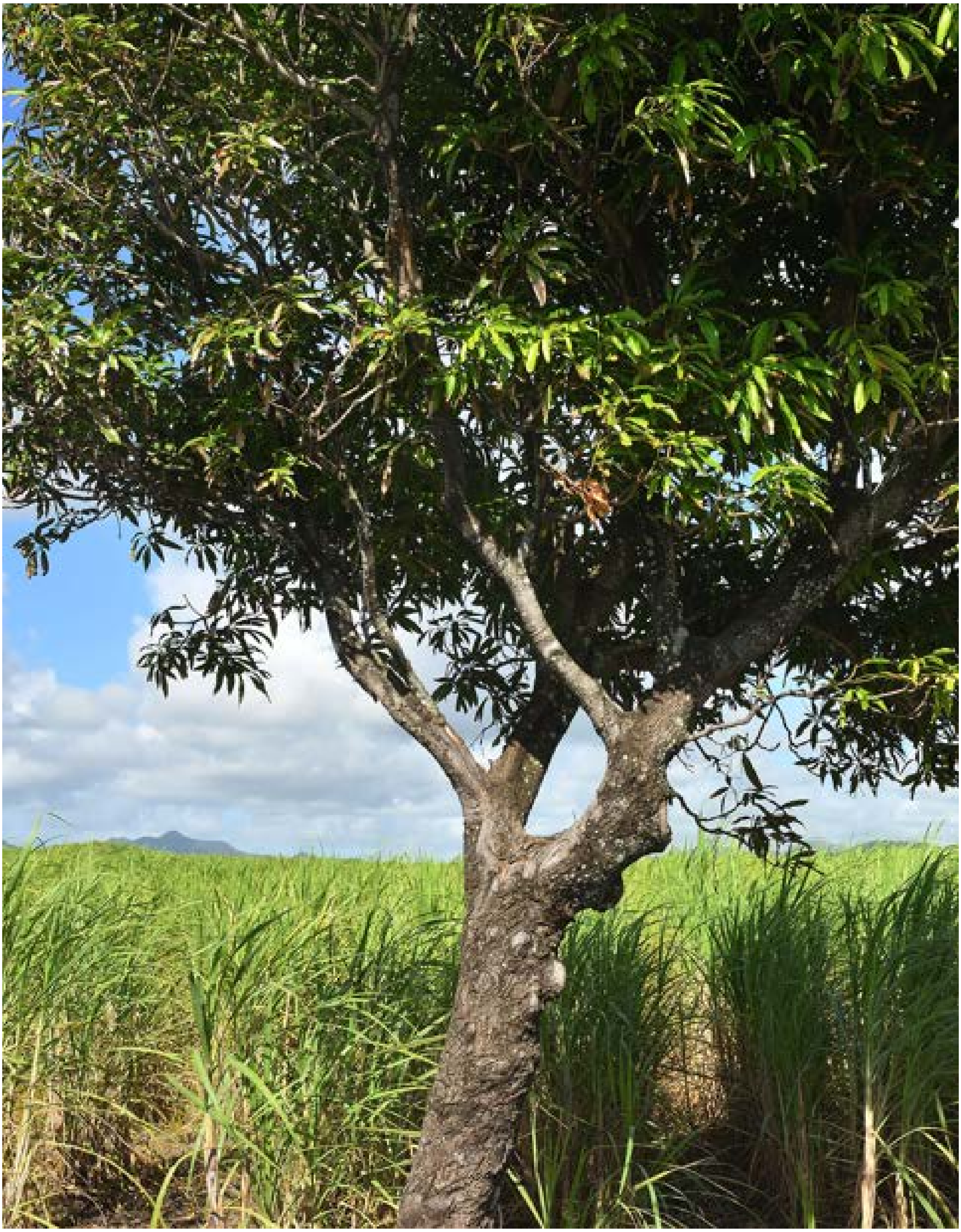
Implementing this initiative has not been easy, with some of the main obstacles being the difficulty of designing a monitoring system capable of measuring the impacts generated, and the coordination of logistical aspects, as each workplace context varies. For example, some mills have lodges for workers where purifying equipment can be installed to guarantee access to safe drinking water. But in cases where workers do not live in shelters, it is difficult to determine the origin and purity of the water they consume. In addition, it is necessary to implement training activities to generate awareness and commitment, and to reach agreements between different actors in this sector, such as workers' associations and sugar mills.

In addition to hydration, the implementation of a schedule which includes regular breaks is encouraged, with the aim of ensuring that workers take a 15-minute break for every two hours of work in the field. However, it is not always easy to encourage workers to take such breaks voluntarily because their pay is based on the amount of cane they cut: stopping to rest can affect their income in the short term.

This project has been in development for five years and has the potential to be scaled up as there is interest on the part of the mills in continuing to improve workers' conditions. This interest is closely linked to the growing labor shortage in the agricultural sector in general, which results in an increasing need to improve living and working conditions in the field. Today, working conditions may be a decisive factor in employee retention, even more so than economic remuneration.

Some the impacts of the project identified by the producers' associations include lower turnover and greater worker loyalty, higher productivity during cutting hours, and other indirect results such as improved worker health through increased access to better quality water.

This initiative reflects the advances in social responsibility that have already been achieved in Central America on similar issues, where guaranteeing hydration and rest for field workers and even offering one day off per week are already the norm.



Trees in sugarcane crop can provide shade to cutters. Photo credit: ©znm666.

Hacienda Alguimar/Balsora, Colombia. Photo credit: ©López Ochoa Family

.

4.9

Living the Future Today:

Benefits of Adopting Sustainable & Regenerative Agroecological Practices in Colombia

"Healthy soil is our true legacy and the future of humanity."

Since 1991, Hacienda Alguimar/Balsora in Colombia, run by third-generation farmers, has been producing sugarcane on an area of 240 hectares. Today, it produces an average of 135 tons/ha of organic-sustainable sugarcane, 10% higher than the average production for conventional agro-industrial sugarcane in Colombia.

Although Alguimar/Balsora began as a conventional sugarcane producing farm, over the last 30 years it has transitioned to organic-sustainable production, developing greater climate resilience, and lessening its impact on ecosystem resources. In this transition, the López Ochoa family has been dedicated to continually improving their organic-sustainable production by implementing farm-based and administrative practices that reduce pressure on the agroecosystem, as well as improving social conditions, which ultimately help improve the productivity and profitability of the crop. This dedication is how they now hold organic certification from the European Union (EU), the United States (USA-NOP), and the Colombian national standard (NM).

Alguimar/Balsora's objective is to achieve self-sufficient sugarcane production through sustainable, regenerative agroecological practices which reduce GHG emissions and increase carbon capture, with an emphasis on social responsibility to improve the working conditions and wellbeing of its workers while improving soil health. These factors are understood as the keys to guaranteeing its continued existence for future generations.

The use of technology is one of the central pillars for improving the efficiency of management practices, such as the **early identification of insects harmful to the crop** and **weed control**. Drones are also used to **optimize fertilizer use** and **estimate weed coverage**, as well as to support other administrative tasks such as **delineating the farm area**. In the future, the family hope to further reduce the use of external agricultural inputs, giving priority to their own on-farm production of organic inputs. They aim to improve the recovery and conservation of biodiversity by planting areas of vegetation other than crops and hope to start using robots for certain practices.

POSITIVE IMPACTS OF OUR RESULTS COUNTERACT PARADIGMS

COST FROM CONVENTIONAL TO ORGANIC/SUSTAINABLE PRODUCTION:

PRODUCTION COST + 12% AND PROFITABILITY > 35%

Climate change
- 10% TCH above market (135 vs 122).
- 25 cm vs 40 cm decompaction depth.
- 100+ tons GHG capture per hectare/year.
- 0.93 tons GHG emitted per hectare/year.
- 70+ tons O2 emitted per hectare/year.

Irrigation & Pollutants
- 60% water/irrigation reduction (3200 to 1300 m^3).
- 33% irrigation events reduction (6 to 4 events per cycle).

Land Degradation
- 76.5% increase in SOM in 12 years (1.7% to 3.3%).
- Less crop renovation compared to the sector (9 vs 5.2 cuts).
- Use of harvest residues, microorganisms, compost, and green manure for crop nutrition.

Deforestation
- Ecological restauration plan and study of beneficial weeds.

Employment
- Annual training plan.
- 12.3 years for employee rotation.
- 100% employment generation.

AND 100%:
- Synthetic fertilizers elimination – organic use only.
- Herbicides elimination – manual and mechanic removal.
- Biological and natural control of insect populations.
- Cane burning elimination.

KEY AGRICULTURAL PRACTICES

1992 - 2000

Economic and On-Farm Approach: Increase production by using synthetic products and controlling costs.

- Design and leveling of farm.
- Implementation of drainage system.
- Use of windows pipes irrigation system.
- Biological control of *Diatrea spp*.
- Liquid fertilization with vinasse and diluted N.
- Perform soil analysis every five years.
- Formalize labor contracts and establish fair salaries.
- Investment in research & development.
- Document tasks, labor hours, inputs, consumption, use and maintenance of machinery, among others.

2001 - 2009

Environmental Awareness + Global Vision: Perform field sustainable practices and learn about global certifications and their requirements.

- Use of sugarcane residues for soil improvement.
- Use of inoculated and decomposer microorganisms to reintegrate residues into the soil.
- Elimination of sugarcane burning.
- Use of green manures (legumes).
- Use of alternative crops such as soybeans, sorghum, corn (integrated and rotational).
- Reduction in the use of synthetic inputs.
- Use of Personal Protective Elements (PPE).
- Formalization of employees' training.

2010 - 2016

People + Business Vision: Transform the administrative management with a vision of people and business. Compliance with sustainability indicators.

- Generation of direct employment (15% increase) and contractors (100% increase).
- Improved employee infrastructure.
- Elimination of the use of ripeners.
- Implementation of manual and mechanical weed control.
- 50% reduction in the use of synthetic fertilizers.
- Use of efficient microorganisms for pest and disease control.
- Processes development and documentation.
- Developed indicators.
- Started the use of the cloud communicating farm and office.
- Started Avenzza, the consulting practice.

2017 - 2022

Organic and Digital Transformations: Aim to become organic-sustainable, strengthen the use of digital technology and run farm open days for the public.

- Use of humidity sensors (matric potential).
- Use of drones for fertilization and administrative management.
- Use of digital equipment for tractor control and monitoring.
- Compliance with the Bonsucro production standard.
- Creation of biological corridors.
- Use of harvest cane residues for soil cover.
- Use of compost.
- Reduction of decompaction depth.
- Weeds incorporated as a source of organic matter.
- Design and adoption of new implements for the field.
- Performed soil and foliar analysis.
- CO_2 capture and GHG emissions measured.
- Compliance with local standards (Cenicaña sustainability guide).

Bourbon-Rohr
(Cheribon)
Hauptgegenstand der ae-
gyptischen Zuckerrohrcultur
Bourbon-Rohr
(Cheribon)
nat. Gr.
G. Schweinfurth

5 | REFERENCES

Saccharum officinarum - Berlin Botanical Garden, Germany CC BY-SA.

Altieri, M. A. (1999). The ecological role of biodiversity in agroecosystems. *Agriculture Ecosystems and Environment*, *74*, 19–31.

Arévalo, L. F., Vasco R, G. F., Albino-Bohórquez, A., Morales, J., Bacca, T., Arévalo, L. F., Vasco R, G. F., Albino-Bohórquez, A., Morales, J., & Bacca, T. (2021). Coffee crop weeds: refuge and food source for pests' natural enemies. *Revista de Ciencias Agrícolas*, *38*(2), 36–49. https://doi.org/10.22267/RCIA.213802.157

Arroyo, E. A., Romero, J. I., Sanzano, A., & Madrid, F. (2020). *Incidencia del fósforo en la producción de caña de azúcar*.

Asocaña 2021. Aspectos generales del sector agroindustrial de la caña. Informe anual 2020-2021. Web page. Retrieved from: https://www.asocana.org/modules/documentos/vistadocumento.aspx?id=17545

Avilez, O., Ulloa, M., Westby, L., Gonzalez, E., & Flores, G. (2021). *Best Management Practices Manual - For the Cultivation of Sugarcane in Belize*.

BEROE. (2022). Organic Sugar Europe Market Intelligence. Organic Sugarcane Europe. Web Page. Retrieved from: https://www.beroeinc.com/category-intelligence/organic-sugar-europe-market/#:~:text=Which%20countries%20are%20the%20global,is%20approximately%203%2C20%2C000%20tons

Bharathi, Y., Prabhakar Reddy, T., Shahana, F., & Vijay Kumar, M. (2017). Variability trends for brix content in general cross combinations of sugarcane (Saccharum Spp.). *Agriculture Update*, *12*, 2795–2799. www.researchjournal.co.in

Blanco, Y., & Leyva, Á. (2007). Las arvenses en el agroecosistema y sus beneficios agroecológicos como hospederas de enemigos naturales. *Cultivos Tropicales*, *28*(2), 21–28. http://www.redalyc.org/articulo.oa?id=193217731003

Bordonal, R. de O., Carvalho, J. L. N., Lal, R., de Figueiredo, E. B., de Oliveira, B. G., & la Scala, N. (2018). Sustainability of sugarcane production in Brazil. A review. *Agronomy for Sustainable Development 2018 38:2*, *38*(2), 1–23. https://doi.org/10.1007/S13593-018-0490-X

Brasileiro, B., Marinho, C., Costa, P., Peternelli, L., Resende, M., Cursi, D., Hoffmann, H., & Barbosa, M. (2014). Genetic diversity and coefficient of parentage between clones and sugarcane varieties in Brazil. *Genetics and Molecular Research*, *13*(4), 9005–9018. https://doi.org/10.4238/2014.October.31.15

Bustillo Pardey, A. E. (2013). *Insectos Plaga y Organismos Benéficos del Cultivo de la Caña de Azúcar en Colombia*. Cenicaña. www.cenicana.org

Calle D, Z., Molina C, C. H., Molina D, C. H., Molina D, E. J., Molina E, J. J., Murgueitio C, B., ... & Murgueitio R, E. (2022). *A highly productive biodiversity island within a monoculture landscape:*

El Hatico nature reserve (Valle del Cauca, Colombia). In Biodiversity Islands: Strategies for Conservation in Human-Dominated Environments (pp. 279-304). Springer, Cham.

Campari, J. (2021). Los sistemas alimentarios y la propuesta de vías de acción y objetivos de investigación (en línea, teleconferencia). *Diálogo Virtual Independiente Para La Cumbre de Los Sistemas Alimentarios (FSS) 2021: Ciencia, Tecnología e Innovación Para Transformar Los Sistemas Alimentarios de América Latina*.

Campbell, B. M., Beare, D. J., Bennett, E. M., Hall-Spencer, J. M., Ingram, J. S. I., Jaramillo, F., Ortiz, R., Ramankutty, N., Sayer, J. A., & Shindell, D. (2017). Agriculture production as a major driver of the earth system exceeding planetary boundaries. *Ecology and Society*, *22*(4). https://doi.org/10.5751/ES-09595-220408

Canegrowers. (2017a). *Fertiliser application improvements*. https://www.canegrowers.com.au/page/cane-to-coast/nutrient-management/fertiliser-application-improvements

Canegrowers. (2017b). *Nutrient management*. https://www.canegrowers.com.au/page/cane-to-coast/nutrient-management

Carmo, J. B. do, Filoso, S., Zotelli, L. C., de Sousa Neto, E. R., Pitombo, L. M., Duarte-Neto, P. J., Vargas, V. P., Andrade, C. A., Gava, G. J. C., Rossetto, R., Cantarella, H., Neto, A. E., & Martinelli, L. A. (2013). Infield greenhouse gas emissions from sugarcane soils in brazil: Effects from synthetic and organic fertilizer application and crop trash accumulation. *GCB Bioenergy*, *5*(3), 267–280. https://doi.org/10.1111/J.1757-1707.2012.01199.X

Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). *Guía para el manejo integrado de plagas del cultivo de maíz*. Informe técnico No 152, CATIE, Turrialba, Costa Rica, 1990.

Cegnicaña. (2017). *Guía de buenas prácticas agrícolas en caña de azúcar*.

CENICAÑA. (1995). *El cultivo de la caña en la zona azucarera de Colombia* (C. Cassalett Dávila, J. Torres Aguas, & C. Isaacs Echeverri, Eds.).

CENICAÑA. (2015a, March 17). *Abonos orgánicos en el cultivo de la caña de azúcar*. Abonos Orgánicos En El Cultivo de La Caña de Azúcar. https://www.cenicana.org/abonos-organicos/

CENICAÑA. (2015, March 17). *Maduración de la caña*. https://www.cenicana.org/maduracion-de-la-cana/

CENICAÑA. (2015b, March 17). *Riego con caudal reducido*.

CENICAÑA. (2018, May 31). *Uso de sensores para el control del riego. Cartilla didáctica*.

CEPAL, FAO, & IICA. (2021). *Perspectivas de la Agricultura y del Desarrollo Rural en las Américas: una mirada hacia América Latina y el Caribe 2021-2022*.

Chacón, J. F. (2019). *Protocolo para la producción de caña de azúcar en áreas de interés ecológico*. www.centroamericaresiliente.org

Chauhan, B. S., Ali, H. H., & Florentine, S. (2019). Seed germination ecology of Bidens pilosa and its implications for weed management. *Scientific Reports 2019 9:1*, *9*(1), 1–9. https://doi.org/10.1038/s41598-019-52620-9

Cheesman, O. D. (2004). Environmental Impacts of Sugar Production. *The Cultivation and Processing of Sugarcane and Sugar Beet*. CABI Bioscience UK Centre.

CONADESUCA. (2016). *Vinazas: alternativas de uso*.

Córdova-Gamas, G., Salgado-García, S., Castelán-Estrada, M., Palma-López, D. J., García-Moya, E., Lagunes-Espinoza, L. D. C., & Córdova-Sánchez, S. (2016). Opciones de fertilización para el cultivo de caña de azucar (saccharum spp.) en Tabasco, México. *Agroproductividad*, *9*(3), 27–34. https://www.redib.org/Record/oai_articulo2286847-opciones-de-fertilizacion-para-el-cultivo-de-ca%C3%B1a-de-azucar-saccharum-spp-en-tabasco-m%C3%A9xico

Cruz Valderrama, J. R. (2015). *Manejo eficiente del riego en el cultivo de la caña de azúcar en el valle geográfico del río Cauca*. Centro de Investigación de la Caña de Azúcar de Colombia.

de Andrade, S. J., Cristale, J., Silva, F. S., Zocolo, G. J., & Marchi, M. R. (2010). Contribution of sugarcane harvesting season to atmospheric contamination by polycyclic aromatic hydrocarbons (PAHs) in Araraquara city, Southeast Brazil. *Atmospheric Environment, 44(24), 2913-2919.*

Digonzelli, P. A., Scandaliaris, J., Alonso, L. G. P., Giardina, J. A., Casen, S. D., Romero, E. R., Fernández, J., Javier, U. M., Fernanda, T. M., & Neme, L. (2019). *CAPÍTULO 6 | Manual del Cañero*.

Dudley, N., & Alexander, S. (2017). Agriculture and biodiversity: a review. *Biodiversity*, *18*(2–3), 45–49. https://doi.org/10.1080/14888386.2017.1351892

Echeverri Sánchez, A. F., Urrutia Cobo, N., & Barona Ramírez, S. M. (2020). Vulnerabilidad de fuentes hídricas superficiales de la cuenca del río cerrito a la contaminación difusa agrícola. *Revista de Investigación Agraria y Ambiental*, *11*(2), 117–130. https://doi.org/10.22490/21456453.3136

Fairagora Asia. (2022). *Regenerative agriculture for sugar cane in Thailand*.

FAO. (2021). El estado de los recursos de tierras y aguas del mundo para la alimentación y la agricultura. *Sistemas al límite*. https://doi.org/10.4060/cb7654es

FAO. (2022, July 25). *Land & Water*. The Importance of Sustainable Water Management.

FAO. (2022a). *Propiedades Químicas. Portal de Suelos de la FAO*. https://www.fao.org/soils-portal/soil-survey/clasificacion-de-suelos/sistemas-numericos/propiedades-quimicas/es/

FAO. (2022b). *Secuestro de Carbono en el Suelo|Portal de Suelos de la FAO*. https://www.fao.org/soils-portal/soil-management/secuestro-de-carbono-en-el-suelo/es/

FAO. (2022c). *Statistical Yearbook: World Food and Agriculture 2021*. https://www.fao.org/3/cb4477en/online/cb4477en.html

FAO. (2022d, May 19). *AGROVOC Multilingual Thesaurus*. AGROVOC Multilingual Thesaurus. https://agrovoc.fao.org/browse/agrovoc/es/page/c_389fe908

FAOSTAT. (2022). *Food and agriculture data*. https://www.fao.org/faostat/en/#home

Fernandes Carlos da Costa, A., Monteiro Rolim, M., Maria Bonfim-Silva, E., Euzébio Simões Neto, D., Regis Maria Pedrosa, E., & Farias França Silva, Ê. (2016). Accumulation of nitrogen, phosphorus and potassium in sugarcane cultivated under different types of water management and doses of nitrogen. *AJCS*, 10(3), 362–369. https://doi.org/10.21475/ajcs.2016.10.03.p7205

Gazaffi, R., Oliveira, K. M., Souza, A. P. de, & Garcia Franco, A. A. (2014). Sugarcane: Breeding methods and genetic mapping. In *Sugarcane bioethanol — R&D for Productivity and Sustainability* (pp. 333–344). Editora Edgard Blücher. https://doi.org/10.5151/blucheroa-sugarcane-sugarcanebioethanol_33

Ghube, N. B., Kadlag, A. D., & Kamble, B. M. (2017). Impact of different levels of organic and inorganic fertilizers on growth, yield and quality of preseasonal sugarcane ratoon in Inceptisols. *Journal of Applied and Natural Science*, 9(2). https://doi.org/10.31018/jans.v9i2.1281

Gisele, S. de A., Cristiane, de C. M., Ayres, de O. M. J., Amarildo, P., Osmar, R. B., Ana, C. B. C., Jaime, H. dos S. J. uacute nior, Deise, A. O. K., & Luis, F. A. (2016). Impact of harvesting with burning and management of straw on the industrial quality and productivity of sugarcane. *African Journal of Agricultural Research*, *11*(28), 2462–2468. https://doi.org/10.5897/AJAR2016.11014

Gonçalves, C. A., de Camargo, R., de Sousa, R. T. X., Soares, N. S., de Oliveira, R. C., Stanger, M. C., Lana, R. M. Q., & Lemes, E. M. (2021). Chemical and technological attributes of sugarcane as functions of organomineral fertilizer based on filter cake or sewage sludge as organic matter sources. *PLOS ONE*, *16*(12), e0236852. https://doi.org/10.1371/JOURNAL.PONE.0236852

Gordon, E., Davila, F., & Riedy, C. (2022). Transforming landscapes and mindscapes through regenerative agriculture. *Agriculture and human values*, 39(2), 809-826.

Guimarães, G., Lana, R. de P., Rei, R. de S., Veloso, C. M., Sousa, M. R. de M., Rodrigues, R. C., & Campos, S. de A. (2016). Sugarcane production fertilized with poultry litter. *Revista Brasileira de Saúde e Producao Animal*, *17*(4), 617–625. https://doi.org/10.1590/s1519-99402016000400006

Guzmán Casado, G. I., & Alonso Mielgo, A. M. (2009). *Aprovechamiento y control de Flora Arvense*. Ministerio de Agricultura, Alimentación y Medio Ambiente.

Haggard, B., and P. Mang. 2016. *Regenerative development and design: A framework for evolving sustainability.* Hoboken: Wiley.

ILO. (2017). *Child labour in the primary production of sugarcane*.

Jaramillo J, D. F. (2002). *Introducción a la ciencia del suelo*. Universidad Nacional de Colombia.

Jean Dodds, W. (2020). Food Contamination with Glyphosate and Other Herbicides. *Biomed J Sci & Tech Res*, *004214*(3). https://doi.org/10.26717/BJSTR.2020.25.004214

Jonkman, I. (2015). Smallholder farmers in the sugar industry: opportunities for a living income.

Joseph, J. P., & Anilkumar, N. (2018). *Decentralised agro-biodiversity conservation: A multi stakeholder participatory experiment*.

Joshi, B. K., & Upadhya, D. (2019). On-farm Conservation Approaches for Agricultural Biodiversity in Nepal. *Journal of Agriculture and Natural Resources*, *2*(1), 14–35. https://doi.org/10.3126/janr.v2i1.26012

Kasambala Donga, T., & Eklo, O. M. (2018). Environmental load of pesticides used in conventional sugarcane production in Malawi. *Crop Protection*, *108*, 71–77. https://doi.org/10.1016/j.cropro.2018.02.012

Kaur, N., Bhullar, M. S., & Gill, G. (2016). Weed management in sugarcane-canola intercropping systems in northern India. *Field Crops Research*, *188*, 1–9. https://doi.org/10.1016/j.fcr.2016.01.009

Latam Climate Summit. (2022). *Sesión 3: Transformación del sector agropecuario ante los desafíos de adaptación en escenarios de cambio climático en Latinoamérica*.

Lian, T., Mu, Y., Ma, Q., Cheng, Y., Gao, R., Cai, Z., Jiang, B., & Nian, H. (2018). Use of sugarcane–soybean intercropping in acid soil impacts the structure of the soil fungal community. *Scientific Reports*, *8*(1), 1–10. https://doi.org/10.1038/s41598-018-32920-2

Luo, S., Yu, L., Liu, Y., Zhang, Y., Yang, W., Li, Z., & Wang, J. (2016). Effects of reduced nitrogen input on productivity and N2O emissions in a sugarcane/soybean intercropping system. *European Journal of Agronomy*, *81*, 78–85. https://doi.org/10.1016/j.eja.2016.09.002

Martinelli, L. A., & Filoso, S. (2008). Expansion of sugarcane ethanol production in Brazil: environmental and social challenges. In *Ecological Applications* (Vol. 18, Issue 4). www.ibge.org.bri

McIntyre, B. D., Herren, H. R., Wakhungu, J., & Watson, R. T. (2009). Agriculture at a crossroads: global report. International assessment of agricultural knowledge, science, and technology for development (IAASTD). Island Press, Washington DC.

Medina Giménez, M. O., Fatecha Fois, D. A., & Rolón Paredes, G. A. (2011). Efecto de la fertilización mineral, orgánica y órgano-mineral en la producción de caña de azúcar de segundo año.

Investigación Agraria, *13*(1). https://www.agr.una.py/revista/index.php/ria/article/view/211

Millennium Ecosystem Assessment. (2007). Millennium Ecosystem Assessment. Retrieved from https://www.millenniumassessment.org/documents/document.439.aspx.pdf

Miranda, J. R., & Ariedi, V. R. (2015). Cultivo Orgânico Da Cana-De-Açúcar, Manejo Ecológico E Biodiversidade Faunística Associada.

Mohammadi, N. K., & Pankhaniya, R. M. (2017). *A Review on Intercropping in Sugarcane*. https://www.researchgate.net/publication/332786633

Molina Durán, C. H., Molina Castro, C. H., Durán, E. J. M., Molina Echeverry, J. J., & Castro Molina, J. P. (2022). *Principios Agroecológicos en la Producción de Caña de Azúcar Orgánica*.

Montagnini, F. (2022). *Biodiversity Islands: Strategies for Conservation in Human-Dominated Environments* (F. Montagnini, Ed.). Springer. https://doi.org/10.1007/978-3-030-92234-4

Moore, P. A., Daniel, T. C., Sharpley, A. N., & Wood, C. W. (1995). Poultry Manure Management: Environmentally Sound Options. *Journal of Soil and Water Conservation*. https://www.researchgate.net/publication/43274171

Nadeem, M., Tanveer, A., Sandhu, H., Javed, S., Safdar, M. E., Ibrahim, M., Shabir, M. A., Sarwar, M., & Arshad, U. (2020). Agronomic and economic evaluation of autumn planted sugarcane under different planting patterns with lentil intercropping. *Agronomy*, *10*(5). https://doi.org/10.3390/agronomy10050644

Nava-López, L. F., Camacho-Millán, R., Aguilar-Medina, E. M., Romero-Navarro, J. G., Sosa-Pérez, R., Ruiz-Abitia, A. I., Cárdenas-Cota, H. M., & Ramos-Payán, R. (2017). Biofertilizer formulation from Azotobacter and Azospirillum regional isolates and its effect on sugar cane (Saccharum officinarum) in greenhouse. *Mexican Journal of Biotechnology*, *2*(2), 183–195. https://doi.org/10.29267/mxjb.2017.2.2.183

Navarro-Pedreño, J., Belén Almendro-Candel, M., Zorpas, A. A., & Hatano, R. (2021). The Increase of Soil Organic Matter Reduces Global Warming, Myth or Reality? *Sci*, *3*(1), 18. https://doi.org/10.3390/SCI3010018

Nestlé. (2021). Nestlé unveils plans to support the transition to a regenerative food system. Web Page. Retrieved from: https://www.nestle.com/media/pressreleases/allpressreleases/support-transition-regenerative-food-system

Nestlé. (2022). Sugar sourcing. https://www.nestle.com/sustainability/sustainable-sourcing/sugar

Nestlé. (2022a). *Nestlé agriculture code.*

Nestlé. (2022b). *Regenerative Agriculture - One Pager*. https://www.nestle.com/sites/default/files/2021-09/regenerative-agriculture.pdf

Nestlé. (2022c). *Sustainable water management in agriculture*. https://www.nestle.com/Sustainability/Water/Sustainable-Water-Efficiency-Agriculture

Nestlé. (2022d). *The Nestlé Agriculture Framework*. https://www.nestle.com/sites/default/files/2022-07/nestle-agriculture-framework.pdf

Newton, P., Civita, N., Frankel-Goldwater, L., Bartel, K., & Johns, C. (2020). What Is Regenerative Agriculture? A Review of Scholar and Practitioner Definitions Based on Processes and Outcomes. *Frontiers in Sustainable Food Systems*, *4*. https://doi.org/10.3389/fsufs.2020.577723

OECD & FAO. (2021). *Agricultural Outlook 2021-2030*. OECD. https://doi.org/10.1787/19428846-en

OECD, & FAO. (2020). *World sugar crops production 2020-2029*.

Orgeron, A. J., Gravois, K., & White, P. (2020, December 14). *Can Sugarcane Production Be Improved with Cover Crops?* https://www.lsuagcenter.com/profiles/lbenedict/articles/page1607983287143

Ortiz Laurel, H., Salgado García, S., Castelán Estrada, M., & Córdova Sánchez, S. (2012). Perspectivas de la cosecha de la caña de azúcar cruda en México. *Revista Mexicana de Ciencias Agrícolas*, *3*(SPE4), 767–773. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-09342012000900020&lng=es&nrm=iso&tlng=es

Pang, Z., Fallah, N., Weng, P., Zhou, Y., Tang, X., Tayyab, M., Liu, Y., Liu, Q., Xiao, Y., Hu, C., Kan, Y., Lin, W., & Yuan, Z. (2022). Sugarcane–Peanut Intercropping System Enhances Bacteria Abundance, Diversity, and Sugarcane Parameters in Rhizospheric and Bulk Soils. *Frontiers in Microbiology*, *12*. https://doi.org/10.3389/FMICB.2021.815129/FULL

Pinto, L. D. C. M. (2019). Estimation of greenhouse gas emissions in the agro-industrial system of sugarcane in Piauí, Brazil. *Ciência e Natura*, *41*, e50. https://doi.org/10.5902/2179460X36777

Plaisier, C., van Rijn, F., van der Ende, H., & Koster, T. (2017). *Towards a sustainable sugarcane industry in India: baseline results on Solidaridad's programme: Increasing water use efficiency in sugarcane growing in India*. https://doi.org/10.18174/413767

Proforest. (2022). Regenerative Agriculture Handbook: Proforest inputs on Social Issues. Grey document.

Rajula Shanthy, T. (2010). Participatory varietal selection in sugarcane. *Sugar Tech*, *12*(1), 1–4.

Ramos Sandoval, I. N., Aquino Mercado, P. R., Peralta Jiménez, J., & Salvador Juárez, I. (In review). International Analysis of Labor Conditions in the Sugarcane Harvest fro Apreciation in Mexico. Conadesuca.

Raza, H. A., Amir, R. M., Idrees, M. A., Yasin, M., Yar, G., Farah, N., Asim, M. A., Naveed, M. T., & Younus, M. N. (2019). Residual impact of pesticides on environment and health of sugarcane farmers in Punjab with special reference to integrated pest management. *Journal of Global Innovations in Agricultural and Social Sciences*, 79–84. https://doi.org/10.22194/jgiass/7.814

Rehman, A., Qamar, R., & Qamar, J. (2014). Economic Assessment of Sugarcane (Saccharum officinarum L.) through Intercropping. *Journal of Agricultural Chemistry and Environment*, *03*(03), 24–28. https://doi.org/10.4236/jacen.2014.33b004

Rivera Pedroza, L. F., Álvarez Saa, G., Sardi Saavedra, A., Castañeda Portilla, M. A., & Vargas Orozco, G. A. (2020). *Cana Biodiversa: conservación de franjas vegetales, opciones socioeconómicas para comunidades rurales y sostenibilidad de la agroindustria azucarera*.

Rivera, P., Escobar, F., Philpott, S., & Armbrecht, I. (2020). The role of natural vegetation strips in sugarcane monocultures: Ant and bird functional diversity responses Agriculture, Ecosystems & Environment. 289. https://doi.org/10.1016/j.agee.2019.106603

Rodríguez Hurtado, L. A., & Valencia Montenegro, J. J. (2015). *Preparación de suelos para la producción sostenible de caña de azúcar*.

Rodríguez Tassé, D., Barbosa García, R. N., García Perú, A., & Urquiza Ricardo, A. (2020). Plantación en surcos de base ancha, alternativa tecnológica para reducir el porcentaje de arvenses en caña de azúcar. *Centro Agrícola*, *47*(1). https://redib.org/Record/oai_articulo2841656-plantaci%C3%B3n-en-surcos-de-base-ancha-alternativa-tecnol%C3%B3gica-para-reducir-el-porcentaje-de-arvenses-en-ca%C3%B1a-de-az%C3%BAcar

Romero, E. R., Alonso, L. G. P., Casen, S. D., Leggio Neme, M. F., Tonatto, M. J., Scandaliaris, J., Digonzelli, P. A., Giarcina, J. A., & Fernández de Ullivarri, J. (2018). Fertilización de la caña de azúcar. Criterios y recomendaciones. *Manual del cañero* (pp. 75–84). EEAOC.

Ruíz, N., Lavelle, P., & Jiménez, J. (2008). *Soil Macrofauna Field Manual*.

Sandoval Legazpi, J. de J., Aguirre García, Á., Arellano Panduro, A. de J., & de Santiago Mumford, A. M. (2012). Conocimiento y manejo de los abonos orgánicos por productores de caña de azúcar de El valle grullo-Autlán, Jalisco. *Revista Iberoamericana de Las Ciencias Biológicas y Agropecuarias*, 1(1), 1–23. https://www.ciba.org.mx/index.php/CIBA/article/view/12

Statistical Institute of Belize (SIB). 2022. Population and housing census 2022. Belmopan, Belize C.A.

S. N. Singh, Pushpa Singh, R. K. Rai, & A. D. Pathak. (2018). Vegetables intercropping with autumn planted sugarcane. *Indian Institute of Sugarcane Research,* 65–68.

Sadeghian KH, S., & Madriñan M, R. (2000). *La actividad microbiana -C02 en suelos cultivados en caña de azúcar con y sin quema* (No. 3; 50). https://www.redib.org/Record/oai_articulo509755-la-actividad-microbiana-c02-en-suelos-cultivados-en-ca%C3%B1a-de-azucar-con-y-sin-quema

Saleem, A., Irshad, M., Eneji, A. E., Hassan, A., Mahmood, Q., & Irshad, U. (2017). Fractionation of phosphorus in soils amended with poultry manure co-composted with sugarcane and cabbage wastes. *Biosci. J.*, *33*(5), 1230–1241. https://seer.ufu.br/index.php/biosciencejournal/article/view/37179/20827

Sanclemente Reyes, O. E., Ararát Orozco, M. C., & de la cruz Cardona, C. A. (2015). Contribución de Vigna unguiculata L. a la sustentabilidad de sistemas de cultivo de caña de azúcar. *Revista de Investigación Agraria y Ambiental*, *6*(2), 47. https://doi.org/10.22490/21456453.1404

Sarria, P., & Preston, T. R. (1992). *Reemplazo parcial del jugo de caña con vinaza y uso del grano de soya a cambio de torta en dietas de cerdos de engorde*. Livestock Research for Rural Development. https://www.lrrd.cipav.org.co/lrrd4/1/sarria.htm

Schwarzbach, N., & Richardson, B. (2015). *A bitter harvest: Child labour in sugarcane agriculture and the role of certification systems*.

Secretaría de Salud México. (2018). Enfermedad renal crónica: un problema de salud pública | Secretaría de Salud | Gobierno | gob.mx. Enfermedad Renal Crónica: Un Problema de Salud Pública. https://www.gob.mx/salud/es/articulos/enfermedad-renal-cronica-un-problema-de-salud-publica?idiom=es

Segnini, A., Carvalho, J. L. N., Bolonhezi, D., Milori, D. M. B. P., da Silva, W. T. L., Simões, M. L., Cantarella, H., de Maria, I. C., & Martin-Neto, L. (2013). Carbon stock and humification index of organic matter affected by sugarcane straw and soil management. *Scientia Agricola*, *70*(5), 321–326. https://doi.org/10.1590/S0103-90162013000500006

Shamsul Arefin, Md., Ariful Islam, Md., Mokhlesur Rahman, Md., Abdul Alim, Md., Hassan, S., F. K. Soliman, M., M. Hassan, M., Bhatt, R., & Hossain, A. (2022). Integrated Nutrient Management Improves Productivity and Quality of Sugarcane (Saccharum Officinarum L.). *Phyton*, *91*(2), 439–469. https://doi.org/10.32604/PHYTON.2022.017359

Showler, A. T. (2015). Effects of compost and chicken litter on soil nutrition, and sugarcane physiochemistry, yield, and injury caused by Mexican rice borer, Eoreuma loftini (Dyar) (Lepidoptera: Crambidae). *Crop Protection*, *71*, 1–11. https://doi.org/10.1016/J.CROPRO.2015.01.020

Silveira, H. C. S., Schmidt-Carrijo, M., Seidel, E. H., Scapulatempo-Neto, C., Longatto-Filho, A., Carvalho, A. L., Reis, R. M. V., & Saldiva, P. H. N. (2013). Emissions generated by sugarcane burning promote genotoxicity in rural workers: A case study in Barretos, Brazil. *Environmental Health: A Global Access Science Source*, *12*(1), 1–6. https://doi.org/10.1186/1476-069X-12-87/FIGURES/2

Smartcane BMP. (2022a). *Irrigation and drainage management*. https://smartcane.com.au/wp-content/uploads/2018/10/SmartcaneBMP_fact-sheet_Module-2.pdf

Smartcane BMP. (2022b). *Natural systems management*. https://smartcane.com.au/wp-content/uploads/2018/10/SmartcaneBMP_fact-sheet_Module-6.pdf

Smil, V. (2000). Phosphorus in the environment: Natural Flows and Human Interferences. *Annual Review of Energy and the Environment*, *25*(1), 53–88. https://doi.org/10.1146/annurev.energy.25.1.53

Solidaridad. (2020). *A decade of sustainable sugarcane initiatives*.

Soto Estrada, A., Landeros Sánchez, C., & Hernández Pérez, J. M. (2020). Groundwater Contamination due to the Use of Agrochemicals in Sugar Cane Agroecosystems. *Agro Productividad*, *13*(11). https://doi.org/10.32854/AGROP.V13I11.1835

Soloviev, E., and G. Landua. 2016. Levels of regenerative agriculture. Terra Genesis International. http://www.terra-genesis.com/wp-content/uploads/2017/03/Levels-of-Regenerative-Agriculture-1.pdf

Souza Rodrigues, J. de, & Aguiar Alves, P. L. da C. (2020). The effects of sugarcane ripeners drift in non-target crops. *Horticulture International Journal*, *4*(5), 174–174. https://doi.org/10.15406/HIJ.2020.04.00178

Stacciarini, T. C., Neto, A. R., Alves, J. M., & Marques, M. G. (2021). Supplementary Nitrogen Fertilization in Sugarcane. *Journal of Agricultural Science*, *13*(7), 1. https://doi.org/10.5539/jas.v13n7p1

Sugarcane Org. (2022). Labor conditions. Webpage. Retrieved from: Labor Conditions https://www.sugarcane.org/sustainability-the-brazilian-experience/labor-conditions/

Tabriz, S. S., Kader, M. A., Rokonuzzaman, · M, Hossen, · M S, & Awal, · M A. (2021). Prospects and challenges of conservation agriculture in Bangladesh for sustainable sugarcane cultivation. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-021-01330-2

Tang, X., Jiang, J., Huang, Z., Wu, H., Wang, J., He, L., Xiong, F., Zhong, R., Liu, J., Han, Z., Tang, R., & He, L. (2021). Sugarcane/peanut intercropping system improves the soil quality and increases the abundance of beneficial microbes. *Journal of Basic Microbiology*, *61*(2), 165–176. https://doi.org/10.1002/jobm.202000750

Tfouni, S. A., & Toledo, M. C. F. (2007). Determination of polycyclic aromatic hydrocarbons in cane sugar. *Food Control*, 18(8), 948–952.

Tfouni, S. A., Souza, N. G., Neto, M. B., Loredo, I. S., Leme, F. M., & Furlani, R. P. (2009). Polycyclic aromatic hydrocarbons (PAHs) in sugarcane juice. *Food chemistry*, 116(1), 391-394.

TNC. (2021). *Three Things to Know About Nature-Based Solutions for Agriculture*. https://www.nature.org/en-us/what-we-do/our-insights/perspectives/three-things-nature-based-solutions-agriculture/

TNC. (2021a). *Resilient Central America Final Report, October 2016 - June 2021*. Retrieved from: https://www.resilientcentralamerica.org/wp-content/uploads/Recursos/Informes/Reporte%20Final%20ResCA-v2%20low.pdf

USDA. (2022). *Soil Health | NRCS Soils*. Soil Health. https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/

Velasco-Velasco, J. (n.d.). *Los biofertilizantes y la producción de caña de azúcar (Saccharum spp.)*. Retrieved July 24, 2022, from https://revista-agroproductividad.org/index.php/agroproductividad/article/view/516/396

Villegas T, F., & Arcila A, J. (2003). *Maduradores en Caña de Azúcar. Manual de procedimientos y normas para su aplicación*. www.cenicana.org

Volverás-Mambuscay, B., González-Chavarro, C. F., Huertas, B., Kopp-Sanabria, E., & Ramírez-Durán, J. (2020). Effect of the organic and mineral fertilizer on the performance of sugarcane yield in Nariño, Colombia. *Agronomy Mesoamerican*, 31(3), 547–565. https://doi.org/10.15517/AM.V31I3.37334

Wang, E., Attard, S., Linton, A., McGlinchey, M., Xiang, W., Philippa, B., & Everingham, Y. (2020). Development of a closed-loop irrigation system for sugarcane farms using the Internet of Things. *Computers and Electronics in Agriculture*, 172, 105376. https://doi.org/10.1016/j.compag.2020.105376

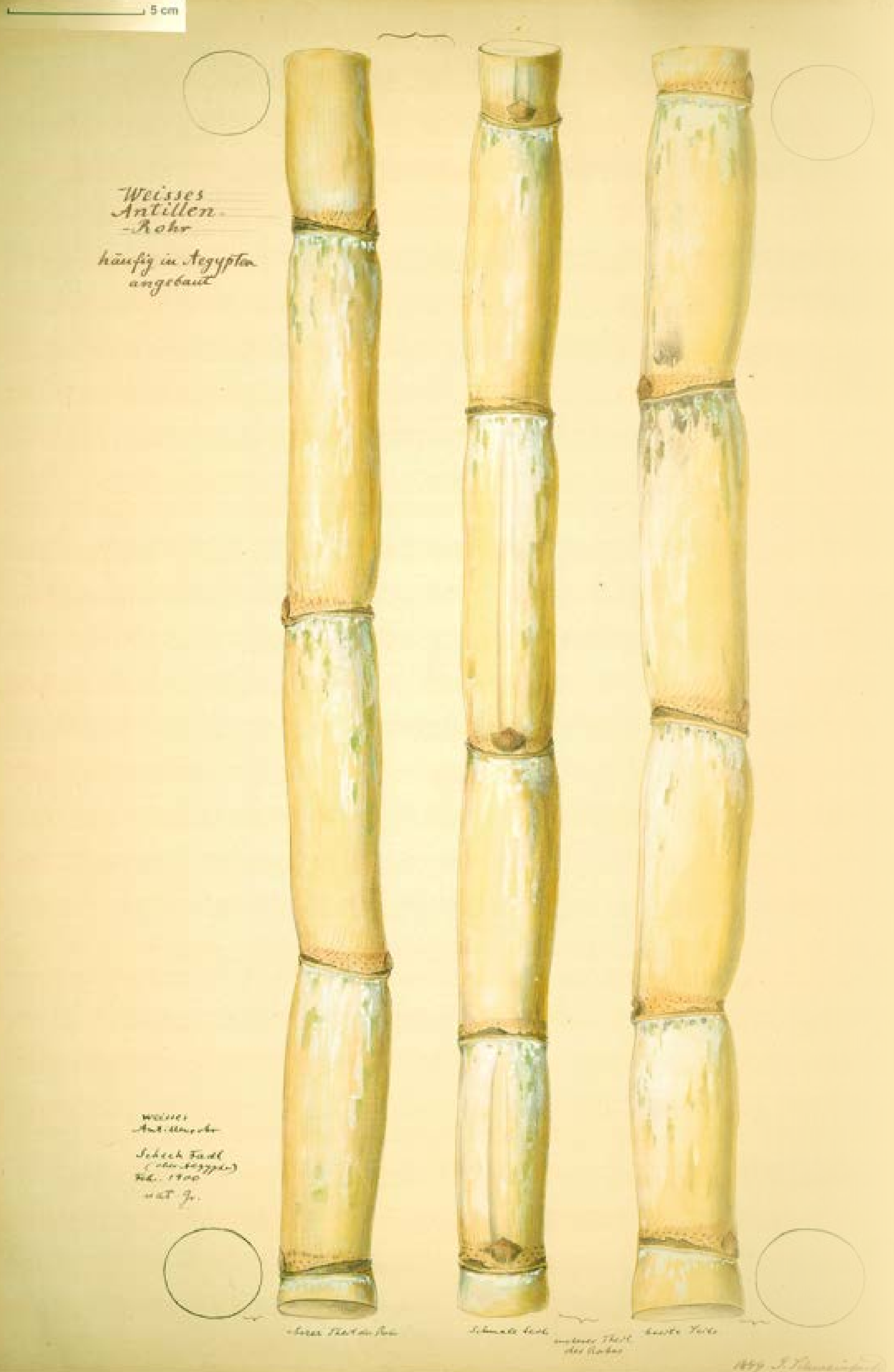
White, P. M., Williams, G., Viator, H. P., Viator, R. P., & Webber, C. L. (2020). Legume Cover Crop Effects on Temperate Sugarcane Yields and Their Decomposition in Soil. *Agronomy 2020, Vol. 10, Page 703*, *10*(5), 1–12. https://doi.org/10.3390/AGRONOMY10050703

Willerton, N. (2019). *Organic Sugar Outlook*. USDA Agricultural Outlook Forum. Wholesome Sweeteners. PDF Presentation.

WWF. (2015). *Sugarcane Farming's Toll on the Environment*. https://www.worldwildlife.org/magazine/issues/summer-2015/articles/sugarcane-farming-s-toll-on-the-environment

Zapata Cadavid, Á., & Uribe Trujillo, F. (2021). *Caso de estudio sobre la producción agroecológica de caña de azúcar a través de prácticas regenerativas en El Salvador*.

Zapata, A., Uribe, F., Molina, CH., & Molina, E. (Eds.) (2022). *Manejo Agroecológico de la Caña de Azúcar. La experiencia colombiana en caña regenerativa* (Unpublished Manuscript).


5 cm
Weisses
Antillen-
Rohr
häufig in Aegypten
angebaut
Schech Fadl
Feb. 1900
nat. Gr.
schmale Seite
unterer Theil
des Rohres
breite Seite

6 | ANNEXES

Saccharum officinarum - Berlin Botanical Garden, Germany CC BY-SA.

HUMAN RIGHTS: POLICIES AND GUIDES (COMPLIANCE OF THE 30 HHRR ARTICLES)

SOCIAL PRACTICE	**BRIEF DESCRIPTION** DEFINITION	**KEY LINKS** & INFORMATION
Right to liberty and security	"Focus on protecting individuals' freedom from unreasonable detention, as opposed to protecting personal safety. A right to personal freedom. This means a person must not be imprisoned or detained without good reason."	Article 5: Right to liberty and security
Freedom of expression	"Right to hold your own opinions and to express them freely without government interference. This includes the right to express your views aloud (for example through public protest and demonstrations) or through published articles, books or leaflets television or radio broadcasting, works of art, the internet and social media."	Article 10: Freedom of expression
Freedom of assembly and association	"Everyone has the right to freedom of peaceful assembly and to freedom of association with others, including the right to form and to join trade unions for the protection of his interests."	Article 11: Freedom of assembly and association
Protection from discrimination	"Protect you from discrimination in the enjoyment of those human rights set out in the European Convention of Human Rights. Article 14 is based on the core principle that all of us, no matter who we are, enjoy the same human rights and should have equal access to them."	Article 14: Protection from discrimination

FAIR LABOR PRACTICE

SOCIAL PRACTICE	**BRIEF DESCRIPTION** DEFINITION	**KEY LINKS** & INFORMATION
Appropriate family work: child education and safety	"Participating in some farm activities can give children an opportunity to develop skills and a sense of belonging to the community and their families. However, this should not interfere with schooling and should not imply hazardous activities or risks."	Child labor in farming
Decent work	"People-centered policies that reduce inequalities must be implemented. These include social protection measures, wage policies, strengthened labor inspection, increased female labor market participation, and protecting collective bargaining." And simultaneously this should "Ensure equal opportunity and reduce inequalities of outcome, including eliminating discriminatory laws, policies and practices and promoting appropriate legislation, policies and action."	Decent work

WORK SAFETY & HEALTH FRAMEWORKS

SOCIAL PRACTICE	**BRIEF DESCRIPTION** DEFINITION	**KEY LINKS** & INFORMATION
Operational Manuals/ Codes of Practice	"Codes of Practice provide guidance on safety and health at work in certain economic sectors (e.g. agriculture, forestry), on protecting workers against certain hazards (e.g. chemicals, airborne substances), and on certain safety and health measures (e.g. occupational safety and health management systems; ethical guidelines for workers' health surveillance; recording and notification of occupational accidents and diseases; protection of workers' personal data; safety, health and working conditions in the transfer of technology to developing countries)."	Code of Practice on Safety and Health in Agriculture
Safety and Health Manuals (PPEs)	Sugarcane stakeholders should include "coherent occupational safety and health policy, as well as take action to promote occupational safety and health and to improve working conditions. This shall be developed by taking into consideration national conditions and practice. A call for the establishment and the periodic review of requirements and procedures for the recording and notification of occupational accidents and diseases, and for the publication of related annual statistics should also be included."	International Labor Standards on Occupational Safety and Health

WORK SAFETY & HEALTH FRAMEWORKS

SOCIAL PRACTICE	BRIEF DESCRIPTION DEFINITION	KEY LINKS & INFORMATION
Support and guidance systems (Human Resources & risk management)	Practice management that promotes the "protection of workers by eliminating or minimizing work related hazards and risks. It should also benefit businesses through better organization of working practices potentially increasing productivity." It is important to adopt Human Resources (HR) "management systems on the workplace, to improve the working conditions, maintain workers' rights and combat labor challenges, such as labor turnover. A layout for an effective HR department, should consider the final application of HR Functions. HR also encourages the companies' management to better comply with the national labor law."	Risk Assessment & Human Resources Management

JUST AND INCLUSIVE BUSINESS RELATIONSHIPS

Just business agreements	Strive to "make agricultural markets fairer and more competitive, taking into account concerns such as food security and the environment. Ongoing talks led to a historic decision to abolish agricultural export subsidies and new rules for other forms of farm support."	Food trade

JUST AND INCLUSIVE BUSINESS RELATIONSHIPS

SOCIAL PRACTICE	**BRIEF DESCRIPTION** DEFINITION	**KEY LINKS** & INFORMATION
Fair prices and trade	Strive for "shorter value chains which allow more direct access for producers' organizations (cooperatives, producer associations etc.) to markets, create a form of 'producer's minimum wage' which is applicable as soon as the price on the world market rises above this minimum price, the engagement of producers in a democratic and transparent functioning of their organizations and in providing a quality product which meets the demands of the market and have independent control with respect to the commitments of producers' organizations, buyers, processors, and distributors." "When fair trade is in conjunction with measures intended to create an environment which is favorable for production (with technical help available, access to funds, training and an infrastructure) as well as the active participation of Producers' organizations it brings positive impacts".	Fair trade & Market access
Responsible supply schemes	"In the realm of international trade rules, transparency refers to the degree to which trade policies and practices, and the processes by which they are established, are open and predictable. There should be no bypass of the review and accountability procedures, to avoid widespread discrimination, arbitrary decision making, and even corruption. Existing trade agreements must contain transparency provisions, and the WTO agreements stipulate a range of obligations."	Principles of trading systems & Trade in times of crisis (COVID-19)

RESPONSIBLE NEIGHBOR AND COMMUNITY MANAGEMENT

SOCIAL PRACTICE	**BRIEF DESCRIPTION** DEFINITION	**KEY LINKS** & INFORMATION
Reduction of community risks	"Encourage the engagement of all the relevant stakeholders: target communities, local service providers including small contractors, and local governments. Participatory processes should be ensured during consultations and activities to enable vulnerable groups in a community, such as women, youth, people with disabilities, indigenous and tribal people, and elderly, to have a voice in decision-making and to actively participate in the development and sector process."	Local resource based (LRB) approaches and community infrastructure
Engagement in local participation and governance instruments	"The governance of tenure is a crucial element in determining if and how people, communities and others are able to acquire rights, and associated duties, to use and control land and forests". "Non-state actors including business enterprises have a responsibility to respect legitimate tenure rights acting with due diligence to avoid infringing on the rights of others. They should include appropriate risk management systems to prevent and address adverse impacts."	Responsible governance of tenure

Gebändertes
Rohr
(rubanée)
gebaut in Oberaegypten

nat. Gr.

Gebändertes Rohr
‚rubanée‘
Scheich Fadl (Oberäg.) Feb. 1900
mit einer ungewöhnlichen [illegible]
[illegible] ([illegible]) Rinde

gelb - purpurn gestreift

Streifen in [illegible] [illegible]

Stock [illegible]; der Wachsanflug
[illegible] sich [illegible]

Knospen flach u. [illegible]

Wurzelknoten undeutlich,
mit [illegible] Ringwulst
über dem Knoten

G. Schweinfurth fec.
1899

7 ADDITIONAL RESOURCES

Saccharum officinarum - Berlin Botanical Garden, Germany CC BY-SA.

Sugarcane farm. Photo credit: © somsak.

This section provides additional information to learn more about sugarcane production and the diversity of management practices that can be applied in different regions of the world.

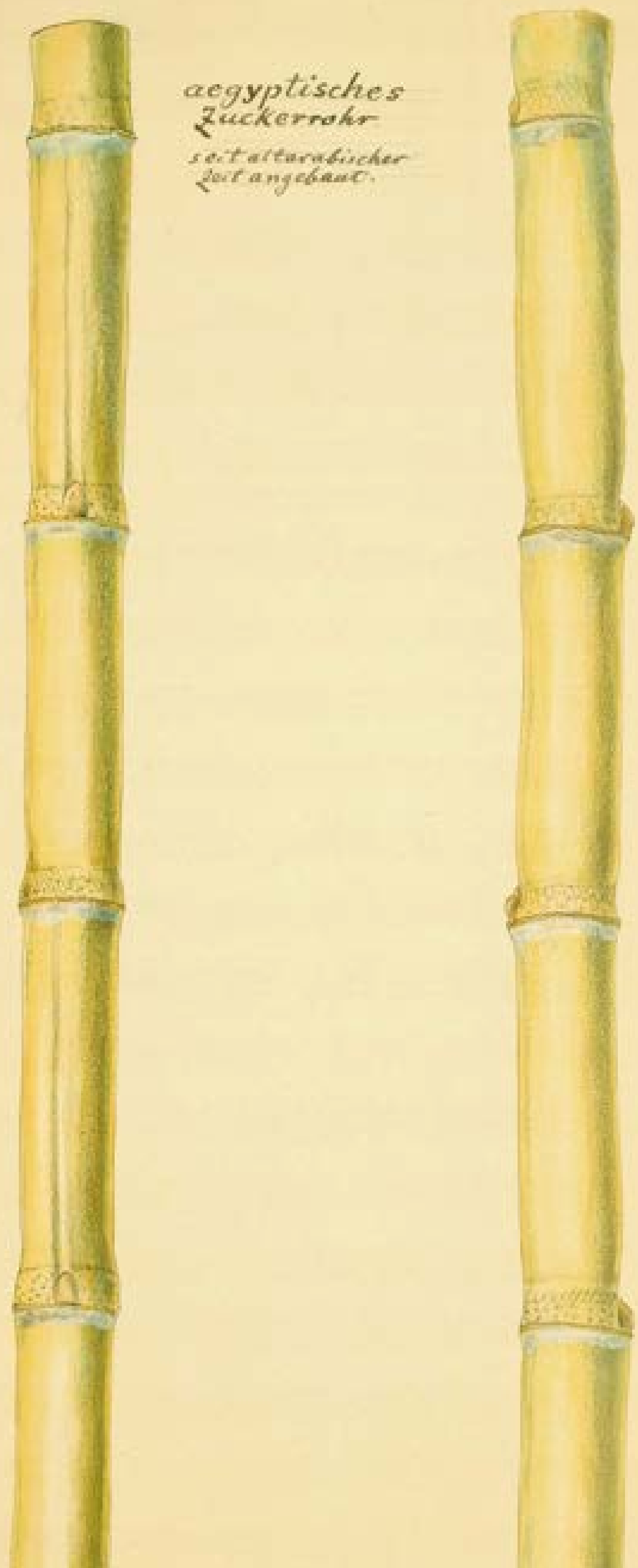
Once again, we emphasize that these practices should be adapted according to the agro-climatic conditions of each region, the challenges that the producer seeks to address, and the resources needed to implement them in the most efficient way. Technical support is also an essential factor for making better decisions and making regenerative production a more beneficial process with reduced risks for the producer.

Note: Some of the resources listed here do not directly promote the use of regenerative practices for sugarcane cultivation, as they are still focused on conventional production.

Source	Type	Country	Language	Institution
Regenerative Agriculture	Website	Worldwide	English	Nestlé
Sugar Research Australia's eLibrary	Online library	Australia	English	Sugar Research Australia
sra Nutrient Management Tools	Guidelines and factsheets	Australia	English	Sugar Research Australia
sra Biosecurity Tools	Guidelines and factsheets	Australia	English	Sugar Research Australia
sra Farming sistems and harvesting Tools	Guidelines and factsheets	Australia	English	Sugar Research Australia
sra Pests and diseases Tools	Guidelines and factsheets	Australia	English	Sugar Research Australia
sra Varieties Tools	Guidelines and factsheets	Australia	English	Sugar Research Australia
sra Weeds Tools	Guidelines and factsheets	Australia	English	Sugar Research Australia
sra Soil Health Toolbox	Guidelines and factsheets	Australia	English	Sugar Research Australia
sra Irrigation and energy Tools	Guidelines and factsheets	Australia	English	Sugar Research Australia
sra Publications	Manuals and booklets	Australia	English	Sugar Research Australia (sra)
Cenicaña Publications	Book	Colombia	Spanish	Cenicaña
Cenicaña Informative series	Factsheets	Colombia	Spanish	Cenicaña
Cengicaña Publications	Online library	Guatemala	Spanish	Cengicaña
SASTA Laboratory Manuals	Guidelines	Africa	English	South African Sugar Technologists' Association (SASTA)
SASTA Essencial Reading: Agriculture	Articles	Africa	English	South African Sugar Technologists' Association (SASTA)
CINCAE Informative Letters	Booklets	Ecuador	Spanish	Centro de Investigación de la Caña de Azúcar del Ecuador
CINCAE Publications: Disease management	Guidelines	Ecuador	Spanish	Centro de Investigación de la Caña de Azúcar del Ecuador
CINCAE Publications: Pest management	Guidelines	Ecuador	Spanish	Centro de Investigación de la Caña de Azúcar del Ecuador
CINCAE Publications: Soil management and fertilization	Guidelines	Ecuador	Spanish	Centro de Investigación de la Caña de Azúcar del Ecuador
CINCAE Publications: Seeds and breeding	Guidelines	Ecuador	Spanish	Centro de Investigación de la Caña de Azúcar del Ecuador
CINCAE Publications: Sugarcane variety	Guidelines	Ecuador	Spanish	Centro de Investigación de la Caña de Azúcar del Ecuador
Agricultural Science and Technology Information (AGRIS)	Database	Worldwide	Several	FAO
South African Sugarcane Research Institute e-Library	Online library	Africa	English	South African Sugarcane Research Institute (SASRI)
CAROcanne media library	Online library	France	French	CAROcanne
CAROcanne technical papers	Guidelines	France	French	CAROcanne
LSU Ag Center Publications	Online library	USA	English	LSU College of Agriculture
Sugarcane.org Infographics	Infographic	Brazil	English	Sugarcane.org
Sugarcane.org Library	Online library	Brazil	Several	Sugarcane.org
Soil Health Assessment	Guidelines	USA	English	United States Department of Agriculture (USDA)
Cropland In-Field Soil Helath Assessment Worksheet	Guidelines	USA	English	United States Department of Agriculture (USDA)
Soil Macrofauna Field Manual	Guidelines	Worldwide	English	FAO
FAO Soils Portal	Online library	Worldwide	Several	FAO
Research & Development SRIF	Online library	Fiji	English	Sugar Research Institute of Fiji (SRIF)

aegyptisches Zuckerrohr

seit altarabischer Zeit angebaut.



„Belledi" Rohr

zum Essen in Aegypten
von Alters her schon
u. auf allen Märkten
feilgeboten

(weniger zuckerreich, aber
mit mehr Glanz [illegible])

Rohr dünnschalig
Rinde [illegible]
fast ohne Wachsreif
Glieder cylindrisch gerade
[illegible]
[illegible]
[illegible]

Wurzelknoten deutlich
zwischen deutlichen [illegible]
[illegible]

Knospen klein, flach
u. anliegend, oval spitz

Farbe gelblich grün
fast ohne Wachsreif

mit tiefer Längsfurche
an der Knospenseite

(nat. Grösse)

von der [illegible] Seite

von der flachen Seite

8 | GLOSSARY

Saccharum officinarum - Berlin Botanical Garden, Germany CC BY-SA.

Canopy

The top layer of plants formed by their leaves. Pp 90

Crop renovation

Field renewal refers to pulling out the sugarcane stocks from a field in preparation for the planting cycle. Renewal is required when crop productivity declines and phytosanitary problems become more frequent (Cenicaña, 1995). Pp 57

Dormancy

Period during which organisms suspend growth and development, often to conserve energy when environmental conditions are adverse. Pp 103

Entomopathogenic fungi

Parasitic microorganisms infect other organisms, especially arthropods, causing disease or killing them through direct contact with their cuticle. They are used in organic agriculture as bio-insecticides. Pp 104

Eutrophication

Phenomena in which large algae blooms happen in a waterbody because there is a high input of fertilizers. The algae bloom affects the normal functioning of the waterbody and its biodiversity (less light, oxygen, nutrients). Pp 17

Green water
Water from the atmosphere that becomes available to plants as precipitation. And estimated 80% of agricultural water globally is green water (CRS, 2016). Pp 98

Infiltration
The passage of water through the soil surface (Cruz Valderrama, 2015). Pp 43

Monocropping
Producing a single crop in a same field year-after-year, commonly used in mainstream agriculture. Pp 19

Mycorrhizal
a symbiotic association between plant roots and fungi which benefit the host plant by enhancing nutrient and water uptake. Pp 118

NDC
A Nationally Determined Contribution is the climate action plan each country submits to cut emissions and adapt to climate impacts as part of the Paris Agreement. Pp 16

PAHs / PAH
Policyclic Aromatic Hydrocarbons (PAHs), a class of chemicals formed during incomplete combustion or pyrolysis of organic matter and considered contaminants with mutagenic and carcinogenic effects (Andrade et al., 2010 & Silva et at., 2010 cited by Silveira et al., 2013). Pp 50

Planetary boundaries
are the “safe limits” beyond which the Earth system will be destabilized. There nine planetary boundaries are land-system change, freshwater use, biogeochemical flows, biosphere integrity, climate change, ocean acidification, stratospheric ozone depletion, atmospheric aerosol loading, and introduction of novel entities. Pp 17

Soil moisture
Soil moisture content estimates the amount of water retained in the soil after a rainfall or irrigation event accounting for percolation losses. It can be measured directly or indirectly, in the laboratory or in the field (Rodríguez Hurtado & Valencia Montenegro, 2015). Pp 44