University of Zurich[UZH]

Herbicides in times of troubled supply chains. The influence of socioeconomic factors on the use of herbicides in Costa Rican pineapple plantations

GEO 511 Master's Thesis

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27.04.2023
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Date of submission:

27.04.2023

Acknowledgments

This thesis has been an interesting, intense, insightful, and enriching experience for over a year. I am so happy and grateful for all the acquaintances I made along my journey. My thesis wouldn't have been feasible in this form and certainly not as pleasant and instructive without the outstanding support of many people.

First, I want to express my gratitude to Prof. Dr. Christian Berndt. Dear Christian, I still remember how excited I left our first meeting in November 2021 when you told me about your new research project on herbicide markets. I am incredibly grateful for the opportunity you gave me to conduct my thesis within the scope of this research project. Also, thank you for being able to count on your broad expertise, guidance, and constructive feedback and for the financial and administrative support that made this extended research possible. Thank you for your trust!

Dear Sole, even though being in the middle of handing in your own Ph.D. thesis and living in another country, I felt supported not only because of your expertise about pesticides and pineapple but also because your virtual door was always open for me. Your kind words and positive attitude were a great motivation! Furthermore, your broad network of contacts made my research much smoother. Thank you also for introducing me to the concept of feminist ethics care in academia. You truly are a great role model for women!

Dear Andrés, thank you for opening the doors of CIEP to me, for the insightful sessions about Costa Rican pineapple industry and agriculture, for the helpful feedback, and for providing me with much-needed coffee, a table, and a desk!

To all my interview partners, without any doubt, you have contributed the most important content to this work, and my research would not have been possible if you had not received me, shared insights about the Costa Rican pineapple industry, and given me your trust and time despite my linguistic limitations.

Furthermore, I am very grateful for the generous and unbureaucratic support from the Nachwuchsförderungsfonds of Geography Alumni UZH.

Querida Sharon, querido José Pablo y Jesús, ¡gracias para compartir su oficina, cafés y charlas conmigo!

Last but not least, and maybe most importantly, I want to express my deep gratitude towards my family for their unconditional financial and emotional support during my time in Costa Rica and my academic career. Special thanks to my brother Florian for proofreading my thesis! I feel very privileged, and I am deeply grateful for having you!

Abstract

Costa Rica has become the world leader in exporting fresh pineapple within the last decade, which came along with a substantial increase in the dedicated land (Montiel 2015). The intensive production of pineapple requires large quantities of fertilizers and pesticides (Echeverría-Sáenz et al. 2012). Due to its economic importance and its alleged environmental and social implications, pineapple cultivation for export has been one of the most successful and controversial topics in Costa Rica during the last 20 years (Vargas 2019). At the same time, Costa Rica is internationally known as a "green republic" thanks to the large area of protected zones, various national parks, and its ecotourism. Scholars argue that pineapple monocropping contradicts its marketing strategy to present itself as an eco-friendly destination (Brown, Flint, and LaMay 2020; Sanchez 2018; Vagneron, Faure, and Loeillet 2009).

Due to the controversial nature of the pineapple sector, this study sought to determine which socioeconomic factors explain the high dependence on herbicides. The analytical framework combined the concepts of the Herbicide Revolution, uneven geographies, and literature on the importance of Extension Services. An inductive approach was chosen for the research, with data collected through 14 semi-structured interviews with important actors from the pineapple and agrochemical sector, including state actors, pesticide industry representatives, pineapple producers, chambers, agronomists, and consultants. This thesis used, in this sense, an innovative approach as it tried to link socioeconomic factors with the high use of herbicides through the perspective of producers and different actors. Hence, as opposed to previous research on Costa Rican pineapple production, it focused instead on influencing factors that explain the use of herbicides rather than the outcomes of this dependency.

The study shows that several socioeconomic factors explain the dependency of the pineapple industry on herbicides, but some of them also have the potential to reduce it. While certifications, MRLs, and precision agriculture force or help producers to rationalize their use of herbicides, weak state regulation, issues in the registration process for new agrochemicals, market- and environmental challenges, and the absence of public extension services are factors contributing to the herbicide dependency. Furthermore, supply chain disruptions for agrochemical inputs could promote the use of more alternatives, such as manual weeding techniques or biological pest control.

List of abbreviations

FECON	Federación Costarricense Para la Conservación de la Naturaleza: Costa Rican Federation for Nature Conservation
PRI	Hawaii-based Pineapple Research Institute
CANAPEP	La Cámara Nacional de Productores y Exportadores de Piña: Chamber of Costa Rican pineapple producers
COSAP	Comisión Socio Ambiental de la Piña: Socio-environmental Commission of Pineapple of CANAPEP
CGR	Contraloría General de la República: Control institute of the Legislative Assembly that oversees the use of public funds
IPM	Integrated pest management
IRET	El Instituto Regional de Estudios en Sustancias Tóxicas de la Universidad Nacional: Regional Institute for the Study of Toxic Substances
MAG	Ministerio de Agricultura y Ganadería de Costa Rica: Ministry of Agriculture
MEIC	Ministerio de Economia, Industria y Comercio de Costa Rica: Ministry of Economy, Industry and Commerce
PINDECO	Pineapple Development Company
PNUD	Programa de las Naciones Unidas para el Desarrollo: United Nations Development Programme
SFE	Servicio Fitosanitario del Estado**:** The agency responsible for the country's pesticide registry
UCR	Universidad de Costa Rica

Definitions

- **Agrochemical:** Fertilizers and pesticides used in agriculture (MAG and IICA 2019)

- **Biostimulants:** Substances such as micro-organisms that stimulate the natural nutrition processes of plants. They are used in combination with fertilizers to benefit nutrient uptake and reduce nutrient application rates (EU 2019)

- **Herbicide:** Substances used to control undesirable vegetation (US EPA 2015)

    - **Systemic Herbicide:** The herbicide is absorbed by the roots or foliage and kills the whole plant by moving through its vascular system Lingenfelter 2007)
    - **Contact Herbicide:** The herbicide kills only the part of the plant that is directly contacted by the chemical (Lingenfelter 2007)

- **Integrated pest management (IPM):** Pest control strategy that uses pest control methods with the least possible risk to people, property, and the environment and takes into account economic aspects (United States Environmental Protection Agency, 2023)

- **Maximum residue limits (MRLs):** Maximum Residue Limits (MRLs) define the highest level of pesticide residue that is legally tolerated in or on imported food (FAO 2023a). These limits are regulated by the Codex Committee on Pesticide Residues (CCPR), based on recommendations made by the FAO/WHO Joint Meeting on Pesticide Residues (JMPR). MRLs are essential in reducing residues by forcing producers to comply with them.

- **Pest:** Any plant or animal species, breed or biotype, or pathogenic agent damaging crops (MAG and IICA 2019)

- **Pesticide:** Substances or a mixture of substances intended to prevent, destroy or control any pest such as human or animal diseases, undesirable species of plants or animals negatively interfering with the production, processing, storage, transportation, or marketing of food, agricultural products, wood, and wood products or animal feed. The term includes substances intended for use as plant growth regulators, defoliants, desiccants, agents to reduce fruit density or prevent premature fruit drop, and substances applied to crops before or after harvest to protect the product against deterioration during storage and transport (MAG and IICA 2019). The term pesticides include fungicides, insecticides, herbicides, and nematicides (Araya et al. 2014)

- **Pesticide Residue:** Any specific substance present in food, agricultural commodities, or animal feed due to a formulated chemical pesticide, the technical active ingredient, adjuvants, and related substances. The term includes any derivative of a formulated chemical pesticide, technical grade active ingredient, associated adjuvants and substances, such as conversion products, metabolites and reaction products, and impurities considered to be of toxicological significance (MAG and IICA 2019)

- **Precision farming:** Precision farming is an agricultural management approach that uses modern technology such as sensors, GPS mapping, and other data analytics to measure and respond to crop variability. Optimizing process inputs can help increase crop yields while reducing production costs and environmental impacts (Hoye 2018).

- **REDD+**: (Reducing Emissions from Deforestation and Forest Degradation and the Role of Conservation), The international forest and climate protection program REDD+ aims to limit deforestation and promote reforestation through financial incentives (United Nations 2023)

- **Weeds:** Weeds are traditionally defined as a plant that grows opportunistically where it is not wanted and competes with crop plants for nutrients, water, sunlight, or other resources. Its presence among crop plants can lead to yield losses due to competition for shared resources such as light, water, and nutrients (Allaby 2010; Argüelles and March 2022). Weeds have unique capacities, such as reproduction and adaptation to external conditions that disturb and reconfigure dynamics in agriculture and other sectors. Their presence can disrupt the uniformity of crops and change their standardized aesthetics when competing with light, for example. Therefore, their presence is not valued and is described as insurgent and disruptive (Argüelles and March 2022).

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1. Introduction

Pineapple cultivation for export has been one of the most successful and controversial topics in Costa Rica during the last twenty years (Vargas 2019). From an economic point of view, pineapple is an important tropical fruit in the world market, and Costa Rica has become the world leader in exporting fresh pineapple (Montiel 2015). According to pineapple company reports, the sector generates 28'000 direct and 105'000 indirect jobs and contributed to 34.7% of the agricultural GDP in 2022 (CANAPEP 2022c; Ramírez et al. 2022). Despite its economic importance, the pineapple sector in Costa Rica has come under criticism. One reason is the increasingly visible process of pineapple production expansion and its alleged environmental and social implications (Vargas 2019). Within the last thirty years, the dedicated land to pineapple production has multiplied. According to official figures, the area under cultivation has increased from 10'000 to 44'000 hectares, but satellite images currently estimate it at over 60'000 hectares (MOCUPP 2021; Valverde and Chaves 2020). Former forest areas, cattle farms, or traditional crops have been transformed into vast territories covered by pineapple. The expansion of the pineapple activity brought about the construction of industrial plants for harvesting and packaging the product, drastically changing the landscape in several parts of the country (Maglianesi-Sandoz 2013).

Pineapple cultivation in monocultures resulted in a high level of intensive pesticide application due to dense planting patterns, pest pressure, and a need to speed up the maturation process (Echeverría-Sáenz et al. 2012; Maglianesi-Sandoz 2013). In 2009 widespread protests took place in Costa Rica due to pesticide contamination of regional waterways, harming the local ecosystem with detrimental health consequences for many pineapple-producing communities throughout the country (UNDP 2022). In 2018, the University of Costa Rica (UCR) detected pesticides in water sources in the northern zone linked to pineapple activity (Rodriguez 2020). Within five years, Costa Rica has increased its imports of agrochemicals by 37% (from 13.1 million kg of active ingredients in 2015 to 20 million in 2020) (Programa Estado de la Nación 2021). A part is re-exported to other Central American countries, but the vast majority is used within the country. This makes Costa Rica one of the world's most intensive pesticide users (Fecon 2020). In 2020 pineapple was after banana, the crop in Costa Rica with the highest use of pesticides in absolute terms, which reflects the extent of the pesticide dependence of the pineapple industry (Castro 2021).

The expansion of pineapple was supported by different political incentives and tax exemptions for export crops (León 2020; Vagneron et al. 2009). The pineapple industry and the Costa Rican state advertise that the industry creates jobs and is vital for the development of rural areas, but various authors point out contradictions to the country's "green" image (Araya et al. 2014; Brown et al. 2020; Galt 2008a; Thrupp 1991). Costa Rica's pineapple monocropping industry and ecotourism have simultaneously expanded since the 1980s (Brown et al. 2020): *"Costa Rica's prodigious use of pesticides, as well as the burgeoning plantation sector that these agrochemicals support, exacerbates the tensions between extraction and preservation at the heart of the country's development model"* (Castro-Vargas and Werner 2022:1). For about a decade, agrochemicals and pineapple expansion have dominated the social agenda, and communities close to pineapple plantations have urged the government to regulate pesticide use (Programa Estado de la Nación 2021). In 2017, the government banned Bromoacil, a commonly used herbicide, in pineapple production. In 2021 the government promised further regulations on a range of other agrochemicals (BananaLink 2021). However, loose regulations in the use of pesticides and state benefits such as tax exemptions for the import of

pesticides and on export crops challenge the state's pesticide reduction goals (El Mundo 2018; International climate initiative 2022). Thus, different scholars agree that pineapple monocropping contradicts the country's marketing strategy to present itself as an eco-friendly destination (Brown et al. 2020; Sanchez 2018; Vagneron et al. 2009).

Lately, global events such as the Covid-19 pandemic or the Russian invasion of Ukraine have affected the agricultural supply chain. Closed borders, for example, have repeatedly led to supply bottlenecks highlighting the underlying dependencies of international trade chains (van der Ploeg 2020). Factory shutdowns have led to shortages of agricultural chemicals, whereas port congestions led to rising freight costs and labor shortages further exacerbated supply difficulties (Unglesbee 2021). According to a newspaper article from February 2023, the effects of the Covid-19 pandemic are still affecting the industry with increased costs for inputs such as herbicides and fertilizers (Fresh Plaza 2023). This has crucial implications for producers' use of agrochemical inputs; Shattuck (2021) states that capital and labor are critical determinants of pesticide[1] adoption, especially for herbicides.
Further, Little and Sylvester (2022) characterize financial capital as necessary for absorbing the consequences of Covid-19 disruptions. They assert that farmers who were not highly indebted could withstand the loss of income relatively well. In contrast, highly indebted farmers or farmers without other financial income struggled. While supply chains slowly recover, the pineapple industry faces new challenges. At the end of February 2023, CANAPEP, the chamber of Costa Rican pineapple producers, warned that the pineapple sector had lost US$60 million within the last six months due to the low exchange rate (Arce 2023).

Given the existence of different challenges that are affecting the pineapple sector, the question arises of how these influence pineapple producers. The role of weeds has received little attention in geographical research on agriculture and plays a crucial role in the use of pesticides and environmental governance and policy (Argüelles and March 2022): *"Weeds are an "enemy" to be defeated in the ongoing effort to dominate nature"* (Binimelis et al. 2009:627). Furthermore, herbicides play a crucial role in pineapple production due to its susceptibility to weeds, slow growth, shallow root system, and low, competitive ability and are a primary weed control method (Valverde and Chaves 2020). Hence, the challenges mentioned above can impact weed control methods if supply chain disruptions result in shortages or delays in the delivery of herbicides.

Literature suggests that various socioeconomic factors play a role in the management of pesticides. Their use does not result merely from economic considerations but depends on farmers' understanding of health, environmental, and regulatory risks. Galt (2008b) found a significant decrease in pesticide use among Costa Rican farmers who received agricultural education. Furthermore, labels such as Rainforest Alliance and customers demand more careful use and handling of pesticides, leading companies to rationalize pest control (Galt 2007; Jansen 2017a).

To better understand the factors that drive herbicide use in Costa Rican pineapple plantations, the concept of the Herbicide Revolution and literature on the privatization of Extension Services will be introduced. In contrast, the theory of uneven geographies will help me to frame my master thesis from an economic-geographical point of view (Chapter 2). Chapter 3 will give contextual background about

[1] The present study focuses on herbicides, which are considered as a subtype of pesticides. However, most literature and also some of the findings referred to the general use of agrochemicals and pesticides, therefore they are mentioned repeatedly in this study.

the history of Costa Rica as a producer of export crops, caught between the reputation of a sustainable tourism destination and intensive monocultures. It explains how Costa Rica became renowned as a green republic (Chapter 3.1), gives a short introduction to the Costa Rican pineapple industry (Chapter 3.2), and explains how it depends inextricably on the use of agrochemicals and the challenges associated with it (Chapter 3.3). Chapter 3.4 presents the research questions. The entire process of qualitative research is documented in Chapter 4, where the sampling strategy and data collection (Chapter 4.1) and the data analysis process (Chapter 4.2) are described. Furthermore, the personal experience of the fieldwork is reflected upon (Chapter 4.3) before a critical reflection follows to conclude the description of the method (Chapter 4.4.).

The interview and field observation results are presented in Chapters 5-7 and discussed more deeply, connecting them with the research literature and the research questions. Chapter 5 describes the status quo of current weed control practices implemented in pineapple plantations. Chapter 6 summarizes challenges for pineapple producers, while Chapter 7 discusses the role of standards and extension services on herbicide use. Chapter 8 aims to answer the research questions. For this purpose, the findings are discussed with the concepts of the Herbicide Revolution, extension services, and uneven geographies. Furthermore, ideas for further research are given, and the theoretical and practical contributions of the study are discussed. In the final Chapter, 9, the most important findings are recapitulated, and a conclusion is drawn.

2. Theory and conceptual framework

This Chapter conceptualizes and frames the factors that drive herbicide use in Costa Rican pineapple plantations from an economic-geographic point of view. I will introduce the concepts of the uneven geographies and Herbicide Revolution and complement them with literature on extension services.

2.1 Uneven geographies

Uneven development is one of economic geography's central topics and means that the economy develops unevenly across different regions, sectors, or social groups, resulting in disparities in wealth, power, and opportunity (Smith 1984). In a geographical context, the term uneven development can be equalized with uneven geographical development. This unevenness can refer to various economic indicators such as employment rates, income levels, and economic growth rates and has been described by different authors at all geographic scales - from intra-urban disparities to subnational regional differences to uneven international development. The concept of uneven development challenges the idea that economic growth and development are always positive and instead highlights the negative consequences that can arise from uneven growth patterns (Christophers 2009).

One of the key factors driving uneven development is the concentration of capital in certain regions or sectors. In human geography, uneven development is understood as an inevitable - or at least very probable - consequence in a capitalist mode of production, where development in one place is directly linked to underdevelopment in another (Christophers 2009). Capital tends to accumulate in areas where profits are highest, which can lead to the concentration of economic activity in certain regions or sectors. There are different approaches to uneven development in economic geography and related fields (Werner 2019). Some see uneven development as global market integration's "dark side".
In contrast, others see global production networks as channels of unequal value distribution, thus reproducing global inequality as the benefits and costs of production are distributed unevenly across the production network. Lead firms or powerful intermediaries may capture a disproportionate share of the value created, while others, such as laborers or smaller suppliers, receive a smaller share of the benefits. The concentration of economic power in certain regions or countries can lead to unequal relationships between nations and regions, as wealthier regions or countries exploit resources and labor from less developed regions. This can result in unequal power relations and perpetuate global inequalities (Werner 2019).

According to David Harvey (2005), accumulation by dispossession is the capitalist response to overaccumulation and is supported within the scope of neoliberal reforms. Mechanisms such as privatization and commodification necessarily go hand in hand with dispossession. In this context, the expansion of agrarian capitalism processes has led to different social and environmental conflicts, such as disposing of land and wealth for the rural population, which is relocated to agrarian capital (Harvey 2005). Harvey describes how capitalist expansion inherently produces conditions of uneven geographic development across space. To reproduce and sustain itself, it needs a "spatial-fix". The spatial-fix refers to capital overcoming economic difficulties by expanding to new geographic spaces or creating new markets. This expansion can take various forms, such as the appropriation of new territories, the exploitation of new resources, the creation of new industries, and the opening of new consumer markets (Harvey 2000).
Massey (2004) sees the spatial structuring of relations of production as unequal relationships that imply positions of dominance and subordination and henceforth as an element to which any concept

of uneven development must relate: *"Market relations are also conducted over space, and these too may involve systems of unequal power relations, and of domination. Relations between small and large firms come to mind"* (Massey 2004:112). For example, one element that reflects uneven development for Massey (2004) is places' social composition and inequality. Different occupational groups belong to other parts of the division of labor, which are spatially distributed according to production structures and a hierarchical ordering. The location of headquarters in one country reflects the social composition of this place as it attracts high-status, white-collar jobs, while other regions, primarily rural, will be composed of mainly less well-paid and manual work*: "For that distribution of distinct occupational (and social) groups is itself one reflection of a perhaps more fundamental structuring of inequality between those areas – that carried by the organization between them of the relations of production"* (Massey 2004:113). She concludes that the concept of spatial structures can be used to analyze economic relations between regions and the geography of the social relations of production underlie any particular form of uneven development in capitalist societies. Christophers (2009) describes uneven development as a tendency in which not only some countries develop more rapidly than others, but certain cities or regions to "get ahead" and stay there. This phenomenon of geographical clustering of economic activity is described as "economies of agglomeration" or "economies of localization" by different economists.

Werner (2019) and Berndt (2018) claim that the theoretical framework of uneven development is becoming popular in economic geography again after several decades of relative negligence. While it first included global commodity chains, it later focused on global value chains (Berndt 2018; Werner 2019). This shift is also interesting from the perspective of Massey (2004), who argued almost twenty years ago: *"The structures of uneven development are constantly evolving (…) There is, in other words, a relationship between the periodization of an economy and its regionalization – its forms of uneven development"* (Massey 2004:122). According to Smith (1984), capitalism involves contradictory geographic tendencies toward "differentiation" and "leveling". Geographical differentiation occurs through capital, but at the same time, capital is paradoxically a "leveler" of production conditions. For Smith, these two opposing tendencies and their contradiction cause unequal development. He sees this process as dynamic, meaning there don't exist static disparities in levels of geographical development, and places can develop while formerly "developed" places relapse (Smith 1984).

Although Costa Rica has experienced significant economic growth in recent years, not all areas and sectors have benefited equally. Economic growth has mainly concentrated on urban areas, such as the capital city of San José, while particularly rural areas have not seen the same level of growth and development. This uneven development has resulted in disparities in income, education, healthcare, and other social and economic indicators (van Noorloos and Steel 2016; Vanegas et al. 2015). Scholars describe the link between the dominance of monoculture crops such as banana and coffee and uneven development in Costa (see Araya et al, 2014, Galt 2008b, Herrera-Rodríguez 2013, León 2022). While these crops have historically been crucial for Costa Rica's economy, they have also negatively impacted the environment and local communities.

Shattuck (2021) argues that pesticides' intensive use, regulation, and adverse environmental and social impacts have historically been unevenly distributed worldwide. Hence, uneven development can shed light on the distribution of benefits and undesirable outcomes of the pineapple industry across different countries within the context of current challenges. Uneven development can help to analyze herbicide issues in pineapple production from two sides. On the one hand, different authors argue that

global production networks shape and are being shaped by uneven development (see Werner 2022, Smith 1984, Taylor 2007). On the other hand, Werner (2022) suggests that a chemical geographies perspective can broaden the traditional standpoint of production network studies by using "agricultural inputs" as starting points for critical commodity chain analyses: "*The chemical inputs that were largely considered only in so far as they (failed to) stabilize commodity assemblages can be unpacked as commodities in-and-of themselves to gain a better grasp of the shifting problematic of agri-food networks and their multidimensional relationships to uneven development"* (Werner 2022:239).

Thus, uneven geographies can help understand global value chains in the herbicide market and analyze the reasons and impact of supply shortages in pineapple production. For my thesis, I will use the concept of uneven geographies on an international and regional scale. I will elaborate on how the benefits and opposing sides of pineapple farming are unevenly distributed across the country and between Costa Rica as a producer country and countries importing pineapple.

2.1.1 Supply chains in the context of uneven development

Werner (2022) argues that supply chains can be viewed as temporarily stabilized outcomes of uneven development and as factors contributing to their ongoing shaping. This is particularly true when firms and business networks reorganize to adapt to different pressures (Werner 2019): "*Solutions are circumscribed by the institutional arrangements consolidated through the dominant production arrangement. The power relations between monopoly shippers and growers, along with institutional dynamics of scientific research shaped by the capital accumulated through those unequal relations, are the key determinants of production network restructuring in the face of novel pathogen emergence"* (Werner 2022:238). Also, Smith (1984) argues: *Supply chains are mechanisms to coordinate and combine capital's diverse commodification strategies not simply 'in' space but through the production of uneven development".*

Campling and Havice (2019) in Werner (2022) argue that supply chains are constituted in and through the environment. Werner (2022) hence contends that nature is neither an input nor output; its value is appropriated through the functional coordination of these spatially distributed activities: "*(…) "if capitalism is seen as a way of organizing nature, then supply chains are its most tractable form (…) In the throes of the Anthropocene and a global pandemic, more research on global supply chains is centering nature in substantive and diverse ways while expanding the remit of inherited GVC/GPN framework"* (Werner 2022:235).

I argue that supply chain disruptions can intensify unevenness in the herbicide and pineapple trade context. In times of supply chain disruptions, new south-south phenomena of pesticide trade have further exacerbated uneven geographies, as associated risks and opportunities of supply chain disruption are now even more imposed on countries of the global South (in this case, Asian supplier countries and Latin American purchaser countries). In contrast, the global North remains less affected.

2.1.2 Pesticides in the context of uneven development

Werner (2022) describes how agribusiness corporations transferred risks of "unruly" natures through the process of establishing out-grower schemes (linking smallholder farmers with domestic and international buyers) while sustaining control through supply chain governance. However, she claims: *"surprisingly little attention has been paid to the pesticides and fertilizers at the heart of these*

networks, framing these as mere 'inputs' for the final consumer good. Similarly, in political ecology, the focus on farmer decision-making has tended to neglect this 'off-farm' capital, which so often sets the parameters for what farmers do and how they do it" (Werner 2022:238). Agrochemicals are commodities in their own right and not just production inputs, and, as such, they become active agents that contribute to market success and put this success in danger (Werner et al. 2022).

In their article about uneven development of glyphosate, Werner et al. (2022) argue that the increase in the consumption of glyphosate, the most widely used herbicide worldwide, reflects uneven development consisting of shifting firm networks, policies, and trade (Werner et al. 2022): *"Marketization and commodification of glyphosate as a contradictory and always incomplete process driven by exclusions, devaluations, and more-than-economic logics that remake geographies of uneven development"* (Werner et al. 2022:21). While the pesticide geography was shaped for a long time by agrochemicals that were primarily produced (and consumed) in the Global North and exported to the Global South, a shift has taken place whereas middle-income countries have become principal producers and exporters. This has led to a new pesticide geography characterized by new south–south dynamics (Werner et al. 2022).

For the case of Costa Rican agriculture, Galt (2009) argues that consumers in the North can demand perfectly produced commodities all year around without being bothered by the consequences of the production system on the environment or workers. Furthermore, they can claim pesticide use rationalization through monitoring pesticides in food imports, but rather out of personal concerns for their health than out of solidarity with the farmers in the global south. In contrast, the state in developing countries lacks the resources to prioritize residue testing and/or is not as responsive: *"Lamentably, the privileges of the North, accumulated during the colonial period, remain entrenched in the post-colonial period and continue to be manifested in the "micro-events" of Costa Rican farmers' pesticide use"* (Galt 2009:25). Brown et al. (2020) argue that the pineapple production practices observed in Costa Rican may be emblematic for the state to put the right to profit over health and environment while "*the Global South are disproportionately shouldering the human health, environmental, and economic consequences of the Global North's demand for cheap agricultural commodities"* (Brown et al. 2020:n.p.).

Castro-Vargas and Mempel (2023) claim that *"Pesticides have become pervasive in agricultural landscapes, carrying with them logics of violence while also interacting with colonial and racist legacies"* (Castro-Vargas and Mempel 2023:8), referring to an example of Colombia where the herbicide glyphosate was used for a coca eradication campaigns. These so-called sacrifice zones in the global south are intrinsic to the logic of uneven development (Castro-Vargas and Mempel 2023).
I argue that pesticides can additionally intensify unevenness in the context of pesticide use. As mentioned earlier, the southwards shift in production and trade of pesticides has created uneven geographies. While the global North has restricted the use of pesticides, it still benefits from cheap imported commodities from the global South, produced by using pesticides (of which some of them are) banned in the global North. Consequently, the global South disproportionately bears negative effects such as environmental pollution by pesticides (Werner 2022).

2.2 Herbicide Revolution

The "Supermarket Revolution" has transformed supply chains, making export commodities subject to standards related to their aesthetic appearance. The pressure to meet quality and volume required significantly more intensive pesticide use (Shattuck 2021). Thrupp (1991) describes how already in the 1980ies, heavy applications of fungicides, herbicides, and nematicides were used in banana plantations to meet stringent cosmetic and quality standards demanded by buyers in the U.S. and Europe, which did not go unnoticed: *"The main adverse effects are agroecological problems such as pest resistance and resurgence of secondary pests, harm to human and animals' health, and accumulation of residues which create health risks and economic damage in some cases. Moreover, the benefits and costs of pesticide use are distributed inequitably in society, whereby the problems are borne primarily by the rural poor"* (Thrupp 1991:2). The concept of the circle of poison, introduced by Weir and Schapiro in 1981, can be identified as the first concept that describes the geography of pesticides. It illustrates how certain pesticides produced but banned in the Global North continued to be exported to the Global South. The circle finally closed when these pesticides returned to the Global North as pesticide residues in fruits and vegetables (Weir and Schapiro 1981).

However, at the beginning of the 90ies, the U.S. Department of Agriculture started to reject shipments when pesticide residues exceeded international standards in fresh foods (Thrupp 1991). Castro-Vargas and Mempel (2023) claim: *"Although 'circles of poison' constitutes an umbrella term relevant to a body of scholarship in political ecology and environmental justice, it is not in itself sufficient to explain the intricacy of pesticide networks"* (Castro-Vargas and Mempel 2023:6). Hence, they refer to the concept of "pesticide complex" which was proposed by Galt (2008), which emerged out of the need for revised empirical data, global information and research about pesticide including its use, trade, regulation, and effects. Throughout the turn of the millennium, the export sector in developing countries became increasingly affected by public and private residue regulations from industrialized countries. Galt argues that pesticide use between exporting and importing countries is assimilating: *"Basically, pesticide use in industrialized countries and export production in developing countries are no longer worlds apart as suggested in circle of poison thinking"* (Galt 2008b:796). According to him, a within-country divergence instead of a between-country divergence is taking place in the use of pesticides in developing countries. However, he argues that the use of highly hazardous pesticides continues in the production for national markets, as these are not typically subject to strong pesticide residue regulations.

Since the emergence of Galt's "pesticide complex" concept, the global pesticide industry has been further transformed over the last decade. Large firms such as Bayer-Monsanto or Syngenta-ChemChina have merged, while market entry and expansion possibilities have opened up for generic firms from the global South (Castro-Vargas and Werner 2022). Three significant changes could be observed in the pesticide industry in the first two decades of this century: a decrease in the number of new patents with the simultaneous expiration of old patents, the consolidation of the generics industry, and the positioning of China as a global leader in the pesticide industry (Castro-Vargas and Mempel 2023; Shattuck 2021a; Werner et al. 2022).

The term Herbicide Revolution refers to the recent and rapid adoption of off-patent herbicide formulations in countries of the Global South. Since 1950 the use of chemical pesticides has grown fast in developing countries and overlapped with the expansion of agricultural production (Thrupp 1991). Next to Asia, Latin America has had the highest pesticide use increase over the past decades. Between

2000 and 2015, the value of the pesticide market in Latin America grew from $4 billion to $12 billion (Shattuck 2021). Official trade data shows that global herbicide exports nearly quadrupled between 2000 and 2017 and substantially increased more than other pesticide exports (COMTRADE 2022; Werner et al. 2022). With rising rural wages, labor for mechanical and manual weed management practices has become more costly, while prices for agrochemicals have dropped. These factors make the substitution of labor with agrochemicals attractive (Shattuck 2021a).

The herbicide revolution describes the rapid adoption of herbicides and new types of south-to-south and south-to-north production networks (Werner et al. 2022). These new networks deliver off-patent herbicide formulations and low-cost Asian suppliers, increasing availability and driving down herbicide costs: *"For the first time in history, more pesticides are now being produced in Asia than the US and Europe"* (Shattuck 2021:239).

Different factors driving the adoption of herbicides are subsumed under the term "Herbicide Revolution." As Shattuck (2021) argues: *"The factors driving increased pesticide use (…) are many and overlapping, and there is relatively little data on the subject"* (Shattuck 2021a:243). Hence, there is a need to understand better the reasons for pesticide use in middle-income countries such as Costa Rica, as their role in the current configuration of the pesticide complex has changed over the last decades. On the one hand, Costa Rica produces and exports pesticides itself. On the other hand, it is a significant consumer of pesticides (Galt 2008b; Werner et al. 2022). The Herbicide Revolution concept will help me understand the rapid increase in herbicide use in Costa Rica.

2.3 Privatization of Extension Services

Galt (2008b) finds a significant effect of decreasing pesticide use intensity for farmers who received agricultural education. In contrast, the use of credit increases pesticide use intensity as historically, Costa Rican banks have required agrochemical use for credit distribution (Galt 2008a). Agricultural extension describes advisory services for farmers, such as for the use of agronomic techniques or pesticides. While this service formerly used to be organized by the state, a shift has occurred in the private sector. At the end of the 80s, Thrupp (1988) claimed that public education and information on pesticide use and pest control were nonexistent in Costa Rica. According to Aga (2019), a shift from the public to the private sector has occurred due to a withdrawal of state support for agriculture while non-traditional export agriculture has been promoted.

The virtual non-existence of state extension services providing technical support led to farmers' dependency on retailers for technical advice. Aga (2019) describes for India how private extension services build on the legacy of public extension by recruiting graduates from agricultural universities. However, the goals of private extension services diverge from public extension. Their primary goal is to increase sales of agrochemicals, and, unlike public extension services, they do not engage in broader rural transformation, development, poverty alleviation, or social justice. This reduces the advice to applying company products, often not addressing specific issues farmers face. Furthermore, the knowledge of agents of pesticide companies is mainly tilted in favor of big farms, while knowledge of the practices of small farmers is relatively shallow. Thus, agents can often not address specific questions of farmers, but farmers still appreciate their visits and a point of contact, a role that the government no longer plays: Private extension services present themselves as listeners and friends of the farmers and have overtaken a role that public extension agents were meant to perform in the past (Aga 2019).

Aga (2018) calls commercial companies merchants of knowledge. During his fieldwork in India, he observed how farmers would come into shops and describe various issues with their crop: *"(…) the retailer, situated at the point of sale, is in a position to exercise influence over what farmers buy, by making sense of and tailoring, rightly or wrongly, these bits of information for the specific requirements and conditions that the latter report. The confusion and gaps in knowledge among farmers allow the retailer to push products he wants to push. For instance, I have seen farmers simultaneously buy the same fungicide under two different brand names, belonging to two different companies"* (Aga 2018:20).

Even though Aga (2018) claims that this type of advisory service rarely satisfied farmers, they didn't see any alternative source of advice and felt constrained by their dependence on the retailer for subsequent purchases of inputs. The uncertainty of climate change further increases this dependency: Changing climate conditions challenge farmers, and extreme weather events such as erratic rainfall patterns worse increasingly aggressive pest and fungal complexes (Aga 2018, 2019). Furthermore, commercial companies provide some troubleshooting knowledge and decrease farmers' risk by extending credits. Aga (2018) concludes that the dependency on the retailer for knowledge stems from three significant reasons: First, to an increasing extent, farmers are cultivating non-traditional crops in which they have little experience. Second, the state has decreased the provisioning of agricultural credit. Finally, the space vacated by public extension services has been reclaimed by retailers as part of liberalization: *"This provides fertile ground for the corporate marketing of agrichemicals, as medicine for crops and for the changing agrarian relations and conditions of cultivation"* (Aga 2019:1461).

Unlike other producers, such as the banana industry, Costa Rican pineapple growers do not have a trade association or research centers supporting producers helping to generate technological and technical advice for producers. Consequently, technical assistance has been mainly in the hands of private companies, especially those marketing pesticides (Vargas 2021). Multinationals invested in safe use programs to apply pesticides in partnerships with local pesticide regulators. These programs promote pesticide use while limiting regulation (Shattuck 2021b).

In a survey, Galt (2008) observes that most potato farmers in Costa Rica rely almost entirely upon agrochemical salespeople for pest management, while farm visits by the Ministry of Agriculture (MAG) rarely occur despite their promotion of Integrated pest management (IPM). Figure 1 illustrates the findings of a survey from 2011 exploring the source of technical assistance for Costa Rican farmers. It shows that commercial companies play the most crucial role and market their products directly on farms. Since some growers know very little about agrochemicals, they buy the products recommended by these companies without knowing if they are the most suitable (Dirección de Estudios Económicos 2011). The same observation is made by Castro (2021), who claims that because some producers know little about agrochemicals, they buy what the commercial companies recommend. A study in 2002 found that extension services affiliated with pesticide companies increase farmers' use of pesticides (Wiebers et al. 2002). In 2011 the Ministry of Economy, Industry and Commerce MEIC reported the irrational use of agrochemicals in Costa Rica due to wrong doses, which can generate pest resistance (Montiel 2015).

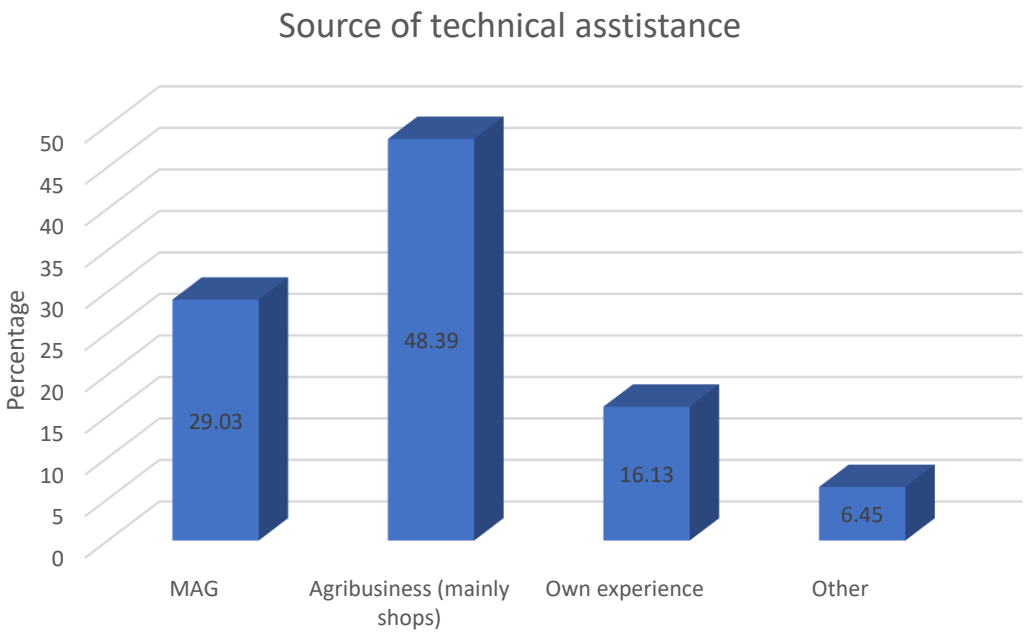

Figure 1:Technical assistance for farmers. Reference: Own work with data from Ministerio de Economía, Industria y Comercio (2011)

Different authors see thus the reason for the rapid increase of pesticide use in Costa Rica in the process of weakening agricultural extension services provided by the MAG in the mid-1990s and hence the dependence on private-sector actors (Dirección de Estudios Económicos 2011; Galt 2008a; Shattuck 2021b; Vargas 2021). This claim is also supported by a recent study from Wuepper et al. (2021) where they found that Swiss farmers who are advised by public extension services use more often preventive measures against an invasive pest, while farmers who are advised by private extension services use rather synthetic insecticides (Wuepper et al. 2021).

The concept of agricultural extension and its shift from the public to the private sector can support the reconstruction of the "last mile" of pesticides. Identifying crucial actors and their role in the distribution of herbicides to pineapple producers in Costa Rica can be helpful in understanding the role of agricultural extension in promoting and facilitating the adoption of herbicides by farmers. According to Wuepper et al. (2021), a transformation to more sustainable farming systems depends on farmers' production and technology choices which, in turn, rely on information and social learning. Furthermore, the privatization of agricultural extension is also interesting because it potentially conflicts with the national pesticide reduction target, as the state hands over part of its control to private actors.

3 Context

The following Chapter will give background information about Costa Rican pineapple production and agricultural history. This contextual classification is considered necessary to better understand the research subject of this master thesis. The first part will explain how Costa Rica became renowned as a green republic, followed by a short introduction to the Costa Rican pineapple industry. It explains how it depends inextricably on agrochemicals' use and the associated challenges. Eventually, the research questions and the Methodology will be introduced at the end of the Chapter.

3.1 Costa Rican exceptionalism

Costa Rica contains 3.6 percent of the world's estimated biodiversity, and one-fourth of the country's surface is under some environmental protection. These factors play a crucial role in contributing to the country's "green" reputation (OECD 2017). With its democratic legacy and technical capacity, Costa Rica has supported a green development model grounded on protected areas and ecotourism for several decades. However, Costa Rica's reputation as a green republic entails an inevitable paradox: while being a global leader in conservation policy, the country represents simultaneously a center of practices, innovations, and technologies in favor of monoculture agro-exports (Galt 2008b; Ramírez 2020): *"Ironically, Costa Rica's pineapple monocropping and ecotourism industry have simultaneously expanded since the 1980s"* (Brown et al. 2020:n.p). In this context, different scholars mention the exceptional character of Costa Rican's neoliberal development, referring to the adoption of market-led regulation while promoting social democratic norms and environmental protection (Castro-Vargas and Werner 2022; Galt 2008b; León 2022; Ramírez 2020): *"We know very well that similar conflicts and dilemmas are part of the reality of other countries around the world, but Costa Rica is a special case. Though it is a small and unimportant country in global geopolitics, it has historically assumed a critical role as a testing site for sustainable development policies. This has reinforced the idea of Costa Rica as an exceptional place, previously supported by the image of a progressive democratic system in a region characterized by armed conflict and authoritarianism"* (Ramírez 2020:2).

As Brown et al. (2020) state, an analysis of the political ecology of the pineapple industry must take into account the region's political history. To understand how Costa Rica has come to its reputation as a "green republic" while being an essential producer of export crops, I deem it necessary to take a brief look at the economic and political history of Costa Rica, which explains the idea of Costa Rica as an exceptional place.

Costa Rica's image as an exceptional nation is a historical construct whose origins still represent a lively debate. Historically, the Costa Rican economy has been mainly based on extracting natural resources for processing and sale in international markets (León 2022). At the end of the 19th century, an authoritarian military leadership was established, which was favorable to the expansion of capitalist agro-export, whose purpose was to provide liberal progress through the "civilization" of the lower classes of the population (Molina Jiménez 1988). Different scholars see as the origin of Costa Rican exceptionalism the model of social democratic governance that gradually emerged during the 20th century consolidating with a strong welfare state in the 1940s (Ramírez 2020:5). This process can be seen as the result of an unusual coalition of agro-exporting interests, the Catholic Church and the Communist Party that had initiated a series of ambitious social reforms at the state level to address the global economic effects of the 1930s Depression and World War II in Costa Rica. The post-war period promoted an expansion of this welfare state, facilitated by one of the highest economic growth

rates in Latin America during the 1950s and 1960s (Edelman 1998). The strengthening of the geopolitical relationship between Costa Rica and the United States supported this growth. Ramírez (2020) describes this collaboration as crucial for forming an image of Costa Rica as a politically stable and peaceful country while being receptive to external ideas and influence. In the 1970s, the Costa Rican state exerted considerable influence on society, employing one-fifth of the labor force and accounting for one-quarter of the gross domestic product (Edelman 1998). Thus, the combination of a welfare state based on a reformist and conciliatory model combined with a stable electoral system was seen as the basis of Costa Rican exceptionalism (Ramírez 2020).

Like most Latin American countries, Costa Rica was marked in the 1970s and 1980s by a structural crisis and was struggling with debt payments and the rise of what has come to be known as neoliberalism (León 2020). Ramírez (2020) sees the debt crisis as a source of the peculiar tensions between conservation and development. The increase in oil prices, falling coffee prices, and the growth of interest rates on public debt caused Costa Rica to declare a moratorium on its obligations in 1981 and suffer from one of the highest per capita debts in the world (Capitán 2003). The debt forced the country to undertake structural adjustment under the supervision of the World Bank and the International Monetary Fund. It demanded a significant reduction in public spending, privatizing a part of the public sector, and eliminating import tariffs that protected the domestic economy from international competition. The crisis pressured the agro-export market to increase crop production to earn needed foreign exchange, which also increased the use of imported agrochemicals (Thrupp 1988).

International actors were eager to profit from existing agricultural economies under the general premise of market-based reforms. Together with the United States Agency for International Development and other international actors, the Costa Rican government launched infrastructure programs to reduce domestic trade barriers for transnational agribusinesses (Brown et al. 2020). Costa Rican implemented a series of structural adjustment programs to deepen linkages with the global market through the national economy's liberalization, transnationalization, and privatization (León 2020). Thrupp (1988) described Costa Rica’s economic development policy for this time as mixed. While it entailed social welfare and democracy to some extent, exemplified by its strong public health care system, public education, and social services, the policies also supported export agriculture based on agrochemicals, serving the interests of the agrochemical industry and large producers. The Costa Rican state was obliged by international financial institutions to adopt policies such as tax exemptions that benefitted international firms like Del Monte and Dole (Vagneron et al. 2009) and were trying to attract foreign investors and transnational companies in 1990 (PROCOMER 2022).

Non-traditional exports where seen by the government as a means to expand the economy and repay debts (Brown et al. 2020). For rural areas, this led to promoting tourism and cultivating nontraditional crops for export markets, such as pineapple, oranges, and palm oil (León 2020). However, the export promotion led to the abandoning support for the small and medium-sized producer sector oriented to the domestic market. As a result, a significant part of the national agricultural sector went into crisis, while new activities, such as pineapple cultivation, were emphatically promoted (León 2020). These neoliberal adjustments of Costa Rican agriculture coincided with the third food regime. Non-traditional exports and the shift away from traditional agricultural commodities and towards higher-value, processed, and manufactured goods can be seen as critical features of the third food regime. The third food regime promotes modern technologies and production practices crucial for export crops (Pechlaner and Otero 2008).

At the same time, the expansion of Costa Rica's livestock agroindustry provoked rapid deforestation (Edelman 1998), and in thirty years, forest cover had decreased from 50% of the national territory to less than 20% (Evans 2010). Initially a problem not addressed by structural adjustment, deforestation in Costa Rica became a matter of interest for international financial organizations towards the end of the 1980s because they considered the future national dependence on timber imports as a future threat to the trade balance (Ramírez 2020:11). National campaigns to protect remaining forests and can be described as starting point for the establishment of Costa Rica's image as a "green republic" (Ramírez 2020).

The U.S. administration at the time saw Costa Rica as a potential showcase for a prosperous and stable capitalist democracy in the face of Central America's military dictatorships. Given its sudden geopolitical significance, Costa Rica received large amounts of international aid, allowing it to deal with the most damaging effects of the economic recession (Edelman 1998). Ramírez (2020) concludes that a threefold crisis - debt, geopolitical and environmental - and the external assistance from the United States (USAID) were critical factors for the establishment of neoliberalism and organizing the nation's natural resources accordingly (Ramírez 2020:12).

In the mid-1990s, President José María Figueres Olsen (1994-1998) suggested a "*sustainable development a la tica*". León (2020) describes "*Tico-style sustainable development*" as combining the general understanding of sustainable development and further intensifying neoliberalization. This idea was based on two assumptions: an understanding of its identity based on export crops, especially coffee, with a concern for protecting nature (Evans 2010; León 2020). During his administration, Figueres signed a structural adjustment project with the World Bank, which included a set of large and very unpopular cuts in the public sector and the liberalization of the banking sector. Furthermore, he prioritized trade politics, signing a Free Trade Agreement with Mexico (León 2022). The efforts of the government for the conservation of nature can be described through the creation of policies, such as payments for environmental-services (Costa Rica was the first country to do so), but also through the promotion of ecotourism in rural areas, as a way to offset the adverse effects of extensive cattle ranching and the expansion of monocultures (Sanchez 2018). Different environmental organizations have identified the country as a role model and its role as a promoter of REDD+ to reduce deforestation and forest degradation. In the 1980s, tax exemptions were established for the tourism sector (Brown et al. 2020). In 2002, the United Nations International Year of Ecotourism, Costa Rica was acknowledged worldwide as an ecotourism destination. In 2019 the country received over 3 million tourists, a considerable number compared to its own 5 million inhabitants (ICT 2022).

As far as rural areas are concerned, the sustainable development scheme expanded in a somewhat contradictory way. On the one hand, agriculture for export commodities continues to be seen as one of the engines of the desired economic growth but on the other hand, deforestation is seen as the antithesis of both the conservation of the environment and the promotion of eco-tourism. The country's environmental protection zones doubled in size between the mid-1990s and 2017, reaching almost two million hectares (Corrales Chaves and Alemán 2017), while the production of export crops such as coffee, bananas, sugar cane, pineapple, and palm oil – has grown by 60% between 1984 and 2014. During the same census period, the country's agricultural land decreased by 20% (around 600,000 hectares) (OCARU 2017). This raises the question of how the amount of land devoted to

monocultures, mainly pineapple, could expand parallel to conservation areas as agricultural land decreased in the same period (León 2020).

León (2022) argues that the geographic expression of sustainable development has been uneven and disparate in Costa Rica. While urban areas have become dominated by the service economy and commerce, rural areas have been transformed into export-oriented plantations (mainly banana, oil palm, pineapples, and other tropical fruits), national parks, or tourist enclaves for the adventurous spirits or those who prefer first-world comforts amidst exuberant nature. Infrastructure investment follows this pattern, with the best roads extending from the capital to plantations, ports, national parks, and tourist enclaves, while roads within and between rural communities are neglected. The result is a set of fragmented landscapes in which experience, and thus understanding of the country, is deeply differentiated along class and location, with an apparent fracture between urban and rural (León 2022). What defines Costa Rica in comparison to other countries is, according to Ramírez (2020), the geographic separation in the promotion of complete conservation in some areas while intensive agro-industry has been developed in other areas. This process is supported by state policies that promote intensive forms of production and other forms of extractivism but simultaneously finance protected areas and payments for environmental services (Ramírez 2020): *"Throughout the government there is generally a conflict between the desire to comply with the laws and support the green lifestyle that Costa Rica holds in such high esteem and the desire the maximize profits and expedite development by taking unsustainable shortcuts"* (Araya et al. 2014:16).
Hence, Costa Rica successfully positioned itself at the forefront of sustainable resource management and environmental conservation thanks to creating protected areas, investments in ecotourism, environmental programs, and recent decarbonization strategies. At the same time, Costa Rica has also become a leader in experimentation with plantation economies (Ramírez 2020).

3.2 Pineapple sector in Costa Rica

3.2.1 History of pineapple production in Costa Rica

Pineapples have been grown in Central America since at least the colonial period. However, the type of pineapple we know today has been grown in Costa Rica for only 50 years, initially for local consumption and, to a lesser extent, for the industrialization of pulp, jams, marmalades, and canned products (León 2020).

In 1961, Dole, Del Monte, and the Maui Pineapple Company formed a consortium to fund the creation of the Hawaii-based Pineapple Research Institute [PRI], which developed a set of new hybrid varieties. One hybrid in particular, "73-114," caught the attention of scientists for its sweet flavor and yellow coloration, to the point that it was later renamed MD2, after Millie Dillard, the wife of the CEO of the Maui Pineapple Company (Amar et al. 2015). However, this variety was not immediately geared toward commercial production. At the end of the 1970', Del Monte began to explore the possibility of moving its declining pineapple production in Hawaii to other locations where production costs (labor and land) were lower, climatic conditions favorable, and cultivation land available (Bartholomew et al. 2012). In Latin America, Costa Rica presented itself as an attractive destination thanks to the presence of Del Monte and its reputation for political stability. The new variety had several advantages; not only did it taste sweeter and contained more significant amounts of vitamin C, but it was also larger and more uniform in size than other varieties and had a longer shelf life, which meant that it could open up access to more distant markets, such as Europe (León 2022).

Between 1977 and 1978, the first industrial pineapple plantations in Costa Rica in the canton of Buenos Aires, in the south of the country, by the Pineapple Development Company (PINDECO), a subsidiary company created by Del Monte, were established. At the time, the land the company set up (about 4,000 hectares) was pastures, mostly unused by local landowners. In addition to these accessible lands suitable for the new crop, a relatively cheap and accessible labor force made Costa Rica an attractive production site for Del Monte (León 2020). By the end of the 1980s, PINDECO received the highest amount of credits from the Costa Rican government compared with other corporations, which bolstered a boom in fresh pineapple exports and attracted foreign investment from other companies (Vagneron et al. 2009).

By the mid-1990s, Del Monte had shifted its entire Costa Rican production from the Cayena Lisa to the MD2 variety. In 1997, the MD2 variety accounted for only 20% of Del Monte's pineapple sales but 64% of its profits (Solera and Porras 2017). As mentioned in the Chapter before, several incentives were granted in 1990 to promote export crops such as pineapple. For example, tax exemptions on import tariffs of raw materials, equipment, and sales indirectly subsidize exports. For example, credit for the staple crop sector oriented to the domestic market was reduced by almost 90% between 1980 and the 2000s, and technical support shifted from these products to new export-oriented crops (León 2022).

The extension of pineapple production began around the year 2000 when the cultivation of the variety MD2 expanded and replaced the Cayena variety (Fresh Plaza 2022; PROCOMER 2020). The MD2 variety was well accepted in international markets and encouraged domestic producers to increase their production and improve cultivation practices, positioning Costa Rica as the world's leading exporter of fresh pineapple (Arroyo and Leon 2017). During this time, Del Monte secured a highly controversial patent on the rights to the MD2 hybrid, which would result in a protracted legal dispute with Dole. In 2003, Del Monte was forced to give up its claims to the exclusive control of the MD2 hybrid, opening the door for other companies, such as Dole and Fyffes, to create and market their golden pineapple varieties (Solera and Porras 2017). The MD2 variety transformed the world market for fresh fruit and the price at which it could be sold, which was three times higher than that for other varieties (Amar et al. 2015). In the same year, the National Chamber of Pineapple Producers and Exporters (CANAPEP) was founded as a private, non-profit organization to encourage pineapple producers (CANAPEP 2022d).

Seeing the high prices that the fruit received in world markets, pineapple production expanded from the canton of Buenos Aires to the country's northern region (the cantons of Los Chiles, Upala, and Guatuso), in the border region with Nicaragua. The plantations are mainly spread throughout the length and breadth of the Northern, Caribbean, and Pacific (PROCOMER 2020). Figure 2 shows that pineapple production today concentrates mainly in three regions: The Huetar Norte Region is the most important in terms of the amount of territory dedicated to pineapple cultivation (49% of production), followed by Huetar Atlántica (29% of production) and Region Pacifico (22% of production) (Cámara Nacional de Productores y Exportadores de Piña 2022). These regions account for 90% of Costa Rican pineapple production. The pineapple farms I interviewed were all located in the zone of Huetar Norte in the canton of San Carlos. According to an agronomist I spoke to, this region has three advantages compared to other regions: First, its proximity to the port of Limon, secondly year-round rainfall that makes irrigation unnecessary and third natural drainage thanks to the topography (D.H, 2022).

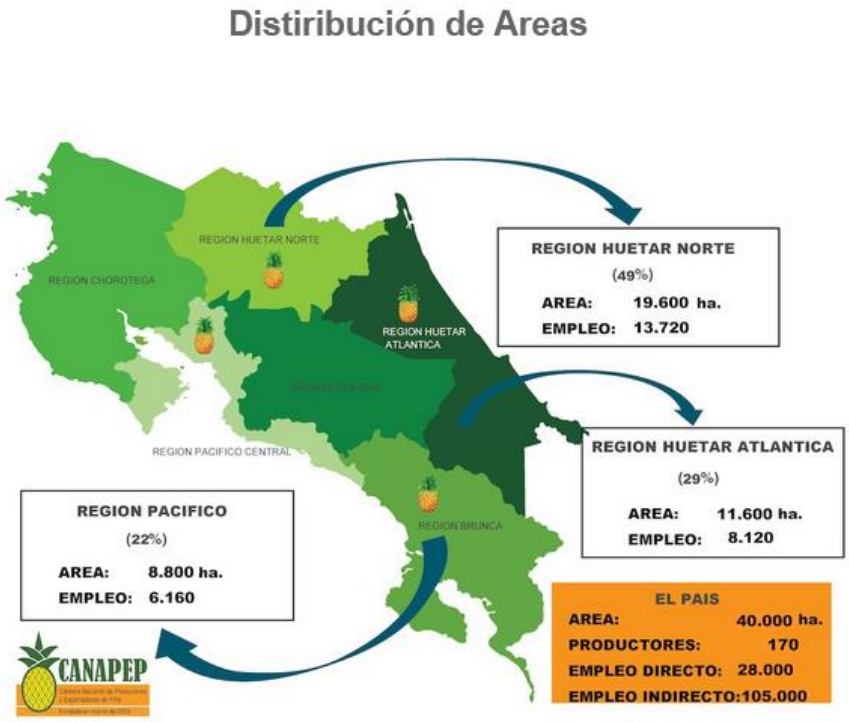

Figure 2: Pineapple cultivation areas (area), number of producer (productores) and number of direct and indirect employees (empleo). Reference : Canapep, 2022

All these places have in common that they were formerly traditional agricultural regions. However, the expansion would not have been possible without the technological changes that occurred with the introduction of the MD2 variety. Previously, the types of climatic conditions in which pineapple could be grown on a large scale were limited. However, with the new variety and its technological package, excessively dependent on agrochemicals (around 30 kg/ha compared to the national average for crops of approximately 18 kg/ha), the agricultural frontier was expanded by employing technology (León 2022). PINDECO introduced a technological package that included the change of the variety, the mechanization of the production process and harvesting, and cultivation techniques, including fertilization and the application of agrochemicals for pest and disease control. Furthermore, other factors such as soil quality, temperature, humidity, solar radiation, displacement of livestock activity, a crisis in the traditional agricultural sector, instability in the banana sector, low land prices, proximity to export ports, and the promise of better income contributed to a rapid expansion (Arroyo and Leon 2017). Brown et al. (2020) argue that the rapid expansion in production was stimulated by a growth in demand but achieved by a shift from small-scale farming to large-scale monocropping (Brown et al. 2020).

Before the turn of the millennium, it was estimated that there were about 11,000 hectares of pineapple plantations distributed between the southern and northern zones of the country. However, the increase in the number of growers and hectares dedicated to the fruit's cultivation multiplied with export opportunities (CANAPEP 2022d; Sánchez 2019). A study coordinated by the United Nations Development Programme (PNUD) estimated the cultivated land for pineapple production through satellite imagery for 2019 at more than 66 thousand hectares (MOCUPP 2021). This number is remarkably higher than official data from 2021, which estimated 40’000 hectares (Ramírez et al. 2022). Furthermore, MOCUPP reports that more than 5 thousand hectares of forest had been lost in riverbanks and wetlands between 2000 and 2015 due to pineapple activity, and 1’482 hectares of

pineapple plantations were found in Protected Wildlife Areas (MOCUPP 2021). The Federación Costarricense Para la Conservación de la Naturaleza (Fecon) blames the state for inaction: "*It is known that the institutions in charge of enforcing environmental legislation are not doing their job or only deficiently. Therefore, they are complicit in the environmental destruction that the country is suffering according to Article 57 of the Forestry Law*" (Angulo 2019).

In a newspaper article published in 2017, Abel Chaves, president of CANAPEP, stated that the report from MOCUPP was inaccurate and that the unproven expansion was the result of the "migration" of producers from other crops such as coffee, citrus, macadamia nut, rice, beans, sugar cane, among others, to pineapple. In addition, he cited that Costa Rica's forest cover had increased from 1.2 to 1.4 million hectares in the same period. Chaves concluded that "*the word expansion has been used politically charged in the case of pineapple*" and that *"an incorrect message is being presented and the image of a sector that has been successful is being befouled"* (CANAPEP 2017).

The annual growth of productivity (11.25 % per year) has made pineapple the most dynamic and competitive agricultural product in Costa Rica during the last decade (Leiva and Vargas 2017). Costa Rica today enjoys an international reputation as a leader in pineapple cultivation, and its expertise is also in demand in other producing countries (J.V, 2022). In 2021 around 70% of global pineapple shipments were supplied by Costa Rica (FAO 2022). There are about 1,300 producers throughout the country and 122 exporters. CANAPEP estimates that pineapple production in Costa Rica creates 28'000 direct jobs and 105'000 indirect jobs (CANAPEP 2022c). Figure 3 illustrates that the central consumer countries of Costa Rican pineapple are the United States (50%), followed by European countries (PROCOMER 2022).

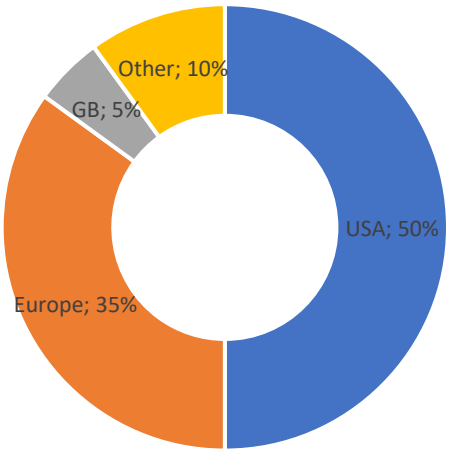

Figure 3: Destination of exported pineapple in 2021. Reference: Own work with data from Procomer (2022)

Figure 4 shows that pineapple is the most important export crop for Costa Rican economy, accounting for 34.7% of the agricultural GDP (Ramírez et al. 2022).

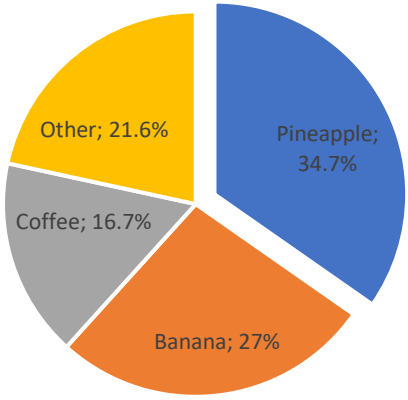

Figure 4: Value of exports of the main products of the agricultural sector in Costa Rica. Reference: Own work with data from Ramírez et al., 2022

3.2.2 Agronomic features of pineapple production

Pineapple requires a tropical climate with temperatures between 20 and 30 °C and fertile soil to grow and produce fruits. Nitrogen and Potassium are the most important nutrients for pineapple. Nitrogen influences yield and the latter fruit quality, while in the early stages of crop development, phosphorus contributes to root development. Irrigation is only necessary during the dry season in regions without rainfall (MAG and IICA 2019; Sandoval and Torres 2011)

Figure 5: Pineapple plant fifteen days after flower induction. Reference: Picture taken by author during a field visit in Pital, December 2022

The ripe fruit is obtained 135 days after the flower emerges (Sandoval and Torres 2011). It comprises between 50 and 200 small fruits around the same central axis; each shell scale is a fruit that grows from a flower, which merges into a syncarp (Bartholomew et al. 2003). Up to 70’000 pineapple plants are planted per hectare (Chamber of R&D manufacturers, 2022). Flower induction, sometimes called “forcing,” is a chemical treatment with Ethylene used approximately one year after planting the pineapple to uniformize and reduce the harvest period to meet market demands. The effectiveness of the treatment depends on the plant's development stage and the climatic conditions (Bartholomew et al. 2003). The different stages of the ripening process after flower induction can be seen in Figure 5&6.

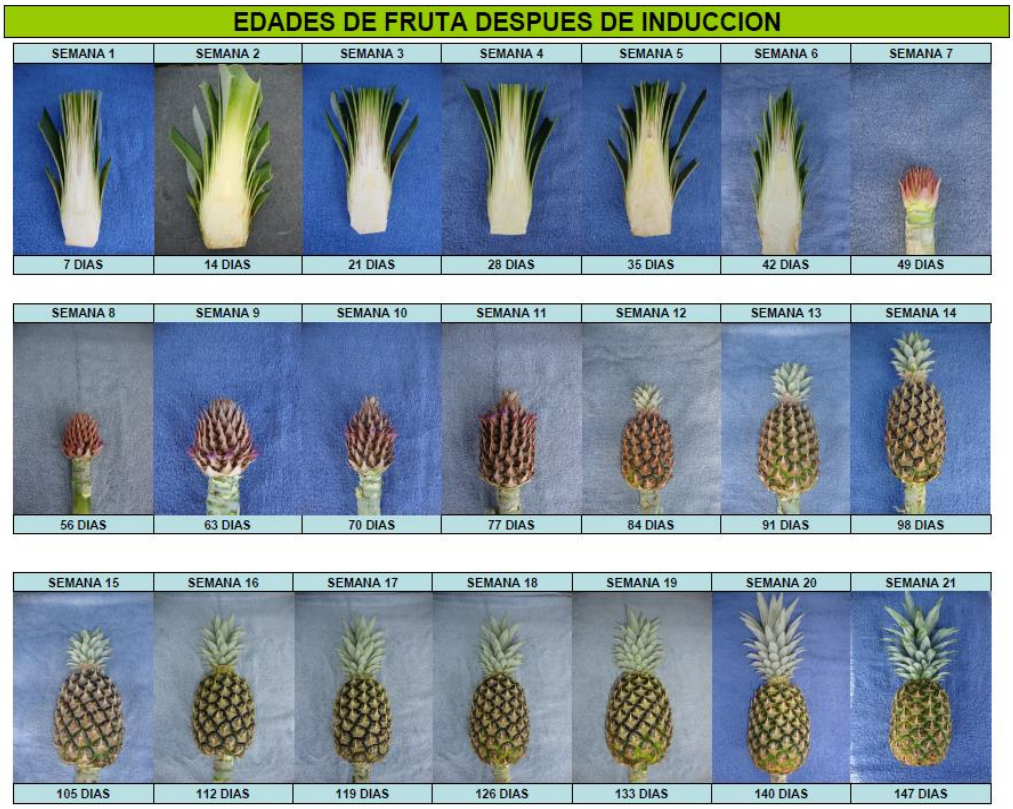

Figure 6: Development stages of pineapple after flower induction. Reference: LSP1

The pineapple harvest occurs approximately five months after flower induction (Sandoval and Torres 2011). Weed control can be done chemically, manually, and mechanized about four times yearly, preventing weeds from competing for moisture, light, and nutrients (Sandoval and Torres 2011). Herbicides in pineapple cultivation are mainly applied during the land preparation process, hence during the first four months (D.H, 2022). After planting, the first chemical application should be made immediately after, before the scions emit their roots; the second, directed to the soil, is made from month six to month eight after planting before the plantation completely covers the surface of the land. Once the fruit has developed, herbicides cannot be applied anymore, and manual weeding has to be used to eliminate weeds that escaped prior chemical treatments (Ávila 2011). The crop cycle is illustrated in Figure 7.

Figure 7:Pineapple crop cycle. Own work

After the pineapple harvest, about 300 tons of crop waste (green foliage) per hectare remains on the field and needs to be quickly removed or treated to prevent the attraction of the fly *Stomoxys calcitrans* which lays its eggs in the rotting foliage. These flies are a problem for cattle farmers, as they bite livestock by feeding on their blood. The standard way to accelerate the organic material's drying process is using a desiccant herbicide such as Paraquat, especially during the rainy season. However, other treatments can also be applied, such as physically burning fields (forbidden in Costa Rica) or manually chopping foliage and incorporating the material into the soil (Solórzano et al. 2015). Figure 8 illustrates a pineapple field after the application of a desiccant herbicide.

Figure 8: Pineapple crop after the application of a desiccant herbicide. Reference: Picture taken by author while a field visit in Pital, December 2022

3.3 Pesticide use in Costa Rican pineapple production

Today, Costa Rica is known as a country with high use of pesticides in agriculture, averaging 34.45 kg of active ingredient per hectare and year, which is higher than in OECD countries and also higher compared to other countries in the Americas with similar agricultural conditions, such as Colombia, Ecuador and Guatemala (Vargas 2021). While some data is available on pesticide imports and sales in Costa Rica, there is limited information on actual pesticide use and their potential environmental and health impacts (see BananaLink 2021; Bravo et al. 2011; Galt 2009). However, different sources describe an increase in pesticide imports over the past decades: *"Imports of pesticide during the past three decades increased more steeply than the area devoted to agriculture in Costa Rica"* (De la Cruz et al. 2014).

While the country imported on average 3.8 million kg of active ingredients in the 1980ies, the imported amount almost threefold to 11.4 million kg in the 2000', which coincided with Costa Rica becoming the lead fresh global pineapple exporter in 2012. In the same period, imported pesticides per hectare of cultivated land grew from 7.5kg to 25.7kg (Bravo et al. 2011; De la Cruz et al. 2014). Between 2015

and 2020, Costa Rica increased its imports of agrochemicals by 37% (from 13.1 million kg of active ingredients in 2015 to 20 million in 2020) (Programa Estado de la Nación 2021). When I confronted the agency responsible for the country's pesticide registry (SFE) about the increased number of imported pesticides, my interview partner did not comment, arguing that she had to see the exact numbers. SFE claims that approximately 50% of the imported active ingredients are being re-exported to other Central American countries and the Caribbean, mainly in formulated products. This contrasts the findings of De la Cruz et al. (2014), who estimated for the period 1977-2009 that eleven to twenty-five percent of the pesticide imported into the country was exported to other Central American countries. Hence, they argue that the vast majority is used within the country, making Costa Rica one of the world's most intensive pesticide users (De la Cruz et al. 2014; Fecon 2020).

Data for quantities of exported pesticides is difficult to compare with import data since export data is based on the much higher volumes of formulated pesticides, as opposed to the import numbers for active ingredients (Bravo et al. 2011). Since 2000 exports have increased by almost 500% (476%), making Costa Rica 2008 an exporter of formulated pesticides for the first time, while exports are expected to increase further (COMTRADE 2022). Costa Rica's role as a regional pesticide exporter was reinforced in 2016 when the Agriculture Ministry expanded tax and tariff exemptions to generic manufacturers for converting imported active ingredients into formulated pesticides for export (Castro-Vargas and Werner 2022).

3.3.1 Apparent use of pesticides

Foreign corporations introduced pesticides to Costa Rica's agriculture in the 1940s (Thrupp 1988). Jansen (2017) argues that despite a rationalization process of pesticide use over the last decade in Costa Rica, it did not necessarily lead to a decrease in its use (Jansen 2017a). "Apparent use" of pesticides refers to the difference between imports and exports of pesticides that a country accounts for per year. Two methods are commonly used to calculate the apparent use of pesticides in a country: The first method does not differentiate between different types of land use, such as crops and pastures. Subsequently, the total apparent use (imports minus exports) of pesticides by the total area is calculated. The other method separates crops from pastures and calculates the use of pesticides separately for agriculture pastures (Vargas 2021). Castro et al. (2021) criticize that the SFE uses the first approach, which implies the implausible assumption that pastures and crops consume equal amounts of pesticides.

When subtracting the estimated use of pesticides used in pastures from crops between 2012-2020, the year-by-year average apparent use of pesticides in agriculture ranges between 24.6 kg and 47.1 kg of active ingredients. This figure is significantly higher than the figures published by the SFE in these years, which estimates the use intensity at 11.5kg active ingredient/ha. However, it corresponds to the ones published by FAO (2011) (with data from the World Resources Institute), which indicates that Costa Rica is the largest pesticide consumer in the world in terms of active ingredient use per hectare (Vargas 2021). Compared to other crops, a broad range of technological inputs, both in terms of chemical inputs as well as phytosanitary material, is used in pineapple plantations (Arroyo and Leon 2017:83). Figure 9 shows that by 2020, pineapple was after banana the crop in Costa Rica with the highest use of pesticides in absolute terms (Vargas 2021). In 2012 16% of the total imported pesticides

were used on bananas and 10.2% on pineapples (Castillo M. et al. 2012). This steep increase is directly linked to the expansion of pineapple over the last 20 years (Vargas 2021).

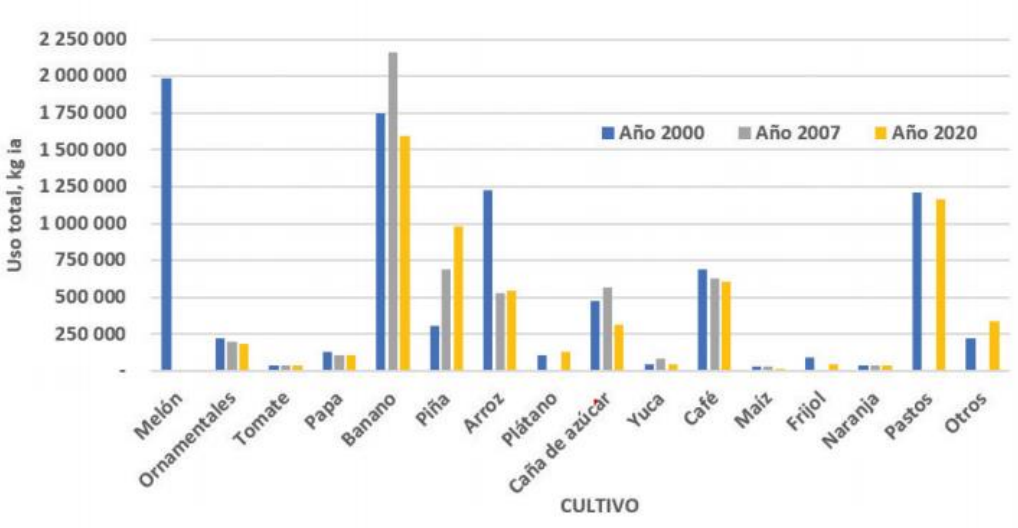

Figure 9: Pesticide use in kg in different crops in Costa Rica. Reference: Castro (2021)

The high productivity of pineapple corresponds, to a large extent, to the intensive use of agrochemicals. In 2014, 98.88 % of the pineapple farms used fertilizers, and 96.09 % used insecticides and fungicides (Leiva and Vargas 2017). In 2019 out of the 64 pesticides registered for use in Costa Rican pineapple cultivation, 53 of them presented some characteristic of hazardousness (toxicity and environmental behavior) that is of concern, in addition to the fact that they have never had an adequate environmental risk assessment that considers the chemical loads used and the conditions of use in the pineapple activity in Costa Rica (Vargas 2019).

3.3.2 Pesticide regulation in Costa Rica

The MAG is responsible for regulating the use and control of pesticides, whereas the General Health Law (Law 5395) and the Plant Protection Law (Law 7664) are of particular relevance. Furthermore, various decrees of regulatory nature clarify, order, and define the use and registration of pesticides (Chacón 2019). However, different scholars argue that despite the existence of a broad regulatory framework for the use of agrochemicals, the flaws lie in the lack of consistent and adequate enforcement (Araya et al. 2014; Chacón 2019; Thrupp 1988; Vargas 2021). Castro (2021) criticizes that adequate control by MAG authorities over the use of pesticides in agriculture does not exist. In 1988 Thrupp claimed that despite many formal laws concerning pesticide use, the Costa Rican government has been relatively ineffective in carrying out laws and undertaking *"badly needed actions*"; several constraints have hindered progress (Thrupp 1988).

In 2004 the Contraloría General de la República (CGR), a constitutional body auxiliary to the Legislative Assembly that oversees the use of public funds, claimed that existing control procedures are inadequate, both at the level of registration and in the control of residues (CGR 2004). Only twenty attorneys worked for the Environmental Administrative Court in 2014 with a gradually decreasing budget to litigate all the cases brought for the entire country (Araya et al. 2014): *"One issue that is made obvious is the fact that many different entities have vague and overlapping responsibilities, which makes enforcement difficult, bribery easy, and blame for faulty enforcement on other sectors a common occurrence"* (Araya et al. 2014:16). One of the last observations made by the CGR was missing

preventive and corrective actions to ensure the chemical safety of fresh vegetables for human consumption by the SFE and MAG (CGR, 2017).

Araya et al. (2014) propose different ways for improvement, such as enforcement mechanisms, and suggest imposing stricter standards on pesticide companies, prohibiting the import of agrochemicals that have been banned for health reasons in other countries, delegating specific aspects of enforcement of regulatory functions to external agencies, conducting quality testing and implementing incentives for farms to utilize IPM practices.

The MAG implemented a program promoting “good agricultural practices” in which they claim that all pesticide applications must be justified and integrated pest management (IPM) principles should be applied for pest and weed control. Priority should be given to the application of preventive measures and non-chemical control methods, favoring practices related to cultural, biological, physical, and other control methods. Periodic evaluations of pests in the field, assessing economic damage threshold, affected zones or areas, and environmental contamination should be conducted to diagnose the impact before applying pest control measures. Furthermore, MAG claims that land selection for pineapple production should consider the previous use of the site and measures against soil or water pollution measures have to be taken, and in the event of an uncontrollable hazard, the pineapple cultivation site has to be discarded (MAG and IICA 2019).

In 2017, Costa Rica established a state-led committee intending to strengthen responsible pineapple production and trade in Costa Rica. This initiative at global level aimed to open a space for dialogue and action for different actors such as representatives of the State, academia, producers, buyers, communities, and civil society organizations. Besides the MAG and Livestock, the Ministry of Environment and Energy, the Ministry of Labor and Social Security, the Ministry of Health, and the United Nations for Development were involved (Brenes 2017). The initiative's primary goal is actions regarding the main challenges of pineapple production, such as maintaining fertile and healthy soils and clean water and guaranteeing sustainable and dignified livelihoods for producers (Brenes 2017). Besides mapping land used for pineapple production registered through the Monitoring System for Change in Land Use (MOCUPP), they are offering support for the implementation of critical actions in sensitive areas such as training, soil management, and control of agrochemicals in implementation in the producing cantons of pineapple for export. The initiative is part of the country's efforts to meet the Sustainable Development Goals (SDGs) (Brenes 2017).

3.3.3 Pesticide pollution

The chemically hazardous nature of pesticides and difficulties in controlling their application make pesticide pollution challenging. Figure 10 shows that wind can carry pesticides to nearby ecosystems during the application or leech into the soil through rinsing and rain runoff. Thereby, sites far beyond application sites can be affected by evaporation and subsequent deposition in the form of rain (Araya et al. 2014).

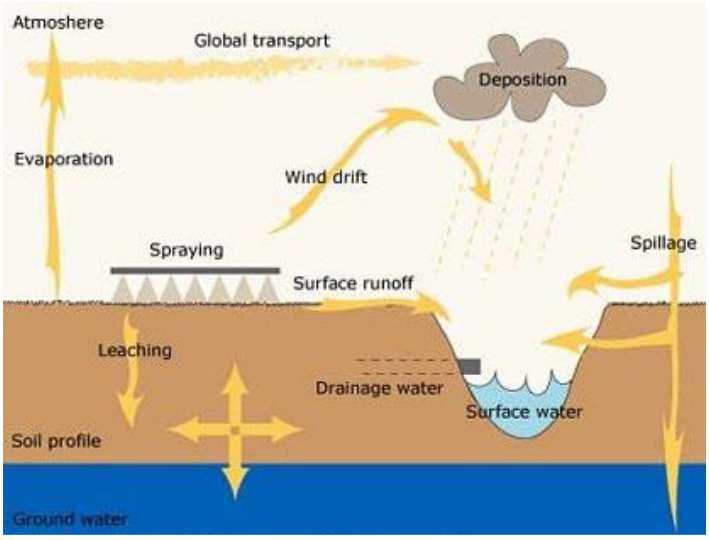

Figure 10: Pesticide spread in the environment. Reference: (SLU Centre for Pesticides in the Environment 2020)

Exceeding dosages can lead to the development of pest resistance because agrochemicals eventually lose their effectiveness. Araya (2014) and Thrupp (1988) describe this process as a vicious cycle of dependency on pesticides. Declining yields lead to more pesticide applications and the need for stronger compounds, which raises economic costs for the additional amount of pesticides and encourages further pest resistance (Araya et al. 2014). In the following parts, different types of pesticide pollution and health consequences will be further discussed.

Water pollution

Numerous water contamination events in pineapple production areas have occurred over the last decades (Cuadrado-Quesada 2020; Montiel 2015; Sánchez 2019). For example, there has been evidence of contamination with pesticide residues from agricultural use in water sources for human consumption in communities in the cantons of San Carlos, the main pineapple-producing area (Vargas 2019). Pineapple is usually cultivated in areas where all other vegetation is erased, contributing to high levels of erosion and runoff, with negative implications for aquatic biodiversity. Mass mortality events among fish populations and the disappearance of many invertebrates are direct consequences (Brown et al. 2020). Fish are particularly susceptible to pesticides as they absorb and retain dissolved synthetical substances in the water through transport through their gills (De la Cruz et al. 2014). The Regional Institute for the Study of Toxic Substances (IRET) of the National University carries out systematic toxicological water analyses throughout the country. It has repeatedly detected the presence of agrochemical concentrations in surface and groundwater sources in communities (Sánchez 2019). However, a big problem in identifying pesticides is that up to 90%, such as Glyphosate, cannot be detected in waterbodies (Henry 2022; Ramírez 2022).

Between 2000-2011, high concentrations of nitrates were found in samples taken in or near pineapple plantations in the wells of the Atlantic zone. Pineapple is the crop with the highest nitrate content, along with bananas and ornamentals in Costa Rican agriculture (Castillo M. et al. 2012). In 2013 a study that investigated the cause of massive fish mortality after rainfall discovered that organophosphates (specifically chlorpyrifos and ethoprofos) used in neighboring banana and pineapple plantations were responsible (Diepens et al. 2014). Another study found a close correlation between certain pesticides in waterbodies and the import of specific agrochemicals into the country (De la Cruz et al. 2014).

Water contamination events led residents and environmental groups to blame pineapple farming for the presence of pesticide residues in water sources intended for human consumption (Vargas 2019). Brown et al. (2020) criticize that long-term studies or official data on water quality in the municipality of Buenos Aires are inexistent, and thus drinking water contamination from pesticides cannot be adequately detected. They claim that multi-year monitoring of the water resources is needed to understand the effects of pineapple monocropping.

Soil contamination

Excessive pesticide use and inaccurately carried out application methods result in pesticide discharges to ecosystems surrounding agricultural land. These traces of pesticides damage both the cultivation area and animal populations inhabiting the surrounding areas as hazardous chemicals can bioaccumulate in their organisms. Additionally, pesticide pollution is hard to eliminate as the chemical characteristics of the pesticide compounds often slow down or make decomposition impossible (Araya et al. 2014). Thrupp (1991) describes a striking example of soil contamination in approximately 6'500 ha in the Pacific banana-growing region of Costa Rica resulting from the accumulation of copper applied in fungicides in banana plantations. Research showed that the root structures of the bananas were shrunken and severely weakened due to the toxicity of accumulated copper. Consequently, the united fruit company abandoned and sold land in this region and bought and cultivated more fertile land over time, *"undertaking a 'migratory' pattern of resource exploitation"* (Thrupp 1991:3).

To combat the pests to which the pineapple crop is susceptible, herbicides and fungicides are used intensively, which causes a deterioration of soil microbiological activity (Montiel 2015). Few studies exist on the residual effects of pineapple plantations. However, a study investigating pesticide accumulation's effects on the soil's capacity to carry out its functions found that organophosphate pesticides favored the soil's degradation and decreased its production capacity (Leal Soto et al. 2014). In another study, Bromacil and Bexazinone were found in pineapple soil samples at depths up to 4m, reflecting the persistence and mobility of these herbicides (Zhu and Li 2002). Scientists and agronomists are concerned that the decline of soil biodiversity on pineapple plantations due to pesticide application might turn the land infertile (Brown et al. 2020). Furthermore, in 2013 traces of different pesticides commonly used in banana, pineapple, and cocoa production were found in blood, fur, and saliva samples of sloths living near agricultural areas (Branford et al. 2014).

3.3.4 Health risks associated with pesticide use

Most of the pesticides used in Costa Rica are highly hazardous to human health and the environment, and many are banned in the European Union (Vargas 2021). In Costa Rica, 80 active ingredients are associated with acute effects on humans, of which only 34 can be used in the European Union. Fifty-eight active ingredients are associated with cancer, of which 42 are not allowed for use in the European Union; 95 active ingredients are associated with other adverse health effects, of which 56 are not allowed for use in the European Union (Vargas 2021).

The National Poisoning Center of the Costa Rican Social Security Fund (CCSS) recorded 8097 pesticide poisonings between 2012-2020. Most cases were men with an average age of 30, and the predominant occupation was agricultural labor. In addition, during the period 2010 to 2020, 58 deaths due to agrochemical poisoning were estimated, excluding suicide and homicide. The deaths occurred mainly in the province of Alajuela, with San Carlos as the canton with the highest mortality. San Carlos is the

principal pineapple cultivation area, with the highest concentration of pineapple farms (Martinez 2022).

The risks of pesticide exposure range from acute headaches, nausea, and eye irritation to chronic issues such as cancer, neurological damage, and endocrine disruption (Araya et al. 2014; Galt 2008b). Although human health risk assessments exist, import levels of highly hazardous pesticides have increased in Costa Rica since the 1970s (De la Cruz et al. 2014).
Pesticide injuries are highest among agriculture workers due to the nature of their work exposing them to chemicals. Exposure is often the result of inappropriate equipment or accidental spills during transfer or mixing. However, estimating the effects of pesticides on agricultural workers is difficult for different reasons. The application of multiple pesticides makes it almost impossible to determine precisely which compound is responsible for which disorders. Also, the frequent movement of workers between different farms makes it difficult to assign individual events to specific farms (Araya et al. 2014).

"A heavy-handed approach to pesticide application paired with loose enforcement of safety standards has resulted in a high number of pesticide-related deaths and illnesses including cancer, sterilization, and pesticide poisoning" (Araya et al. 2014:2). According to Martinez (2022), the current protocol for the regulation of agrochemicals dates back to 2001 and should be updated. Brown et al. (2020) postulate for conducting more studies and risk assessments of occupational pesticide exposure in tropical countries where many agricultural exports are cultivated: *"More research needs to be conducted on how exposure mitigation may require adjustments in tropical versus moderate climates for the sake of worker protections"* (Brown et al. 2020:n.i.).

3.4 Research questions

While a part of this thesis is based on reviewed existing data and literature, it aims to shed light on influencing factors that explain the intensive use of herbicides in pineapple production. While the concerning negative externalities of pineapple production have been relatively well studied, the research questions are motivated by a need to fill a knowledge gap on the reasons for pesticide dependency. According to the United Nations, the issue of pesticide use and knowledge about its effects remains understudied (Galvis and Andrich 2020). Also, Shattuck (2021) argues: *"The factors driving increased pesticide use (…) are many and overlapping, and there is relatively little data on the subject"* (Shattuck 2021a:243). Hence, there is a need to understand better the reasons for the high pesticide dependency in countries such as Costa Rica. Furthermore, existing geographic research on the pineapple industry in Costa Rica has mainly focused on affected communities or peasants (see Galt (2008, 2009), Montiel (2015), Sánchez (2019)).

In contrast, the perspective of larger producers has not yet been considered. According to Lowder, Skoet, and Raney (2016), surveys often lack information about large farms and thus underestimate their contribution. Given the farm concentration in Costa Rica, large plantations play a crucial role in the pineapple sector as their cultivation methods and use of agrochemicals have crucial importance for agriculture. Large farming types mainly entail large plantations for domestic and export markets and are owned by large companies or family-owned. Their production relies on external financing, contract farming, and insurance (Lopez-Ridaura et al. 2021).

This thesis aims to identify several relevant factors that explain the sector's dependence on herbicides for weed control. The first step is to identify the status quo, i.e., herbicides currently used and their alternatives. One economic factor already identified as relevant in advance was the impact of various global events on supply chains. Even though a small but growing body of research exploring the effects of the Covid-19 pandemic and the Russian invasion of Ukraine on agriculture and food systems is emerging, the effects of shortages in the supply chain for agrochemicals are little explored. The question arises of how Costa Rican farmers deal with current challenges in using agrochemicals and whether these challenges promote the use of alternatives to chemical weed control. Lastly, the literature suggests that private standards, extension services, and regulation influence pesticide adoption. Therefore, the following research questions can be derived:

Which socioeconomic factors influence weed control among Costa Rican pineapple producers?

- **Which herbicides and alternatives to chemical weed control do pineapple farmers use?**
- **How do pineapple producers deal with current challenges affecting the supply and use of herbicides in pineapple production?**
- **What is the role of private standards and extension services on herbicide use?**

This thesis uses, in this sense, a new approach as it tries to link socioeconomic factors with the high use of herbicides through the perspective of producers and different actors. The question was, therefore, not “who is most affected by the negative impact of intensive pineapple production” but “which factors explain the high dependency on agrochemicals.” Hence, as opposed to previous research on Costa Rican pineapple production, it focused on influencing factors that explain the intensive use of herbicides rather than the outcomes of this dependency.

4 Research Design and Methodology

This Chapter outlines the research process and explains the methods employed to collect and analyze data. The purpose is to provide a clear and detailed description of the research methods, the personal experience, and the limitations or challenges encountered during the research process and explain how they were addressed.

This master's thesis was conducted within the scope of the SNF-funded research project *"Making herbicide markets: Interactions between production restructuring, agriculture and environment in Latin America and Asia"* by Prof. Dr. Christian Berndt from the University of Zurich. The project explores shifts in the geography of global pesticide production, trade, and use and its environmental and health effects. For this purpose, two case studies in Argentina and Costa Rica are being conducted.

For the present study, a qualitative research design was applied. No predefined hypotheses are tested in qualitative research, but the aim is to gain new findings about the research object. Despite the open and rather explorative character of qualitative research, the researcher must nevertheless have certain assumptions or at least vague ideas about the phenomenon to be studied to formulate overarching research questions (Hohl 2000). In a first step, existing data and literature about the impact of the Covid-19 pandemic on herbicide supply chains were gathered. This included general research on global effects and, where available, more specific research on the impacts on pineapple production and agriculture in Costa Rica. Furthermore, literature about the use of pesticides with a focus on herbicides in pineapple production was collected.

The literature review was intended to serve as a basis for subsequent field research in Costa Rica. I spent five months in Costa Rica between September 2022 and January 2023. Spending much time in the country allowed me to establish regional contacts and identify essential actors. My research stay at the "Centro de Investigación y estudios politicos" (CIEP) at the University of Costa Rica was made possible thanks to the contact of my supervisor Soledad Castro. The CIEP has extensively researched pineapple cultivation in Costa Rica, which has allowed me to benefit from their expertise. The results of this master thesis will be presented to the CIEP in an online feedback session, allowing me to compare my results with their research and experiences.

A common qualitative research method is personal interviews, in which the interviewees freely and openly express their views, experiences, feelings, assumptions, wishes, etc. Semi-structured expert interviews have been chosen as they are considered suitable for the explorative, qualitative nature of the research. An advantage of this interview form is that it leaves space for probing questions that encourage the interviewee to produce more information (Bernard 2006). I deem this interview type helpful for the somewhat controversial topic of herbicide use, as it allowed me to ask further questions if the interviewee was willing to talk about herbicide and pesticide use in general. The word expert refers to someone with in-depth knowledge about the research subject. This can be experts in the "classical" sense, i.e., persons who have acquired a high level of knowledge, skill, or experience in a particular area through their profession or education. However, also individuals who are not considered experts in the classical sense but have a deep understanding of the subject through personal involvement can provide valuable insights. In the sociological sense, every person can have specific expert knowledge, for example, regarding the actors and processes with which they are involved in their daily work or everyday life (Gläser and Laudel 2010). Experts can help to contextualize

complex and new research fields, and hence expert interviews were well suited for this master's thesis, as the specific knowledge of various key actors in the pineapple sectors is essential for answering the research questions.

Furthermore, observations made during the data collection and plantation visits as well as the collection of newspaper articles, complemented the interviews. These observations were recorded in the form of field notes on my cellphone. The field visits of different plantations proofed to be a helpful complement to the interviews as they gave me a completely different insight, which the interviews alone would not have made possible. For instance, I observed pesticide application and the different production steps, from sowing to packaging the harvested fruits, and also got insights into the working culture and mentality.

A crucial aspect of qualitative research is research process's documentation (Steinke 2008). The following Chapter, therefore, provides a detailed overview of the research process of this thesis.

4.1 Data collection

As study region, the pineapple sector in Costa Rica represented through different interview partners from the pineapple and pesticide industry was chosen. The selection of the actors to be interviewed is called sampling and is crucial for the data quality (Kuckartz and Rädiker 2020). According to Gläser and Laudel (2010), the selection of the research group should ideally contribute as much as possible to answering the research question, but also, diversity across the interviewees is desirable. Besides pineapple producers, interviews with relevant actors added to the producer's perspective. The selection was further based on the accessibility of actors. To gain rich insights and allow a broad perspective on the issue, data collection involved fourteen semi-structured interviews with a state actor (N = 1), a representative of the pesticide industry (N = 1), pineapple producers (N = 5), chambers (N=4), agronomists, and consultants (N = 3).

Furthermore, one producer (Golden Pineapple Farms) was unwilling to give an interview but answered some of my questions via mail. The interview partners are presented in more detail in Table 1. Furthermore, I conducted several informal interviews with an environmental activist, a research institute for organic farming (INA), and two representativex of an agricultural program of the United Nations in Costa Rica. These informal interviews served to get better acquainted with the subject and to get a better idea about the problems of the pineapple industry next to the information gained through the literature review. Informal interviews are a type of qualitative research method that involves talking with people in a casual and conversational manner. Besides observations and the collection of documents or formal interviews, they are also part of ethnographic research (Hammersley and Atkinson 2019).

As a first step, important actors from the pineapple and agrochemical sector were identified and contacted via mail, which was quite time-consuming because many actors answered only after repeated inquiries or telephone contact. However, my efforts bore fruit over time as most contacted people were willing to give interviews, and further contacts were forwarded to me through snowball sampling. Interviews were generally conducted in person in the offices of the respective people. Some producers also took me to the field and showed me their plantations. Interviews were conducted between September 2022 – December 2022 in Spanish and English. The interviews lasted between 30 and 120 minutes and were recorded with the interviewees' consent.

The interview guide was based on the reviewed literature and background information from the earlier informal interviews. The construction of the interview guide followed the principle of being as open as possible and structured as necessary (Kuckartz and Rädiker 2020). The focus of the interviews was clearly to let the interviewees speak and to inquire or introduce new topics only where necessary (Gläser and Laudel 2010). I tried to make the interviews feel like a natural conversation, and therefore the structure and specific questions sometimes deviated from the guide while ensuring that all aspects were covered. The interview guide was modified during the data collection process to incorporate feedback and observations. As Gläser and Laudel (2010) recommend and given the diverse background of the interview partners, the structure of the interview guide was adapted for every actor. However, it generally covered challenges for the Costa Rican pineapple sector, the effects of supply chain disruptions on the availability and use of herbicides, the use of herbicides in pineapple plantations, and the role of extension services on the use of herbicides. An example of an interview guide is attached in the Annex.

The interview guide was designed in such a way that interviewees were first asked about general challenges which the Costa Rican pineapple sector is currently facing. The intention was to see what other challenges exist and if they perceive the latter as more pressing than supply chain issues. However, it is evident that my contact mail in which I mentioned the current input crisis certainly influenced them to mention supply chain issues or even to emphasize them more strongly than they would have in a different context. Although this was not planned at the beginning, the transcribed interviews of the producers and the agronomists were anonymized for reasons of standardization, as some interviewees requested this. Hence, fictitious names replaced the names of the pineapple companies, and the agronomists' abbreviations were used. On the other hand, the official names of the chambers and state actors (SFE) were retained, as these actors did not wish to be anonymized, and the designation of the actors is relevant for the analysis. The following table summarizes the conducted interviews.

Table 1: List of interview partners

Actor	Abbreviation	Date
Private sector		
Agronomist and consultant for pineapple producers	J.V	31.10.2022
Agronomist and consultant for pineapple producers	D.H	18.11.2022
Academia		
Agronomist and lecturer - Tecnológico de Costa Rica (TEC)	A.G	29.11.2022
State actors		
Servicio Fitosanitario del Estado	SFE	25.11.2022
Producers		
Gerente General. Middle-scale producer	Sunny Delight Pineapples	26.09.2022
Gerente de Producción. Large-scale producer	Island Breeze Pineapples	30.09.2022
President. Middle-scale producer	Pineapple Haven	18.10.2022
Gerente de operaciones. Large-scale producer	Tropic Delights	20.10.2022
AVP Corporate R&D and Agriculture. Large-scale producer[2]	Golden Pineapple Farms	06.12.2022
Technical and Quality Manager. Large-scale producer	Sunburst Pineapple Co.	13.12.2022
Chambers		
Costa Rican Foreign Trade Chamber	PROCOMER	03.10.2022
Member of the executive board. Cámara de Insumos Agropecuarios	Chamber of R&D manufacturers	04.10.2022
Member of the executive board. Cámara Nacional de Agricultura y Agroindustria	CNAA	18.10.2022
Member of the executive board: Asociación de Formuladores de Agroinsumos	ASOAGRO	20.10.2022
Pesticide industry		
Costa Rican pesticide company	Local pesticide company	15.11.2022

The following table aims to provide more background information on the producers I spoke to, such as their size, certifications, and export countries.

[2] R.C did not agree to give an interview but provided some answers via mail

Table 2: Pineapple farms characteristics

Company	Farm size in ha	Produced amount in tons	Certifications	Organic	Export countries
Sunny Delight Pineapples	1'000	19'000	Biosuisse, EU Organic, USDA Organic Standard, EU Standards, zero pesticides, Rainforest alliance, Fairtrade, Global GAP, campo al plato, PBAE, BRC, BASC,	Yes	EU
Island Breeze Pineapples	2'500	110'000	Global GAP, BRCGS, Rainforest Alliance, ETI-SMETA, BASC, FDA-FSMA, ISO14001, Essential Costa Rica, Ecological blue flag Costa Rica	No	US, Europe, Turkey, and Israel used to export to China
Pineapple Haven	1'300	72'000	Rainforest Alliance, Ethical Trade Initiative, Global GAP, Primus Labs, BRC Global Standards	No	EU, Russia, US
Tropic Delights	3'000	124'000	Global GAP, PMA, BRCGS, Ethical Trade Initiative, Tesco Nurture, M&S Field to Work	No	22 countries, including EU and US
Golden Pineapple Farms	[3]	450'000	ETI, FSCC 22000 Food Safety System Certification, GLOBAL G.A.P., GMP, GRASP, HACCP, ISO 45001, ISO 9001, PrimusGFS, Rainforest Alliance, SCS Global Services Carbon Neutrality, SMETA, SQF: Safe Quality Food, Sustainably Grown Standard, USDA/EU Organic	Yes	[4]
Sunburst Pineapple Co.	3'500	9.5 million boxes[4]	[5]	Yes	EU, Russia Middle East

[3] Not willing to share this information
[4] No data available in tons
[5] Not listed to make tracing impossible

4.2 Data analysis

For the analysis of the empirical data, a content analysis was conducted. According to Mayring (2015), content analysis is a systematic, rule- and theory-guided procedure. Qualitative content analysis involves identifying selected aspects of the data, their conceptualization, and their systematic description (Kuckartz and Rädiker 2020).
As a first step, the recordings of the interviews were transcribed into Spanish or English. Since there are no generally accepted rules for transcription, the transcripts for this study were done according to a set of self-developed rules based on Kuckartz and Rädiker (2020):

- Paragraphs of the interviewer or interviewee are introduced by "I" and "A"
- Transcription is verbatim, which means that the word order and sentence order are retained as accurately as possible, even if they contain errors, to ensure the best possible reflection of the interview
- Shorter pauses are marked by (...), longer pauses are marked by (… … …)
- Filler words such as "ehm" are replaced by $
- External disturbances are noted in brackets, indicating the cause, e.g. (cell phone rings)
- Incomprehensible words and sentences are indicated by "inaudible"

Those transcripts later served as a database for a qualitative content analysis using MAXQDA 2022. According to Kuckartz and Rädiker (2020) and Mayring (2015), analyzing collected data during ethnographic research requires both a systematic and an open approach. Category building is essential for reducing and abstracting the qualitative data for content analysis. Kuckartz and Rädiker (2020) refer to these resulting deductive categories as theoretical categories because they can be derived from theoretical concepts. Data analysis and collection took place in an iterative process; hence I started analyzing some interviews while still conducting others. Based on the interview guide, a deductive coding scheme was first applied to sort and analyze the interview data according to common themes, sorting it into the following overarching categories: Factors that decrease herbicide use, herbicide trade, technological package, farm characteristics, the role of actor, extension services, herbicide distribution ways, challenges, pesticide residues.

Later, an inductive coding scheme was used, and (sub)codes were developed as a further subdivision was necessary. Some of the code categories referred to background information, such as farm characteristics, and have been used to facilitate the contextualization of the study. Each element holding information relevant to the analysis was coded using at least one subcode. Furthermore, the most important quotes were coded as keynotes. The assigned upper codes were then deleted to avoid overlaps. In many cases, it was necessary to code the interviewer's questions as the interviewee's answers were not understandable on their own. If a text section had different relevant aspects, this resulted in overlapping codes. In this case, the function *Complex Coding Query -> Intersection (Set)* and *-> Overlapping* was used to gain an overview of all the segments coded with the desired combination of categories. However, the categories were open and editable until the end, so unexpected findings could always be integrated into the category system. Afterwards, the material extracted from the transcripts was summarized, and any patterns and contrasts were described and finally discussed as results in the following Chapters of this thesis. Spanish quotes used in this thesis were translated into English.

4.3 Personal experience of the fieldwork

The most challenging and time-consuming part was the organization of the interviews. It involved contacting my interviewees in Spanish and much patience to get a response. Although it was challenging to organize interviews, my interview partners were mostly very talkative and took a lot of time for me. I also had pleasant encounters when, for example, one of the interviewees invited me to his family for dinner. Nevertheless, there were also some curious moments, for example, when an interviewer kept asking me questions as if he wanted to test me to see if I understood his explanations.

I am very grateful that different producers allowed me to visit their plantations. On the one hand, these visits were necessary to understand the production processes better and, on the other hand, to get an insight into the mentality and work structures. In addition, the agronomists who took me to their fields were not the same person I had interviewed before, which allowed me a different perspective. Furthermore, the field visits also showed me that many producers themselves suffer from the negative externalities of pineapple cultivation and that they are aware of them. For example, one producer told me the responsible use of herbicides was essential because he grew up in the region and wanted to preserve the land for his children.

During my field visits, I was very impressed to see how industrialized and automated the different production steps are, from planting the crops to harvesting and packing the pineapples. This piecework was mainly reflected in the planting process, where an average worker plants 5000-8000 seedlings daily, being exposed to sun and rain all day (see Figure 14). Rotations in the different processes and between the workers are not taking place. I also realized that some interviewees condescendingly referred to small farmers: *"You need to train them, train them what to do"* (Local pesticide company, 2022). Another interesting aspect was the gendered division of labor, with a clear distinction between the tasks of women and men. While almost only men work on the plantations, the same applies to women in the production plants, packing and sorting pineapples. During my field visits, I was told that women generally worked faster and more precisely when sorting and packing, while the planting and harvesting process was perceived as heavy work. It seemed that social norms and gender roles are still very influenced by the patriarchal "machismo" ideology within the pineapple sector. The male domination was also reflected in my interview sample – among the 14 interviewees, there were only three women. The following photos are impressions I captured during my field visits and reflect some of the different processes and flows.

Figure 12: Harvesting process. Reference: Picture taken by author during a field visit in Pital, December 2022

Figure 11: Planting process of pineapple seedling. Reference: Picture taken by author during a field visit in Pital, December 2022

Figure 13:Packaging process in a plant. Reference: Picture taken by author during a field visit in Pital, December 2022

Figure 15: Sorting process in a plant. Reference: Picture taken by author during a field visit in Pital, September 2022

Figure 14: Spraying of a pineapple field. Reference: Picture taken by author during a field visit in Pital, December 2022

4.4 Limitations of the study design & positionality

Thanks to my extended research stay in Costa Rica, I conducted most interviews in person, visited farms, and gathered rich firsthand data. I deem the choice of qualitative interviews for the research context as suitable, as I could talk to a broad range of actors within the pineapple sector. Unlike a quantitative approach, qualitative research offers the necessary methods for interpreting and describing social factors and their relationship. This allows one to grasp the research subject's complexity and wholeness (Gläser and Laudel 2010). The interview guide allowed me to touch upon different aspects of pineapple production, while the openness of semi-structured interviews encouraged my interviewees to speak freely, which led to numerous new insights, such as the importance of the registration process.

One might wonder if an agronomist perspective wouldn't be more suitable to analyze the use of herbicides in pineapple plantations. However, Thrupp (1988), which studied the cause of the problems related to pesticide use in Costa Rica, argues: *"A structural analysis helps to show that the underlying causes pertain to the broader forces in the political economy. These include the economic and political power and marketing practices of the pesticide companies, which influence the supply and use of pesticides and pesticide information; pressures for short-term profit objectives; the nature of agricultural production, which is dominated by demands of large-scale export producers"* (Thrupp 1988:45). Hence, using insights from economic geography is helpful to explore the interdependency of different factors. For example, the (over)use of herbicides and dependency on old toxic molecules can only be understood considering the registration process, market dynamics, and the distribution of knowledge through extension services.

Several aspects of the research design have implications for the validity of the data collected.
On the one hand, my research relied principally on one single method of data collection and a limited number of interviews (N=14). Combining a more significant number of interviews with additional observational data could have led to further insights, but its collection would have gone beyond the scope of a master's thesis. However, the number of interviews was deemed appropriate and allowed to gather rich information. In qualitative research, sampling usually ends once a target sample size or saturation point has been reached (Parker et al. 2019). I argue that the saturation point was not yet reached, but enough information was collected to answer the research questions. Secondly, to a certain extent, interview partners were chosen by their availability and responsiveness to my interview requests. Some important actors, such as Golden Pineapple Farms, the Chamber of pineapple producers (CANAPEP), or the agency for extension services of the MAG, were not willing to give an interview or never replied. At the same time, I succeeded to conduct interviews with a broad range of actors. Among them were also stakeholders, such as representatives of various chambers, who generally are reluctant to interviews. The snowball sampling method proved particularly helpful, as I only got access to certain contacts through previous contacts.

Qualitative research implies, almost inevitably, a particular social desirability bias. Social desirability is the tendency of interviewees to answer in a way that they think is more socially acceptable than their "honest answer". They do this to project a positive image of themselves and avoid negative evaluations by the interviewer (Lavrakas 2008). As herbicides are a debated topic, the interviewees, especially the producers, might have presented their production methods as more environmentally friendly than they are. Also, my foreign background as a female researcher from Western Europe might have influenced my interviewees, and my limited Spanish proficiency might have led to the retention of

information. During the coding process, I sometimes realized that I didn't ask further questions where it would have made sense.

Although the Latin-American context was somewhat familiar, it was my first time traveling to Costa Rica. Moreover, not coming from an agronomic background and having little knowledge about cultivating exotic fruits sometimes made it challenging to familiarize myself with technical agronomic concepts. My attitude towards industrialized monocropping production systems was rather critical, which was also influenced by the previous literature review and my educational background in human geography, which encourages a critical perspective on globalization processes. Nonetheless, I tried to approach the interviews as objectively as possible, which I mostly succeeded in doing. However, it was sometimes more difficult for me to remain objective with individual actors, for example, when they denied the existence of negative externalities of herbicides.

5 Weed control in pineapple plantations

A crucial part of understanding herbicide use in pineapple plantations is the reconstruction of the technological package regarding the use of herbicides. Regarding the first research sub-question, **which herbicides and alternatives to chemical weed control do pineapple farmers use?,** I asked my interviewees about the cost and the weed control methods they use. Furthermore, I found it important to understand their perception towards the use of herbicides, to understand if they deem a reduction of herbicides necessary and differences in herbicide supply routes across different producers.

I got somewhat diverging answers regarding the cost of the technological package (including all agrochemicals). While D.H told me that the cost per hectare was before the pandemic around 5'000 dollars and increased to 9'000 over the past three years, another agronomist told me that the cost lies between 10'000 and 14'000 dollars per hectare (J.V, 2022). Producers' cost differences largely depend on irrigation (J.V, 2022). Interesting and somewhat contradictory was also the fact that two agronomists told me that in some cases, there are the phenomena of diseconomies of scale, where smaller producers have a cost-benefit as they use manual weeding techniques instead of making a homogenous application: "*For example, with 100 or 120 hectares, you can see your farm perfectly well with just one spray boom, but if you have 150 hectares you will have to use another spray boom, but then you will want to have 240 hectares so that your machinery is well occupied, right? So that, that's a that's a very interesting value in terms of the number of hectares that the producers have, right? Depending on the machinery*" (A.G, 2022). Hence, small producers might not always have the highest production costs.

According to my interviewees, the technological package for pineapple production is very well established, and hence there are no or only little differences between different scales: *"I can bet you that most of the products are almost the same. But some exceptions. But nutrition is about the same, weed control is about the same. Land preparation is about the same. Spray and application is about the same. Type of machines about the same"* (D.H, 2022) or *"the small ones copy the big ones"* (A.G, 2022). A transfer of the technological package took place between larger and smaller producers since many small producers have formerly worked for larger plantations and hence adopted their technological package (Local pesticide company, 2022). However, there might be differences in doses, with a tendency for the chemical load to be higher for small producers as they have less access to precision farming (J.V, 2022).

5.1 Herbicides used in pineapple cultivation

In the following part, the most important herbicides for pineapple production, which my interview partners mentioned, are briefly outlined. It is important to mention that Table 3 does not provide a complete overview of the characteristics of the herbicides used in pineapple but is based on the statements of my interviewees. Even though the technological package is generally well established, there are slight differences between the producers reflected in their answers. Table 3 should be seen as a summary of the interviews, supplemented with additional information on ecotoxicology to better assess these herbicides' hazards. The following paragraphs briefly summarize the main findings of the table.

According to my interviewees, the most commonly used herbicides in pineapple plantations are Ametryn and Diuron. Both are systemic herbicides used in soil preparation and against weeds in the

first months after seeding before forcing. Furthermore, they are not approved in Europe, and the use of Diuron is restricted for certifications such as Rainforest Alliance as it is highly toxic to most water organisms and other species. De la Cruz et al. (2014) claim: *"Paraquat, diuron, pendimethalin and ametryn have high toxicity for aquatic flora. (…) if necessary precautions to reduce transfer and use of hazardous substances in the country are not taken, these substances will reach natural ecosystems and impair aquatic biota of great economic, aesthetic and recreational value"* (De la Cruz et al. 2014:49). From the point of view of ecotoxicology, the widespread use of these herbicides should therefore be of concern.

Almost all herbicides are used during the land preparation, the first four months before the seedlings are planted (D.H, 2022) (see also Chapter 3.2.2). After planting, more applications might be made before the fruit has developed. According to various interviewees, the proportionally largest share of herbicides is applied during postharvest, e.g., Paraquat, which is used to remove green foliage.
However, only one producer mentioned the use of Paraquat, which can only be obtained with a professional prescription, which means its use is restricted. Alternatives to Paraquat exist, such as Fluroxypyr or Tryclopir; however, they are slower acting, which may be one reason their use is not more widespread (A.G, 2022). Tryclopir is a relatively new herbicide produced by the local pesticide company I spoke with. They see great potential in its use as it reduces the chemical load significantly compared to Paraquat. Furthermore, Clethodim, Quizalofop, Oxyfluorfen, Hexazinone, and Haloxyfop were also named frequently. Most of them are not approved in Europe and have moderate ecotoxicology.

Even though Bromacil has been banned in Costa Rica since 2017, it is, according to different interviewees, still being detected in waterbodies (SFE, 2022; CNAA, 2022; Asoagro, 2022). In February 2023, a trial against three pineapple companies, denounced for contamination of water sources with Bromacil in Pital, continues (Delgado 2023). My interviewees explained differently why Bromacil is still detected. Some said it was because of its persistence, while others blamed other sectors, such as the industry, where it is used to clean railroad tracks or by private households in their gardens. Most of my interview partners told me they stopped using Bromacil more than ten years ago, before its prohibition. However, my interviewee from Sunburst Pineapple Co. told me that he was sure that Bromacil was used by most producers until its prohibition, as they did in the company he is working for. In addition, some of my interviewees emphasized the benefits of Bromacil, such as the interviewee from the Chamber of R&D manufacturers, who believes that Bromacil is the most effective herbicide for pineapple. Furthermore, the president of a local pesticide company claimed that alternatives were not as effective, while Sunny Delight Pineapples said that they had to use different herbicides in combination with higher dosages to achieve the same effect.

Table 3: Herbicides used in pineapple production. Reference: Own work with data from interviews and information from (Castillo M. et al. 2012; De la Cruz et al. 2014; Lewis et al. 2016; Pesticide Action Network Europe 2023; Rainforest Alliance 2022; University of Hertfordshire 2023)

Name	Herbicide type	Use	Number of mentions by producers (n=6)	Substitute	Regulation[6]	Ecotoxicology and health effects[7]
Ametryn	Systemic herbicide	Land preparation, 2-3 months after planting (Sunburst Pineapple Co.) Used against Poaceae for sealing the ground (Local pesticide company, 2022)	6		Not approved in Europe	Moderately persistent in soils, persistent in water under certain conditions Highly toxic to amphibia, fish, algae, and aquaticfern and moderately toxic to crustacea, mammals, honeybees, and earthworms Slightly toxic to humans
Bentazon	Contact herbicide	Land preparation Used against Cyperaceae	2	Substitute to Bromacil (Pineapple Haven, 2022)	Approved in Europe Restricted use for Rainforest Alliance (IPM strategy)	Not persistent in soil systems, persistent in water under certain conditions. Moderately toxic to birds, fish, aquatic invertebrates, and earthworms Moderately toxic to humans, it can provoke skin and eye irritation

[6] Information from (Pesticide Action Network Europe 2023; Rainforest Alliance 2022)

[7] Information from(Castillo M. et al. 2012; De la Cruz et al. 2014; Lewis et al. 2016)

Bromacil	Contact herbicide	Used to control different types of weeds	0	Ametryn, Diuron, Bentazon, mulch plastic, and manual weeding techniques are used to substitute Bromacil.	Banned in Costa Rica in 2017 Not approved Europe	Relatively stable substance in soil and water, with the capacity to infiltrate groundwater Low to moderate toxicity to most fauna and flora Moderate oral toxicity
Clethodim	Systemic herbicide	Land preparation, 2-3 months after planting (Sunburst Pineapple Co.) Used against Poaceae (Sunny Delight Pineapples, 2022)	4	It can be used to substitute Quizalofob (Sunny Delight Pineapples, 2022)	Approved in Europe	Highly soluble in water with low volatility. Not persistent in soil or aquatic systems Moderately toxic to birds, fish, aquatic plants, honey bees, and earthworms, less toxic to aquatic invertebrates and algae. Moderately toxic to mammals Skin irritant
Diuron	Systemic herbicide	Land preparation, 2-3 months after planting and for taller weeds (Sunburst Pineapple Co. 2022; D.H, 2022)	6		Not approved in Europe Restricted use for Rainforest	Slightly soluble in water with low volatility. Under certain conditions, it leaches to groundwater. Moderately persistent in soil, may persist in water Moderately toxic to mammals, low toxicity to honeybees

					Alliance (IPM strategy)	Highly toxic to Fish, Crustacea, Algae, and Aquaticfern and moderately toxic to Amphibia Moderately toxic to humans
Fluazifop-P	Systemic herbicide	Land preparation Used for drying the foliage after harvest and to control Poaceae (Local pesticide company, 2022)	1		Approved in Europe Not approved for Rainforest Alliance and Fairtrade	Low solubility in water. Not persistent in soils, moderately mobile in soils No data on ecotoxicology
Fluroxypyr	Systemic herbicide	Used for drying the foliage after harvest (A.G, 2022) Works more slowly than Paraquat (approximately three months) (A.G, 2022)	0		Approved in Europe	Highly soluble in water, low volatility. Not persistent in soils, can be in aquatic systems under certain conditions Moderately toxic to birds and earthworms, toxic to some mammals and honeybees. Low toxicity to most aquatic organisms Low toxicity to humans
Glyphosate	Systemic herbicide (D.H, 2022)	Very effective, has to be applied less than other alternatives (Local pesticide company, 2022)	1		Not approved for Fairtrade Restricted use for	Highly soluble in water, volatile, and does not usually leach into groundwater. Not persistent in soils, can be in aquatic systems under certain conditions Moderately toxic to birds, most aquatic organisms, earthworms, and honeybees

		It can be used to control weeds in pineapple (J.V, 2022) Prices have increased heavily during the pandemic (Local pesticide company, 2022)			Rainforest Alliance (IPM strategy)	Moderately toxic to humans, it can provoke skin and eye irritations
Haloxyfop	Selective &systemic herbicide	Land preparation It can be used to control graminicides (Pineapple Haven, 2022)	3		Not approved in Europe Restricted use for Rainforest Alliance (IPM strategy)	Moderately soluble in water. Persistent in some soils Moderately toxic to birds, mammals, earthworms, and most aquatic organisms, highly toxic to fish Can provoke skin and eye irritation
Hexazinone	Contact herbicide	Land preparation Used against Cyperus Rotundus Highly toxic, a slight overdose can lead to severe problems such as phytotoxicity (J.V,	3		Not approved in Europe Restricted use for Rainforest Alliance (IPM strategy)	Highly soluble in water. Moderately persistent in some soils and mobile Moderately toxic to mammals, low toxicity to birds and honeybees, and most aquatic organisms Highly toxic for humans

		2022 & Pineapple Haven, 2022)				
Metolachlor	Selective herbicide	Land preparation, ten days before planting and second application 2-3 months after planting (Sunburst Pineapple Co.)	2	It can be used to substitute Oxyflurofen or Gylphosate (Sunburst Pineapple Co., 2022; D.H, 2022)	Not approved in Europe Restricted use for Rainforest Alliance (IPM strategy)	Highly soluble in water. Moderately persistent in some soils and moderately mobile Toxic to some mammals, moderately toxic to earthworms and fish, low toxicity to birds and honeybees, and most aquatic organisms Moderately toxic to humans
Oxyfluorfen	Selective and contact herbicide	Land preparation, ten days before planting (Sunburst Pineapple Co.)	3		Approved in Europe Restricted use for Rainforest Alliance (IPM strategy)	Low solubility in water. Persistent in some soils non-mobile Low toxicity to mammals and honeybees, moderately toxic to fish, toxic to some aquatic organisms Can cause cancer
Paraquat	Contact herbicide (D.H, 2022)	Land preparation It needs one week to dry the foliage after harvest (A.G, 2022) An issue is that it only dries the leaves	1	Accounts for 80% of the herbicides applied, according to a Local pesticide	Not approved in Europe Aerial spraying is banned, and	Causes the majority of pesticide-related poisonings and deaths in Costa Rica (IRET 2022) In 1998 a study was conducted on geographical differences in cancer incidence in Costa Rica and the potential relation to pesticide exposure which showed that areas with heavy use of paraquat had increased incidences of different types of cancer (Wesseling et al. 1999)

		without eliminating the stem. Hence the plant can sometimes regrow, which requires another application (A.G, 2022) Very cheap (Local pesticide company, 2022)		company (2022)	paraquat products can only be obtained with a professional 'prescription' (Willis 2016) Not allowed for Rainforest Alliance (Island Breeze Pineapples, 2022)	Highly toxic to Amphibia, Crustacea, Algae, and Aquaticefern and moderately toxic to Fish In the 1970ies, pesticide poisonings were reported in Costa Rica that were mainly provoked by toxic organophosphates and paraquat (Thrupp 1988)
Quizalofop	Systemic herbicide	It can be used to control graminicides (Pineapple Haven, 2022)	3		Not approved in Europe Not approved for Rainforest Alliance	Low solubility in water. Moderately persistent in soils slightly-mobile Moderately to highly toxic to some mammals, earthworms, fish, and most aquatic organisms, low toxicity for birds Liver toxicant, harmful in contact with skin and if swallowed

					and Fairtrade	
Triclopyr	Selective and systemic herbicide	Land preparation	0	Alternative to Paraquat	Approved in Europe Restricted use for Rainforest Alliance (IPM strategy)	Highly soluble in water and high leachability. Persistent in some soils and mobile Moderately toxic for mammals, earthworms, and birds, low toxicity for honeybees, fish, and most aquatic organisms Highly toxic for humans

5.2 Alternatives to chemical weed control

Microbiological weed control

Several interviewees told me that replacing herbicides with biological pest control is more difficult than fungicides, insecticides, or nematicides; therefore, they don't have herbicide alternatives.

However, as mentioned before, at least post-harvest herbicides such as Paraquat can be reduced using microorganisms that help accelerate the degradation process after harvest. Nonetheless, these microorganisms work too slowly to be used independently and can be seen as an addition to conventional herbicides (D.H, 2022). Another advantage of microorganisms is that the decomposed organic material can be used as fertilizer (Chamber of R&D manufacturers , 2022). One agronomist said that the potential of microorganisms has not yet been fully exploited due to production pressures that cause producers to try to complete tillage as quickly as possible. As a result, many growers still rely on postharvest herbicides (A.G, 2022).

Yet, some producers are aware of the potential of alternatives such as Island Breeze Pineapples, which is collaborating with the University of Costa Rica on a research project to find alternatives for the degradation process of the post-harvest foliage, and Pineapple Haven, which is currently conducting trials on alternatives to pesticides. Sunny Delight Pineapples has a laboratory in which they produce microorganisms, organic fertilizers, and alternatives to chemical pesticides, and they claimed that in September 2022, they produced 80% of the agrochemicals they used. As I mainly focused on herbicides during my interviews, I didn't touch upon alternatives to other agrochemicals than herbicides. However, a local pesticide company told me about using biostimulants, which improve plants' nutritional uptake and reduce the use of fertilizers needed.

Mulch plastic

According to an agronomist, the use of mulch plastic is the most crucial change in decreasing the use of herbicides (J.V, 2022). Certain pineapple producers use it to cover the soil, reducing the number of weeds and herbicides applied and increasing the soil temperature while keeping it more stable, allowing a more uniform and faster plant growth. It also eliminates the need for irrigation, as soil moisture is retained, and fewer drainage channels are needed, increasing the area under cultivation (A.G, 2022).

Opinions about the use of mulch plastic are pretty divergent, and answers reached from: "*I think it's wonderful*" (A.G, 2022) to "*using plastic can bring more problems than benefits, if you think that plastic is a solution to not using herbicides, right? Because it contaminates the soil, no matter how hard you try to collect, then there are always pieces left"* (J.V, 2022). However, A.G claimed that the problem of plastic residues could be easily circumvented by removing the plastic in a certain way where the plastic foil is being rolled. However, after the recollection process, there remains a problem with the recycling process of the plastic foil because parts of the soil stick to the plastic and can hence not be recycled. Furthermore, high material costs and manual labor to remove the plastic foil after harvesting make it a relatively expensive method. An agronomist told me during a field visit that a further disadvantage is that the fruits are smaller due to less exposure to sunlight.

Manual weeding techniques

According to D.H., it is best to remove the weeds manually when they reach a specific size, and the patch of weeds is only locally. A.G also told me that he sees a need for using more manual labor in removing weeds to reduce the chemical load through the use of herbicides. Island Breeze Pineapples implemented a manual weed control program which, according to their statements, has greatly reduced their use of herbicides. Furthermore, since Paraquat can only be obtained by a prescription of an agronomist and since it is not approved for use in specific certifications, some producers use a method where the foliage is shredded and incorporated into the soil (Island Breeze Pineapples, 2022). However, different interviewees told me that manual weed control is costly compared to herbicides.

5.3 Changes in the use of agrochemicals

Although some producers told me that they are in search of alternatives to conventional agrochemicals, the chemical load has decreased over the last decade due to certifications, education, and the use of mulch plastic, most interviewees agreed that the technological package hasn't changed much over the last 20 years: *"No Louisa, in fact, in fact, they are* (the agrochemicals they use) *the same as they have been since I started working in pineapple in 2001"* (J.V, 2022). Risk aversion from big companies and resistance to change might be important drivers of this phenomenon: *"Yeah, the CEO of the company is going to ask you, are you put your head for changing this this from this? No, OK. Yes, this is the real question. The big boss is going to say we are producing eighty, 8500 bucks per hectare, the quality is fantastic, our customers are really happy, so what is going to happen if we use this? Are you saying that 100% that the cost is going to be lower with the same yields and the same quality? I can't; I can't bet you. So better do more trials, let's see what happens. This is the reality Louisa" (D.H, 2022).* Furthermore, producers prefer to continue using products they already know (Asoagro, 2022). The interviewee of Sunny Delight Pineapples told me in this context that he sees a need for hiring young agronomists to overcome the resistance against change.

However, precision farming is a factor that decreased the use of pesticides and will potentially continue. Different producers told me that they use precision farming, and according to CANAPEP, most pineapple producers have been using precision farming technologies for approximately five years (Umaña 2022). Using drones, for instance, allows the mapping of farms, measuring plants' size and weight, or identifying plant deficiencies. This information can later be used to locate the spay boom's GPS to reduce the spraying of non-target areas and overlaps (Golden Pineapple Farms, 2022). Furthermore, drone imagery can also help with the early detection of hot spots, allowing to control of the spread of pests and diseases at their initial stages. The availability of real-time weather data facilitates optimizing the use of inputs.

In Costa Rica, there are several precision agriculture research projects being conducted by agricultural universities, including the pineapple growing areas of the country (Quirós-Ramírez et al. 2022). In 2020, the government established "Agroinnovación 4.0", a program jointly developed by the UCR and the MAG to boost agricultural productivity and sustainability, mainly for small producers. During the trial phase, the program allowed a 52% reduction in production costs with an 84% reduction in agrochemical use (Presidencia de la República de Costa Rica 2020). Through the use of drones in pineapple, some farms have managed to reduce the volume of water used in the spraying process from 3'000 to 30 liters per hectare (Umaña 2022).

However, using drones to apply agrochemicals requires permits from the Directorate General of Civil Aviation and registration for aerial application, which poses another challenge regarding the difficulties in the registration process (CNAA, 2022 & Golden Pineapple Farms, 2022). Furthermore, several producers told me that the use is, at the moment, still rather expensive and less developed than for other crops such as banana or rice. In banana farming, for example, precision agriculture has been used for the aerial application of fungicides, insecticides, and herbicides for the last decade. (D.H, 2022, CNAA, 2022). In contrast, the topography of pineapple crops makes precision agriculture more difficult to apply, especially for small producers (Local pesticide company, 2022). Furthermore, digital skills are needed to manage new devices, which still prevents some producers from using them (Umaña 2022). Precision farming will continue to gain importance in pineapple production, but the current potential has not yet been exhausted for the abovementioned reasons.

5.4 Pesticide perception

To understand the reasons for the intensive use of pesticides in pineapple plantations, I thought it was important to know the attitudes of my interviewees toward the use of agrochemicals. I avoided asking them directly about their opinion but most casually disclosed it.

My interview partners generally criticized the media for contributing to a negative perception of pesticides as they perceive media coverage as one-sided. My interviewee from Asoagro even told me that she believes the media coverage on agriculture was not based on scientific facts but ideological issues. The published pesticide study by PNUD mentioned in Chapter 3.2.1 was very well received by the media and led to a heated public debate. My interviewee from SFE called the study a lie and accused PNUD of using data they had never seen, while CNAA criticized the media for not consulting the agrochemical industry's perspective, which he called *"A war against the agricultural sector."*

I was also struck by how emotionally charged the debate around the topic is when I spoke with SFE, and my interviewee became defensive when I asked her slightly critical questions about pesticide use in Costa Rica: "*It depends on your perception because not all agrochemicals are bad, if you are asking me, you are asking me a question as if they were all bad."* Another interviewee justified the use of old molecules, which have been banned in Europe for many years, by questioning the studies that are done in Europe: *"Yes, and because $ nobody has demonstrated that they really $ are, are contaminating people or the environment right … … … (laughs) I know that you are from there, but if Europe bans something, do not means that is bad, because the people is very, very political in that issue, right? Many products are banned in Europe but are using in the United States or Japan, or Australia. Or all the rest of the countries but $ here a product is taking out of the market or banned when they really demonstrate that they can affect a person or environment or the crop or the workers whatever $ they, they can be banned and in the past, we have done that. But this one at least these ones do not have any demonstration that are making any problems like that so"* (Chamber of R&D manufacturers, 2022*).*

An often-used justification for the use of agrochemicals is the argument that agrochemicals are a necessary "evil" to ensure food security and that not the pesticides themselves are the problem, but their incorrect application: "*And that's the secret of chemicals, if you use it correctly, they work correctly. If you use them wrong it's a problem for the environment yes"* (Local pesticide company, 2022). Different actors told me that they perceive the environmental critique they are facing as a significant threat: *"The environmental issue, which has been a controversy since pineapple production began $ so yes, as a chamber, we consider that pineapple production has been demonized, that is, in*

Costa Rica, pineapple and people automatically associate it with agrochemicals, poisons, and everything" (CNAA, 2022). This argumentation line is interesting, as it corresponds to the one of Abel Chaves, the president of CANAPEP, who argued that the reputation of the pineapple sector has become ruined (3.2.1). CNAA and Asoagro countered the environmental criticism arguing that the pineapple sector was of vast economic importance and created many jobs in rural areas. Depending on different sources, pineapple activity generates between 28'000 and 48'000 jobs in Costa Rica (Brenes 2017; Cámara Nacional de Productores y Exportadores de Piña 2022).

Generally, my interviewees were not very critical of the use of pesticides, arguing that production without them was impossible while denying any criticism of the sector. The only producer who spoke positively about restricting the use of pesticides was my interview partner from Sunny Delight Pineapples. According to its information, Sunny Delight Pineapples already dispense with many pesticides and replace them with microorganisms and other alternatives.

5.5 Herbicide distribution ways

To reconstruct the last mile of herbicides to the fields, I asked my interviewees where producers purchased their agrochemicals. According to the Chamber of R&D manufacturers, there are three distribution ways for agrochemicals: Large companies such as Del Monte buy their agrochemicals directly from the agrochemical producers such as Bayer, Syngenta, or Rimac. These companies have local dealerships where the medium and small growers buy directly from or through regional distributors. A larger producer told me that since the pandemic, they started to skip the intermediaries and negotiate directly with the producers or importers, which allowed them to decrease their costs (Tropic Delights, 2022).

One agronomist criticized that they have very little control over the molecules that are used as no policy in place stipulates that only agronomists may sell agrochemicals but also technicians of agricultural colleges can do so: "*I assure you that I can buy, in some, somehow, the most toxic product in the country that exists on the market, I'm sure it can be done, someone sells it"* (A.G, 2022). Interestingly, another agronomist said he sees easy access to agrochemicals as an advantage.

Small producers have two disadvantages regarding the prices at which they buy agrochemicals. In a report from 2011 analyzing distribution channels of agrochemicals in Costa Rica, small and medium-sized producers stated that they could not purchase large volumes and, therefore, could not obtain discounts (Dirección de Estudios Económicos 2011). Secondly, a well-defined technological package allows larger producers to negotiate the volume at annual or perennial prices (J.V, 2022). Consequently, smaller producers buy inputs at the current market price and are more subjected to price fluctuations. Furthermore, smaller producers with liquidity problems were forced to buy from sellers that would give them credits, limiting their bargaining power and ability to acquire lower-priced inputs (Dirección de Estudios Económicos 2011). However, smaller producers who sell their pineapple to larger producers might be able to purchase their agrochemicals from these large producers at a better price (Chamber of R&D manufacturers, 2022).

6 Current challenges for pineapple producers

To better understand pineapple producers' production conditions and realities, I deemed it important to start the interviews by asking about current challenges to answer the second research question: **How do pineapple producers deal with current challenges affecting the supply and use of herbicides in pineapple production?** Besides the price increase for agricultural inputs, the registration process for new agrochemicals was the most frequently mentioned challenge that the pineapple sector in Costa Rica is currently facing. In the following section, different challenges will be discussed.

6.1 Troubled supply chains?

During the lockdowns, factory shutdowns have led to shortages of agricultural chemicals, whereas port congestions led to rising freight costs, and labor shortages further exacerbated supply difficulties (Unglesbee 2021). Most interviewees confirmed my assumption that they are currently facing supply shortages. However, interviewees' answers regarding (temporarily) missing inputs were somewhat inconsistent. While many agreed that challenges in the supply of inputs were reflected in price increases, not all interviewees agreed that the supply of herbicides and agrochemicals, in general, was affected.

Global events such as the Covid-19 pandemic and the Russian invasion of Ukraine affected the supply of agrochemical inputs and led to significant price increases: *"Now during the pandemic, the high input costs are barbaric"* (Tropic Delights, 2022) or *"a big challenge and it's been especially the last two years, the prices of the, of the fertilizers, right? For the producers, it has been a battle without limit, and the same for us. Because, because the, the, the rise in prices has obviously not been at all a fault of the agrochemical companies, right? But everything has come from outside, right? From the Ukrainian issue, then the issue of the containers"* (Asoagro, 2022). The price for the technological package has risen between 40% (according to Tropic Delights) and 50% (according to Sunburst Pineapple Co.) and currently[8] remains at this level. However, not all inputs are affected to the same extent. Fertilizers are most affected by the price increase, for which prices have increased up to 300%. Urea, for example, increased from $20 per 50 kilograms to $70.00 per 50 kilograms (D.H, 2022). A large producer said: *"(…) fertilizers like urea increased 300%. So we were paying nearly $300 three years ago, and now and we went there, it was a point in which we paid $1250 a ton. So it increased four times the original price"*. The price increase for herbicides is lower compared to other agrochemicals and ranges between 20% (according to Sunburst Pineapple Co.) and 30% to 50% (D.H, 2022). However, some herbicides have been highly affected as well. According to a local pesticide company, the prices for Glyphosate have risen from $3.60 per kilogram to $14 or $15 per kilo.

One agronomist told me that some countries reduced their acreage of essential crops such as wheat because of the problems of obtaining inputs, which affected the agrochemical industry and downsized its operations. He named the example of Yara fertilizer closing down operations in the United Kingdom, which significantly impacted the supply of fertilizers and increased the prices. Other producers mentioned that the Chinese government forced their producers to stop temporarily exporting specific agrochemical inputs as they were needed for domestic agriculture (Tropic Delights, 2022, Pineapple Haven, 2022).

[8] November 2022

Another factor that increases the prices for agrochemicals is the price of petroleum, which is the primary raw material for manufacturing some fertilizers and synthetic agrochemicals. Furthermore, one agronomist told me that Costa Rica, as a small country, has only little bargaining power compared to larger countries: "*There was a very strong pressure to purchase inputs in the market because there was going to be a shortage of inputs, so there was a very large purchase from all these countries and the small markets, such as Costa Rica, because we are invisible in the input market, we had shortages" (A.G, 2022).* This was also mentioned by CNAA: *"we are a very small country and we do not have the power to say, send us three ships of fertilizer" (CNAA, 2022).*
Almost all producers mentioned the increased prices for carton boxes. The president of a local pesticide company told me that the price for carton boxes currently accounts for 20% of the total costs: *"So let's say you sell a box of pineapple for $6 the box may be above $0.50. I: That's a lot. A: It's horrible".*

The answers regarding the timeframe in which producers were most affected by the price increase varied between the interviewees. A local pesticide company said they were most affected in the first year and a half of the pandemic and in 2022, while Sunny Delight Pineapples in 2021, Island Breeze Pineapples from December 2021-January 2022, and CNAA in March and April 2022. These different statements could be related to differences in the supply chain, with price increases being passed on to producers faster or slower, depending on the trader. This is supported, for example, by the fact that a local pesticide company, as a producer of agrochemicals, was the first to experience a price increase for active ingredients. However, different actors affirmed that the prices have stabilized over the last few months. According to the local pesticide company the Covid-19 pandemic had a more significant effect on the costs than the current challenges related to the war and ongoing lockdowns in China.

6.1.1 Container shortages

At the beginning of 2022, container shipping found itself in the deepest crisis it has ever seen. Global lockdowns have led to a shift in consumer spending from services to e-commerce. This has put the container supply chain under unprecedented strain, with shocks such as the six-day Suez closure in March 2021. Container shipping disruptions for agricultural products have been especially severe on high-value commodities such as dairy, meat, fruits, and vegetables. Most agricultural products are being shipped as Backhaul, which means that they are being transported as a return movement of a container from its destination to its original point of departure. However, agricultural products are of low value compared to electronic devices such as computer chips or smartphones, and therefore high-value items have been prioritized (Yergin et al. 2022). Different interviewees mentioned in this context the competition for containers as a challenge.

Container shortages affect the pineapple industry twofold. On the one hand, essential imported inputs have temporarily become scarce; on the other hand, most pineapple is exported in containers. The president of a local pesticide company, which imports active ingredients from Asia, explained how they were affected by price increases for active ingredients and time lags: *"Before the pandemic, the delivery would take 30 days, while it took up to 90 days during the pandemic. Prices for a container rose from 2'000 to $20'000: So sometimes you buy technical that was worth 20'000 or $30'000, and the price of transportation was almost as much as the technical inside"*. He sees two reasons for the significant delays: firstly, freight from China was delayed due to the country's lockdowns, and container ships were later stuck in Los Angeles and Manzanillo, Mexico, to unload. According to him, the

transport prices are currently[9] still $ 5'000 per container, meaning they have decreased significantly but are still more than double as much as before the pandemic. Also, the president of the Chamber of R&D manufacturers, said: "*For example, here in our company, we import some things from China, and before COVID-19, we pay like 3'000 dollars of a freight from China to Costa Rica. And now we are paying $ a 13'000 for the same".*
From the export perspective, pineapple transport costs doubled from $4000-$4500 to $7000-$8000 per container (D.H, 2022). CNAA mentioned that one of the most significant challenges for the export sector is the increasing tariffs for APM Terminals, a port operating company. There has recently been an increase of 12% in taxes, while in the previous year, these prices increased up to 30%.

6.1.2 Shortages of agrochemical inputs

Already in 2021, shortages of key herbicides have been predicted for 2022. Bayer, for example, announced in early 2022 that its ability to supply glyphosate was constricted due to the pandemic's challenging global trade flow effects (Pucci 2022).

My interview partners replied very divergently to the question of how they were affected by supply shortages. Answers reached from: *"Oh, of course. Certain ingredients you could not get access to. You just want to buy it, and they say no we don't have, we're not producing"* and *"Sometimes we were asked for formulations we just didn't have… … That was it. I mean we had no choice" (Local pesticide company, 2022),* to *"Ok, let's see, as I said, we have not had shortages, right? So there has not been a shortage, but the problem that occurred was with prices" (Asoagro, 2022).* One producer told me that they are struggling up to today in obtaining some agrochemical inputs: "*Some plants were closed due to pandemics, the high costs of transportation, logistics and all that, meant that we were more or less two months without the products in the quantities we required, after that, prices have been rising, normalizing a little ... to be able to supply us, but even today we have some products that are still not available at 100%"* (Island Breeze Pineapples, 2022). However, the same producer also claimed they didn't have problems with herbicides; instead, other inputs, such as fertilizers, were affected, especially Urea, Phosphorus, and Potassium. This was also confirmed by another large producer that claimed, "*There were months like six months without ammonium nitrate in Costa Rica. Boric acid, which we also use as a fertilizer, also limited calcium nitrate mono ammonium and maybe phosphate, they are those types of fertilizers where really limited, for a while".* An explanation for why fertilizers were more affected than herbicides was given by Sunny Delight Pineapples, who claimed that there is a much higher demand for fertilizers than herbicides.

At first glance, these different answers seem contradictory, but an explanation could be the size of the producers. Among the interviewees that claimed that herbicides were not affected by supply shortages, there were mainly large producers or actors that work or advise large producers (Golden Pineapple Farms, J.V, Island Breeze Pineapples). Golden Pineapple Farms, one of the country's biggest producers, claimed they had no knowledge about supply shortages for herbicides but were affected by shortages of fertilizers. During a field visit, an agronomist confirmed that pesticide producers temporarily stopped providing smaller producers to continue providing larger ones. Differences in the supply chain of agrochemicals for different-sized producers might imply that larger producers tend to have long-term contracts directly with pesticide producers. Thus, owing to economies of scale, they

[9] November 2022

can purchase their inputs cheaper than small-scale producers, and having direct contracts with pesticide producers might give them more bargaining power in obtaining inputs.

6.1.3 Strategies to deal with shortages

One producer described the procurement process of agrochemicals as a challenging game in which the producers have to identify the optimal moment to buy their inputs, depending on demand and supply: *"It's part of the game of this, right? To know this supply and demand, and when to buy, when not to buy and what to stock, but it's not that easy, because that, that represents a cost, a high financial cost, and then you have to, you have to be very careful with it"* (Tropic Delights, 2022). The following sections will discuss different strategies to deal with shortages.

Substitution of missing inputs

Several interviewees agreed that if there are delays in deliveries of herbicides, they can substitute these products. According to the Chamber of R&D manufacturers and D.H, substituting herbicides is relatively easy, as many options are on the market. This supports what producers told me they would do; adapt the technological package and substitute some products. Another producer claimed that to prevent resistance, they had to rotate the molecules regularly, so they would already rotate before. Rotation is easier for herbicides than fertilizers or insecticides because more registered products (generics) are on the market for substitution, which is not the case for fertilizers (Tropic Delights, 2022). Sunny Delight Pineapples also told me that substituting, especially fertilizers, is difficult. Golden Pineapple Farms claimed they were testing alternatives they could use in case of shortages or significant price increases. Another producer claimed: "*We have been able to find them, yes, but sometimes it's not the number one or number 2 in the list, but we have to go to number 3"* (Sunburst Pineapple Co., 2022). Another producer described how the substitution of magnesium created some deficiency at the plant level because the new input did not supply the nutrients the plant needed, and the results were worse than they had expected. The same happened with nitrogen and phosphorus; hence, this producer fertilizes now with salt instead of urea, ammonium nitrate, or potassium chloride. Another producer mentioned a "sunblock" they had to substitute, but the substitutes worked less well; consequently, a higher percentage of their fruit got sunburnt and rejected for aesthetic reasons. Figure 16 shows an alternative to chemical sunblock, where a piece of paper protects the fruit from solar stress. Hence, there are possibilities to substitute, but in some cases, they do not seem as efficient as the input they usually use. Furthermore, only products can be used which are registered for use in pineapple, which somewhat limits substitution possibilities.

Figure 16*:* Paper covering the small pineapple fuirt to protect it from sunburns. Reference: Picture taken by author during a field visit in Pital, December 2022

Manual weeding and biological pesticides

A crop consulting company claimed farmers would likely resort to plowing fields for weed control in case of missing agrochemical inputs and that especially *"the no-till guys will have the biggest issue"* (Pucci 2022). Some producers told me that the lack of specific inputs affects productivity or increases their labor costs, as they would replace an herbicide with manual removal of weeds, which is more expensive. According to a local pesticide company, plowing the land is an essential substitution for post-harvest herbicides such as Paraquat. However, many people consider it a problem, as it destroys the structure of the soil. Island Breeze Pineapples uses, for example, more organic fertilizers and biological pesticides, and regarding weed management, more manual weeding techniques than before the supply chain issues emerged. Another producer claimed that due to the pandemic, they saw the need to "mirar fuera de la caja," think outside the box, and find new ways. They started, for example, one year ago, to produce some biological pesticides they were formerly buying to decrease their costs (Tropic Delights, 2022).

Sunny Delight Pineapples claimed that they see the input crisis as a chance for finding new, more environmentally friendly products: *"We took the step and made the changes, the transition, $ we had already been doing it, and currently the market and the crises have put more pressure on us to make these changes or to start making them."* They produce 80% of their pesticides, replacing agrochemicals with alternatives. Another producer told me: *"In some cases, it is not exactly like a radical change of suppliers $ but what we have had to do is to select and reach agreements with these suppliers $ to change the way of sourcing, in a win-win for both parties"* (Tropic Delights, 2022). Their supplier sells them some ingredients to produce organic pesticides, which allows them to decrease their costs. They started their lab only one year ago, which suggests that the input crisis was a trigger to produce

alternatives to conventional agrochemicals themselves: *"We are not the, the, the pioneers in this, let's say, in the pineapple industry there are several who do that $ then, but this is a product of the same need that has been ... and then opens those doors, open those windows, those windows of possibilities".* Another producer told me referring to biological pest control: *"the market and the crises, have put more pressure on the market to make these changes or to start making them"* (Sunny Delight Pineapples, 2022).

Using fewer chemical inputs

Different interview partners confirmed that many farmers (mainly small-scale) would use fewer inputs such as fertilizers and pesticides: *"And there's a funny thing that happens Louisa, because ... when there are problems in agricultural production systems, the first thing producers stop doing is buying fertilizer $ ... and unfortunately that's the last thing they should do"* (A.G, 2022). Consequently, this affects the size of the fruits, the sugar content, and the susceptibility to pests. According to D.H, this is directly reflected in the yields: "*If you don't invest the right amount of fertilizers and some pesticides and cultural cares, you're going to see the result very, very, very fast. So you can pass from 8500 boxes per hectare in the first crop to 6000. $. And I have seen a lot of people broken, closing their pineapples".* However, they claimed this problem existed before the pandemic but was exacerbated over the past three years.

Consequently, more fruit is being rejected. This coincides with the observations I made during my field visits. The agronomist of Pineapple Haven showed me pineapple fields of small producers full of weeds because, according to him, the farmer had used no or fewer herbicides. Furthermore, he showed me some of their pineapple fields where the plants were smaller because they had used fewer fertilizers. Island Breeze Pineapples also confirmed that they did not only have to substitute inputs but also decrease the general use of it, especially for fertilizers and, in some cases, agrochemicals.

Changing crop

The consequences of disruptions in the supply chain entail, in some instances, a switch from high-input crops to crops that are less intensively dependent on inputs such as fertilizers and herbicides (Yergin et al. 2022). None of the plantations I interviewed had to decrease their operations, but I was told that some small-scale producers had to reduce their cultivated area, switch to other crops, or even close or sell their farms. According to D.H and Pineapple Haven, many producers returned to other cultures, such as cattle, yucca, papaya, or sugarcane. For larger producers changing crops is more complicated, as they have very specific infrastructure developed: "*So, changing crops is like the last option, like, for me $ because you have to see what you do, remember that a lot of pineapples is very intensive, so if it is three or four hectares, that's good, but if it is 100, 200 ... And where is the market? And what is my risk? And it may be that the crop that is currently ... so to speak, fashionable, does not have the climatic and geological conditions to be able to plant it in that part of the country.."* (CNAA, 2022).

However, Island Breeze Pineapples explained how they had to "sacrifice" other activities such as investments in CAPEX to maintain the production at the normal level: *"What the company has done is to sacrifice other areas in order to be able to keep feeding the plants without lowering production, because lowering production puts us in trouble, right? And we depend on that, basically, we are a thousand people who work and depend on that production, so the company has stopped investing in other areas, such as CAPEX, in order to supply more resources to the area of agricultural inputs and maintain production"* (Island Breeze Pineapples, 2022). A local pesticide company told me that in

sectors other than pineapple, farmers have let their fields lie fallow, given the price increase for inputs. Furthermore, most producers affirmed that they switched to other suppliers: *"I would say if a pineapple company used to buy from us and we didn't have, they just bought it from someone else that did, and then they run out, and they bought it from someone else. $ That happened a lot"* (Local pesticide company, 2022).

Hence, it can be concluded that pineapple producers have been affected by supply shortages for agrochemical inputs, especially fertilizers, while herbicides haven't been affected to a greater extent. Also, different alternatives exist that can be used to replace an herbicide in case it has been temporarily unavailable. However, all producers agree that herbicide prices have significantly risen over the last three years. As I did not speak to smaller producers, the differences between the farm sizes can only be based on statements from larger producers. However, it seems that small-scale farmers struggled most with agrochemical shortages and mainly resorted to manual weeding techniques, as they did not have the financial means to build up own laboratories to produce biological pesticides. However, the resulting additional costs have also forced some smaller producers to switch to less pesticide-intensive crops or even close or sell their farms.

6.2 Pesticide registration in Costa Rica

"*So now we have the transnationals, the patented products, the generic products, and also the green people. Between those three, we have such a big fight that we cannot register, no one can" (Local pesticide company, 2022).* According to Castro-Vargas and Werner (2022), the registration process in Costa Rica is known to be ineffective. While most of the country's pesticides exist in administrative limbo, few new compounds have been approved comparatively. Costa Rica has seen a two-decade effort to modernize the country's pesticide registry (Castro-Vargas and Werner 2022). The issues the country faces regarding its troubled pesticide registration process are essential to summarize to understand their influence on the offer briefly and hence the choice of herbicides for farmers.

In 2020 the Director of SFE admitted that the pesticide registry 'had collapsed,' as new registrations suffered countless delays and attempts to regularize old registrations couldn't be efficiently evaluated (Castro-Vargas and Werner 2022). The registration process is perceived as (one of the) most pressing challenges for the pineapple sector: *"Registration, it's a problem here, I mean. Huge, huge problem"* (Local pesticide company, 2022) and "*Another challenge in Costa Rica is agricultural inputs, but it is not a supply issue, it is not a supply issue, it is a political issue, because in Costa Rica ... the policy of registration of new phytosanitary molecules is very complicated, it is a struggle that has been going on for many years*" (J.V, 2022).

As my awareness and knowledge about this quite complex issue rose from interview to interview, I started to adapt the interview guide after a while and included an additional question about the perception of the registration process. My interviewees perceived the registration process generally as being driven by ideological ideas rather than on a technical base. They criticized that politicians involved in the registration process generally lack knowledge about agrochemicals and are hence against their registration: *"Unfortunately, there is, I feel, a lack of political will because they have not really sat down to understand what is going on, have they? There is another problem, also very ideological, of some of the authorities, right? Where they simply have a very clear idea that we don't want any more agrochemicals, right? And then we want everything to be at a more organic or natural level, right? (...) And I really tell yoau that, that happened here, sometimes our authorities are a little*

bit, as we say in Spanish, más papistas que el Papa[10]*?"* (Asoagro, 2022). The perception is that politicians are generally against the use of agrochemicals as they are afraid that changing the registry could damage their political image, and only the voices of the opponents of agrochemicals are heard: *"In our political space, those who speak out the most are those who are opposed to the use of agrochemicals"* (A.G, 2022).

6.2.1 Role of the Ministries in the registration process

New pesticide registrations for domestic use are almost inexistent in Costa Rica. Castro-Vargas and Werner (2022) see one reason for disagreements within and between actors such as Ministries, juridical bodies, and other regulating authorities. Jansen (2017b) describes how different institutional rationalities are applied by different Ministries involved in pesticide regulation (namely the Ministries of Agriculture, Health, and Environment) and juridical complexity. For example, the Attorney General and the Constitutional Chamber of the Supreme Court rule based on Health Law, thus dissolving or reinterpreting pesticide-related decrees or their implementation by the MAG.

Some of my interviewees see the conflict between the three Ministries as a reason for the paralyzed registration process. Especially the Ministry of Environment is being blamed for hindering the registration process. According to a local pesticide company, the Ministry of Environment and the Ministry of Health told them that they weren't in favor of registering new products: "*So we were in a meeting with them and they told us look, you know we're going to fight every day so you will never ever register another product*" (Local pesticide company, 2022). SFE, however, denied the existence of conflicts between the different Ministries: "*Yes... we try to collaborate, yes, we do want to make it clear, don't we? That we, the three Ministries do work conscientiously and technically, no, we do not decide based on personal interests".*

After a few interviews, I got a bit confused by the term "ambientalistas" because different actors were referring to the employees from the Ministry of Environment as ambientalistas. However, it is essential to mention that besides the Ministry of Environment, there is an environmentalist movement, "ecologista" movement, which is a civic movement that engages in the political debate of different socio-environmental struggles. Castro-Vargas and Werner (2022) explain the term as follows*: "Just as many ecologistas perceive the state as a mediator for, or an agent of, agribusiness capital, the pesticide industry views part of the state bureaucracy as a redoubt for radical environmental interests"* (Castro-Vargas and Werner 2022:5). Hence, in retrospect, it is not always clear whether interview partners use the word "ambientalistas" to refer to the "ecologistas" movement or the Ministry of Environment. However, it can be said that both actors are portrayed as scapegoats in the registration process by different actors.

Asoagro believes that the voice of opponents of agrochemicals is heard more because they have much more funding and resources to finance publicity campaigns, leading in their perception of a misconception about agrochemicals in public. This argument is interesting because the ecologista movement is primarily a civil society movement and presumably has few financial resources. An agronomist that generally endorsed the positive aspects of agrochemicals called the opponents of agrochemicals "a necessary evil" as they raise awareness and generate political pressure for regulating the misuse of agrochemicals such as Bromacil (J.V, 2022).

[10] Spanish expression which translates into "more Catholic than the Pope"

6.2.2 Role of the pesticide industry in the registration process

For many years, there has been a conflict between transnational research-based companies (R&D) and the producers of generic pesticides. R&D companies such as Bayer and Monsanto focus on researching and developing new products. In contrast, the Generics invest little in research to develop, register or advertise new pesticides. This allows them to compete with lower prices*: "Any costs incurred for toxicological studies required for first registration would eliminate this competitive advantage"* (Jansen 2017b:50). A general claim is that by increasing the competition in the pesticide market, the generic industry reduces agricultural production costs and thus reduces the cost of food for consumers (CIPAC/FAO/WHO 2008 in Jansen 2017b). This argument was also used by farmers involved in the registration process: In 2008, a group of farmer organizations marched with 2,000 farmers in San José, lobbying for quick registration of the generic pesticides, in particular using the argument of lower prices (Jansen 2017b).

The conflict concerns mainly the use of risk data that a company has to provide when registering a particular product (Jansen 2017a). Risk data refers to chemical identity, efficacy, environmental, and health safety data. When a generic company wants to register a product, they rely on the procedure for equivalence assessment, meaning they have to show that their product is equivalent to a product already registered (Jansen 2017b). Once the patent for a molecule has expired, a reference profile should be established, allowing for the registration by equivalence of generic active ingredients. Generic firms criticize that R&D firms hamper this process by refusing to provide reference profiles (Castro-Vargas and Werner 2022). Procuring risk data is expensive, as it requires studies that show the product's efficacy and safety for the specific crop. Costa Rica does not conduct studies for new products registered for the first time as these studies are costly and mostly carried out in Europe or the United States (SFE, 2022). However, European countries generally don't test their molecules for use in pineapple, as they have little financial incentives to do so due to the size of the pineapple market (A.G, 2022; Local pesticide company, 2022).

A local pesticide company, which produce itself generics, told me that the conflict between the generic and R&D sector started in the early 2000s when in their opinion, R&D companies were trying to enforce legislation that would impede the generic sector to register, which led to a big legal fight: *"The fight became so big, so big, so big that now neither they can they register nor we can register"* (Local pesticide company, 2022).

In Costa Rica, the Chamber of R&D manufacturers represents R&D companies, whereas Asoagro represents the generic sector. Jansen (2017) argues that the state's need for the industry to endorse regulation was also referred to during his interviews with state officials and mentioned in newspaper articles. Jansen (2017b) argues that consensus meetings between the MAG with the different branches of the pesticide industry to arrive at a consensus about regulating equivalence, the ownership of data, and temporary registration of products with incomplete risk data reflected the importance of political legitimacy: the state looking for business approval of regulation (Jansen 2017b).

However, recently R&D companies and the generic sector increasingly cooperate for registry reform. Castro-Vargas and Werner (2022) see two main reasons for this change: the transnationalization of the Costa Rican generics sector and increasing commercial and strategic links between the two sectors to influence state regulation. While both chambers agreed that there was an interest to work together in

particular interests, Asoagro criticized the government for doing policies favoring the R&D companies and that the current legislation concerning the reference profiles does not give them legal certainty. Furthermore, another interviewee told me that he believes the government favors large pesticide companies over "innovative" new ones by processing their registries faster, which he was referring to as corruption (D.H, 2022).

Industry representatives argue that the registry's collapse forces farmers to rely on older-generation pesticides banned in European countries and the USA and could thus lead to a loss of export markets due to restrictions on these compounds (Castro-Vargas and Werner 2022). This is in line with the view of the producers, which say the registration process limits them a lot at the production level and prevents them from producing more environmentally friendly as they cannot use new products on the market with a lower chemical load: *"And, and we want to use something else, but just you know, there are a few products there available, but we just don't have them registered in Costa Rica. So that's that's a big limitation"* (Sunburst Pineapple Co., 2022). Another agronomist told me: "*I think it is absurd because these new molecules are already molecules that use less active ingredient per hectare, they are molecules that have already been approved by developing countries, they have been studied a lot, and here we have to continue with the same old molecules because new ones cannot be registered"* (J.V., 2022).

The slow registration process does not only limit the choice of herbicides and agrochemicals in general but sometimes also their application. Golden Pineapple Farms told me, for example, that they were using a drone for applying some herbicides, which allowed them to considerably reduce the chemical load and amount of water for application. However, they were banned from using it as the products they used were not registered for aerial application in pineapples. Hence, although the drone applies the herbicide at the same height as the spray boom, the product must be registered first for aerial application. CNAA said*: "I wish that was allowed and that would be a change because no, you wouldn't be spreading so much, right? $ more controlled ... but yes, the issue of changes of products, is practically not taking place because of the registration problem".*

Furthermore, alternatives to agrochemicals, such as microbiological or organic pesticides, require the same information as an agrochemical to register, meaning producers can only use alternatives they produce themselves but cannot import them from abroad unless registered: "*Yes, yes, yeah. And usually, it's not enough with what you can produce on the farm. Yes, because the the the pest here and the insects and bacteria are very, very high. It's very difficult to control them just with what you produce in your own farms. And there are very good organic products in the market and we do not have them"* (Chamber of R&D manufacturers, 2022). Since the registration for fertilizers is easier than for agrochemicals, some organic pesticides are registered as fertilizers (J.V, 2022).

SFE themselves mention two reasons for the slow registration process: A lack of personnel and incomplete applications. According to SFE, since the involvement of the three Ministries (MAG, the Ministry of Environment, and the Ministry of Health) in 2007 in the registration process, fewer products have been registered. All three Ministries lacked the personnel to attend to the number of pending registries which caused delays. However, SFE claims that since 2018 they have been able to register some more products, as all three Ministries hired additional people. However, they affirmed that no single product had been registered for use in pineapple since 2007. The other reason for the

slow registration process is, according to SFE, that some registry applications come without complete requirements, such as risk assessments they request.

Producers perceive the registration process as an economic threat, making it more challenging to compete with other countries that can register new compounds they cannot access in Costa Rica (Chamber of R&D manufacturers, 2022). In early 2021, Laura Bonilla, then President of the Costa Rican Chamber of Exporters, proposed a law that would allow confirmed declarations for registration of active ingredients and formulations and grant a ten-year validity to all registrations currently active and in the process of renewal. The effort was united with the interests of the business sector to secure legacy registrations without revised risk data but bypassed the Ministerial process by appealing to the legislature. 2022 elected President Chaves declared during his election campaign that a pesticide registry without providing any risk data was one of his top 5 priorities. Soon after the elections, Chaves signed a decree to allow registrations to be made by compiling studies from one or more OECD countries (Castro-Vargas and Werner 2022). A new regulation is underway to facilitate the registration process through homologation and recognition of data and studies from other OECD countries. This would allow SFE to accelerate the registration process (SFE, 2022). However, A local pesticide company told me that the generic sector will work against the regulation as it doesn't allow them to register generic products and would eliminate access to reference profiles.

Even though further analysis of this conflict would go beyond the scope of this thesis, I consider it essential to understand its role in explaining the sector's dependency on old molecules.

6.3 Environmental challenges

6.3.1 Overuse and illegal use of pesticides

Although the majority of my interviewees were not particularly critical of the use of agrochemicals, some described the dependency on agrochemicals and the challenge of finding alternatives as a problem. In this context, several mentioned the issue of overuse of pesticides: "*There is a culture that has to ... that must change, that if they are told that you have to use this cup for one liter of water, it is one cup for one liter of water, and there are producers that use two or three cups for one liter of water*" (CNAA, 2022). One agronomist told me that he frequently sees producers applying excessive amounts of Nitrogen and Potassium or using products without knowing their function or biological efficacy (J.V, 2022). In the context of misuse or overuse of pesticides, mainly small producers are being criticized.

According to A.G (2022), small producers have fewer control mechanisms and less reputational risk as they are less exposed to the public eye than larger producers. However, Sunburst Pineapple Co. told me that while he believes many small producers don't like to be told what to do, he does not believe that they produce irresponsibly because they usually have a place attachment, a personal identification with the region in which they produce, unlike large companies with headquarter abroad. Some agronomists I interviewed mentioned the importance of nutrition, arguing that well-nourished plants are more resistant to pests and can help decrease pesticide use.
A report about supply routes of agrochemicals in Costa Rica found in 2011 that the irrational use of products not only causes pest resistance due to the under or overuse of agrochemicals but increases production costs (Dirección de Estudios Económicos 2011). Responsible use of agrochemicals is therefore crucial from an environmental perspective and also economically relevant.

However, not only the overuse of agrochemicals is an issue but also the use of prohibited or unregistered substances. According to a local pesticide company, many producers illegally use Paraquat, which is forbidden for the most common certifications such as Global Gap or Rainforest Alliance and can only be obtained with a professional prescription. Since Paraquat is classified as a pesticide with the highest level of toxicity, its use requires a special prescription from a licensed agronomist (Willis 2016). Sunburst Pineapple Co. confirmed that especially large companies use illegal substances, and he referred to them as sometimes reckless and profit-driven. Furthermore, different interviewees confirmed that some producers illegally buy pesticides from neighboring countries not registered in Costa Rica.

6.3.2 Climate and pest pressure

The tropical climate is often used to justify the pesticide intensity, arguing that high pest pressure requires certain pesticides. Canapep claims on its website: "*Europe has a very different way of producing. Why? Well, they can produce only six months a year. They can produce only half of the year, the other half of the year they can't. When, when it freezes, ground everything dies, insects, everything. Here we have a 12-month period in which are insects year-round, 24/7, 365. So the problems here are very different than the problems you have there"* (Local pesticide company, 2022), or "*There are pests, and there are... insects, and there are fungi, and there are, right? There is no way that they can be treated other than with agrochemicals, right?"* (Asoagro, 2022).

A large producer described, for example, why many producers use agrochemicals to decompose the foliage after harvest: *"It may rain for three consecutive weeks, and there is no way we can get a tractor in there. There is no way you can get an application. You can get anything, so really nothing works like no matter what you have, it doesn't work. And under those circumstances, is, is you don't have a lot of alternatives to control the flies"* (Sunburst Pineapple Co., 2022). Also, Canapep claims on its website that the goal of pesticide-free production is impeded by different pests (CANAPEP 2022b).

Different producers told me that despite the use of microorganisms that help to accelerate the decomposition process, they are dependent on additional (chemical) measures such as the use of Paraquat as the decomposition process is not fast enough: "*Because it's, you know, under an ideal situation it, it can, you can do everything, and it would be perfect, but because of the intensity of the severity or the weather conditions that we face sometimes it's just really difficult*" (Sunburst Pineapple Co., 2022). Some producers uproot the plants after harvesting, remove them from the field and feed the foliage to livestock, but for this producer, this was not possible due to the size of their operation, harvesting three hectares per day.

Producers agree that they are affected by climate change, with rainy and dry seasons no longer delineated, making heavy rainfalls, longer dry spells, and extreme weather situations more likely. In turn, this complicates the planning for pineapple farmers and entails uncertainty. After heavy rainfall, preparing the soil for planting is challenging, as heavy machines can compact the soil, destroying its structure and preventing water infiltration. Under these conditions, not only the roots of the pineapple plant do not develop well, and the susceptibility to fungal diseases such as Phytophthora, Fusarium, or other pathogens increases. Furthermore, transport routes to the port in Limon are sometimes closed after floods or landslides (A.G, 2022).

6.4 Market challenges

Different types of market pressure challenge producers. Producers describe how difficult it is to run an economically viable business because the pressure to produce cheaply is very high, and profit margins are shrinking yearly. In recent years there has been talk of an economic crisis due to the reduction of prices in international markets. Nevertheless, the behavior of pineapple expansion, in terms of the area, reflects a sustained growth from 2000 to 2018 (Vargas 2019). In the context of economic pressure, many interviewees also mentioned the comparatively high labor cost in Costa Rica compared to neighboring countries and other pineapple producers. The registration process issues exacerbate competition with other producing countries, as other countries have access to cheaper and newer agrochemicals making them more competitive. In this context, CNAA also sees a drawback in Costa Rica's role as a pesticide exporter as the country exports formulations not approved in Costa Rica. In the following part, different market challenges are elaborated.

Different producers told me that the quality standards and the aesthetic requirements of customers in Europe and the United States are challenging, and up to 30-40% of the produced amount is rejected. Producers sometimes justify the use of agrochemicals to prevent aesthetical damage: *"So, any damage that may appear within the plantation, you have to control it $ ... And what do you control it with? With agrochemicals $ it is a, it is an imbalance due to a marketing issue"* (A.G, 2022).

Interestingly, one producer perceives the concentration of supermarkets in Europe as a problem (Pineapple Haven, 2022) as they depress prices, while another mentioned market concentration in generic pesticides. He argues that while Chinese companies first flooded the market with inexpensive generics, prices have risen over the last few years: *"And it seemed to me that the strategy that China applied in the agrochemical sector is reduced price to the minimum and force big companies to be sold so they will buy it and now they have bought it, there are no lower prices anymore. They have raised the prices of their generics, yes (…). So these guys came in, brought the prices to the lowest. It started breaking other companies and forcing them to sell it. They bought it, and now they control the price (…) But the pandemic, you know, was a great excuse. And then the containers and then the ships and then the limited supply, so you know this is all to me planned out and artificially managed to screw us up"* (Sunburst Pineapple Co.).
However, the pineapple industry itself is also heavily affected by market concentration. According to a local pesticide company, between 2017-2019, many small producers went bankrupt and had to sell their farms. Over the last century, large producers such as Dole or Del Monte have acquired many medium-sized plantations (Sunburst Pineapple Co.). Furthermore, many small and medium-sized farmers don't export themselves and thus sell their fruits through export companies such as the ones mentioned above. However, according to a local pesticide company, this dependency on other companies poses a significant risk because if demand for pineapple falls, export companies that produce themselves will no longer buy from smaller companies. As mentioned before, it was mostly the small farmers affected by the pandemic which had to lower the frequency of applying agrochemicals and fertilizers. However, one producer told me he saw a chance for small farmers to operate more independently from transnationals by finding their way into niche markets.

As mentioned before, the market demand for year-round production entails intensive production when climate conditions are not ideal (A.G, 2022). Pineapple flowering is triggered by a combination of factors, including the plant's age, environmental conditions, and certain hormones in the plant

(Sandoval and Torres 2011). Keeping a year-round production is further hindered by the natural flowering of the MD2, which happens when temperatures drop below 18 degrees Celsius. Although the direct effect of the low temperature on natural flowering is not exactly known, low temperatures probably favor ethylene production, the hormone that stimulates flowering (Cunha 2005). Consequently, the fruit ripens faster than the producers had planned, causing scheduling problems affecting the timing and quality of the fruit (J.V, 2022). Furthermore, fields must be cleared quickly after harvesting to prevent the fly *Stomoxys calcitrans* from laying its eggs in the rotting foliage and preparing the land for the next planting period. To meet these market pressures, producers try to decrease production risks as much as they can, which entails the intensive use of chemical inputs (A.G, 2022).

Another challenge that is not related to the use of pesticides but which nevertheless was mentioned by many interviewees is the problem of drug trafficking. Over the last years, drugs have been repeatedly found hidden inside fresh pineapple shipments, which producers fear is staining the image of the pineapple industry.

7 The role of private standards and advisory services

As discussed in Chapter 2.3, different scholars have studied the influence of extension services on the use of pesticides (e.g., Galt (2008), Thrupp (1988), Aga (2019). During my interviews, I also learned about other factors that influence the use of herbicides and agronomic practices, such as the importance of certifications. Their relevance to the pineapple sector is discussed in the following Chapter with regards to the third research question: **What is the role of private standards and extension services on herbicide use?**

7.1 Extension services

7.1.1 Role of private extension services

Large-scale pineapple producers generally have their R&D department and do not depend on external advisory services. According to the Chamber of R&D manufacturers, this is reflected in the higher quality and yield of larger producers, as they have the resources to develop more sophisticated applications specifically tailored to their farms. However, some large-scale producers who buy pineapple from smaller producers affirmed that they support the latter with advisory services. Sunny Delight Pineapples, for example, advise their producers regarding alternative inputs, such as microorganisms they produce in their laboratory. For this purpose, they developed an app called PINEAPP which helps producers to identify pests and diseases and provides information about agrochemicals and alternatives. However, for most large-scale producers, these advisory services seem to be more limited to residual controls than actual advising: *"We, we make sure that they comply with a lot of our requests, which are requests from the supermarkets and from our clients so that we do and at the same time we provide support, technical support to them as required" (*Sunburst Pineapple Co., 2022*)* or *"we have a technical team that checks them, that checks the products and also that we check the residue analysis every week when they are going to be exported if they have any residue problem, we reject the fruit before exporting it"* (Pineapple Haven, 2022).

According to J.V (2022), who advises pineapple farmers throughout Latin America, Costa Rica has no culture of hiring external, independent advisors because the pesticide companies are filling this gap, which he considers as a problem: "*They do that technology transfer, it's not, it's not a technology transfer, in my opinion, right? Because it doesn't exist, generally, the ... these companies are more focused on selling than giving an advisory service, right?* (…) *Because all the information, in one way or another, that exists among the producers is shared through the agrochemical suppliers, right? While it is true, the information is not technically very solid"* (J.V, 2022). While large plantations do not justify hiring an advisor as they already have agronomists, smaller producers often lack the financial means to buy these services (Local pesticide company, 2022). The pesticide companies that sell their products to pineapple farms play the most crucial role in advisory service. My interviewees took a rather critical view of this: *"Chemical companies are really interested in selling agrochemicals"* (D.H, 2022), or: "*Yes, they do have a role in advising, but many times, in many cases, the companies are there to sell $ Do you understand? So, as producers, we always have to be responsible, to go ahead verifying that it is not only to sell, but also to verify that we do not have residue problems"* (Pineapple Haven, 2022), or *"The seller is the first one to advise, that's not right, but that's how it happens"* (A.G, 2022).

The local pesticide company I spoke with has its own extension program to advise farmers in Costa Rica and Central America targeting small and medium farmers, teaching them IPM practices: *"So you tell me it seems kind of obvious, but it's not it is not so if you're applying an agrochemical in Guanacaste*

and you have all the equipment, and it's a 38 degrees it's almost hell to be in one of those suits. You know, so people tend to take them off. It's just too hot" (Local pesticide company, 2022). However, this program does not advise pineapple farmers as they say that they are not specialized in pineapple, but they currently have research projects underway for new herbicides and nematicides for the pineapple sector.

In 2006 CANAPEP created the Socio-Environmental Commission of Pineapple (COSAP), an organ to strengthen, regulate and support pineapple producers (CANAPEP 2022d). COSAP comprises producers, exporters, and different ministries such as the MAG and the Ministry of Environment and collaborates with public universities. Since 2018 CANAPEP/COSAP has promoted the use of a Technical Manual for Sustainable Pineapple Production, which guides producers to use environmentally friendly processes in five areas: Environmental Control, Social Responsibility, Occupational Health, Personnel Training, and Operational Control (CANAPEP 2022a). Despite being in contact with Canapep for several months, I was, unfortunately, unable to speak to them. However, only one interviewee mentioned COSAP; hence, I assume they play a minor role in advising pineapple farmers.

7.1.2 Role of public extension services

According to my interviewees, the government does not have an essential role in advising pineapple farmers. When I asked D.H where farmers would get advisory services from, his answer was simply: *"Not from the government" a*nd further: *"The government, the extension is department in the country is a mess. I'm so sorry for that"* (D.H, 2022). However, when I asked him if he wished that the government would do more, he denied arguing that the bureaucracy of the government was just too complicated: "*No, not really. I mean … And of course, everyone wants a piece of advice, right, but the bureaucracy involved with the government, I think, is too much that I don't think it would really make a difference, yes"* (D.H, 2022). Another interviewee said: *"The government do not give any help to the growers here. They do not do what they have to do"* (Chamber of R&D manufacturers, 2022). Even though farm visits are taking place by people from the MAG, their role is more perceived as controlling the farmers instead of providing any advisory service: *"Yes, they are just they're going to visit just saying what, what kind of herbicide are you using? Ametryna and Diuron. OK, good, see you"* (D.H, 2022). "*They visit the farms looking for problems or checking, but do not make any contribution, and visits are once a year" (Pineapple Haven, 2022).*

J.V, as well as the CNAA, claim that the government lacks resources to do proper research, which would allow a technological transfer to the producers. According to the pesticide company I spoke with, the small amount of taxes they pay (since they are mostly exempt from taxes) would be earmarked for educational purposes, but apparently, the money is not used for that purpose: *"Do they spend on education? No"* (Local pesticide company, 2022). However, according to A.G, younger people are replacing older agronomists in governmental bodies, leading to more innovative approaches. Furthermore, he says the state has participated punctually in advisory services. For example, when the MRL for carbaryl, an active ingredient, was lowered, it could no longer be used. In this situation, the state saw an urgency to ask Del Monte to share its technology to control that pest with alternatives to carbaryl.

The SFE offers an annual training program on Good Practices to teach farmers how to apply agrochemicals correctly. However, when I asked the SFE where producers could obtain information about alternatives to agrochemicals, my interviewee strongly avoided the answer, arguing they are not

in a position to tell the farmers which products to use without having scientific studies, on which they could base recommendations: "*we have no studies in that sense $ in Costa Rica there is still no study that indicates that this product substitutes this other one, it does not exist ... so it would be irresponsible for any of us to tell a producer, stop using this one and use this other one when we cannot show you a study"* (SFE, 2022). Only one producer and one chamber positively referred to the SFE, claiming they work closely to review pest issues and fly management and help facilitate the pineapple export process to Israel (Island Breeze Pineapples, 2022, Asoagro, 2022).
Furthermore, my interviewee referred to the MAG that offers extension services to producers, but since they never responded to my interview request despite being contacted several times, I could not personally evaluate their role. However, my findings from the interviews are in line with the literature on Costa Rican extension services, which suggests that the government only plays a minor role in advising farmers (see Thrupp 1988, (Dirección de Estudios Económicos 2011; Galt 2008a; Montiel 2015; Thrupp 1988; Vargas 2021).

7.2 Organic certifications

To understand the role of organic pineapple production as an alternative to conventional production, I included a question on organic pineapple farming in my interview guide. Only 1.5% of exported fresh pineapple from Costa Rica is organic (Fresh Plaza 2022). Although several interviewees confirmed that demand for organic pineapple is increasing, production remains a niche market, according to CNAA. The Chamber of R&D manufacturers and Procomer see a small but good market in organic pineapple that pays better prices than the conventional market, and an increasing demand for organic pineapple from Europe is reflected in companies seeking organic certifications. Sunny Delight Pineapples exports organic pineapple and claims an increasing interest in it, but purchases are not increasing due to the price markup. In general, producers flagged the high production costs compared to the comparatively low-price surplus they would get. According to Sunny Delight Pineapples, the price markup and the additional costs for producing organic pineapple lay between 30% to 40% and are balanced, but it entails a higher productive risk as organic pest control is less efficient.

Some producers claimed they would be willing to produce more organic if the market paid a higher price. Here again, producers stress pest pressure to justify their dependency on agrochemicals. D.H told me that organic certifications for Europe and the United States have different requirements, complicating production. Furthermore, it is not easy to meet customers' expectations, as they expect organic pineapple to have the same size and visual appearance as conventionally produced pineapple. The agronomist of Golden Pineapple Farms used to produce organic pineapple himself between 2005 and 2014 but had to give up their operations because of price fluctuations which were also caused because of mislabeled fruits that were sold as organic, which pushed prices down: *"I feel like there is people cheating. Or I I knew at the time that there was people cheating. And they would, were willing to offer at lower price" (Golden Pineapple Farms, 2022).*

7.3 Surface water residues and maximum residue limits (MRLs)

Pesticide regulations of industrialized countries create "regulatory risk", forcing Costa Rican exporters to avoid pesticide residues. In 2007, Galt described how exporters in Northern Cartago and the Ujarrás Valley took pesticide residue transgressions seriously since the cost of violations corresponds to the loss of a shipment worth $10,000 or more (Galt 2007). According to D.H, the consciousness about the potential damages of misuse of agrochemicals has significantly risen over the last years thanks to MRLs.

According to a local pesticide company, mainly small producers producing for the local market come up with residues. This observation is in line with Ryan Galt's one that especially goods produced for the local market come up with residues, as there is less economic and institutional pressure here compared to the export market. However, the fact that pineapple and other export crops do not exceed the maximum allowed residues was repeatedly used to justify a responsible use of agrochemicals: "*Pineapples have 0 residues when you eat them, that means that the chemicals must have been applied correctly. If they would not be applied correctly then there will be residues, kind of logic"* (Local pesticide company, 2022).

Regarding the criticism of residues of agrochemicals, several of my interviewees downplayed that limits for residues in waterbodies are regularly exceeded and claimed that the values were set too low: "*When in fact, for example, what is being counted as limits, right? First of all, the first point, let's say, is that the limits we have for, for the, for example, the water issue is a limit that is quite, almost impossible to comply with, let's put it that way, right?"* (Asoagro, 2022). Another interview partner countered that residues were not a health concern and that the media were playing up the situation: "*Obviously when you say I found an agrochemical in water, how can you explain that to the all the population that yes it can be there and you can drink that. Because it's a very small part. You can found gasoline in that water, you can find a lot of things in that water, and you still can drink it because they, the LMRs"* (Chamber of R&D manufacturers, 2022). The MRLs are also used to justify the use of controversial pesticides which are banned in Europe: "*Because we have had no reason to cancel them, in fact, Costa Rica exports a lot of pineapple to Europe and if Paraquat is applied here we have never had any return for residues, so why are we going to ban it?"* (SFE, 2022).

7.4 Certifications from importing countries

Furthermore, besides the MRL, certifications play the most crucial role in the choice of pesticides. Not only international public interventions but also the market itself demands a more careful use and handling of pesticides, which led companies to rationalize pest control (Galt 2007; Jansen 2017a). According to Procomer, companies try to align their strategy to what their clients are asking, which is, in many cases, a reduction in the use of agrochemicals. Golden Pineapple Farms, for example, manages some fields differently to meet the specific needs of various markets. As can be seen in Table 2, all producers have different certifications. The most common ones are Global GAP and Rainforest Alliance, both restricting certain pesticides and promoting IPM practices. Some producers see the requirements from importing countries as regulatory risks, as they could potentially prohibit the agrochemicals they use. Nonetheless, different interviewees told me that they can always find alternatives: "*Everything is important until the product is prohibited because you have to say, well I, I need to do my best for trying to find another option $ or what to do"* (D.H, 2022) and *"there will always be alternatives, there are always alternatives"* (Tropic Delights, 2022).

8 Discussion

This thesis investigated the relevance of socioeconomic factors influencing herbicide use in Costa Rican pineapple production. The results will be discussed along the three sub-questions: **a) Which herbicides and alternatives to chemical weed control do pineapple farmers use?, b) How do pineapple producers deal with current challenges affecting the supply and use of herbicides in pineapple production?, c) What is the role of private standards and advisory services on herbicide use?** This Chapter discusses the findings and draws a link between the results and the theoretical framework. In addition, the significance of the results for the study and beyond is discussed.

8.1 Weed control methods in Costa Rican pineapple plantations

Controlling weeds is essential in pineapple cultivation, erasing all weeds that could compete with the plant for light, water, and nutrients. Therefore, the pineapple plant is planted in completely bare soil. However, not only is the presence of weeds considered a problem, but perhaps even more importantly, the remains after harvest of the pineapple plant itself are undesirable. Argüelles and March (2022) describe the relationship between weeds and industrialized agriculture as follows: On the one hand, weed resistance allows agrochemical players to control agriculture through the demand of industrial agriculture for instruments to control weeds, such as herbicides. On the other hand, weeds resisted the biological homogeneity in agriculture sought by agrochemical actors. In other words, undesirable plants continue to grow, and new products and technologies must be developed to control them as they continue to cause economic losses and environmental problems.

The most commonly used herbicides in pineapple plantations are Ametryn and Diuron. When considering the whole technological package, the chemical load of herbicides to control undesired plants play a relatively minor role as they are only used during the land preparation and the first months after sowing. However, the leverage for herbicide reduction is greatest for postharvest herbicides for two reasons; on the one hand, these herbicides account for the largest share of herbicides used in pineapple cultivation, and on the other hand, promising mechanical and biological alternatives such as the shredding of crop waste and microorganism exist. Nonetheless, the price and efficiency (microorganisms need longer to decompose the material) are still barriers preventing producers from using them. Research on these alternatives and financial incentives in the form of direct payments for their use could provide an additional incentive to compensate for the financial losses resulting from the longer processing time.

Few organic alternatives exist to date, and, in many cases, the only way to replace herbicides is by using manual weeding techniques. The findings regarding the use of manual weeding techniques are in line with the literature on the Herbicide Revolution; the availability of low-cost herbicides compared to high labor costs makes the use of manual weeding techniques rather unattractive for most growers. However, the ecotoxicology and hazards of the most frequently used herbicides, such as Ametryn and Diuron, make their use questionable and the search for alternatives necessary. The technological package for pineapple has not changed much over the past 20 years. Not only did PINDECO introduce a well-defined technological package at the beginning of the 2000s, but due to the issues in the registration process, the number of pesticide alternatives in general and herbicide alternatives more specifically is limited.

Despite the divided opinions on the use of mulch plastic, I argue that it is a promising method to reduce the dependency on herbicides. The problem of plastic waste and pollution could be circumvented using soil-biodegradable plastic mulches and appropriate recycling methods (Madrid et al. 2022). Furthermore, the relevance of precision farming is likely to increase further. The R&D sector is promoting their adaption through research, investing in technologies, and collaborating with farm machinery companies (Fox 2018), while larger pineapple companies are already applying it. Hence, current trends indicate that it has the potential to reduce both pesticide use and production costs and is, therefore, of interest in uncertain economic times (Quirós-Ramírez et al. 2022). However, the high acquisition costs will likely be an entry hurdle, especially for smaller producers. Quirós-Ramírez et al. (2022) argue that it is important for Costa Rica that farmers recognize the benefits of precision farming and that public policies should influence perceptions of the usability and performance of new devices such as drones or smart irrigation systems. Regarding its use in pineapple, they also argue that the technology has to be further calibrated to the crop's specific needs, such as water requirements or diseases.

A barrier to adopting alternatives to herbicides is the resistance to change. Different interviewees mentioned that risk aversion is a problem in adopting changes in the technological package, mainly among older agronomists. It will therefore be interesting to see how this risk aversion will change with a new generation of young agronomists. Furthermore, the attitude towards agrochemicals is still rather uncritical, and the opinion that their use is indispensable is widespread. It often seemed to me that awareness of the hazards of agrochemicals is somewhat limited or downplayed. This is, for example, reflected in the argument that not pesticides per se are problematic but their incorrect application. Improper use of pesticides is undoubtedly problematic, but this argument downplays the general hazardousness of agrochemicals and the differences between their level of toxicity. Another example is that compliance with MRLs is used to justify a responsible use of agrochemicals, although the compliance says nothing about environmental residues, such as surface water residues. I see the missing awareness of the hazards of agrochemicals as a major obstacle to adopting alternative weeding practices.

8.2 Current challenges affecting the supply and use of herbicides in pineapple production

Supply chain disruptions

Covid-19 has been a significant factor in driving supply disruptions that highlight the inherent dependencies and the vulnerability of international trade chains that make the global food system subject to many interdependencies between countries. Restrictions on the movement of people and goods have significantly strained local, regional, and global supply chains and tested the resilience of food systems (van der Ploeg 2020). Supply disruptions and price increases for the technological package have been challenges for pineapple producers since the outbreak of the Covid-19 pandemic. The Russian invasion of Ukraine further exacerbated these challenges. Factory shutdowns decreased the produced amount of agrochemicals, while container shortages raised freight costs, leading to a significant price increase for essential agrochemicals. Furthermore, export bans from the Chinese government further intensified the shortage and exemplified the interdependency of the global food system.

Even though herbicides are less affected, producers sometimes had to find alternatives to substitute them, and the substitution did not always work very well. Some producers used more manual weeding techniques, which increased their costs, or incorporated biological pesticides. Other producers had to switch to crops or agricultural activities less intensively dependent on agrochemicals, such as yucca or cattle farming. This development is interesting, as a shift in the opposite direction (from traditional crops to pineapple) took place from the 80s onwards thanks to state incentives, which made pineapple more profitable than other crops. However, this shift exemplifies how much the profitability of pineapple is dependent on access to cheap agrochemicals and state incentives such as tax reductions. According to a newspaper article from February 2023, shortages of fertilizers are reflected in smaller yields, which led to tight pineapple supplies (Fresh Plaza 2023).

Supply chain issues have to a certain extent, fostered the use of alternatives to agrochemicals when specific inputs were unavailable, or their prices increased. Supply chain disruptions thus had the potential to reduce dependence on herbicides by forcing producers to seek alternatives. For example, those producers who switched to organic pesticides and invested in infrastructure to produce them themselves will certainly have a sustainable change in their technological package in the long term. However, as market prices for agrochemicals slowly stabilize again, it can be assumed that many producers will resort to using herbicides, making herbicides the predominant instrument in controlling weeds. The fact that substituting herbicides with manual labor is more costly reflects the dependency of the pineapple industry on agrochemical inputs. These findings are very much in line with the literature on the Herbicide Revolution, as the principal reason for the high dependency on herbicides is the availability of low-cost herbicides which substitute manual weeding practices. Hence, as long as herbicides are so much cheaper than alternatives, switching to a more sustainable technological package may be difficult to achieve.

Regarding the timeframe, not all actors were and are affected to the same extent, which could be related to differences in the supply route, with price increases being passed on to producers faster or slower, depending on the trader and their purchase quantity. Where possible, producers did switch to other vendors. Even though I didn't speak to small producers, they seem to be most affected, according to my interviewees. Firstly, most of them lack the financial capital to absorb higher input prices, and secondly, small purchase quantities give them little bargaining power and make them less of a priority for agrochemical companies. Consequently, some, mainly small producers, would use fewer inputs, resulting in lower output quality and yields. The lower output quality is especially problematic due to Western retailers' aesthetical and quality standards, which reject norm deviations.

Supply chain disruptions might exacerbate unequal power relations between small and large firms. As Smith (1984) claims, geographical differentiation occurs through capital, which is reflected in the extent to which producers are affected by supply chain disruptions. In this case, supply chains contribute to the ongoing shaping of uneven development as production networks are being restructured through the consequences of supply chain disruptions (Werner 2022). Agrochemicals can become active agents that contribute to market success as well as put this success in danger which is for pineapple producers reflected in the dependency on the availability of agrochemicals. Pineapple farmers are struggling as their yields decreased due to bad weather conditions, but prices have not increased to cover higher input costs (FAO 2023b). The fact that the cost increase for producers has not yet been fully passed on to the customers can be interpreted in a way that Costa Rica is shouldering the economic consequences of the Global North's demand for cheap agricultural commodities.

Furthermore, out-grower schemes (linking smallholder farmers with domestic and international buyers), which Werner (2022) describes, can also be observed in Costa Rican pineapple industry. Most export companies buy fruits from small producers in addition to their production. This allows them to outsource parts of the production risk while sustaining control through supply chain governance.

Registration process

Costa Rica's registration process for agrochemicals reflects the country's inconsistency between environmental protection and its plantation culture: *"Despite Costa Rica's environmental image, an anti-pesticide view did not play any role in this whole discussion. The hegemonic view was that environmental and health concerns could be addressed with proper risk regulation, not by banning pesticide use"* (Jansen 2017b:13). Castro-Vargas & Werner (2022) argue that the registration process is a manifestation of tensions in the context of the country's strained green development model. While Costa Rica maintains its reputation as a leader in sustainable development, it faces a profound contradiction between environmental protection and capital accumulation. The regulatory dispute calls into question the environmental policy in the country.

The pineapple industry uses the registration process to justify its dependency on the intensive use of older-generation pesticides. Some argue that the problems in the registration process prevent them from producing in a more environmentally friendly way. The reasons for the issues with the registration process are many and complex, and further analysis would go beyond the scope of my master's thesis. However, the most important drivers of the issues in the registration process I identified were the interest conflict between various actors, such as the three Ministries, the ecologista movement, and the business conflict between R&D and generic companies. Furthermore, politicians' tendency to think in election cycles leads to a preference for short-term returns over longer-term interests. Consequently, some politicians might be more interested in addressing popular concerns instead of dealing with conflicting interest parties in the registration process.

The fact that Costa Rica depends on risk data from abroad and countries of the Global North generally don't have an interest in testing their molecules for use in pineapple reflects a further imbalance within the pesticide industry and hence evidence for the existence of uneven geographies: While the global North benefits from cheap food imports, there is little incentive to provide risk assessments for crops outside of Europe, which are not perceived as economically important. Furthermore, risk assessments in tropical countries, which consider these places' climatic and geographic conditions, are largely inexistent (Brown et al. 2020).

The issues in the registration process hence force producers to use old-generation herbicides. The latter also poses a risk for producers regarding certifications and residue regulation from the importing countries. When importing countries restrict the use of old ban specific molecules for imported products, it could become difficult for Costa Rican producers to find alternatives. Furthermore, there is also an economic disadvantage in not being able to use newer molecules, as some of them would, according to my interviewees, allow them to produce cheaper.

According to Castro-Vargas and Werner (2022), the current registration process is from an ecological as well as from a social perspective detrimental: *"The bulk of registrations in Costa Rica today exist in a state of administrative ambiguity that remains unclear even for those responsible for managing the process"* (Castro-Vargas and Werner 2022:16). The dependency on old molecules, leads to

accumulation of residues which creates health risks as well as ecological damage, which the rural population must bear. Hence, there is an uneven development on two scales: within the country (rural population vs. urban population) and on an international level (Costa Rica as a pineapple producer vs. importing countries).

Environmental and economic challenges

The pest pressure in a tropical country is higher than in countries with temperate or mediterranean climates. However, pest pressure is used to legitimize the pesticide intensity in Costa Rican agriculture. Castro-Vargas and Werner (2023) describe monocultures as fragile agroecosystems whose homogenization and the relocation of plants to other habitats explain their vulnerability to disease, pests, and climatic pressure. The current intensive production method combined with the effects of climate change, which make extraordinary weather events such as heavy rainfall more probable and the pest pressure of a tropical country, is reflected in a high dependency on agrochemicals. In 2022, for example, bad weather conditions affected the pineapple supply from Costa Rica (FAO 2023b). The challenges of year-round demand for pineapple further exemplify how alienated the production realities are for the other end of the world; pineapple production does not follow the climatic conditions but the demand of the consumer countries. Considering that only the introduction of the MD2 enabled an expansion of the agricultural frontier through technology and intensive use of agrochemicals (León 2022), it can be questioned how suitable the current production sites are for pineapple cultivation in monocultures.

The decomposition of the post-harvest foliage exemplifies intensive production methods. Especially during the rainy season, drying herbicides such as Paraquat are used after the harvest. Although there are alternatives, such as microbiological degradation, its use is limited because it requires more time than post-harvest herbicides, and most farmers want to reseed as soon as possible. As León (2022) argues, the fly *Stomoxys calcitrans* can also facilitate the expansion of pineapple, as its presence repeatedly ruined nearby cattle farmers and forced them to sell their land to pineapple producers. The enormous amount of pesticides used in crop production drifts into nearby communities, contaminating homes and fields and making any other agricultural activity almost unviable. In addition, heavy machinery destroys the gravel and dirt roads they share with neighboring communities, making them unusable during the rainy season. Thus, climate and environmental conditions simultaneously challenge pineapple production and encourage expansion.

Some of my interviewees seem to be aware of the problems related to the dependency and the over- & illegal use of some agrochemicals. Although this assumption is only based on the statement of a single producer, the repeated detection of Bromacil after its banning in waterbodies suggests that this herbicide is still being used illegally. According to my interviewee from Sunburst Pineapple Co., the plantation he works for still had large quantities of Bromacil in storage when the ban came into force. This might indicate that large producers can buy and store great quantities of agrochemicals due to long-term supply contracts.

However, producers repeatedly picture themselves as victims of a one-sided media debate and defend the use of agrochemicals with the economic relevance of the pineapple industry as an employer. Hence, sometimes it seemed to me that if they didn't have any good reasons left to counter environmental critique linked to pineapple production, they would resort to incoherent arguments to protect the pineapple industry.

The environmental critique the pineapple sector faces can be interpreted as a response to uneven geographies. Rural communities that are affected by pollution from pineapple plantations and are bearing the undesirable outcomes of the pineapple industry raise their voices against multinationals or Costa Rican companies with headquarters in the urban zones. Hence, the pineapple sector is contributing to a fragmented landscape, as described by León (2022), with the rural areas being affected by the negative externalities of pineapple production whereby they do not benefit or profit only very little from the economic value, while the headquarters of these companies (based in the capital city or abroad) benefit from the turnover. The market concentration which is taking place in the pineapple sector can further intensify this type of uneven development as a larger share of the turnover flows away from the producer regions to the headquarters of large companies.

There are a variety of indicators that reflect the unequal distribution of negative externalities of the pineapple industry between rural and urban populations. For instance, between 2010-2020, San Carlos, located in the principal pineapple cultivation area, was the canton with the highest mortality rate due to agrochemical poisoning (Martinez 2022). Furthermore, the effects of climate change can further exacerbate unevenness, given the disproportionate vulnerability of the global south (Landrigan 2021). Hence, agriculture in Costa Rica might be more affected by climate change than in Europe and the United States, which are the main customers of Costa Rican pineapple. The overuse of herbicides is furthermore emblematic of the Herbicide Revolution. Thanks to the availability of low-cost, generic Asian suppliers, the availability of herbicides has highly increased, and therefore, the efficient use of inputs has lost its relevance from an economic perspective. Aesthetic requirements producers are facing can be seen as a direct consequence of the Supermarket Revolution, and its link to the use of agrochemicals to meet these quality requirements were already described by Thrupp (1991) in banana plantations in Costa Rica. The link between a lack of public extension services and the overuse of herbicides is discussed below.

The environmental and economic challenges are partly in conflict with each other but reinforce the challenges of the pineapple industry. For example, the postharvest foliage is seen as a problem from both an economic and an environmental perspective, as it attracts the fly on the one hand and has to be cleared as soon as possible to replant the land. However, if the organic material is dried using a desiccant herbicide such as Paraquat, which can make the land permanently infertile, this can be problematic not only from an environmental point of view but also from an economic one. Organic farming could potentially reduce pesticide use and be an economical alternative due to growing demand. However, even though organic farming methods make efforts to reduce intensive pesticide use, an issue is that many organic producers still produce in monocropping systems, which leads to erosion and biodiversity loss (Brown et al. 2020).

8.3 The role of private standards and extension services on herbicide use

Different instruments from the private and public sectors influence herbicide use. Generally, it can be said that the government plays a relatively weak role in providing incentives to reduce the use of agrochemicals in the pineapple sector.

Extension services

According to my interviewees, governmental extension services are almost inexistent for Costa Rican pineapple producers, and technological transfer is taking place through private extension services. While larger producers tend to have their R&D departments and are hence not dependent on external advisory services, smaller producers often have no choice but to use the services of the pesticide companies. The role of independent private consultants is minor in Costa Rica.

During the interviews, I noticed that many of my interviewees openly criticized the fact that the government does not provide (sufficient) public extension services and that they felt neglected by the government. Annual visits by the SFE serve to review residuals rather than taking an advisory role. The lack of an advisory role was further brought to my attention during the interview with the SFE, where I didn't get an answer about where farmers can get information on alternatives to agrochemicals. The absence of public extension services is especially disadvantaging for small producers. Hence, it can be said that the lack of extension services is a continuation of the structural adjustments that have taken place in Costa Rica since the 1980s, resulting in negligence of support for small producers. These findings about the inexistence of extension services are in line with the literature and earlier research about extension services in Costa Rica. Due to the virtual non-existence of state extension services, farmers highly depend on advisory services from pesticide companies. Even though Aga (2018) claims that this type of advisory service rarely satisfies farmers, they don't see any alternative source of advice and feel constrained by their dependence on the retailer for subsequent purchases of inputs. This conflicts with the government's promises for further regulation, as the state hands over a crucial part of its control and influence to private actors.

Aga (2019) describes how private extension services benefit from the legacy of public extension by recruiting graduates from public agricultural universities. This also holds for Costa Rica, as all five public universities offer programs in agricultural sciences, using tax revenues to finance the training of professionals. Since the state indirectly trains these people, it would have a great leverage effect on the use of pesticides if it were to employ them for providing public extension services. Given the importance of extension services for the responsible use of pesticides, the absence of public extension services is detrimental for a sector highly dependent on agrochemicals. The dependency on advisory services is further increased by the uncertainty climate change brings: Increased extreme weather events and changes in temperature or rainfall, worse increasingly aggressive pests, and fungal complexes (see also Aga 2018, 2019). Hence, more research is needed in this area, but it is questionable to what extent it will be provided by the private sector, and therefore, the public sector must take over this task. Extension services could also address the problem of under- or overuse of agrochemicals, affecting surrounding communities and leading to pest resistance, fostering stronger compounds and hence tying producers into a vicious cycle of pesticide dependency.

The role of private and public regulation

Despite the 2017 established state-led committee for strengthening responsible pineapple production, most interviewees did not know about the initiative or did not assert it importance. The fact that this

committee plays only a minor role for the MAG is also evident from the fact that no information about the program can be found on its website. The mismatch between promises by the state to do something about the negative externalities of pineapple cultivation without delivering on them can be seen as emblematic of the tension between conservation and development. While the state presents itself as a green republic and is committed in some areas, it continues to promote policies that primarily serve the interests of large companies. Hence, the private sector currently has a more important role in reducing pesticide use through residue limits from importing countries and market mechanisms such as certifications. As MRLs define maximum levels of pesticide residues in the end products, they can reduce the use of pesticides shortly before the harvest, which is desirable from a health perspective. However, given that herbicides in pineapple are mainly used during the land preparation process, it is not surprising that herbicide residues within the fruits are not an issue for pineapple producers.

Pesticide residue limits are regularly transgressed in waterbodies, indicating pesticide overuse is an issue. During my visits to pineapple farmers, I noticed that it is pretty common for rivers to flow through plantations. Although there are buffer zones between the pineapple fields and the rivers, the fact that the pineapple fields are drained and the water flows directly into the rivers suggests that pesticides leak into waterbodies. This assumption is supported by various studies that found pesticide residues in waterbodies (see also Cuadrado-Quesada 2020; Montiel 2015; Sánchez 2019). A study from 2012 found that different pesticide residues from pineapple production were frequently detected in water samples collected across the Jiménez River watershed, among them Ametryn, Bromacil, and Diuron (Echeverría-Sáenz et al. 2012). One agronomist who took me to the field stated that he did not see a problem because the MRLs were not exceeded (Tropic Delights). I see an interesting point here in the different argumentation lines. On the one hand, the MRLs are used to justify moderate pesticide use, but at the same time, residues in waterbodies are downplayed, and the relevance of residues in the environment is questioned. I argue that this argumentation line reflects the existence of uneven geographies; While the global North has rationalized the use of pesticides by monitoring pesticide residues in food imports, residues continue to occur in the environment of the producer country. Although the circle of poison theory might be obsolete, it still serves to explain why pesticides that are banned or restricted in western countries still occur in the global south due to weak regulations and enforcement mechanisms.

Furthermore, certifications from importing countries such as Rainforest Alliance or GlobalGAP are crucial incentives in reducing the use of pesticides to get access to markets. All of the producers I spoke with have several certifications, and some manage fields within their acreage differently to comply with multiple certifications, giving them access to different markets.

The concept of place attachments which describes a personal identification with the region where a producer works, may also play an underestimated role. Smaller producers, unlike large international companies, often have a connection to the place of production because they have grown up in the region, and their families have been farming in the area for generations. For example, one producer told me that he found the responsible use of pesticides essential because he grew up in the region and wanted to preserve the land for his children. Hiring local people with place attachment could hence be a way to support sustainable production systems.
Furthermore, an agronomist told me that genetic modification of pineapple could be a solution to reduce the dependency on agrochemicals. However, in Costa Rica, a genetic modification that targets the tolerance of agrochemicals is practically prohibited (A.G, 2022). Given the current legislation and

the controversies about genetically modified organisms, I argue that its use is not a helpful instrument but might become relevant in the future.

Future of pineapple production

It is difficult to predict the future of pineapple production and its use of herbicides, as many factors affect the industry. Producers are concerned about the future because they feel pressured, mainly for market reasons. Many producers face their future with some apprehension, mainly due to the mentioned challenges. Some claimed they felt pressured to meet many different demands simultaneously, such as producing more sustainable but cheaper while being denied new pesticides due to the issues with the registration process. Furthermore, they see the market concentration process continuing to intensify, making the future for smaller producers even more difficult. There is tremendous pressure to reduce production costs to remain competitive with low-wage countries like the Philippines.

Without regulation, this pressure is likely to intensify the use of agrochemicals further while forcing smaller producers out of the market: *"I see it every day. I think yeah, it is more demanding on the farmer on, on everything, social, environmental, and economical aspects. We have, we comply with very strict environmental laws in Costa Rica. We complied with strict labor laws and we also comply with all the certifications we have 13 certifications that I work with (…) So it's, it's difficult as a farmer. So even, even under those circumstances, I still love what I do. And you know? If, if you look at the big picture and the long-term perspective, I think pineapple is doing well. We have a couple bad years, and better years should be coming our way. That's how I see it. That's how it has always been. You know, every five-seven years, we have a bad year, bad prices, bad consumption, low consumption, all of that, and then it comes back up, and it stabilizes"* (Sunburst Pineapple Co., 2022).

One way to remain competitive and increase value added would be to replace parts of the fresh pineapple that is exported with processed products as some companies are already doing: "*Partly due to the Covid crisis, more and more growers in Costa Rica are instead selling their volumes to the processing industry"* (Fresh Plaza 2023). The effects of the Covid-19 pandemic are still influencing the industry with increased costs for inputs, lower demand, and lower prices, while costs for fertilizer increased. Accordingly, some Costa Rican producers and exporters are now focusing on new markets such as Israel and the Middle East (FAO 2023b; Fresh Plaza 2023).

Considering the economic pressure, environmental problems, and the registration process, it is questionable whether sustainable pineapple production in its current form is possible. In my opinion, a fundamental rethinking of the production conditions is necessary. My interviewees agreed that even though precision farming is still expensive, they expect it to play an increasingly important role in the future, which could help reduce the dependency on agrochemicals. According to Procomer, less fresh pineapple will be exported and partly replaced by dried or frozen pineapple in the future. This trend was also confirmed during my visit to Tropic Delights, which is currently finishing a large cold store for frozen pineapple under the free trade zone modality and hence supported by the government through tax exemptions. Procomer sees the advantage of exporting a processed product in allowing the pineapple sector to reposition itself in the market and circumvent difficulties in exporting fresh pineapple. Furthermore, it could also open chances for small farmers to find their way into niche markets.

8.4 Theoretical and practical contributions of the study

The contributions of this master thesis hold valuable insights on both a practical and theoretical level. It shed light on the complexity of socioeconomic factors contributing to a high pesticide intensity in the pineapple sector. Although the impact of the pineapple industry on humans and the environment is hotly debated, the study attempted to make a non-judgmental analysis of the mechanisms that explain the high herbicide dependence.

For this thesis, the theory of the Herbicide Revolution was combined with the theory of uneven geographies and extension services to assess the dependency of Costa Rican pineapple plantations on herbicides. The three approaches complemented each other well and provided an analytical framework to answer the research question since they are all three helpful in contextualizing the (uneven) distribution of properties such as knowledge, power, and externalities within the pineapple industry. Given that the concept of uneven geographies and the Herbicide Revolution operate on different levels of abstraction, herbicide dependency can be seen as an outcome of the Herbicide Revolution and uneven geographies as an impact of the herbicide dependency. Herbicide dependency is an outcome that results directly from the herbicide revolution and different socioeconomic factors, while impact refers to the broader effects or changes resulting from herbicide dependency and indirectly also from the Herbicide Revolution. The benefits and costs of rapid adoption of off-patent herbicide formulations in countries of the Global South are distributed asymmetrically between the producer and consumer countries, resulting in uneven development. Even though the Herbicide Revolution also explains why regions develop unequally, it mainly serves to understand the current outcomes of herbicide adoption and the underlying processes leading to them.

The concept of uneven geographies offers a theoretical framework to contextualize the inequalities brought about by the Herbicide Revolution by highlighting how they are spatially organized and distributed across regions and communities. It proved helpful in analyzing the effects of supply chain disruptions and the role of herbicides as a driver of uneven development. The literature on extension services has complemented the two theoretic concepts by providing literature on one of the most important drivers in explaining herbicide dependency in Costa Rican pineapple production. Due to the diverse background of my interview partner and the topic's complexity, the study can be considered as a summary of the different socioeconomic aspects that drive herbicide use in pineapple production.

In summary the overarching research question - **which socioeconomic factors influence weed control among Costa Rican pineapple producers?** - can be answered as follows:
The results show that the reasons for the herbicide dependency are various and complex. The most important drivers identified in this study are weak regulation on the use of pesticides, issues in the registration process, different market and environmental challenges, and the absence of public extension services. Factors that potentially reduce the herbicide dependency are certifications, MRLs, and precision farming and potentially the effects of supply chain disruptions. The following Figure (16) represents the relationship between the theoretical concepts and the empirical data, illustrating the influence of these socioeconomic factors on herbicide dependency, while connecting them with the concepts of the Herbicide Revolution and uneven geographies.

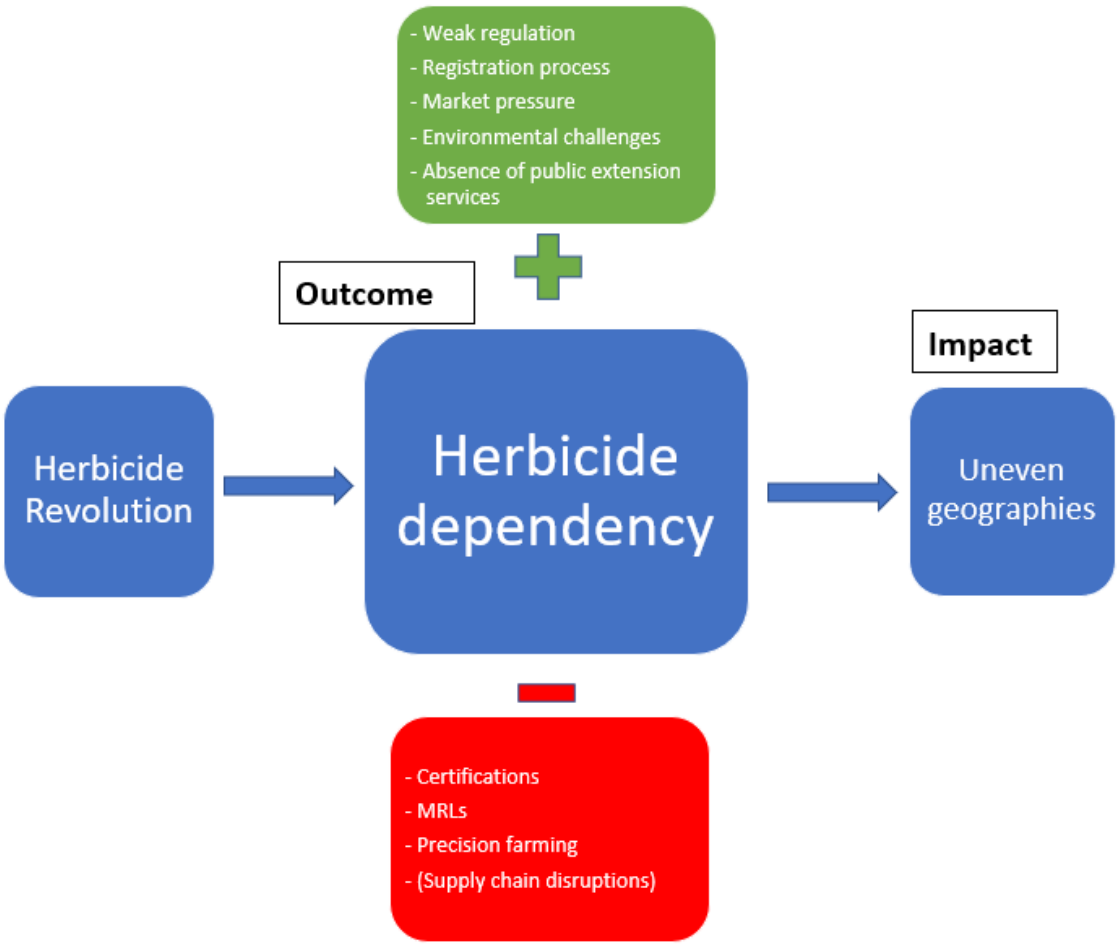

Figure 16:Theoretical framework diagram. Own work.

Furthermore, given that existing geographic research on the pineapple industry in Costa Rica has mainly focused on affected communities or peasants, this thesis took an innovative approach by including the perspective of larger producers in studying the Costa Rican pineapple sector and thereby fulfilling a knowledge gap. Concerning the concentration processes which are taking place in the pineapple sector, the importance of large-scale producers will further grow. Therefore, including their perspective is essential to understand the challenges and realities of the sector and should encourage further research to incorporate larger producers in research about pesticides in Costa Rican agriculture.

Although pesticide use in Costa Rican agriculture is controversial, I could still speak with many actors. However, the concerns about public perception are reflected in the reluctance of some actors to speak publicly about pesticide use. This is also reflected in the study of Brown et al. (2020), who were unable to speak with PINDECO, despite several attempts. At the end of the 1980s, Thrupp (1988) found a different panorama, where the banana industry shared with her their inner data and lots of documentation on pesticide use. This is interesting as it could indicate that research in the area of pesticides has become more difficult, despite its increasing importance from a scientific and societal perspective.

As one of the earlier products within the scope of the research project: *"Making herbicide markets: Interactions between production restructuring, agriculture, and environment in Latin America and*

Asia," this study hopefully serves as a starting point for further research within the project by disclosing some of the factors that explain the high dependency on herbicides and the role of regulation in Costa Rican agriculture.

Despite focusing on herbicides, the thesis often referred to general pesticide use since most socioeconomic drivers relate to the general use of agrochemicals and a clear distinction between pesticides and herbicides is, in many cases, not possible. Interviews with additional actors would be necessary to understand the underlying socioeconomic factors contributing to the high herbicide dependency in more depth. It would be interesting to focus on individual socioeconomic factors or stakeholders for further research. There are many opportunities to do in-depth research, focusing, for example, only on pineapple producers and differences between producers of different scales. The role of certifications also emphasizes the customers' role in reducing the chemical load in pineapple production. A study about the role of certifications and the demand for more sustainable production could contribute to a better understanding of the demand side's influence. Furthermore, comparing the regulation with other pineapple-producer countries would be interesting to analyze their strategies and challenges, as these could also have important implications for Costa Rican agriculture.

The potential for supply chain disruptions to lead to a long-term change in the use of herbicides will only become apparent in the future. Therefore, it would be interesting to conduct a study about the potential of supply chain disruptions to promote the use of alternatives and investigate their impact on the sustainability of pineapple farming. Furthermore, it would be interesting to analyze the supply chain's resilience for biological herbicides to see whether they are less affected by supply chain disruptions than conventional herbicides. Lastly, precision agriculture seems to have great potential for reducing the use of agrochemicals, and its relevance will further increase with the use of artificial intelligence. Therefore, this aspect should be included in future research.

9 Conclusion

This study aimed to assess which socioeconomic factors drive the high dependency on herbicides in Costa Rican pineapple plantations. It has shown that herbicide use depends on several complex factors, such as state regulation, the registration process, market-, and environmental challenges, the absence of public extension services, certifications, and MRLs. However, these factors could not be captured in all their complexity within the scope of this thesis. Instead, an attempt was made to gain insight into factors considered by the interviewees as relevant and, where possible, how they deal with challenges.

Supply chain disruptions have different effects on dynamics in the pineapple sector. On the one hand, small producers seem to be most affected, and therefore market concentration processes in the pineapple sector might further intensify and exacerbate unequal power dynamics between smaller and larger companies. On the other hand, supply chain disruptions have shown that they have the potential to stimulate changes in herbicide use because they have forced producers to use alternatives.

The study also demonstrates that even though the pineapple industry is to date still dependent on hazardous herbicides, certifications and education are having a positive impact on reducing the detrimental environmental consequences. The awareness of agrochemical pollution is becoming an increasingly important topic within the industry, and the demand for organic pineapple is increasing. Customers could contribute to a more ecological pineapple production with a higher tolerance for visual “defects” in fruit or a willingness to pay more for organic pineapple. Even though the demand for organic pineapple seems to increase, producers perceive organic production as uncertain and controversial due to various reasons such as fluctuating prices, missing alternatives to substitute banned pesticides, and different requirements across organic certifications.

In line with existing literature around the role of extension services, the thesis showed that a crucial barrier for (missing) knowledge about more environmentally friendly alternatives to traditional agrochemicals stems from lacking public extension services. Pineapple producers largely depend on advisory services from the pesticide companies they buy their inputs from. Thus, despite the increasing efforts from some producers to decrease the chemical load, it is difficult for them to make this transition to a more ecological production without the external help of independent or public advisory services. The absence of public extension services is likely to become more problematic if the consequences of climate change will drive the pest pressure even higher.

As León (2020) argued, the *“sustainable development a la tica“* suggested in the mid-1990s continues until today. Elements of sustainable development can be found in various fields. In 2022, Costa Rica was producing 98% of its electricity from renewable sources (Climate Council 2022), adding to Costa Rica’s eco-friendly agenda and presenting the country as a model of “clean“ energy (Brown et al. 2020; Ramírez 2020). In 2022 the country received 2.3 million tourists and is therefore well on its way to regaining the number of tourists it received before the pandemic (over three million in 2019) (Madriz 2023). According to the Costa Rican National Tourism agency, the country aims to develop the tourism sector further and receive 3.8 million tourists by 2027 (Madriz 2022).

However, the results indicate that pineapple production takes place in the context of uneven development. Costa Rica and the pineapple industry are winners and losers of its success. Producers are under great pressure to produce cheaply and meet customer demands while facing criticism from

environmental groups and civil society. At the same time, they benefit from loose regulations in the use of pesticides and state benefits such as tax exemptions for the export of pineapple and the import of pesticides (El Mundo 2018; International climate initiative 2022). These exemptions can be seen as a further intensification of neoliberal state policy with the agro-industry benefitting from low taxation and regulation due to fear of the government losing contributions to GDP and economic development opportunities in rural areas. This is reflected in the expansion of pineapple plantations and the continuation of structural adjustments such as the absence of public extension services. Herrera-Rodríguez (2013) argues that the uneven geographic transformation in Costa Rica requires its maintenance and expansion of unattractive places fenced off from the view of tourists, investors, and upper-class Costa Ricans. Fragmented and idealized landscape distract from the consequences of actions taken within the paradigm of neoliberal sustainable development (Herrera-Rodríguez 2013).

Consequently, the state incentivizes a continuation of environmentally harmful agriculture based on mono-crops. The positive and negative externalities of the pineapple industry are unevenly distributed on a regional and a global level. Rural areas are being affected by the negative externalities of pineapple production, while the headquarters of these companies (based in the capital city or abroad) benefit from the turnover: "*Moreover the benefits and costs of pesticide use are distributed inequitably in society, whereby the problems are borne primarily by the rural poor"* (Thrupp 1991:2).

Pineapple production clearly shows that there is no such thing as an environmentally friendly monocropping system. This is illustrated by the example that even organically produced pineapple causes erosion and biodiversity loss (Brown et al. 2020). In this context, it is questionable whether eliminating all weeds is necessary. Weeds also play a crucial role in ecosystems as they can help avoid erosion by binding the soil, can increase soil fertility, and are used to attract helpful fauna in preventing plagues (Argüelles and March 2022). In pineapple cultivation, low soil cover and steep slopes impact water loss through runoff and soil erosion, especially in the early stages (Hernández and Florentino 2004). Hence, the existence of some weeds could potentially counteract these problems and have an ecological advantage. However, this is likely to be difficult to implement in monocultures, which are dependent on homologation of the process flows.

Pineapple intensification has detrimental health and environmental consequences, such as pest resistance or water contamination. The most evident cases of this type occurred in the canton of Limón close to the Caribbean coast. As a result of this situation, some municipalities in the region attempted to declare a moratorium on the expansion of pineapple cultivation, which was rejected in the constitutional process, as the proposing municipalities did not have the technical arguments to support such a measure (Vargas 2019). Henceforth, the outcome of the trial currently underway against the three pineapple companies accused of contaminating water sources with Bromacil is of transcendent importance as it would be the first time that mono-crop companies would be held responsible for water contamination (Delgado 2023). This process is particularly interesting from an uneven development perspective, as it has the potential to at least partially compensate the population affected by water pollution and force the pineapple industry to use agrochemicals more responsibly.

Weed management will continue to be a challenge for the pineapple industry: "*Weeds and humans chase each other in a biologically intimate relationship that is ubiquitous and persistent*" (Argüelles and March 2022:57). However, if the country wants to keep its reputation as a green republic, it has to take actions in the field of consistent enforcement of environmental policies. There is a need for adequate

environmental risk assessments of pesticides and calculations of the apparent use, which differentiates between pastures and crops and investments in public extension services. Their implementation will necessarily require greater spending, which could be financed by eliminating tax exemptions for the pesticide and export mono-crop industry. *"Sustainable utilization of pesticides will ultimately be the result of a balancing of social, economic, political, and environmental factors taking into account the interests of a variety of stakeholders including both large and small scale farmers, pesticide producers, government agencies, and the citizens of Costa Rica both in their capacities as agricultural consumers and as people exercising the right to a healthy environment and a quality of life uninhibited by pesticide pollution"* (Araya et al. 2014:24,25).

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11 Annex

11.1 Interview guidelines

Example: Guide for producers

Introduction & farm organization

- Can you please introduce yourself and your role in xxx?
- What is the role of xxx in the Costa Rican pineapple market?
- How many kg of pineapples does your company produce annually and per hectare?
- How many producers work for you?
- What is the share of output (or hectares) of your own plantations compared to contracted plantations?
- What is the average production area of a farm?
- Do you produce also organic pineapple?

1. Challenges: What challenges/problems do you experience as pineapple producer?

How has pineapple production in general changed in the region? (e.g. in terms of crop varieties, modernization, use of pesticides fertilizers or genetic engineering, size of farms, household structures).

- What are the main challenges at the moment for you?
- How do you encounter these challenges?
- There is a national debate about how pesticide registration represents an important challenge for agriculture production. Some sectors have named this situation as a registration gridlock. Is this affecting your company?

2. Challenges due to the input crisis: How is your business affected by supply bottlenecks of agrochemicals?

- Are you currently or over the past 2.5 years experiencing supply shortages in important agrochemical inputs?
    - If yes, which substances are affected?
    - Herbicides: What about Ametrina, Diurón, Paraquat, Haloxyfop, Quizalofop, Cletodim?
- How do you deal with these shortages?
- Are missing inputs affecting production in any way?
- Do you see possibilities to substitute the lacking inputs chemically and/or manually (with other agrochemicals, manual weeding techniques such as ploughing fields for weed control) or by switching to other suppliers?
- Is switching to other crops an option for you?

3. Inputs in general

- What are the biggest changes in the use of agrochemicals over the last 10 years?
- How do you purchase agrochemicals? Do you have direct contracts with producers?
- Which are the herbicides you most commonly use for pineapple production (besides Ametrina, Diurón, Paraquat, Haloxyfop, Quizalofop, Cletodim?

- Since the banning of Bromacil in 2017, has this herbicide been replaced by another one? If yes, which one?
- On your website you describe how precision farming can help to reduce the use of agrochemicals. Do you have any examples?
- What role do biological fertilizers or organic pesticides play?
- Are you outsourcing some of the tasks such as spraying of herbicides?
- How do quality standards and labels influence your production methods?
- During the past decade, the generic sectors of China and India have become major players in the production of AI while some R&D companies are reducing their pesticide sales. Do you consider that this global trend is also taking place in Costa Rica?

5. Advisory services

- Where from do your farmers receive advisory services?

    - Are you working with external private extension companies?

    /or

    - have a research center specifically for the sector to help producers with technological development and technical assistance?

    /or

    - Are you working with governmental extension companies?
- Are you outsourcing some of the tasks such as spraying of herbicides?

6. Closing question

- How do you see the future for pineapple production in the region/for Costa Rica?

Conclusion
- Additions or important topic not addressed so far?
- Thanking for participation & gift

11.2 Example transcripts

1. I: No sé si usted tiene, tiene alguna pregunta antes que empiece con mis preguntas.
2. A: No, no, no … Iniciemos.
3. I: Tal vez podría contarme un poco en general, sobre … sobre su empresa … y su trabajo.
4. A: Ok … Yo trabajo para xxx, es una empresa.
5. I: Una pregunta ¿Es xxx o xxx?
6. A: xxx
7. I: Ah, ok, xxx, sí.
8. A: Sí … … …
9. I: Ah, sí, perfecto, gracias. Es porqué leí en algún lugar xxx.
10. A: Es que esa es la forma en que se pone en el correo $ que pone … digamos en el correo mío de Gerencia de Operaciones xxx $ que es Visa, xxx S-A, de hecho … xxx a muchos les llama la atención porque suena como lo de las tarjetas, ¿verdad? $ pero este nombre está compuesto por los apellidos de la familia … es xxx.
11. I: Ah, ok, lo entiendo.

12. A: Si, esto es una, una empresa familiar $ que tiene más de 33 años de fundada $ y que en los últimos tres años ha ido evolucionando para pasar a ser una empresa corporativa $ … en estos momentos tenemos aproximadamente unas 3000 hectáreas de piña $ … estamos diversificados, tenemos ganado, tenemos unas 1.500 cabezas de ganado … exportamos, producimos y exportamos piña, piña fresca, piña deshidratada y piña congelada.
13. I: Y ¿las hectáreas son solamente sus propias fincas o también tienen otros productores que producen para usted?
14. A: Ah, no, todo es de nosotros, solo que, lo que producimos es en fincas que manejamos nosotros mismos.
15. I: ¿Y cuántas fincas son en total?
16. A: En ocho las vemos como razones sociales, son tres fincas.
17. I: Tres fincas.
18. A: Tres fincas, sí.
19. I: ¿Y todas son de zona de Pital?
20. A: En la zona norte, nosotros tenemos desde … Río Cuarto, aquí que queda cerca de Pital $ hasta Los Chiles, que es en la frontera con Nicaragua.
21. I: También más en el norte.
22. A: Sí … OK, entonces tenemos el ganado, nosotros también exportamos, producimos y exportamos tubérculos, todo lo que es yuca, todo ese tipo de tubérculos, tenemos una planta para eso, de hecho, los inicios de la empresa, fue en eso, fue en tubérculos … y después se fue diversificando y, y hoy en día no es el principal, el tubérculo, sino la piña también $ también tenemos sembrado y exportamos rambután … no sé si lo conoces.
23. I: ¿Tiene un otro nombre también? no, como…
24. A: En Costa Rica le llaman mamón chino.
25. I: Sí, mamón chino, sí, es la estación en este momento, ¿no? Para...
26. A: Acaba de pasar, al menos en esta zona ya pasó, $ … pero esa producimos y exportamos también, fuera de eso, digamos, la empresa maneja todo lo que es transporte … todo lo que es maquinaria amarilla, todo lo que son dragas … … … bajots, todo ese tipo de cosas, se tiene una división que le da el servicio a las mismas empresas $ entonces tenemos un poquito de todo, un poco de todo, y es una empresa que viene creciendo, digamos, en estos momentos $ … de hecho, en estos momentos estamos en un desarrollo que, si me permites, te puedo mostrar algo $ no sé qué, no sé qué tanto tiempo tienes.

11.3 Codebook

Codesystem

- Factors that decrease pesticide use
  - Education
  - Changes in the use of agrochemicals
  - Regulation (+)
    - Maximum residue limit
    - Environmental laws
    - Influence European Union
      - Certifications
  - Sustainable pineapple production
    - Organic pineapple production
      - Perception organic
    - Protection zones pineapple
    - Initiatives for sustainable pineapple production
- Pesticide trade
  - Costa Rica as pesticide formulator
    - Export agrochemicals
    - Generic sector
  - Origin of pesticides
- Technological package
  - Biological pest controll
    - Plastic foil
    - Manual weeding techniques
  - Pesticide management and differences between scale
  - Herbicides
    - Ametryn
    - Bentazon
    - Bromcacil
    - Cletodim
    - Diuron
    - Fluazifop-P
    - Fluroxypyr
    - Glyphosate
    - Haloxyfop
    - Hexazinone
    - Metolachlor
    - Oxyfluorfen
    - Paraquat (+)
    - Quizalofob
    - Tryclopyr
- Divers
  - Conflict Pindeco Dole
  - Corruption
  - Genetic modifications
  - Subsidies
  - Future pineapple production
  - Pineapple sector as employer
  - Plantation culture/mentality
  - Agronomic features pineapple
    - Drying plant after harvesting
    - Technology/agronomist transfers to other countries
    - Soil pineapple

- Production sites
- Precision farming
- Export countries
- History of agriculture in CR
  - pineapple expansion
- zona franca
- Key quote
- Farm characteristics
  - Outsourcing tasks
  - Region
  - Farm Size
  - Produced amount
  - Certifications
  - Representation of interests
  - Own plantations/external plantations
  - Products (+)
  - Export countries
  - General characteristics
  - Organic
  - Biological pest control
- Pesticide perception
  - Study PNUD
  - Individual perception pesticides
  - Public opinion about pesticides
    - Response to critique
    - Role of medias
- Extension services
  - Extension service of producer themselves
  - Role of vendors
  - Role of government in extension service
    - Courses by the government
  - Role of private extension services
  - Role of Canapep/COSAP
- Pesticide distribution ways
  - Small producers
  - Large producers
  - Medium producers
  - Important actors
- Challenges
  - Environmental challenges
    - Disposing green material/flies
    - Environmental critique
    - Overuse of pesticides
      - Illegal use of pesticides
    - Pests
    - Climate
    - Mismanagement of soil
  - Market challenges
    - Finding new markets
    - Quality standards
    - Increased costs in general
      - Competition with other producer countries
      - credits (+)
    - Merging of companies (+)

Challenges for small producers
Drugs in export process
Agronomic challenges
Natural flowering
Nutrition
Registration process
Lack of staff
Conflict R&D/generic
Research expensive (+)
Perception registration process
Perception of government
Perception Ambientalistas
Supply shortages
transport prices (+) (+)
Carton box price increase
Missing inputs
Price increase inputs (+)
Consequences
Quality decrease in fruit
Substituting with other inputs (+)
Manual weeding techniques
Using Biological Pest control
Changing vendor
Using less inputs
Sacrificing other areas of business
Closing/reducing operations
Changing crop
No consequences
Delay in production
Pesticide Residues
Residues in water
Regulation
Role of actor
Members of actor
political role (+)
Paraphrasen

12 Statutory Declaration

I hereby declare that the submitted Thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the Thesis.

Zurich, 27.04.2023 

Date, Place Signature