



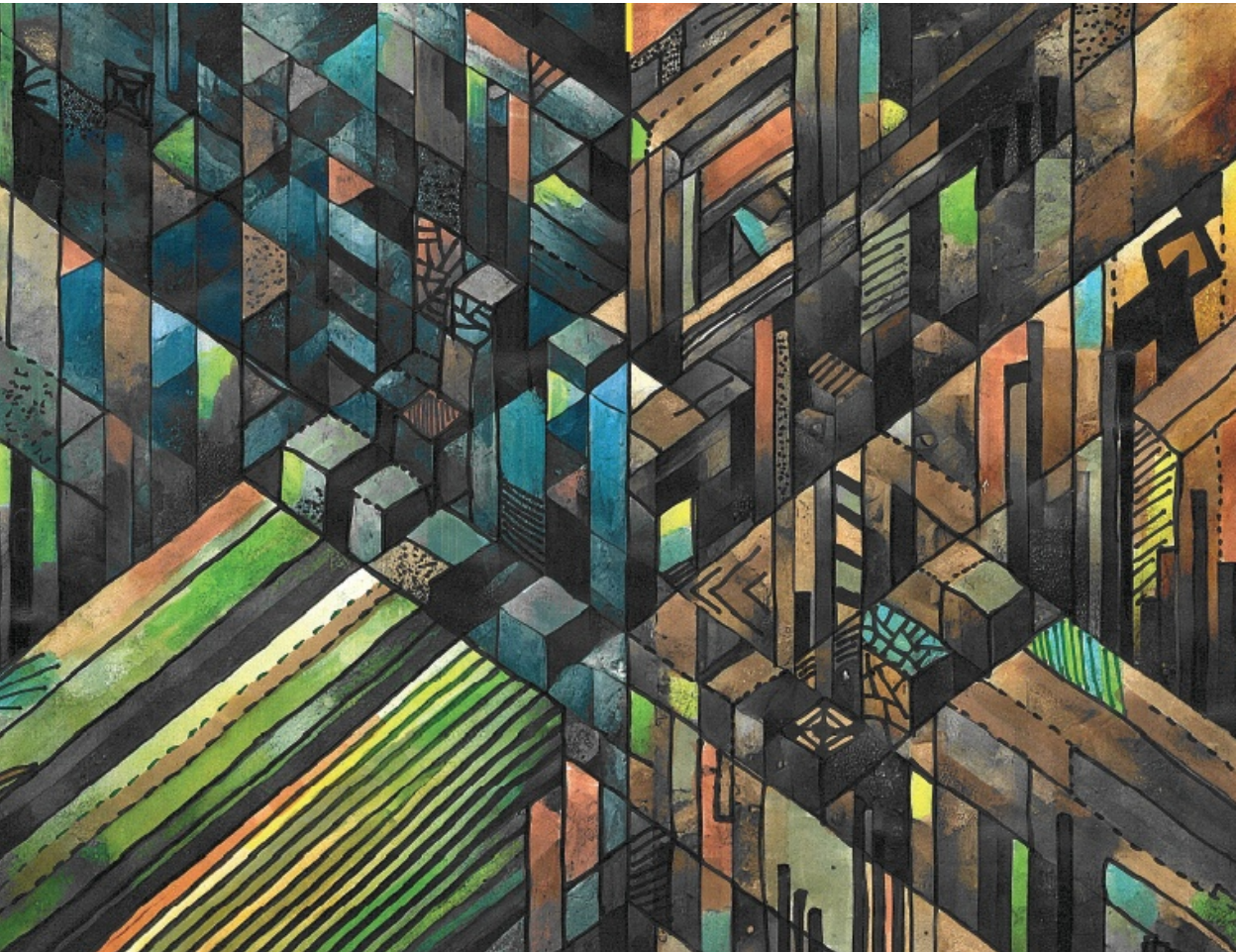
Stockholm  
University

Stockholm Studies in Economic History 75

# Productivity and Plunder

Soybean frontier expansion and soil nutrient loss in the Argentine countryside

Enrique Antonio Mejía





# Productivity and plunder

## Soybean frontier expansion and soil nutrient loss in the Argentine countryside

**Enrique Antonio Mejía**

Academic dissertation for the Degree of Doctor of Philosophy in Economic History at Stockholm University to be publicly defended on Friday 28 February 2025 at 13.00 in Hörsal 5, Hus B, Södra Huset, Universitetsvägen 10 and online via Zoom, public link is available at the department website.

### Abstract

This compilation thesis investigates how Argentina's rapid soybean expansion since the 1970s has fueled economic growth while causing significant environmental and social consequences, particularly soil nutrient loss. Existing research has overlooked critical gaps, including the under-representation of historical analyses connecting past agricultural expansion (primarily led by wheat) to current soybean dynamics, limited integration of biophysical and social analyses in understanding soil nutrient loss, insufficient comparisons of subnational differences in soybean production, and a need for more integrated interdisciplinary methods linking historical, ecological, and political-economic processes. This research combines economic history and political ecology in an interdisciplinary approach, applying key concepts such as commodity frontiers and social costs. The study employs a mixed-methods design that integrates quantitative and qualitative data. Historical analysis draws from agricultural censuses, localized agronomic studies, and production and trade databases as well as secondary sources and other grey literature to trace the development of soybean agriculture. Nutrient budget calculations for nitrogen, phosphorus, and sulfur are based on subnational agricultural production data and trade statistics. Additionally, expert interviews, primarily with agronomists, provide critical insights into contemporary regional production practices. The Pampas ecoregion is examined across all three papers, while two of them feature comparative subnational case studies of the Pampas and the Dry Chaco ecoregions, represented by Southern Córdoba and Eastern Santiago del Estero, respectively. Findings reveal stark regional differences: in the Pampas, long-established agrarian systems have supported production intensification, leading to gradual but persistent soil nutrient loss. In contrast, Eastern Santiago del Estero's rapid agricultural expansion into fragile ecosystems has caused higher levels of nutrient loss due to minimal soil management. These trends are intensified by global market pressures, particularly European demand, which has historically incentivized extractive production over sustainable practices. This study concludes that soil nutrient loss is not external to the productive process, nor is it a technical issue that can be solved through economic incentives and technological fixes. Instead, it is a structural consequence of Argentina's historical integration into global commodity markets. Moreover, it shows that while geographical variation and historical ruptures clearly exist, the structural patterns of Argentina's insertion remain dominant drivers. By linking historical legacies and global economic forces to uneven agricultural development, this research offers critical insights into the long-term social and ecological consequences of global agricultural production.

**Keywords:** *Argentina, soybean, commodity frontier, land tenure, international trade, soil nutrient loss.*

Stockholm 2025

<http://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-237118>

ISBN 978-91-8107-080-4  
ISBN 978-91-8107-081-1  
ISSN 0346-8305

**Department of Economic History and International Relations**



**Stockholm University**

Stockholm University, 106 91 Stockholm



PRODUCTIVITY AND PLUNDER

Enrique Antonio Mejía





# Productivity and Plunder

Soybean frontier expansion and soil nutrient loss in the Argentine countryside

Enrique Antonio Mejía

©Enrique Antonio Mejía, Stockholm University 2025

ISBN print 978-91-8107-080-4

ISBN PDF 978-91-8107-081-1

ISSN 0346-8305

Cover art created by Enrique Antonio Mejía using mixed-media

Printed in Sweden by Universitetservice US-AB, Stockholm 2025

## **To those yet to come**

Know that some among us sought to understand the patterns of the world we inherited, even as we stumbled through the contradictions of our own making. Forgive us for what we left undone.



# Contents

List of figures and table .....	i
List of papers .....	iii
Summary .....	v
Resumen .....	vii
Sammanfattning .....	ix
Acknowledgements .....	xi
Preface .....	xv
1. Introduction .....	1
1.1 Sojización in Argentina .....	2
1.1.1 The research problem .....	4
1.2 Research aim, questions, and design .....	6
1.2.1 Paper abstracts .....	9
1.3 Structure of the dissertation .....	11
2. Critical debates .....	13
2.1 The political economy of soybeans and the making of a botanical bastard .....	14
2.1.1 The ascendancy of soybean as a market response .....	16
2.1.2 The ascendancy of soybean as a historically-contested commodity .....	17
2.2 Agrarian history of agrofood commodity production in Argentina .....	20
2.2.1 Agrofood commodity production as an expression of comparative advantage ..	22
2.2.2 Agrofood commodity production as an expression of structural underdevelopment .....	23
2.3 Argentine soil nutrient budgets .....	26
2.3.1 Soil nutrient loss as an external and technical issue .....	27
2.3.2 Soil nutrient loss as systemic .....	28
2.4 Lacunae in the historical, regional, and structural studies of Argentine soybean agriculture and soil nutrient loss .....	30
2.4.1 Situating this dissertation .....	32
3. Systemic perspectives and analytical lenses .....	35
3.1 Towards a systemic understanding of sojización in Argentina .....	35
3.1.1 Social-ecological systems .....	37

3.2	The soybean as a lens .....	40
3.3	The historical and geographical dimensions of commodity frontiers .....	42
3.3.1	The frontier dynamics of deepening, broadening, and flexible shifting.....	45
4.	On mixed-methods and sources .....	47
4.1	Meso-scale comparative approach .....	48
4.1.1	Nutrient budget calculations .....	50
4.1.2	Expert interviews.....	51
4.1.3	Interpretative framings .....	53
4.2	Data selection and usage .....	53
5.	Key insights and contributions .....	57
5.1	Historicizing Argentine soybean frontier expansion .....	57
5.2	(Re)Conceptualizing systemic soil nutrient loss as a social cost .....	59
5.3	Subnational regional divergences and global pressures.....	60
5.4	Innovative methodologies and interdisciplinary integration .....	60
6.	Conclusions and other considerations.....	63
7.	References .....	65
8.	Supplementary material for expert interviews .....	81
8.1	Anonymized list of respondents in chronological order .....	81
8.2	Interview guide .....	81
8.2.1	Auxiliary interview questions.....	83

# List of figures and table

Figure 1: Argentine soybean area, production, yields, and exports .....	3
Figure 2: Map of Argentine soybean production areas in hectares .....	5
Figure 3. Share of global soybean production by end-use .....	15
Figure 4. Stages of the literature review .....	31
Figure 5. Status of the Planetary Boundaries. ....	39

## *Figures within individual paper manuscripts not listed*

Table 1: Summary of methods and materials used in each article .....	55
--	----



# List of papers

**Paper 1:** Five decades of soybean agriculture: Soil nitrogen exports and social costs in the Argentine Pampas, 1970–2021

**Paper 2:** Historicizing *sojización* in the Argentine countryside: Something profoundly new or old wine in new bottles?

**Paper 3:** Divergent landscapes: Exploring structural drivers of soil nutrient loss in two Argentine soybean frontiers



# Summary

This compilation thesis investigates how Argentina's rapid soybean expansion since the 1970s has fueled economic growth while causing significant environmental and social consequences, particularly soil nutrient loss. Existing research has overlooked critical gaps, including the under-representation of historical analyses connecting past agricultural expansion (primarily led by wheat) to current soybean dynamics, limited integration of biophysical and social analyses in understanding soil nutrient loss, insufficient comparisons of subnational differences in soybean production, and a need for more integrated interdisciplinary methods linking historical, ecological, and political-economic processes. This research combines economic history and political ecology in an interdisciplinary approach, applying key concepts such as commodity frontiers and social costs. The study employs a mixed-methods design that integrates quantitative and qualitative data. Historical analysis draws from agricultural censuses, localized agronomic studies, and production and trade databases as well as secondary sources and other grey literature to trace the development of soybean agriculture. Nutrient budget calculations for nitrogen, phosphorus, and sulfur are based on subnational agricultural production data and trade statistics. Additionally, expert interviews, primarily with agronomists, provide critical insights into contemporary regional production practices. The Pampas ecoregion is examined across all three papers, while two of them feature comparative subnational case studies of the Pampas and the Dry Chaco ecoregions, represented by Southern Córdoba and Eastern Santiago del Estero, respectively. Findings reveal stark regional differences: in the Pampas, long-established agrarian systems have supported production intensification, leading to gradual but persistent soil nutrient loss. In contrast, Eastern Santiago del Estero's rapid agricultural expansion into fragile ecosystems has caused higher levels of nutrient loss due to minimal soil management. These trends are intensified by global market pressures, particularly European demand, which has historically incentivized extractive production over sustainable practices. This study concludes that soil nutrient loss is not external to the productive process, nor is it a technical issue that can be solved through economic incentives and technological fixes. Instead, it is a structural consequence of Argentina's historical integration into global commodity markets. Moreover, it shows that

while geographical variation and historical ruptures clearly exist, the structural patterns of Argentina's insertion remain dominant drivers. By linking historical legacies and global economic forces to uneven agricultural development, this research offers critical insights into the long-term social and ecological consequences of global agricultural production.

# Resumen

Esta tesis de compilación investiga cómo la rápida expansión de la soja en Argentina desde la década de 1970 ha sido un fuerte factor de impulso en el crecimiento económico del país, y simultáneamente, ha generado importantes consecuencias ambientales y sociales, en especial, la pérdida de nutrientes en el suelo. La literatura existente no aborda suficientemente algunas cuestiones clave; carece de un enfoque histórico que pueda conectar el ‘boom’ de la soja la acelerada expansión agrícola (liderada por el trigo) del pasado. También hace falta estudios que presta más atención a diferencias subnacionales y a enfoques interdisciplinarios que conecten los procesos históricos, ecológicos y político-económicos, incluyendo un análisis integrado de aspectos biofísicos y sociales para una comprensión más holística del agotamiento de los nutrientes. Esta investigación combina de manera interdisciplinaria a la historia económica con la ecología política, aplicando conceptos clave como fronteras de "commodities" y costos sociales. El estudio emplea un diseño de métodos mixtos que integra datos cuantitativos y cualitativos. El análisis histórico se basa en censos agropecuarios y otros datos estadísticos además de fuentes secundarias y literatura “gris” para rastrear el desarrollo de la agricultura sojera. Los cálculos del balance de nutrientes para nitrógeno, fósforo y azufre se basan en datos regionales de producción agrícola y estadísticas comerciales, complementados con entrevistas a expertos, principalmente agrónomos, que aportan una perspectiva profunda sobre las prácticas productivas actuales en diferentes regiones. Los tres artículos analizan la ecorregión de la Pampa. Dos de ellos incluyen estudios de caso comparativos de la Pampa y del Chaco Seco, representados por el sur de Córdoba y por el este de Santiago del Estero, respectivamente. Los hallazgos revelan marcadas diferencias regionales: en la Pampa, sistemas agrarios consolidados han permitido la intensificación productiva, lo que ha provocado una pérdida gradual pero constante de nutrientes en el suelo. En contraste, la rápida expansión agrícola en el este de Santiago del Estero sobre ecosistemas frágiles ha generado una severa pérdida de nutrientes debido a la escasa gestión del suelo. Estas tendencias se ven intensificadas por las presiones del mercado internacional, especialmente la demanda europea, que incentiva una producción extractiva por encima de prácticas sostenibles. Este estudio concluye que la pér-

dida de nutrientes del suelo no es externa al proceso productivo ni un problema técnico que pueda resolverse mediante incentivos económicos o soluciones tecnológicas. Más bien, es una consecuencia estructural de la integración histórica de Argentina en los mercados globales de materias primas. Además, muestra que, aunque existen variaciones geográficas y rupturas históricas, los patrones estructurales de la inserción de Argentina siguen siendo los principales impulsores. Al vincular los legados históricos y las fuerzas económicas globales con el desarrollo agrícola desigual, esta investigación ofrece perspectivas críticas sobre las consecuencias sociales y ecológicas a largo plazo de la producción agrícola global.

# Sammanfattning

Denna sammanläggningsavhandling undersöker hur Argentinas snabba expansion av sojajordbruk sedan 1970-talet har drivit på ekonomisk tillväxt samtidigt som den har medfört betydande miljömässiga och sociala konsekvenser, särskilt när det gäller förlust av näringsämnen i jorden. Befintlig forskning har förbisett kritiska luckor, såsom bristen på historiska analyser som kopplar tidigare jordbruksexpansion (främst ledd av vete) till dagens sojaproduktion, den begränsade integrationen av biofysiska och sociala analyser för att förstå näringsförluster i jorden, otillräckliga jämförelser av subnationella skillnader i sojaproduktion samt behovet av mer integrerade tvärvetenskapliga metoder som länkar samman historiska, ekologiska och politisk-ekonomiska processer. Denna forskning kombinerar ekonomisk historia och politisk ekologi i en tvärvetenskaplig ansats och tillämpar centrala begrepp såsom ”commodity frontiers” och sociala kostnader. Studien använder en mixed-methods-design som integrerar både kvantitativa och kvalitativa data. Den historiska analysen bygger på jordbruksstatistik, lokala agronomiska studier, produktions- och handelsdatabaser samt sekundära källor och annan grå litteratur för att kartlägga utvecklingen av sojajordbruket. Näringsbudgetberäkningar för kväve, fosfor och svavel baseras på subnationella produktionsdata och handelsstatistik. Dessutom ger expertintervjuer, främst med agronomer, viktiga insikter i dagens regionala produktionsmetoder. Ekoregionen Pampas undersöks i alla tre artiklar, medan två av dem innehåller jämförande subnationella fallstudier mellan ekoregionerna Pampas och Chaco Seco, representerade av södra Córdoba respektive östra Santiago del Estero. Resultaten visar tydliga regionala skillnader: i Pampas har sedan länge etablerade jordbrukssystem möjliggjort en intensifiering av produktionen, vilket har lett till gradvis men ihållande förlust av näringsämnen i jorden. I kontrast har den snabba jordbruksexpansionen till känsliga ekosystem i östra Santiago del Estero orsakat högre nivåer av näringsförlust på grund av bristande vård av marken. Dessa trender förstärks av globala marknadskrafter, särskilt den europeiska efterfrågan som historiskt har drivit på en utvinningsbaserad produktion snarare än hållbara metoder. Studien drar slutsatsen att utarmningen av jordens näringsämnen inte är en extern faktor för produktionsprocessen, och det är heller inte en teknisk fråga som kan lösas med ekonomiska incitament och teknologiska lösningar. Snarare är det en

strukturell konsekvens av Argentinas historiska integration på globala råvarumarknader. Dessutom visar studien att även om geografiska variationer och historiska brytpunkter existerar, förblir de strukturella mönstren av Argentinas globala integration de dominerande drivkrafterna. Genom att koppla historiska arv och globala ekonomiska krafter till ojämn jordbruksutveckling ger denna forskning viktiga insikter i de långsiktiga sociala och ekologiska konsekvenserna av global jordbruksproduktion.

# Acknowledgements

**Matilda and Lisa**, to simply acknowledge the work, guidance, and motivation that you have graciously given me over these past four and half years would be a disservice. Without your support, this dissertation would have been significantly more challenging to complete, and for that, you have my deepest appreciation and respect. Additionally, **Janken**, you deserve praise for stepping in as assistant supervisor and generously donating your time, experience, and insights, ensuring that this dissertation was completed in a reasonable timeframe and fashion. Where Matilda and Janken, have pushed me to develop my knowledge and conceptual understanding of history, agronomy, and political economy, Lisa was there to foster not only my understanding of social-ecological systems, but truly *deep* ecological processes and concepts.<sup>1</sup> I could not have asked for a more insightful, patient, and thought-provoking constellation of supervisors. While the errors and limitations in this dissertation are mine alone, its successes are shared with you all. To the three of you, thank you.

**Josefin**, I am indebted to you as you have given me immeasurable support, understanding, and curiosity. Thank you for pulling me up when I fell down, for picking things up where I fell short, and for lifting us up when I fell behind. I love you dearly, and reaching this milestone would never have been possible without your efforts and sacrifices. This is for me as much as it is for you and us.

To my parents, **Kathy and Pedro**, thank you for always trusting me to go out into the world to follow my dreams. Thank you for being such great role models in various capacities and for teaching me the lessons that make me the man I am today. To my brothers, **Jason, Kyle, and Christian**, I always make the joke that neither of us are the black sheep in the family, we all are. From each of you, I have learned something and I hope that we all continue to grow and do our best to make each other proud. To my Swedish family, **the Stagges**, thank you all for so quickly accepting me as your own. You are all truly extraordinary people and I look forward to growing as a family.

---

<sup>1</sup> In reality, this is a bit of a generalization as all three are competent interdisciplinary researchers and these distinctions may not have always been so clear cut.

At my second home these past few years, the Department of Economic History and International Relations, I thank **Rodney** for not only providing critical and helpful feedback in his capacity as a greenlight reader for this dissertation, but just generally as a colleague and fellow human who has always made me feel competent and worthy of my position. All of my respect and gratitude to the PhD candidates that have come and gone during my time at the department. Every one of you deserves praise, especially those that dedicated their valuable time and energy to represent us in the PhD Council. Thank you, **Jorge**, for always being someone I could talk to and practice my Spanish with. I want to thank **Li, Daniel, Olov, Gustav, Yeonju, Pontus, Anthony, and Therese** for always swinging by my office and checking in on me. But again, the entire PhD cohort made this journey all the better. I thank **Johan and Lisa** for their support over the years and for fruitful dialogue during my PhD performance reviews. Thank you, **Gonzalo**, for your vibrancy and generosity, you are one of the greats to ever great. Thank you, **Mark**, for always sharing the California love and helping me escape from the pressure of academia by giving me so many interesting and thought-provoking books. Thank you, **Fia, Jonathan, Carolina, and Steve** for all the friendly banter and important discussions. And finally, to **the Wizards of Oz**—those that work in the shadows—both in **administration and IT**, thank you for all that you do to keep the engine running, I know it has been difficult these past few years. Importantly, I am truly grateful towards **Johannes** for all of your help and guidance. It is truly remarkable how you always managed to find the time to help me overcome some administrative problem and make me feel seen.

At the Stockholm Resilience Centre, I have had innumerable insightful and inspiring conversations. To my PhD cohort, you are all remarkable people and give me hope that a better world and future is obtainable. Again, everyone deserves praise, and it is unfair that I will not list you all by name, but please know that I am super appreciative of all of you. **Kajsa** and **Diana**, you both in particular have been a great support through this all, it has been a pleasure. **Stephen and Liam**, you were once only great friends, but in the end, we also became colleagues, congratulations on your PhD positions!

To all my friends outside of academia that have had to deal with my flakiness, periods of ups-and-downs, and long-winded tirades on politics, history, and soybeans, thank you. **Lee, Santos, Derek, and Aaron**, we no longer live near each other, but your friendships are dear to me and I'm thankful that we remain friends despite the distance. **Nico and Huai-Tse**, from our fun times in Lund to all of us pursuing our PhDs now, thanks for being such solid friends. To the Stockholmers that adopted me, **Joe, Colleen, Pelle, Sara, Sergii, and Emily**, you are all the best.

Thank you to my informants in Argentina that I had the pleasure of interviewing: your trust, expertise, and collegiality were instrumental to this research. An enormous thanks goes to the staff at the Dissertation Support at the Stockholm University library. Without them, this thesis would be an udder mess and perhaps never have been printed. Thanks also goes to all of the organizers and participants at the various workshops, conferences, and seminars I have attended throughout these years whose inputs have all been incorporated into this dissertation. I thank the Jan Wallander and Tom Hedelius Foundation and Tore Browaldh Foundation for financing the first three years of this doctoral project. Thank you to the Elisabeth and Herman Rhodins Memorial Foundation and the John Söderbergs Scholarship Foundation for financing my field visits to Argentina. And a final thanks to the organizers of the European Rural History Organization and staff at Babeş-Bolyai University of Cluj-Napoca for generously covering travel and participation costs so that I could present part of this dissertation at the Rural History 2023 conference.



# Preface

*Frontiers* are strange things—both dividing lines and unique spaces, both endings and beginnings. They are processes and they are thresholds where transformation can occur—not only to land, but to people and ecosystems. In a lived sense, frontiers are intimate. They demand decisions about identity, purpose, and belonging.

For me, frontiers have more so been a material reality rather than an abstraction. As a first-generation Chicano growing up in Southern California, I grew up in a liminal space where my identity was constantly called into question—by society, by my peers, and, most importantly, by me. I was never Mexican enough and never American—*white*—enough. To be a Chicano, for me, has been to proclaim, forge, and seize an identity mired in contradiction and inadequacy. But in this space, I have had the opportunity to reinvent, to shapeshift, and to construct something entirely new.

My journey through academia has also mirrored the dynamics and characteristics of the frontiers that I am fascinated by: a constant negotiation of boundaries, an unsteady straddling of past and present, home and elsewhere. As I sit here in the *ivory* halls of academia, I feel out place—not because I am far from family, friends, and the landscapes of my upbringing, but because I am a product of the working class: of hands that build, till the soil, and cook and serve food. As the first person in my family to earn a Bachelor's degree—let alone pursue a PhD—I carry the weight of that history with me. Moreover, working-class labor paid my rent, tuition, and loans, as I worked full-time jobs in parallel to completing my Bachelor's and Master's programs.

Even in my research agenda, I occupy a frontier space. Though this dissertation is fundamentally a study in economic history, I myself am an interdisciplinary researcher, who brings a theoretical and methodological toolkit that also incorporates human ecology, rural sociology, anthropology, agronomy, and sustainability science. Because of this, I analyze frontiers as formative places, shaped by historical forces, where economies expand and contract, erasing possibilities while creating others. They are never static: they broaden, deepen, and shift. They force movement—of people, commodities, and ideas. And while they promise transformation, they also leave scars. To study frontiers, as it is to live within them, is to

wrestle with their contradictions as they coalesce and emerge as something unexpected.

As I write this Preface, I am acutely aware that I now wander within the limits of a new frontier. On one side is a PhD candidate preparing to defend his dissertation, and on the other—just beyond the borderland—lies a great unknown: a vast sea (or maybe even a plain) of ambitions to chase, setbacks to overcome, lessons to learn, and triumphs to savor. But I am hopeful because, in uncertainty, I have always found possibility—and, as Anthony Bourdain (2006) once said,

Maybe that's enlightenment enough—to know that there is no final resting place of the mind, no moment of smug clarity. Perhaps wisdom [...] means realizing how small I am, and unwise, and how far I have yet to go.

Thank you, dear reader, for indulging not only this brief reflexive moment, but the research I will present hereafter. May this work, like the frontiers it aims to understand, serve not as an endpoint but as a threshold—one that invites further contributions, questions, and explorations beyond its limits.

Enrique Antonio Mejía  
Stockholm, Sweden  
January 2025





# 1. Introduction

During my doctoral studies, I traveled to Argentina for five weeks between April-May 2022 and for three weeks in July 2024. While most of my time was spent in the capital, Buenos Aires, visiting archives and libraries, writing, and attending the Expo Rural agricultural conference, I managed on both occasions to make my way further into the interior. During the first trip in 2022, I rode a bus from Buenos Aires to Rosario during the last week of April. Perhaps best known internationally as the hometown of professional footballer Lionel Messi, Rosario is located in Santa Fe province and is the second-largest city in Argentina. It hosts one of the country's main ports due to its proximity to the Pampas, Argentina's agricultural heartland, and its central location along the Río Paraná, which flows through Brazil and Paraguay. Incredible wealth, whether biophysical or monetary, also flows through this industrial city.

Importantly, it serves as a conduit for “green gold”. That is, soybean (*Glycine max*) is transported to Rosario from the Argentine countryside where it is either shipped raw or first processed in one of the numerous mills into meal, oil, or increasingly into biofuel before export. Yet, despite all this gold, poverty plagues the outskirts of the city. As Pablo Lapegna (2016, pp. 25–26) discovered through ethnographic work on social movements and environmental politics in Argentina, a large portion of the population living in the makeshift shantytowns in the peri-urban zone come from elsewhere in the country, driven off the land by the expansion of soybean production.

Outside of the metropolitan area, just beyond these shantytowns, is what one interviewed agronomist (July 25, 2024) referred to as the “Triangle of Soybean”—the area between Rosario in Santa Fe province, Pergamino in Buenos Aires province, and Río Cuarto in Córdoba province. Within the Triangle is a landscape that numbs the senses. During the harvest period in 2022, it stretched endlessly, a monotonous horizon of matured, golden soybean stalks that erased all distinctions and depth. When I returned to the area at the onset of winter and just after the soybean harvest in 2024—via bus from Buenos Aires to Córdoba, the land was marked instead by absence. Though wheat was often planted after soybean and some producers

had embraced cover crops, the sheer scale of fallowed land was staggering—remnants of a season already forgotten and a profound manifestation of both ecological and visual exhaustion.

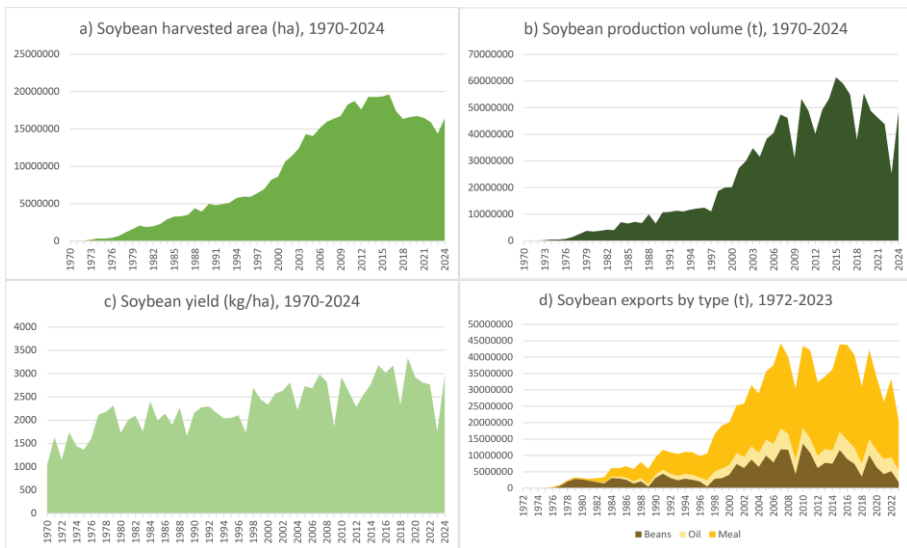
The landscape I experienced during my visits into the Triangle of Soybean is fundamentally different than what would have been just 50 years ago. Prior to the emergence of soybean as a commodity in Argentina, this landscape was predominantly characterized by mixed crop-livestock farming systems (Álvarez et al., 2014; Viglizzo et al., 2010). Going back further, to the turn of the 20<sup>th</sup> century, this landscape would have witnessed the boom of commodity wheat production that brought tens of thousands of migrant tenant farmers from Europe, radically reshaping the agrarian structure of the region and deeply integrating the Argentine countryside into the global agrofood system (Barsky and Gelman, 2009; Hora, 2001; Scobie, 1964). Even further back in the annals of history, this landscape was once extensive grassland, sparsely populated by indigenous Mapuche peoples. So, while today the population of the region is largely descended from those European settlers, the once prevalent bushy pampas grass (*Cortaderia selloana*) seems to only thrive in drainage ditches alongside the major highways, and soybeans have emerged as the dominant crop, this is historically constructed but not determined—meaning it was not always this way and, importantly, it does not always have to be this way either.

Moreover, this history of drastic land use and land cover change is not confined to the Triangle of Soybean. As I will highlight throughout this dissertation, the expansion of commodity soybean across Argentina has taken different forms—or modalities—depending on where it has occurred, ultimately influenced by historical and place-based conditions. The stark contradictions between abundance and poverty, productivity and plunder, uncovered in this dissertation are suggestive of the extractive nature of commodity frontier expansion, where the fat of the land (Argentina's vast natural resources) and the salt of the earth (the Argentine people) are exploited and dispossessed in order to satiate demand far-removed from the sites of production.

## 1.1 Sojización in Argentina

Argentina's transformation into a global powerhouse of soybean production reflects a profound social-ecological shift with far-reaching consequences. Between 1970 and 2024, soybean agriculture in Argentina expanded from just 30,000 hectares producing under 27,000 metric tons to over 16.5 million hectares yielding 48 million metric tons, reflecting a substantial increase in productivity (**Figure 1**). This production has largely taken place in the Pampas where almost 80% of all soybeans are produced

in just three provinces: Buenos Aires, Córdoba, and Santa Fe. However, political-economic and ecological pressures as well as the almost universal adoption of a new technological package revolving around the use of genetically engineered (GE) glyphosate-resistant seeds, synthetic fertilizers and pesticides, and direct “no-till” seeding have facilitated the expansion of soybean frontiers into the interior provinces of the nation, where agricultural production has until recently remained nominal—for example, in Santiago del Estero province situated within the Dry Chaco ecoregion. Across Argentina, and hispanophone Latin American countries, this expansion is referred to as *sojización*—which directly translates as soybeanization (Álvarez et al., 2015; Baraibar Norberg, 2022; Delvenne et al., 2013; Fogel, 2015).



**Figure 1: Argentine soybean area (a), production (b), yields (c), and exports (d), (1970-2019).** Export data for 1970, 1971, and 2024 were unavailable. Area, volume, and yield data based on SAGyP (2024), and FAOSTAT (2024) for export data.

In Argentina, this logic operates at the intersection of market dynamics, state and subnational policies, technological innovation, and local and regional histories and social-ecologies, underpinning the country’s rise as the third largest producer of soybeans globally. As of the 2024 harvest, Argentina produced 12% of soybeans worldwide, following behind Brazil and the United States of America (the US), who contributed 40% and 28.5% respectively (USDA PSD, 2024). Though Argentina’s contribution to global volumes of soybean is markedly lower, it has become highly specialized in soybean production and trade, where 84% of its soybeans are either processed into products like soybean meal, oil, and biodiesel or exported whole: surpassing Brazil (69%) and the US (59%), respectively

(Calzada and Rossi, 2019; FAOSTAT, 2024). Though predominantly destined to become feed for modern livestock systems as nutrient-dense soybean meal, innovations in the manufacturing of other useful forms (oil and biofuel), financial tools, crop varieties, and agricultural technologies allow soybeans to be flexibly sold on the global market, further entrenching the crops long history of multifunctionality (Baraibar Norberg and Deutsch, 2023; Borrás et al., 2016).

### 1.1.1 The research problem

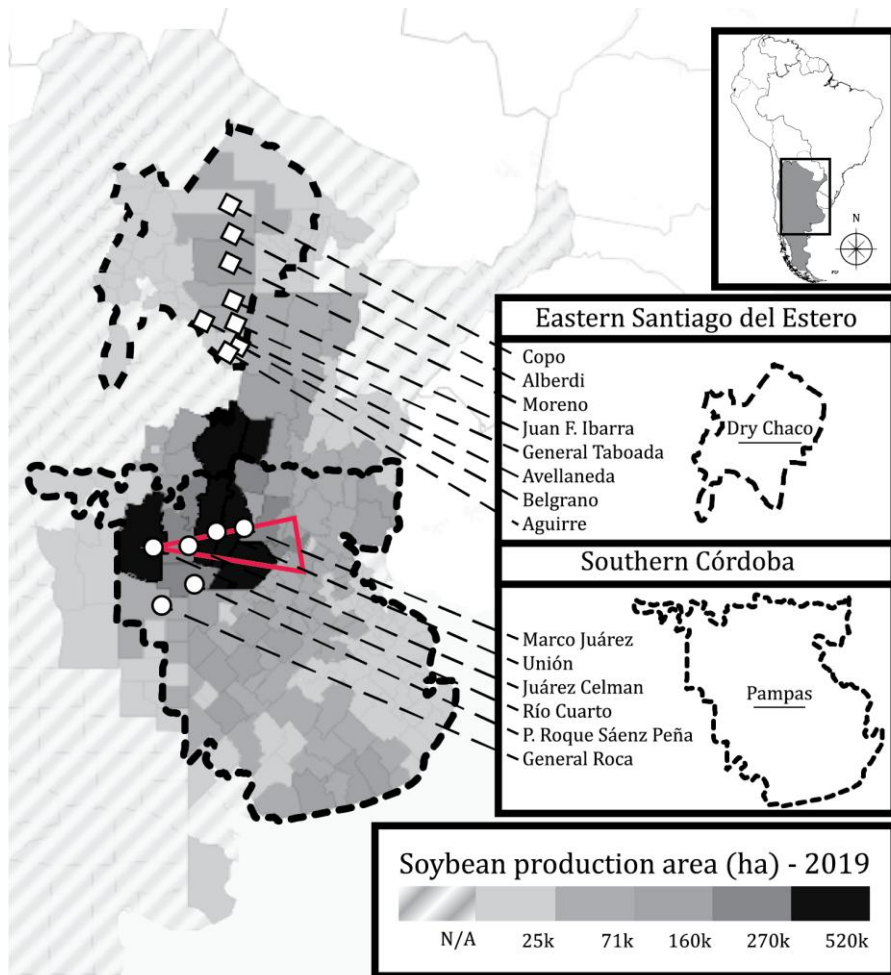
Despite significant economic gains achieved through reduced production costs, increased foreign investment, and export revenue (Phélinas and Choumert, 2017; Trigo and Cap, 2003), the consequences of *sojización* have been substantial and multifaceted. These include: deforestation (Faingerch et al., 2021; Grau et al., 2005), rural exodus (Lapegna, 2016, pp. 25–26; Leguizamón, 2020, pp. 75–76), herbicide resistance in weeds (Binimelis et al., 2009), contributing to the oversaturation of glyphosate in the global food system (Bøhn and Millstone, 2019; Werner et al., 2022), and biodiversity loss (Medan et al., 2011). Among these consequences, soil nutrient loss stands out as an important issue intimately tied to the dynamics of soybean expansion, production, and export (Austin et al., 2006; Díaz de Astarloa and Pengue, 2018; Lavado and Taboada, 2009; Pengue, 2005).<sup>2</sup>

Moreover, recent research has demonstrated that soil nutrient loss varies widely across different subnational regions (Álvarez et al., 2016; Cruzate and Casas, 2017; Koritschoner et al., 2023; Leguizamón et al., 2023). This regional variation reflects wider patterns of uneven development driven by soybean expansion; for example, between the Pampas and the Dry Chaco (Jobbágy et al., 2015; Neiman and Blanco, 2020; Wald, 2016). In the Pampas agricultural core, expansion has been primarily capital and technologically-intensive, occurring on already commodified lands and characterized by medium-sized landholdings (Gras and Hernández, 2014; Maldonado and Bustamante, 2019; Urcola et al., 2015). In contrast, expansion into the Dry Chaco has been predominantly geographically extensive, taking place over non-commodified lands and natural ecosystems, characterized by a highly unequal land tenure system where large estates dominate ownership and access to political and economic capital (le Polain de Waroux et al., 2018; Paz, 2020; Paz et al., 2019). The persistent and uneven

---

<sup>2</sup> Soil nutrient loss resulting from high-yielding soybean cultivation is not isolated to Argentina. According to the United Soybean Board (2024), the governing body that instantiates the US commodity checkoff program for soybeans on behalf of all US soybean farmers, the relationship between soil nutrient loss and commodity soybean is well-understood. In Brazil, Esper Neto et al., (2021) have concluded that modern soybean varieties extract more soil nutrients relative to older varieties, which ought to be accounted for in nutrient management practices.

loss of soil nutrients across subnational soybean producing regions underscores a systemic failure to sustain soil health and ecological integrity, potentially suggesting deeper historical, political-economic, and ecological dynamics that demand critical examination.



**Figure 2: Map of Argentine soybean production areas in hectares (ha) in 2019.** The gradient represents soybean cultivation areas by size, ranging from N/A to 520,000 hectares, for each department. The squared dashed line outlines the Dry Chaco region, and the rounded dashed line outlines the Pampas region. Thin dashed lines indicate the location of departments within the case study areas. Eastern Santiago del Estero (white square) includes Copo, Alberdi, Moreno, Juan F. Ibarra, General Taboada, Avellaneda, Belgrano, and Aguirre. Southern Córdoba (white circle) includes Marco Juárez, Unión, Juárez Celman, Río Cuarto, Presidente Roque Sáenz Peña, and General Roca. The map uses production data and base layer mapping sourced from the TRASE database (Lathuillière et al., 2022). For **Paper 1**, all departments that are within the border of the Pampas ecoregion were used. The red triangle, outlines the area described in the introduction as the Triangle of Soybeans.

While existing studies have examined the drivers of soybean expansion from various disciplines and theoretical traditions, there has been limited engagement with how historical and place-based dynamics contribute to subnational differences in soybean frontier expansion and soil nutrient loss—elaborated in greater detail in the following section on critical debates. To address this, **Paper 1** explores long-term soil nutrient loss in the Pampas, revealing how entrenched structural forces contribute to gradual but persistent soil nitrogen loss—having led to several direct and indirect social costs. **Papers 2 and 3** adopt a comparative lens, analyzing soybean frontier expansion in the Pampas and Dry Chaco ecoregions to illustrate how regional histories and social-ecological conditions shape distinct modalities of frontier expansion and variegated patterns of soil nutrient loss. To focus the analysis more effectively, two subnational case studies are selected to represent the Pampas and the Dry Chaco ecoregions: Southern Córdoba and Eastern Santiago del Estero, respectively. The reasoning for selecting these case studies as well as their unique characteristics are presented in the two papers, but the central logic is that they represent divergent trajectories of frontier expansion despite their geographical proximity and linked agrarian histories. **Figure 2** provides a map of the case study areas in Argentina, also providing the area under soybean production at the departmental level in 2019.

## 1.2 Research aim, questions, and design

This dissertation is situated within the now completed research project titled, *Unequal Exchange and Agrofood Globalization: Nitrogen, Soybeans and Latin America*, funded through the Jan Wallander and Tom Hedelius Foundation and Tore Browaldh Foundation (P20-0258). The overall aim of this larger research project was to examine the historical and contemporary dynamics of nitrogen flows within the Latin American soybean commodity chain, focusing on how Latin America's long-standing role as a global agrofood provider has shaped the evolution of this chain since 1850. It sought to trace the nitrogen cascade within this system and investigate its social-ecological impacts, particularly for small-scale farmers, to understand the intersection of global nitrogen dynamics with regional and local consequences. I have built upon the broader research project's aims, expanding its focus to examine not only soil nitrogen loss, but also phosphorus and sulfur, within the context of soybean frontier expansion in Argentina.

The explicit aim of this dissertation, through the synthesis of **Papers 1, 2, and 3** and this kappa, is to understand how historical processes and place-based factors influence soybean commodity frontier expansion and

soil nutrient loss in the Pampas and the Dry Chaco. To do so, I posited the following research question for each paper:

### ***Paper 1***

*How is export-oriented soybean production in the Argentine Pampas historically embedded within the political economy of asymmetric embodied nitrogen flows, and to what extent does it drive soil nitrogen extraction, export, and unaccounted-for social costs between 1970 and 2021?*

### ***Paper 2***

*What aspects of sojización represent new dynamics, and what aspects reflect historical continuities of agrarian capitalism in Argentina, particularly as they play out differently in the Pampas versus the Dry Chaco?*

### ***Paper 3***

*How do regional differences in soil nutrient loss between the Pampas and the Dry Chaco reflect underlying social costs in Argentina's soybean production model, and why are these deficits challenging to resolve due to global market pressures and historical patterns of agrarian development?*

**Paper 1** investigates how soybean agriculture in the Pampas is historically situated within the political economy of asymmetric nitrogen flows. Its mixed-methods approach integrates a simple mass balance calculation of nitrogen exports with Kapp's (1978) conceptual framework of social costs. I deliberately chose this methodological combination to bridge biophysical measurements with critical social science, ensuring that cascading social-ecological consequences of soil nitrogen loss could be analyzed within a broader historical and political-economic context. The period between 1970 and 2021 was selected to capture the significant shifts in soybean production dynamics, particularly the emergence of commodity soybean and the adoption of the GE technological package.

The development of **Paper 1** revealed key insights about this dissertation's overall research design and process. It demonstrated the potential of biophysical accounting methods to expose structural inequalities embedded in export-oriented agricultural models while highlighting the need to situate such findings within deeper historical and place-based contexts. For example, while nitrogen flows could be estimated, understanding their origins and systemic drivers required a more nuanced historical analysis than

I originally anticipated. These realizations shaped the trajectory of the dissertation, particularly the expanded historical focus and comparative meso-scale analysis in subsequent papers.

The historical approach in **Paper 1** needed to be deeper if I truly wanted to understand what, if anything, was actually unique about the expansion of soybean production in the Argentine countryside. Doing so would also address any blindness embedded in the research design where structures or processes were made significant by virtue of zooming too far into just one of the several commodity crops grown throughout Argentine agrarian history. **Paper 2**, compared modalities of frontier expansion between two case study areas, Southern Córdoba and Eastern Santiago del Estero, to understand whether past economic development and land-use changes have shaped and constrained the possibilities of the present or whether completely new dynamics are at play. It turns out, the expansion of the soybean frontier is deeply embedded in a historical trajectory marked by the previous expansion of commodity wheat, characterized by overlapping patterns of resource extraction, evolving agrarian structures, and the enduring push to align subnational production with global market demands. **Paper 3** makes use of the findings in **Paper 2** to discuss how resolving soil nutrient loss is limited by structural inertia associated with historical patterns of agrarian development.

Yet considering history alone would not have been sufficient; it had to be understood alongside place, with the particularities of the land and the people who inhabit it. Each region, from the fertile and expansive Pampas to the arid forests of the Dry Chaco, tells a different story of soybean expansion—stories shaped by distinct ecological conditions, governance structures, regional communities, and economic pressures. **Papers 2 and 3** adopt a meso-scale comparative approach, avoiding the reductionism of national narratives and the narrowness of localized studies, to explore how place-based factors mediate negative consequences of global agricultural trends. Through this lens, the uneven geography of *sojización* comes into focus. In this way, the dissertation evolved beyond the synchronic, single-region analysis in **Paper 1**, but ultimately remains indebted to the preliminary framework it sought to create.

Moreover, tacit knowledge gained from interviews with agronomists familiar with soybean production and soil nutrient cycles as well as better acquaintance with biophysical and agronomic studies revealed that solely focusing on nitrogen would limit the breadth and strength of the overall research design since the volatility of nitrogen allows it to cascade throughout social-ecological systems and therefore making estimations on nitrogen flows highly complex and prone to uncertainty (multiple interviews)—also something explored by Galloway et al. (2003). Therefore, **Paper 3** includes soil nutrient budgets for phosphorus and sulfur as well—two other

essential nutrients for plant growth (Havlin et al., 2017) and identified as critical nutrients in Argentine soybean production by agronomists (multiple interviews) as well as the literature (Hilbert et al., 2021).

Though this research design concerns the production-side of the Argentine soybean commodity chain, its integration into global markets is central to the theoretical assumptions of all three papers. Specifically, **Paper 1** attempts to position the research within the findings of other studies on the asymmetric biophysical resource flows, or ecologically unequal exchanges, that characterize Argentine production and trade (Díaz de Astarloa and Pengue, 2018; Dorninger et al., 2021; Lassaletta et al., 2019). **Paper 2** situates soybean frontier expansion within historical agrarian capitalist dynamics while highlighting how global economic pressures shape contemporary land-use changes. This integration underscores the interplay of historical patterns and new global demands in driving different modalities of frontier expansion. **Paper 3** discusses how soil nutrient loss in the Argentine countryside is difficult to mitigate in part due to the top-down pressures associated with global market dynamics.

Each paper has been written as a standalone contribution to the study of soybean frontier expansion in Argentina specifically and agrofood globalization more broadly. At times, this kappa will address them individually, while at others, it will weave them together into a unified research project. It will also give explanation to any theoretical or methodological contradictions that tend to be the bane of interdisciplinary research.

### 1.2.1 Paper abstracts

#### *Paper 1: Five Decades of Soybean Agriculture: Soil Nitrogen Exports and Social Costs in the Argentine Pampas, 1970–2021*

This paper examines the social-ecological consequences of the expansion of export-oriented soybean agriculture in the Argentine Pampas, focusing on soil nitrogen exports and the associated social costs. As soybean production has rapidly expanded in Argentina, the Pampas has become a site of drastic land use and land cover change. However, the accompanying intensification has also led to substantial nutrient loss, particularly nitrogen, which raises concerns about the long-term sustainability of the region's agricultural productivity. Moreover, as the Pampas agricultural core is embedded within a global agrofood system characterized by the asymmetric flows of biophysical resources, the importance of studying soil nitrogen loss is highlighted. The analytical framework centers on the concept

of social costs, which attempts to capture the social-ecological consequences of this expansion that are borne by those not benefiting from it. Methodologically, the study calculates a simple mass balance for nitrogen (subtracting nitrogen outputs by the inputs) to demonstrate how nitrogen extraction in the Pampas from 1970 to 2021 has increased over time. Data are drawn from a combination of departmental agricultural estimates and regional agronomic studies, allowing for a comprehensive analysis of nutrient dynamics at the meso-scale level. Moreover, data from secondary literature is used to operationalize K. William Kapp's (1978) theory of social costs to highlight the direct (first order) and indirect (second order) unaccounted for costs of soil nitrogen loss.

***Paper 2: Historicizing sojización in the Argentine countryside: Something profoundly new or old wine in new bottles?***

This study compares the modalities of commodity frontier expansion in Southern Córdoba and Eastern Santiago del Estero during the wheat frontier period (1872-1937) and the soybean period (1970-2019), shedding light on both continuities and new dynamics in agricultural expansion. In Southern Córdoba, the wheat frontier involved flexible shifting, with geographic expansion and production intensification, while Eastern Santiago del Estero experienced broadening of the commodity frontier, bringing new lands into use. During the soybean period, Southern Córdoba saw deepening of the commodity frontier, with intensified production on established land, driven by technological advancements, and the persistence of medium-sized productive units. In contrast, Eastern Santiago del Estero exhibited flexible shifting, characterized by rapid agricultural expansion, significant deforestation, and persistent land tenure conflicts. By examining these divergent trajectories, this study highlights how the dynamics of frontier expansion vary according to subnational histories, providing new insights into the evolving nature of agricultural frontiers in Argentina.

***Paper 3: Divergent Landscapes: Exploring structural drivers of soil nutrient loss in two Argentine soybean frontiers***

This article examines regional variations in soil nutrient loss within Argentina's soybean frontiers, focusing on Southern Córdoba and Eastern Santiago del Estero. Soybean agriculture has rapidly expanded across distinct

agrarian contexts, yet its extractive practices have led to widespread, but varied, soil nutrient loss. Framed within political ecology and K. William Kapp's concept of social costs, the study aims to understand why soil nutrient deficits persist and why they are challenging to resolve within the existing production model. Nutrient budgets for nitrogen, phosphorus, and sulfur were calculated using regional agricultural data averaged between 2015 to 2019, supplemented by qualitative insights from expert interviews and secondary literature. The findings reveal significant differences: Southern Córdoba exhibits nutrient loss driven by intensive production and moderate fertilizer use, while Eastern Santiago del Estero shows rapid loss of vital nutrients due to minimal inputs, extensive and concentrated forms of land tenure, and fragile ecological conditions. Global trade dynamics, particularly the enduring influence of the European Union, exacerbate these patterns. By integrating biophysical analysis with historical and political-economic contexts, this study highlights the systemic contradictions of commodity agriculture and demonstrates how soil nutrient loss is embedded within broader structural pressures.

### 1.3 Structure of the dissertation

This dissertation, composed of an introductory chapter and three individual papers, is an exploration into the complex entanglements of *history* and *place* within soybean frontier expansion in Argentina and resulting soil nutrient loss. To do so, has required an understanding of history as permeating the present rather than simply preceding it, and place as formative rather than as a static backdrop. Moreover, at the heart of this dissertation lies what Jason Moore (2015, p. 139) termed "the dialectic between productivity and plunder," evident in Argentine soybean production. Despite significant increases in inputs, yields, and modernization, nutrients are increasingly extracted from soils and exported to far-flung corners of the world—highlighting an essential extractive aspect of agrofood globalization and the expansion of commodity frontiers more generally.

This introductory chapter, the so-called *kappa* in Swedish academia, synthesizes the greater doctoral research project, highlighting the state-of-the-art in which the research is embedded as well as the theoretical, methodological, and empirical contributions. **Paper 1**, "Five decades of soybean agriculture: Soil nitrogen exports and social costs in the Argentine Pampas, 1970–2021", focuses on the social costs, as outlined by K. William Kapp (1978), and negative consequences of soybean frontier expansion in the Pampas agricultural core, highlighting the extraction of soil nitrogen in the pursuit of productivity. **Paper 2**, "Historicizing *sojización* in the Argentine countryside: Something profoundly new or old wine in

new bottles?” compares the subnational cases of Southern Córdoba in the Pampas and Eastern Santiago del Estero in the Dry Chaco to provide a diachronic analysis of agrarian frontier expansion. By juxtaposing the wheat frontier period (1872–1937) with the soybean frontier period (1970–2019), this paper investigates continuities and ruptures in commodity frontier dynamics. It postulates what is genuinely new about soybean frontier expansion and examines how historical patterns of agrarian capitalism have shaped the development of these regions over time. Finally, **Paper 3**, “Divergent landscapes: Exploring structural drivers of soil nutrient loss in two Argentine soybean frontiers” returns to the same case studies but shifts the focus to the contemporary period. Using nutrient budget calculations for nitrogen, phosphorus, and sulfur, it examines why nutrient deficits persist and are challenging to resolve within the current soybean production model. The analysis foregrounds the structural constraints imposed by global market pressures and historical agrarian development, demonstrating how soil nutrient loss is embedded within broader systemic pressures.

The following section, **Section 2**, provides the overarching context and state-of-the-art for this dissertation by synthesizing key debates and identifying gaps in the literature across three bodies of scholarship: the political economy of soybeans, the agrarian history of agrofood commodity production in Argentina, and Argentine nutrient budget studies. The review focuses on critical debates between competing fault lines within these scholarships as well as within the fault lines themselves. Subsequently, the review identifies specific lacunae within the historical, regional, and structural studies of Argentine soybean agriculture, highlighting the key gaps that this dissertation seeks to address and is situated within. Afterward, in **Section 3**, the analytical frameworks of each paper are distilled into an overall systemic perspective that utilizes the lens of the soybean as a commodity and commodity frontiers as tools for reducing complexity and focusing the research. Departing from this overall approach, in **Section 4**, I synthesize the methodologies of the included papers into an overarching meso-scale comparative approach. In addition, I conduct source criticism and discuss the mixed-methods approach and integration of qualitative and quantitative data throughout the papers. In **Section 5**, I sum up the key insights gained from each of the papers and how taken together they address the previously identified debates and gaps in the state-of-the-art. I conclude the kappa in **Section 6** and offer other brief considerations on the research, the findings, and what may come next.

## 2. Critical debates

As an economic historian, I begin with the proposition that agrarian change and ecological degradation are deeply embedded in long-term historical processes and political-economic structures. Understanding these dynamics requires analyzing how past configurations of power, production, and resource use continue to shape contemporary agricultural frontiers and their uneven outcomes. To investigate the historical processes and place-based factors driving soybean commodity frontier expansion and soil nutrient loss in the Pampas and the Dry Chaco, I engage with three key areas of scholarship: the political economy of soybeans, the agrarian history of agrofood commodity production in Argentina, and Argentine soil nutrient budgets. These areas collectively provide insights into the analytical tools necessary to examine the historical, structural, and ecological dimensions of soybean agriculture and the mechanisms that sustain its uneven development.

These three areas of scholarship, while distinct in their focus, overlap in important ways. Together, they illuminate the interplay between global economic structures, historical land-use patterns, and biophysical processes that define the dynamics of soybean frontier expansion. The political economy of soybeans situates the crop within global trade and the *longue durée* of agrarian change, exploring the economic, technological, and geopolitical forces that drive its expansion. Zooming in from the global, the body of literature concerning the agrarian history of agrofood commodity production in Argentina contextualizes soybean agriculture within longer trajectories of land-use change and agrarian capitalism, focusing on how historical processes have shaped contemporary developments. Lastly, soil nutrient budget studies bring an ecological perspective, quantifying the impact of soybean production and exploring potential drivers. **Papers 1, 2, and 3** engage with these debates in distinct but interconnected ways, and this section situates their contributions within these broader discussions.

I have structured the review of each body of literature around two key fault lines: an identified dominant mainstream narrative and its critical counterpart. This framing clarifies how the literature addresses central questions about the drivers and consequences of soybean agriculture. In

the final subsection, I bring this all together to highlight gaps and unresolved tensions that this dissertation seeks to address; establishing the analytical foundation for understanding how historical, regional, and structural dimensions intersect to shape soybean frontier expansion and its consequences. I also situate this dissertation within these gaps and competing fault lines, setting the stage for the subsequent discussions on the overarching theoretical and methodological frameworks that have guided my research.

## 2.1 The political economy of soybeans and the making of a botanical bastard

Arturo Warman's (2003) *Corn and Capitalism: How a Botanical Bastard Grew to Global Dominance* provides a compelling framework for understanding the trajectory of globalized crops. In his study, Warman dissects the intertwined histories of maize (*Zea mays*) and globalization, revealing how this once culturally embedded staple became subsumed under the relentless logic of the market. He dubs maize as a botanical bastard, a hybrid crop without a clear progenitor and that has been utterly transformed into a globalized chimera far removed from its original cultural and social contexts.<sup>3</sup> The book was originally published in 1988 and Warman passed in 2003. Had he been around to witness the cumulative adverse effects of the North American Free Trade Agreement on maize production in Mexico and the introduction of GE maize, he would have likely lamented how right he actually was in coining the term.

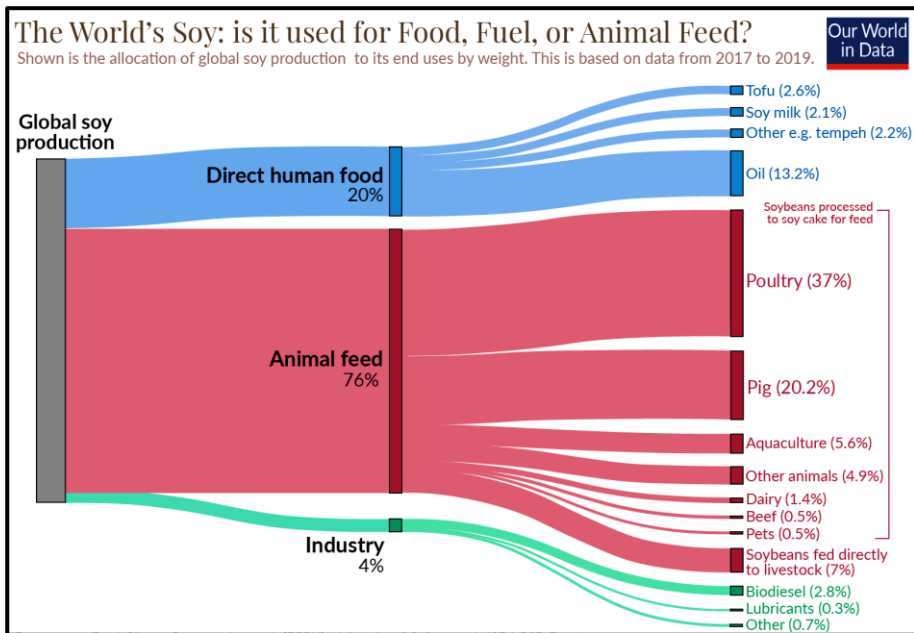
I believe the soybean should also be considered a botanical bastard. Archaeological and genomic research suggests that the modern soybean likely derives from the wild legume, *Glycine soja*, and was first domesticated along the banks of the Yellow River in northern China. Yet, much like maize, its early history "remains shrouded in mist" (Baraibar Norberg and Deutsch, 2023, p. 27). Moreover, and much like maize as well, the continuous development of soybean varieties, technologies, end-uses, and financial instruments represents a process of "flexing," where the soybean has become a versatile crop capable of addressing multiple demands across food, feed, fuel, and industrial sectors (Borras et al., 2016).

This flexibility is rooted in its broad utility as an input into agrofood and agroindustrial systems, where processing yields valuable outputs such as

---

<sup>3</sup> At the time of writing for this dissertation, a genetic analysis has demonstrated that maize was domesticated in several waves and that modern maize is the result of hybridization with two different wild teosinte (*Zea mays* ssp. *Parviglumis* and *Zea mays* ssp. *mexicana*)—flowering plants in the grass family—varieties (Yang et al., 2023).

meal and oil, which dominate global markets as livestock feed and edible oil, alongside soybean derivatives increasingly used in biofuels, bioplastics, and adhesives. Hannah Ritchie (2021) estimated that between 2017-2019, 76% of global soybeans were dedicated to livestock feed, 13.2% as edible oil, and 4% were destined for agroindustrial purposes (**Figure 3**). As key players in the global soy complex anticipate further multiplication of uses and seek to find new markets for soybean derivatives, the soybean's role as a central commodity continues to expand, further shaping and being shaped by market dynamics, technological innovations, and corporate strategies (Borras et al., 2016; Oliveira and Schneider, 2016).



**Figure 3. Share of global soybean production by end-use (2017-2019).** Figure from *Our World in Data*, Hannah Ritchie (2021) using data from USDA's PSD database. Licensed under CC BY 4.0.<sup>4</sup>

The questions of how and why a humble legume such as the soybean has become such an integral component of the contemporary agrofood system have been central to debates within the political economy of soybeans. In the following subsections, I outline two major fault lines in the state of the art that explain this ascendancy: that the soybean was at the right place at the right time and is nothing more than a market response, and that the soybean is a historically-contested commodity embedded in broader structural patterns.

<sup>4</sup> <https://creativecommons.org/licenses/by/4.0/>

### **2.1.1 The ascendancy of soybean as a market response**

One explanation within this debate, which can be described as the mainstream and neoclassical narrative, emphasizes supply and demand dynamics, technological innovation, comparative advantage, and market integration as key drivers for the ascendancy of soybean as a global commodity (Campos et al., 2017; Gale et al., 2019). Soybeans, as a versatile and nutrient-dense crop, are seen as an efficient response to growing global demand for livestock feed, vegetable oil, and biofuels—particularly due to the “meatification” of diets in emerging economies like China and India, which have witnessed increases in their per-capita consumption of animal proteins (Gale et al., 2019; Norse and Ju, 2015; Weis, 2007). This narrative credits technological advancements, such as GE soybean varieties, synthetic fertilizers, herbicides, and no-till farming, with enhancing productivity and enabling the crop’s expansion into new regions (McFarlane and O’Connor, 2014). Public and private investments in agricultural research have further adapted soybeans to diverse climates and increased yields, reinforcing their position in global markets. Framed through the lens of comparative advantage, countries like Brazil, Argentina, and the US are seen as natural leaders in soybean production, leveraging abundant land, favorable climates, and lower costs to specialize in this commodity (Moraes, 2008).

Moreover, following structural reforms in the late 1980s, including the elimination of export taxes, market deregulation, and investments in agricultural research and infrastructure, the agrofood sector of developing countries such as Argentina and Brazil experienced export-led growth and enhanced their competitiveness (OECD, 2006). This was largely a result of the collapse of the Bretton Woods system and the subsequent establishment of the International Monetary Fund and the World Bank (McMichael, 2009). These developments, alongside reduced trade barriers through regional and multilateral agreements, further entrenched Southern Cone countries as major agricultural exporters. In recent years, the trade war between the US and China has further reshaped the geospatial distribution of soybean production, trade, and consumption; where artificial supply-demand gaps are constructed through inefficient tariff schemes (Guan et al., 2019). This all positions soybean production as a driver of economic growth and global food security.

In this narrative, there is nothing particularly special about soybeans, nor particular about the social relations that have shaped—and have been shaped by—its production, trade, and consumption throughout history. It is simply a crop: a crop that is suited to the demands of the market and supplies a variety of uses that make it competitive—the soybean was just in the right place at the right time. Moreover, where and why soybeans are

produced in certain places is explained by respective factor endowments, that is, the quantity and quality of the place's available resources—such as labor, land, and capital—that determine its ability to produce goods. Chad Hart (2017, p. 7), has expressed this rather plainly, where in the current state of the global market, “a soybean is a soybean no matter who produces it or how it is produced”.

An additional dimension of the neoclassical explanation for the global ascendancy of soybeans is the role of financial markets in optimizing production and trade efficiency. From this perspective, the financialization of agricultural commodities, including soybeans, is viewed as an extension of market mechanisms that enhance price discovery, risk management, and resource allocation. Futures markets, such as those in Chicago and São Paulo, allow producers, traders, and investors to hedge against price volatility, thereby reducing uncertainty and fostering stability across the supply chain (Clapp and Isakson, 2018; McMichael, 2014).

Furthermore, the integration of financial actors into soybean value chains is seen as a driver of investment and innovation. Multinational corporations and investment funds inject capital into infrastructure, technology, logistics, and land further integrating soybean producers into global markets and enhancing productivity (Medina, 2022). These financial flows also enable the expansion of production into new regions, aligning resource distribution with comparative advantage. From a neoclassical standpoint, such financial flows are framed as an efficient allocation of global capital, promoting economic growth in producer regions while ensuring that resources meet the demands of international consumers. The financialization of soybeans, in this view, is a natural and beneficial evolution of the market system, enabling the crop to fulfill its role as a versatile and economically vital global commodity (Hart, 2017).

However, throughout the literature, this narrative has faced significant contestation, particularly regarding themes central to this dissertation. Critics argue that it relegates history to a passive role, obscures the distinct place-based contexts in which soybean production has expanded, and downplays the negative social-ecological consequences of this expansion in favor of emphasizing the commodity's perceived economic success.

### **2.1.2 The ascendancy of soybean as a historically-contested commodity**

Critical scholars have challenged the mainstream narrative, reframing the crop as a contested commodity shaped by historical processes, geopolitical struggles, and structural inequalities rather than market rationality or comparative advantage. For example, Brian Lander and Thomas David DuBois (2022) analyze how imperial ambitions in Manchuria during the late 19th

and early 20th centuries transformed soybeans from a subsistence crop to a global commodity. Under Japanese colonial control, soybeans were exported to meet domestic industrial needs, particularly for oil and protein, while innovations in processing—such as crushing soybeans for oil and repurposing the residual cake as fertilizer—set the stage for the crop’s modern industrial uses. This transformation was not simply a market response but a consequence of imperial power, resource extraction, and technological development.

Baraibar Norberg and Deutsch (2023) extend this critique by tracing how global trade systems have shaped the soybean’s development as a commodity. They argue that industrializing nations like Japan and Europe leveraged peripheral regions for soybean production to meet their own domestic demands, embedding the crop within unequal systems of exchange. Similarly, Prodöhl (2023) demonstrates how geopolitical crises, such as Germany’s shortages of fat and protein during World War I, prompted state-led initiatives to integrate soybeans into agricultural and industrial systems. These works contest the notion that the soybean’s rise was driven by comparative advantage, instead revealing how crises, interventions, and inequalities structured its global ascendance.

The shift in soybean production to the Americas during the post-war period marked another critical phase in its development. South America emerged as a dominant producer and exporter, with Brazil and Argentina leading the transformation. Turzi (2017) analyzes this shift as part of a broader pattern of state-led natural resource exploitation—or what Svampa (2019) calls “neo-extractivism”, where monocultures like soybeans became central to the export-oriented economies of the Southern Cone countries. This transition was not merely a response to comparative advantage but a reflection of how parallel processes such as an increased global demand for high-protein feedstocks, particularly in Europe and later China, and an urgent need for states to bolster their coffers for social welfare programs shaped development outcomes.

Under-theorization of how land is incorporated into the global agrofood system for commodity soybean production is another critique of the mainstream narrative addressed in the critical literature. Langthaler (2020), though drawing on neoclassical Ricardian theory, differentiates between geographically extensive frontier expansion into new lands and the deepening of production in already commodified areas. These dynamics illustrate how soybean frontiers are not monolithic but mediated by regional conditions and global forces. For instance, the geographically extensive expansion in South America has been accompanied by, for example, land enclosures, labor exploitation, and deforestation, but has oscillated between periods of extensification and intensification; flexibly shifting as a response to exogenous and endogenous pressures.

Despite their shared critiques, these critical works reveal tensions that underscore the complexity of analyzing soybean production and trade from such diverse and interdisciplinary perspectives. A key contradiction lies in the interplay of structure and agency. Structuralist-leaning approaches, such as those by Baraibar Norberg and Deutsch (2023) and Langthaler (2020), emphasize the enduring influence of global trade systems, imperial histories, and ecological transformations. These frameworks illuminate how power operates through long-term structures that dictate resource flows, labor relations, and production systems. However, such perspectives risk marginalizing the agency of local actors who navigate, resist, or adapt to these systems. Oliveira (2021) addresses this gap by examining how transnational agribusinesses and local and regional communities interact to reshape frontiers, revealing how power operates not just through global systems but also through localized negotiations and contestations.

Methodologically, the literature diverges in its treatment of temporal and spatial scales. Baraibar Norberg and Deutsch (2023) emphasizes how the historical development of soybean as a commodity can be traced through three regimes, with ruptures and reorganization in-between. They argue that there have been strong lines of continuity since the 1950s—defined by a regime characterized by the Great Acceleration and the predominance of agricultural systems premised on economies of scale—in which soy has mainly been inserted as a provider of cheap feed. Their analysis reveals how global demand for soybeans has entrenched patterns of social-ecological exploitation as well as an on-going crisis of legitimacy, which call into question the stability of the contemporary regime. However, the focus of this research is on illuminating continuities and ruptures that help explain the global history of soybean expansion, therefore local or regional moments of rupture, such as subnational political shifts or ecological crises, may be obscured. Prodöhl (2023) provides an example of these ruptures by focusing on specific historical junctures, such as Germany’s wartime need for alternative sources of fat and protein—though, while her work captures the transformative potential of such crises, it also risks fragmenting the broader systemic dynamics that connect these episodes.

Power emerges as another contested concept within the critical literature. Maristella Svampa (2019) critiques the global soybean trade as a manifestation of neo-extractivism, where resources are systematically drained from the Global South to sustain consumption patterns in the Global North. Central to their critique is a refusal of frameworks that position power as a top-down force and overlook the agency of regional actors. Turzi (2017), alongside another study by Baraibar Norberg (2020), contribute to this critique by exploring how producers, policymakers, and agribusiness leaders in different Southern Cone countries have leveraged soybean exports to consolidate their positions within global trade networks. This interplay of

global and regional power dynamics underscores the need for a more nuanced understanding of how power operates across scales.

These contradictions reflect broader methodological and theoretical challenges within the critical literature on soybeans. The tension between structure and agency, the negotiation of global and subnational regional scales, and the contested meanings of power highlight the complexity of analyzing soybean production and trade. While the literature collectively dismantles the neoclassical narrative, it also underscores the need for integrative frameworks that address these tensions.

## 2.2 Agrarian history of agrofood commodity production in Argentina

Soybeans were introduced into Argentina as a botanical “curiosity” and there was significant effort to experiment in the cultivation of the crop for its potential as fodder (Martínez Alvarez, 2012). The earliest account of these experiments are the studies conducted by Professor Tonnelier at the Córdoba research station in 1910. Interest in soybean cultivation slowly grew until 1932 when Río Segundo, an oil mill and refinery in Córdoba, began selling seeds to nearby farmers. Foreign investors became interested and soybean cultivation expanded into neighboring provinces (Shurtleff and Aoyagi, 2009, pp. 37–38). By 1937, soybeans found themselves being cultivated in the far north Misiones and Tucuman provinces, though its presence in such remote and tropical agricultural frontiers would ultimately be limited. Concurrent to these early field tests for soybean, the Argentine countryside was in the midst of a wave of export-oriented grain production, namely wheat. In order to understand the emergence of soybean as a heavily-integrated global commodity in the Argentine countryside, it is important to understand the historical context of export-oriented grain and cash crop production more generally.

Between the years 1872 and 1937, the Argentine agricultural sector exploded from a cultivation area of 580 thousand hectares to over 28 million hectares. This expansion of agriculture resulted from several key factors: the colonization of hinterlands following the Conquest of the Desert, the expansion of railroads that connected these newly colonized areas to major ports, reduced transportation costs to Europe and North America due to innovations in refrigeration and power, a nearly threefold increase in the price of exported wheat between 1888 and 1895, a rising demand for primary products, and the growing incentive for rural elites to lease land to newly arrived European immigrants seeking to turn a profit. As a result,

forest, grassland, and shrub cover all declined as crop cultivation expanded, with grasslands suffering the most dramatic loss.

Despite a number of key crops being cultivated over increasing areas during this expansion, the cultivation of wheat was the most wide-spread and maintained the highest share of all cultivated land; peaking at 42% of all cultivated land in 1895 and just falling briefly behind forage crops in 1914 (INDEC 1939). This was driven by the value of exported wheat generally increasing in the price per kilogram between 1895 and the early 1920s, an economic boost welcomed by the landed class and poor newly-migrated farmers. This is evidenced by the rapid increase in yearly exports and that a significant portion of the wheat produced nationally was destined for export, having an average low of 28% exported in between 1895 and 1899 and an average high of 58% in between 1920 and 1924. All in all, the agricultural sector oscillated around 30% of the national GDP between the years 1900 and 1937 (Mitchell, 1993, pp. 149–150; 275; 516; 778), growing from just 3% in 1875 (Reca, 2006).

During this period, exports of wheat to the global agrofood system drove impressive amounts of land to come under private enterprise, land that was often viewed as just waiting to be conquered (Urien and Colombo, 1914, pp. 303–313). Large-scale structural changes throughout the nation grossly affected agricultural production between the 1940s and 1960s. This period is typically referred to as Argentina's inward-looking import-substitution era, a political-economic strategy brought forth in the context of autarkic responses to the Great Depression and the realization that agricultural terms of trade were deteriorating relative to manufactured goods (Prebisch, 1950; Singer, 1950); thus, to alleviate the perceived dependence on primary production, Argentina adopted the strategy to industrialize via import substitution (Turzi, 2017, p. 118). Power struggles over taxes between the Peronist government and organized rural landlords (Balsa, 2002; Katz and Kosacoff, 2000; Reca, 2006) as well as generally protectionist agricultural policies in the advanced world economies (McMichael, 2009) were also strong barriers to agricultural growth. While exports diminished, agricultural production stagnated. From the 1950s onwards, significant investment into agricultural productivity research was made by public-private partnerships. Particularly, the *Instituto Nacional de Tecnología Agropecuaria*, the National Institute of Agricultural Technology, played a significant role in the research, development, and dissemination of seeds throughout the Argentine countryside. During this period, soybean planted area fluctuated between five thousand to eight thousand hectares. It was not until the 1970s that soybean production began to rapidly expand over traditional forms of agriculture, such as grain production and ranching, and natural ecosystems.

Central to the agrarian history of export-oriented grain production in Argentina is a debate on drivers. A predominant explanation for the rapid expansion is rooted in the theory of comparative advantage, as introduced by David Ricardo in his seminal work *On the Principles of Political Economy and Taxation* (2015 [1817])—and since expanded upon by the works of Eli Heckscher (1949 [1919]) and Bertil Ohlin (1967 [1933]) to encompass advantage in labor, land, and capital. However, critics, largely from more heterodox economic backgrounds, have called into question whether comparative advantage is inherent to Argentine agrarian history or if such advantages were constructed via the structural underdevelopment of the countryside. The following sections outline these two key debates.

### **2.2.1 Agrofood commodity production as an expression of comparative advantage**

The theory of comparative advantage posits that nations benefit from specializing in goods they can produce most efficiently relative to others, maximizing global economic exchange and efficiency. Simply put, countries ought to focus their labor, land, and capital on producing goods where these resources are used most effectively compared to other countries, allowing them to trade for goods that would require disproportionately more of their resources to produce domestically. For Argentina, this principle is argued to have materialized through its specialization in agriculture due to having the natural endowments of the vast fertile Pampean soils, a temperate climate, cheap labor, and a landscape with efficient port access to establish itself as a leading exporter of grains and livestock during the late 19th and early 20th centuries (Barsky and Gelman, 2009; Scobie, 1964).

During the first rapid phase of export-oriented agricultural production Argentine countryside at the turn of the 20<sup>th</sup> century, liberal economic policies, coupled with significant British investments in infrastructure, enabled the development of railroads that connected the Pampas to major ports, facilitating the export of wheat and beef to European markets (Amaral, 1998; Scobie, 1964; Solberg, 1987)—paralleling more global patterns of resource-based development (Barbier, 2010). These developments were complemented by immigration from Europe, which supplied labor and advanced agricultural techniques, further enhancing productivity (Scobie, 1964).

Land concentration in *estancias*, or large estates, played a pivotal role in sustaining this model. While facilitating economies of scale, these estates also entrenched an elite-controlled system of agricultural production, concentrating wealth and power among a small segment of the population (Barsky and Gelman, 2009; Scobie, 1964). State policies further reinforced

this structure by prioritizing export-oriented agriculture over land redistribution or domestic market development. The estancias became synonymous with Argentina's agricultural identity, where the bulk of its wheat and beef exports were produced by migrant tenant labor during this period.

Technological advancements in the early and mid-20th century are argued to have reinforced Argentina's comparative advantage in agriculture. Mechanization and the adoption of agrochemicals at the turn of the century increased productivity (von Motz, 1916, pp. 35-38: 55), paving the way for the introduction of new technologies and high-yielding grain varieties during the Green Revolution decades later. Then between the 1970s and early 2000s, Argentina emerged as the third-largest producers of soybeans globally, driven by GE crops and no-till farming techniques. These innovations diversified Argentina's agricultural output and adapted its export-oriented model to the demands of a changing global market. By focusing on agriculture, the country is argued to maximize the returns on its comparative advantage, achieving significant economic growth and global economic integration. This narrative underscores the efficiency of specialization, with agriculture becoming central to the Argentine national economy.

Despite the coherence of this mainstream canon, internal contradictions highlight the limits of the comparative advantage framework. While large estates enabled economies of scale, they marginalized smallholders and indigenous communities, exacerbating inequalities and challenging Ricardo's assumption of broadly distributed benefits. Furthermore, dependence on export-oriented agriculture left Argentina vulnerable to global market volatility, as demonstrated during World War I and the Great Depression, when declining commodity prices disrupted the economy (Lewis, 1990; Scobie, 1964). The negative social-ecological consequences of agricultural expansion, including deforestation, soil erosion, rural exodus, and the overuse of agrochemicals, also present challenges to the long-term sustainability of Argentina's agricultural model (Cáceres and Gras, 2020; Lapegna, 2016, pp. 25–26; Leguizamón, 2020, pp. 75–76). These contradictions have paved the way for others to critically reexamine the expansion of export-oriented agriculture in Argentina, particularly as it relates to structural underdevelopment.

### **2.2.2 Agrofood commodity production as an expression of structural underdevelopment**

Contrary to supposing that the export-oriented agriculture in Argentina has largely been a success story premised on a comparatively advantageous position in the global agrofood system, other studies on Argentine agrarian history have reflected on a deeply persistent pattern of structural underde-

velopment, a process driven by global economic imbalances and trade inequalities. Such studies typically align with or depart from the Latin American Structuralist School of development thought, which highlighted systemic disadvantages imposed on peripheral economies by the global economic order—which therefore have led to the structural underdevelopment of Latin American countries and explaining the relative “backwardness” to other settler-economies (Bértola and Weber, 2015; Frank, 1969; Street and James, 1982; Sunkel, 1973).<sup>5</sup> Central to this critique are Raúl Prebisch’s (1950) and Hans Singer’s (1950) observations of declining terms of trade, which posit that the value of primary exports had declined relative to industrial imports, locking Latin American countries like Argentina into cycles of dependency and underdevelopment. Christian Dorninger and Nina Eisenmenger (2016) illustrated this dynamic by analyzing Argentina’s biophysical trade flows, revealing how the export of unprocessed commodities imposes ecological burdens on the country while yielding limited economic returns. This has also been further empirically-demonstrated by a number of other scholars (Alonso-Fernández and Regueiro-Ferreira, 2022; Austin, 2010; Infante-Amate et al., 2020; Perez Manrique et al., 2013).

Roldan Muradian and Joan Martínez-Alier (2001) emphasized the social-ecological transformations triggered by global demand for agricultural exports, which have marginalized traditional agrarian systems while exacerbating environmental injustices. Philip McMichael (2009) has connected these trends to the commodification of agriculture under neoliberal globalization, where the penetration of global capital into rural economies has intensified social inequalities—a point which Cristóbal Kay and Robert Gwynne (2000) previously argued necessitates the continued valorization of the Latin American Structural School. In Argentina, this process has displaced smallholders and indigenous communities, concentrating land and resources in the hands of large agribusinesses, a pattern argued to be well-established in the country’s history since colonial times (Barsky and Gelman, 2009; Bulmer-Thomas, 2014).

Contemporary soybean cultivation exemplifies these dynamics. Numerous authors have described how the governance of agricultural booms often prioritizes export revenues over sustainability, resulting in deforestation, soil depletion, and the marginalization of rural populations (Gras and Cáceres, 2020; le Polain de Waroux et al., 2018; Oliveira, 2021; Oliveira and Hecht, 2016; Paz et al., 2019; Piquer-Rodríguez et al., 2018). These outcomes reflect broader patterns of asymmetric biophysical resource

---

<sup>5</sup> Refer to Cristóbal Kay’s (1989) review of the central arguments, theories, and critiques of the Latin American Structuralist School that, in my opinion, is irreplaceable and continues to be the most comprehensive on the matter.

flows (Krausmann and Langthaler, 2019), or ecologically unequal exchanges, and have escalated dramatically in the past forty years, with extractions in this period likely surpassing those of the entire preceding history of the region (Infante-Amate et al., 2020). In analyzing Columbia's international trade from a materialist perspective, Mario Pérez-Rincón (2006) proposed that these ecological unequal exchanges reinforce the critique of the Latin American Structuralists, calling for the development of an ecological Prebisch thesis.

While the Latin American Structuralist critique provides valuable insights into these dynamics, it also faces significant theoretical and methodological challenges. One critique lies in its deterministic framing of core-periphery relations, which often underestimates the agency of peripheral states and local actors. For example, Rok Spruk (2019) contends that it was endogenous political instability and moments of key institutional breakdown that made Argentina “fail” in long-run economic development where other comparable settle economies, like Australia and Canada, prospered.<sup>6</sup> Thus, structuralist analyses risk oversimplifying the complexity of rural transformation, portraying peripheral economies as passive victims of global inequalities, neglecting the role of domestic policies, political struggles, and grassroots movements in mediating these dynamics, a critique supported by the findings of studies on the political economy of agrarian change in Argentina (Baraibar Norberg, 2020; Turzi, 2017). Moreover, the growing complexity of semi-periphery and South-South trade relations—for example, the now expanded role of China as a net-importer of Argentine agrofood commodities as well as the role of Argentina as a net-importer of Paraguayan soybeans (Hetherington, 2020; MINRECIC, 2020; OEC, 2024; OECD, 2019; Sly, 2017)—are also inconvenient patterns not wholly aligned with rigid core-periphery analyses.

Another limitation is the focus on macroeconomic indicators such as terms of trade, which capture overarching trends but fail to account for regional or localized impacts. For instance, Argentina's land tenure system and governance structures play a critical role in mediating the effects of agricultural expansion, yet these factors can be overlooked in Structuralist analyses.

Methodologically, the reliance on aggregate economic data can obscure the differentiated impacts of agrarian change on various social groups. Recent research has demonstrated that the displacement of smallholders and the concentration of land ownership are shaped not only by global market

---

<sup>6</sup> Specifically, Spruk (2019, p. 33) writes, that the “institutional breakdowns triggered by powerful elites were chiefly characterized by uninterrupted forced resignations of Supreme Court justices, declaration of economic and political emergencies, nationalization of firms, prosecution and torture of political opponents, nullification of the 1853 Constitution, rampant government favoritism, and media censorship”.

forces but also by local power dynamics (Lapegna, 2016; Leguizamón, 2020; Paz et al., 2019, 2015; Scobie, 1964; Urcola et al., 2015; Wald, 2016). By prioritizing structural explanations, scholars risk neglecting the lived experiences of rural communities and the diverse ways they navigate and resist these transformations.

The integration of ecological perspectives into structuralist critiques has also revealed methodological tensions where ecological analyses, which rely on biophysical data and material flow accounting, differ significantly from standard econometric approaches (Dorninger et al., 2021). Moreover, when ecological factors are considered, they tend to lack “deep” ecological knowledge, simplifying complex relations—a critique long-levied (Peterson, 2000; Walker, 2005). This divergence complicates efforts to develop cohesive frameworks that address both economic and ecological inequalities.

### 2.3 Argentine soil nutrient budgets

Soil nutrient depletion is a growing concern in Argentina, particularly in regions dominated by intensive soybean cultivation. Studies have consistently demonstrated that the monocultural practices associated with soybean farming have resulted in severe nutrient loss (Cruzate and Casas, 2017; Koritschoner et al., 2023; Lavado and Taboada, 2009; Leguizamón et al., 2023). This loss is further compounded by the lack of nutrient replenishment practices, with farmers often neglecting to use adequate fertilizers or engage in other sustainable land management strategies.

The loss of nutrients is not merely an agricultural challenge but is understood through the lens of externalities, where such environmental consequences of soybean production are not properly integrated into the price of soybeans on the market. As Esteban Jobbágy et al. (2021) highlights, the prioritization of immediate profitability and stable yields over long-term sustainability has resulted in practices that deplete the very resources necessary for future agricultural production.

Contrarily, soil nutrient loss, has been considered systemic and integral to industrial capitalist agriculture, for which the Argentine soybean production model is exemplary. Rather than an externality in need of price adjustment, soil nutrient loss is indicative of necessary cost-shifting in order to realize profit (Kapp, 1978). The result of such cost-shifting is a metabolic rift (Foster, 1999), a fundamental disruption of natural nutrient cycles that reflects how soil depletion has become an inherent consequence of industrial agriculture, disconnecting production from the ecological systems and processes it relies on.

In the following subsections, I present two contrasting perspectives on whether soil nutrient loss is an anomaly that can be solved by internalizing costs or whether soil nutrient loss is systemic to the productive process and in actuality a necessary condition to realize profit under the current political economy.

### **2.3.1 Soil nutrient loss as an external and technical issue**

The expansion of GE soybeans and the adoption of no-till farming, while beneficial in some respects, have not been sufficient to address the underlying issue of nutrient loss and in worst cases land degradation (Bronstein, 2013; Lavado and Taboada, 2009; Pengue, 2005). No-till practices, although effective at reducing erosion, do little to restore lost nutrients. Producers, operating within a system that rewards short-term yields, often avoid investing in the synthetic inputs necessary to replenish soil nutrients, viewing such expenditures as an additional cost rather than an essential investment in the sustainability of their land (Jobbágy et al., 2021).

The lack of synthetic fertilizer rates to counteract nutrient loss is particularly problematic. Synthetic fertilizers, when applied correctly, are argued to be among the most effective tools for replenishing soil nutrients and maintaining agricultural productivity (Fontana et al., 2021; OECD, 2023). However, their underuse in Argentina is driven by several factors, including economic constraints, limited access to credit, and a lack of awareness among producers about the long-term imbalance of soil nutrients. Addressing this issue, according to this mechanistic approach, requires using economic incentives with sustainable practices (Wingeyer et al., 2015).

Within this perspective, soil nutrient loss is predominantly viewed as a technical challenge that exists outside of the core productive process and the result of agroecological conditions, such as yields, meteorological variables, soil conditions, and biological nitrogen fixation rates (Collino et al., 2015; di Ciocco et al., 2011; Portela et al., 2024). From this perspective, nutrient depletion can be effectively managed through targeted interventions, primarily involving technological advancements and market-based solutions. Soil health is regarded as an optimizable component of the production system, where the adoption of innovative technologies—such as precision agriculture tools, improved fertilizer formulations, and GE crops—can mitigate nutrient deficits.

Economic incentives are central to this approach, under the assumption that aligning financial rewards with sustainable practices will encourage farmers to adopt better soil management strategies. Instruments like subsidies for synthetic fertilizers, tax incentives for conservation practices, and payments for ecosystem services are designed to integrate soil health considerations into the economic decision-making processes of producers.

Public and private sectors are seen as pivotal actors in this transition, working together to develop accessible technologies and disseminate knowledge that can enhance nutrient management.

Ultimately, this approach frames nutrient loss as a manageable issue that can be resolved through incremental adjustments. By leveraging economic incentives, policy interventions, and technological development, soil nutrient depletion is positioned as a challenge that can be addressed without disrupting productivity or profitability whilst maintaining the current agrarian system.

### **2.3.2 Soil nutrient loss as systemic**

In the literature on soil nutrient loss in Argentina, few studies have attempted to frame the issue as a systemic and integral aspect of soybean agriculture. Most attempts to do so, largely come from social science perspectives, and lack deep methodological engagement with agronomic and ecological data (Pengue, 2005; Zorzoli, 2021; Zuberaman, 2019).

However, a number of studies have attempted to frame soil nutrient loss as response from institution and behavioral incentives and barriers (Arora et al., 2015; Koritschoner et al., 2023; Leguizamón et al., 2023). Such perspectives challenge the issue of soil nutrient loss as being external to the productive process and instead a critical component, as pointed out by Jobbágy et al. (2021) and Francisco Zazo et al. (2011).

Pengue (2009a, 2009b, 2005, 2004) documented how intensive soybean monoculture, facilitated by GM crops and export-oriented production, has resulted in nutrient depletion at rates far exceeding natural replenishment, among other concerning social-ecological consequences. The lack of crop rotation—a cornerstone of sustainable agricultural practices—has been systematically abandoned in favor of maximizing short-term yields. Nutrient mining, the process by which essential soil nutrients are extracted without adequate replenishment, is central to this model. In several studies over the years, Gustavo Cruzate and Roberto Casas (2017, 2012, 2009) provide evidence that nutrient outflows through soybean exports significantly exceed the inputs from synthetic fertilizers, creating a long-term deficit that undermines soil fertility. These patterns are not incidental but structural, driven by Argentina's integration into global agricultural markets (Díaz de Astarloa and Pengue, 2018; Pengue, 2005; Zuberaman, 2019).

Though the literature on the systemic quality of soil nutrient loss in Argentine soybean agriculture is thin, more general theoretical frameworks such as those analyzing social costs and metabolic rifts, offer insights into the systemic drivers of this consequences of industrial capitalist agriculture. Kapp's (1978) concept of social costs offers a lens through which to interpret these dynamics. Social costs, according to Kapp, are those that

are unaccounted-for in the price of a commodity, the cascading harms and consequences of the productive process that, if internalized, would make realizing profit impossible (see **Paper 1** for a more thorough discussion of Kapp's work and social costs). In Argentina, soil degradation as a social cost is evident in the prioritization of export revenues over the maintenance of regional ecological health. Nutrient loss, while appearing as an unintended consequence, is embedded in the economic logic of monoculture production, where profitability relies on minimizing the immediate costs of replenishing nutrients or restoring soil health. This is grounded in the insights of Jobbágy et al. (2021), who argue that the prioritization of immediate profitability and stable yields over long-term sustainability by Argentine producers has resulted in the reduced use of synthetic fertilizers and the abandonment of mixed-cropping systems—instead they rely heavily on soil nutrient stocks. Moreover, research has shown that, at least in the case of soybeans, intensified production does not limit the geographical expansion of the crop (Hecht, 2005; Neiman and Blanco, 2020). This suggests that increasing productivity often drives further land conversion, exacerbating ecological degradation rather than containing it. Such insights align closely with the central tenet of Jevon's paradox, which suggests that increasing the efficiency of resource use often leads to greater overall consumption of that resource, as the cost savings or productivity gains encourage expanded use rather than conservation (Polimeni, 2008).

I believe John Bellamy Foster's (1999) expansion on Karl Marx's (1992 [1867]) theory of the metabolic rift adds depth to this critique by highlighting the ecological disruptions inherent in capitalist agriculture. The metabolic rift describes the severing of nutrient cycles, where nutrients extracted from the soil are not returned, creating systemic imbalances. In Argentina, the nutrient content embedded in soybeans is exported to consuming nations—notably in the form of protein (Díaz de Astarloa and Pengue, 2018; Guareschi et al., 2019; Lassaletta et al., 2019), essentially mining the soils across Argentina. The reliance on fertilizers fails to replicate the complexity of natural nutrient cycles, resulting in cumulative deficits. Foster's framework situates this disruption as a predictable outcome of agricultural systems designed to prioritize productivity and export over ecological sustainability.

Though, Jason Moore (2017) critiqued Foster's metabolic rift, for its perceived separation of society and nature, arguing that it treats nature as an external domain from which resources are extracted and to which waste is returned. Instead, Moore (2017, 2015) suggested we ought to be reframing nutrient loss as part of capitalism's singularly and inextricable world-ecology. Moore's overall argument would place soil degradation as an intrinsic feature of the appropriation of "cheap nature," where ecological re-

sources, including soil fertility, are systematically exploited to sustain capital accumulation. However, while Moore offered valuable insights into the interconnectedness of economic and ecological systems, his approach risks obscuring the specific material dynamics of soil nutrient loss, which Foster's framework more directly addresses. Moreover, it risks diluting the specificity of soil nutrient loss by subsuming it into broader narratives of capitalist appropriation. Foster's theory is more theoretically apt for understanding soil nutrient loss because it directly addresses the measurable and specific disruptions to nutrient cycles caused by industrial agricultural practices, such as those seen in Argentina's soybean production.<sup>7</sup>

## 2.4 Lacunae in the historical, regional, and structural studies of Argentine soybean agriculture and soil nutrient loss

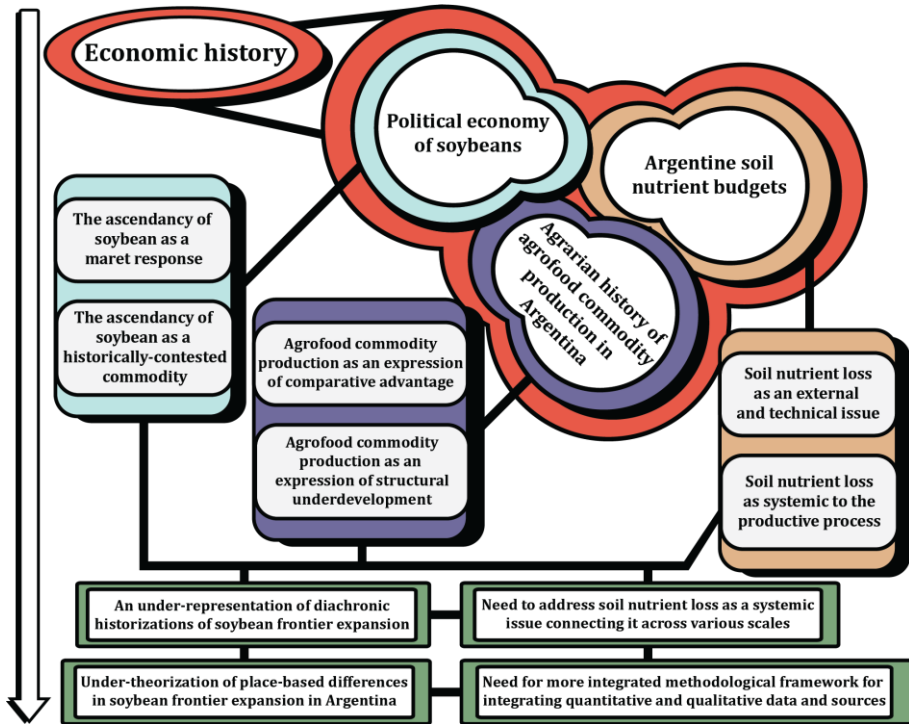
The previous three subsections have mapped critical debates within the state-of-the-art, which are central to the aim of this dissertation. Building on these insights, I propose four overarching lacunae in the literature that warrant further exploration. These include: an under-representation of diachronic historizations of soybean frontier expansion, a need to address soil nutrient loss as a systemic issue connecting it across various scales, an under-theorization and insufficient comparisons of place-based differences in soybean frontier expansion across Argentina, and a need for more integrated and rigorous methodological frameworks for bridging disciplines as well as integrating quantitative and qualitative data and sources for studying soybean expansion and soil nutrient loss (**Figure 4**).

First, the literature remains underdeveloped in addressing how historical processes of agrarian capitalism have shaped and continue to shape the social-ecological dynamics of soybean frontier expansion as it relates to earlier phases of agrofood commodity production. While there is extensive documentation of soybean's rise as a global commodity, these accounts often emphasize technological innovation or market integration without tracing the deeper historical continuities that underpin these developments or how *sojización* in and of itself may be radically different from anything that has happened before. For example, the shift from wheat to soybean as Argentina's primary agricultural export is not a simple story of changing markets or natural endowments but a reorganization of extraction and labor shaped by historical land-use patterns, globalized economic pressures, and

---

<sup>7</sup> I engage with this debate more deeply in **Section 3.1** where I attempt to reconcile these approaches by drawing on their relative strengths.

internal political strife. History, then, ought to be framed as a force that actively defines the present rather than being relegated as simple context.



**Figure 4. Stages of the literature review.** Departing from the general field of economic history (rust orange), I reviewed three interrelated bodies of literature: the political economy of soybeans (blue), the agrarian history of agrofood commodity production in Argentina (purple), and Argentine soil nutrient budgets (tan). From each body of literature, I identified two competing fault lines. The bottom panel present four main lacunae in the literature (green) also identified as a result of the review. Figure created by author.

Second, while the framing of soil nutrient loss as a systemic issue is compelling, the literature falls short in capturing how global forces—such as trade inequities, land commodification, and historical patterns of resource extraction—specifically drive subnational nutrient loss dynamics. Although the structural roots of nutrient loss are well-documented, little attention is paid to the mechanisms that translate these overarching forces into specific regional outcomes, leaving the dynamics of ecological degradation across different contexts insufficiently understood.

Third, subnational disparities in the impacts of soybean expansion are well-recognized but insufficiently analyzed. The intensive agricultural practices in the Pampas sharply contrast with the Dry Chaco's frontier expansion, marked by deforestation, ecological damage, and social displacement. However, these contrasting dynamics are often treated in isolation

rather than examined in tandem to reveal how global pressures intersect with regional ecological and economic conditions, producing uneven patterns of degradation. This lack of comparative analysis obscures the complexity of regionally specific processes within broader systemic contexts.

Finally, there is a noticeable disconnect between the biophysical studies of soil nutrient loss and the political-economic analyses of global trade and power dynamics. On one side, agronomic research meticulously quantifies nutrient extraction, while on the other, political economy scholarship critiques the inequalities embedded in agricultural systems. Rarely are these perspectives integrated to show how nutrient loss is both a measurable biophysical process and a historically-formed issue tied to global trade systems. This fragmentation limits the ability to fully understand the causes and consequences of soil nutrient loss within the broader context of agro-food globalization.

### **2.4.1 Situating this dissertation**

These gaps illustrate the need for approaches that connect historical, regional, structural, and social-ecological dimensions. Addressing these lacunae is not just a matter of filling in blanks but of challenging the assumptions and blind spots that have shaped the study of soybean agriculture, globally and within Argentina. It is exactly here in the gaps within the literature that this dissertation attempts to nestle itself into.

In the scholarship concerning the political economy of soybeans, mainstream narratives emphasize market efficiency, technological innovation, and comparative advantage as drivers of soybean expansion. Critical scholarship, however, highlights how global trade asymmetries, extractive logics, and neo-extractivist dynamics shape the structural conditions of production. While these debates provide valuable insights into global drivers, they often overlook how historical agrarian structures mediate these pressures at the regional level. The agrarian history of agrofood commodity production in Argentina focuses on the long-term transformations of agricultural frontiers, highlighting cycles of expansion, enclosure, and intensification. Yet, these analyses have largely missed the opportunity to connect historical agrarian transformations with contemporary regional variations in soybean production. In the scholarship on Argentine soil nutrient budgets, biophysical studies quantify nutrient extraction and loss but often isolate these processes from their historical and structural drivers. Critical perspectives emphasize that soil nutrient loss should not be framed as a technical failure or externality but as a systemic feature of the soybean production model. However, these perspectives rarely comparatively address subnational differentiation in how these dynamics play out.

Across these three overarching areas of scholarship and the critical debates therein, I have proposed four key gaps: an under-representation of diachronic historizations of soybean frontier expansion, a need to address soil nutrient loss as a systemic issue connecting it across various scales, an under-theorization and insufficient comparisons of place-based differences in soybean frontier expansion across Argentina, and a need for more integrated and rigorous methodological frameworks for bridging disciplines as well as integrating quantitative and qualitative data and sources for studying soybean expansion and soil nutrient loss. By engaging these fault lines and addressing these gaps, this dissertation demonstrates that soybean frontier expansion and soil nutrient loss are not isolated processes but co-constituted outcomes of historical transformations, political-economic pressures, and ecological vulnerabilities. Specifically, **Paper 1** addresses these gaps by demonstrating how nitrogen loss is not simply an ecological problem but an embedded social cost of Argentina's export-oriented production model, shaped by political-economic imperatives—as showcased by an analysis over a fifty-year period and across the entire Pampas ecoregion. **Paper 2** tackles these gaps by comparing historical wheat and contemporary soybean frontiers, showing how historical modalities of frontier expansion—broadening, deepening, and flexibly shifting—continue to shape regional patterns of production and resource use, further expanding the historical and subnational analysis of the dissertation. **Paper 3** bridges disciplines as well as quantitative and qualitative data by calculating soil nutrient budgets for nitrogen, phosphorus, and sulfur for the subnational case studies, revealing how structural constraints and historical patterns produce uneven regional outcomes.

The following sections outline the overarching theoretical and methodological frameworks that this dissertation uses to navigate these challenges and contradictions and achieve its aim of understanding historical processes and place-based factors.



### 3. Systemic perspectives and analytical lenses

Throughout this dissertation, I have directly and indirectly drawn on various theories to frame and analyze the expansion of *sojización* throughout the Argentine countryside and the negative social-ecological consequences that result from it, specifically variegated patterns of soil nutrient loss. While the haphazard use of multiple theories risks eclecticism, I believe the frameworks utilized across **Papers 1, 2, and 3** not only offer unique insights—addressing different aspects of the issues at hand, but coalesce into a greater whole that provides a more systemic understanding of commodity frontier expansion dynamics, soil nutrient loss, and the roles of history and place as powerful drivers. My intention has always been to leverage the strengths of each theory to address the complexity of such systemic research, cognizant of any potential pitfalls of each paper’s framework and of interdisciplinary research more generally.

#### 3.1 Towards a systemic understanding of *sojización* in Argentina

To understand the expansion of commodity frontiers and the persistence of soil nutrient loss in Argentina, I believe a systemic approach to economic history is indispensable—one that recognizes the intertwined nature of human societies and the ecological systems that sustain them, while grappling with the structural forces that drive degradation. Moore’s (2015) world-ecology approach offers a provocative entry point, framing capitalism as a historical process that reshapes human and more-than-human natures in service of presumed endless accumulation. This perspective dissolves the false dichotomy between human societies and nature, viewing them as co-constituted through the relations of production. Support for this is perhaps best represented by the historical emergence of the Anthropocene as new geological epoch, signaling the profound human influence on the planet where disruptions to biogeochemical cycles, biodiversity, and climate are but only some of the material imprints of human social systems on the Earth.

Yet, as Alf Hornborg (2023a, 2023b, 2019) has critically argued in many iterations, the world-ecology framework, while ambitious, risks undermining its analytical strength through its tendency to conflate the reality of material processes (ontology) with the ways we conceptualize and interpret them (epistemology) where the dissolution of the boundary between society and nature into a totalizing “web of life” generates dialectical confusion—a critique fundamentally rooted in critical realism (see: Bhaskar (2008 [1975])). Hornborg (2023a, 2023b) has further emphasized that materiality ought to be centralized as an analytical lens in economic history research, arguing that the biophysical flows of energy and raw materials are not external to historical processes but fundamental to understanding asymmetrical relations inherent to global capitalism.

I argue that these critiques are relevant for understanding *sojización* in Argentina. While the world-ecology perspective offers an important contribution into fostering an understanding of the systemic nature of capitalist expansion, I find its analytical fluidity problematic when addressing the historical and material specificity of processes like soil nutrient loss—the materiality of nitrogen, phosphorus, and sulfur as embodied biophysical resources integrated in asymmetrical trade relations. For example, the dynamics of *sojización* should not be reduced to abstract entanglements of human and more-than-human natures. Instead, I find it more useful to understand these dynamics as being mediated through concrete historical and structural forces, such as the asymmetries of global trade, the historical trajectories of land tenure, and the material cycles of nutrient extraction and depletion.

In this way, Foster’s (1999)—along with Brett Clark and Richard York (2009; 2011)—concept of the metabolic rift offers a sharper analytical lens to address this gap. Building on Marx’s ecological insights, Foster articulates how capitalist production ruptures the metabolic interactions between human societies and ecological systems, severing historical flows of nutrients and energy that sustain both—a rupture that echoes critiques of industrial disruption by earlier writers such as Barry Commoner (1971) and Donald Worster (1990). These rifts are windows into the alienation of societies from the ecological conditions of their existence; refracted via commodity fetishism (see: Marx, 1992 [1867]). More perceptibly, a metabolic rift has materialized vividly in Argentina’s soybean agricultural model, where export-oriented monoculture has eroded—and continues to erode—the social foundations of agrarian life as well as extract vital nutrients from the soil.

While often portrayed as antagonistic, the analytical concepts of world-ecology and metabolic rift need not be mutually-exclusive. Instead, they simply attempt to reconcile the long-standing onto-epistemological debate between *humans-and-Nature* and *humans-in-Nature* in different ways,

fundamentally addressing different research questions and aims. For example, Mindi Schneider and Philip McMichael (2010) have attempted to harmonize these approaches by arguing that metabolic rift should incorporate the world-ecology framework's relational perspective on capitalism and nature while addressing its limitations by emphasizing farming practices and local agroecological knowledge. They contend that repairing the metabolic rift requires not only recognizing capitalism's historical restructuring of social-ecological relations but also engaging with food sovereignty movements as a practical means to reunite social and ecological processes. Discussed later in this section, the concept of commodity frontiers offers another useful harmonization of world-ecology and metabolic rift by framing the expansion of capitalism as a continuous process of relocating social-ecological ruptures to new territories, thereby linking the historical-geographical restructuring emphasized in world-ecology with the systemic disruptions in social metabolism highlighted by metabolic rift.

### 3.1.1 Social-ecological systems

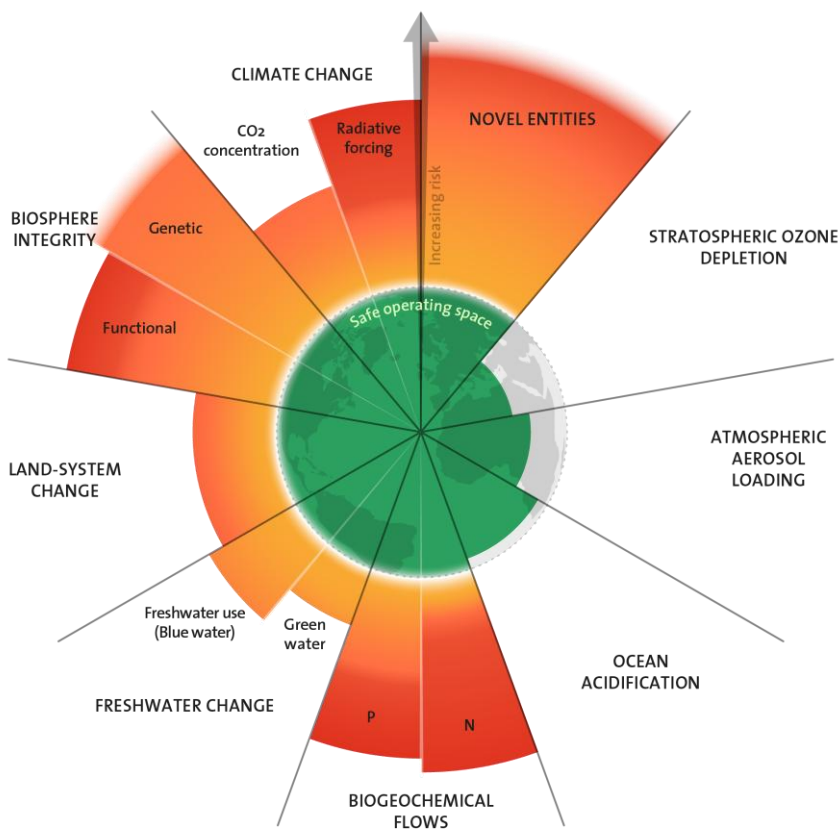
To ground these insights in a more comprehensive systemic understanding, I draw on the concept of social-ecological systems (Berkes et al., 2002). This perspective emphasizes the inherently coupled and dynamic relationships between human societies and ecological processes, emphasizing their interdependence, complexity (for example, non-linearity and presence of multiple drivers) and interaction across scales (Levin et al., 2013). Resilience thinking, explores how social-ecological systems deal with change and continue to develop, sometimes persisting, sometimes adapting, and sometimes even transforming to turn crises into opportunities (Biggs et al., 2015). This perspective nuances the understanding of Argentina's *sojización* by illustrating how agricultural expansion was not a linear or predetermined process but one shaped by agrarian policies, market dynamics, and technological shifts. These interacting forces drove responses that reinforced ecological degradation and social inequalities, revealing how systems can become locked into unsustainable trajectories over time (Schlüter et al., 2019).

Applying this social-ecological systems perspective allowed me to analyze how the expansion of soybean agriculture in Argentina operates through the continuous interaction of social forces and ecological processes. This approach captures the interdependent nature of *sojización*, where social decisions about land use, production models, and economic incentives directly shape, and are shaped by, ecological outcomes (for example the direct and indirect social costs of *sojización* explored in **Paper 1**). In this view, soil nutrient loss emerges not as a technical or external

issue but as a structural consequence of Argentina's integration into global commodity markets and the intensification of agrarian capitalism.

Moreover, adopting a social-ecological systems perspective prompted me to account for multiple scales. While this dissertation primarily takes a subnational regional focus, I am aware that *sojización* in Argentina is intricately linked to the transformations of the broader global agrofood system, where agricultural intensification, industrialization, financialization, and transnationalization have all accelerated since the 1950s (Baraibar Norberg and Deutsch, 2023, p. 156)—deeply embedded in patterns of the Great Acceleration (McNeill and Engelke, 2016) and the logic of neoliberal development (McMichael, 2009). By substituting labor and traditional forms of land use with technologies such as GE crops, synthetic inputs, advanced machinery, and digital tools, this global shift has fundamentally reshaped agricultural landscapes around the world (Flachs, 2020; Robinson, 2018, p. 138). These structural patterns of agrarian development tend to promote ecological simplification, the peripheralization of agricultural production away from sites of consumption—instituting a world-systemic division of labor, and the widening of rifts between human societies and nature (Foster, 1999; Wallerstein, 1974; Worster, 1990). At the planetary level (**Figure 5**), these rifts have widened so drastically that six of nine processes identified as being critical for maintaining the stability and resilience of human societies within the Earth system have been transgressed and pose severe social-ecological risks (Richardson et al., 2023). Through a social-ecological systems perspective, then, it is possible to understand that nitrogen and phosphorus soil nutrient loss in the Argentine countryside cascades and becomes embedded in global patterns of agricultural development that have contributed significantly to the disruption of nitrogen and phosphorus biogeochemical cycles (de Vries et al., 2013; Gorman, 2013; Sandström et al., 2023).

However, social-ecological system frameworks have been rightly critiqued for under-theorizing political and historical factors—often abstracting systems from the power relations and historical trajectories that give them shape (DeVerteuil and Golubchikov, 2016; Fabinyi et al., 2014; Håkansson, 2019; Stojanovic et al., 2016). For example, a social-ecological systems approach might describe the feedback loops driving soil degradation but fail to situate these loops within the historical patterns of land tenure or the unequal flows of global trade. By neglecting the structural conditions of agrarian capitalism, such frameworks risk obfuscating embedded social relations, fetishizing systems as self-contained rather than shaped by historical forces and power dynamics. Additionally, social-ecological system approaches risk veering into overcomplexity if proper system boundaries are not delineated.



**Figure 5. Status of the Planetary Boundaries (2023).** Six of the nine Planetary Boundaries are in the high-risk zone, indicated by an increasing gradient of light to dark orange: Novel entities, Climate change, Biosphere integrity, Land-system change, Freshwater change, and Biogeochemical flows. Three Planetary Boundaries remain in the safe operating space, in green: Ocean acidification, Atmospheric aerosol loading, and Stratospheric ozone depletion. Figure by Azote for Stockholm Resilience Centre, based on analysis in Richardson (2023). Licensed under CC BY-NC-ND 3.0.<sup>8</sup>

To address these critiques, scholars have sought to integrate systems perspectives, including resilience thinking, with economic history (Barai-bar Norberg and Deutsch, 2023; Langthaler et al., 2023; Myrdal, 2022), agrarian political economy (Bernstein, 2016; Buttell, 2001; Pain et al., 2021) and political ecology (Börjeson, 2014; Ernstson, 2013; Håkansson and Widgren, 2016; Peterson, 2000). I believe it is necessary to employ focused analytical lenses, rooted in critical realism, that disentangle the structural and historical dynamics of social-ecological systems while

<sup>8</sup> <https://creativecommons.org/licenses/by-nc-nd/3.0/>

defetishizing the commodity relations at their core. Critical realism provides a dual perspective: it acknowledges that reality exists independently of human perception, yet it also recognizes that our understanding of this reality is socially and historically mediated.

The soybean itself serves as one such lens. As both a crop and a commodity, the soybean embodies the intersections of global trade, agrarian transformation, and ecological disruption. This lens is put into use across all three papers.

Focusing on the expansion of commodity frontiers has also provided another lens to reduce the complexity of the social-ecological systems framework across **Papers 1, 2, and 3**. This lens, as it has been employed throughout this dissertation, is deeply rooted in political ecology and the historical and geographical insights of the French Annales school, namely the work of Marc Bloch (2015 [1931], 1992 [1949], 1967 [1928]). Political ecology, in this sense, emerges as a guiding theoretical approach that interrogates the historical and geographical configurations of power, labor, and resource extraction in shaping commodity frontiers. Through its lens, the expansion of frontiers is revealed as neither natural nor inevitable but as a deeply historical political process of territorial appropriation, capturing the dual processes of "broadening"—the incorporation of new lands into the circuits of capital—and "deepening"—the intensification of resource extraction and production on already commodified land—and the oscillation between the two.

Together, these lenses—soybean as commodity and frontier expansion as process—have allowed me to examine the coupled relations of human societies and nature with greater specificity and analytical consistency. They illuminate how the social-ecological system of Argentine soybean production operates within and is shaped by the broader dynamics of global capitalism. As discussed in the following subsections, these lenses also reveal how historical trajectories of agrarian development, such as the prior expansion of the wheat frontier, continue to shape the logics and outcomes of contemporary soybean production. By situating soil nutrient loss within these broader processes, this dissertation moves beyond abstract accounts of system complexity to a more grounded understanding of how specific historical, social, and ecological forces interact.

## 3.2 The soybean as a lens

The theoretical framework of using soybeans as an analytical lens in this dissertation draws on multiple intersecting traditions and examples throughout the wide-corpus of commodity studies and histories. Particularly, the works on soybeans by Baraibar Norberg and Deutsch (2023) and

Langthaler (2020; 2023) have been critical sources of inspiration for the novel integrations of mixed-method and interdisciplinary economic history research designs. Importantly, both Baraibar Norberg (2022) and Langthaler and Schüßler (2019) as well as Berndt et al. (2020) engage with the work of Karl Polanyi (1944) to reject historical determinism highlighting that commodification is never fixed, but instead a transitional phase—which has also been particularly inspirational. For this dissertation, I indirectly draw on Marx’s (1992 [1867]) notion of commodity fetishism as the foundational critique departing from these studies, emphasizing how the current political economy of producing, distributing, and consuming commodities obscures the historical social-ecological relations that produce them. By examining soybeans from this point of departure, the studies presented in **Papers 1, 2, and 3** contribute to a unified theoretical framework that defetishizes the commodity and situates it within broader systems of global capitalism, agrarian change, and social-ecological crises to address the overall aim of understanding how historical processes and place-based factors influence soybean commodity frontier expansion and soil nutrient loss in the Argentine countryside. Soybeans, as analyzed in the three papers, exemplify this dynamic by going beyond the understanding of the legume as only an agricultural output and global market input, instead they are understood as being laden with historical and social-ecological contestation underpinning their production.

Building on this foundation, the three papers collectively extend the lens of soybeans to incorporate Moore’s (2000) concept of the commodity frontier, which argues that the relentless drive for capital accumulation pushes agricultural systems into new ecological, geographic, and technological frontiers. **Paper 2**, for example, situates soybeans as both drivers and products of this frontier expansion, demonstrating how their cultivation has intensified agricultural systems (deepening) while simultaneously extending agriculture into new territories (broadening) (Banoub et al., 2021; Carlson, 2001; Kröger and Nygren, 2020; Langthaler, 2020).

The soybean lens is further refined through the integration of a political-ecological approach, which interrogates the scalar tensions and systemic contradictions inherent in modern commodity production. Political ecology critiques the reductionist framing of ecological issues as isolated from political-economic systems, emphasizing instead their entanglement with global trade, history, and place-based dynamics (Watts, 2021). While a political-ecological approach serves as a guiding framework for the research designs of **Papers 1 and 2**, **Paper 3** applies this perspective explicitly, revealing how the production of soybeans shifts social costs, such as soil nutrient loss and deforestation, and that global market pressures and historical structures reinforce these dynamics and make them difficult to resolve.

What unifies the theoretical contributions of these papers is their shared commitment to defetishizing soybeans and situating them within the historical and structural processes of agrarian capitalism. The social costs and interpretive framing of **Paper 1**, the integration of active history and commodity frontiers in **Paper 2**, and the application of social costs and political ecology in **Paper 3** converge to create a robust framework that bridges multiple scales of analysis—from subnational land use and land cover changes in the Argentine countryside to the global systems of trade and consumption that are formative of them.

Through this unified framework, **Papers 1, 2, and 3** contribute to addressing the identified research gaps in the literature review (**Section 2.4**) by integrating historical, regional, and systemic analyses to illuminate how the interplay of agrarian capitalism, place-based social-ecological conditions, and global trade dynamics shape both the expansion of the soybean commodity frontier and the regional processes of soil nutrient loss in Argentina. This approach bridges disciplinary boundaries and methodological divides (explored in the subsequent **Section 4**), offering a coherent framework that captures the interconnectedness of historical forces, subnational disparities, and biophysical changes within the broader context of agrofood globalization. Soybeans, like other commodities such as sugar, coffee, maize, or cotton, encapsulate the contradictions of global capitalism, from their fetishized economic form to their social-ecological impacts. By defetishizing soybeans and embedding them within these theoretical traditions, this dissertation can not only deepen our understanding of agrarian capitalism but also provide critical insights into the historical and systemic pressures shaping the modern world.

### 3.3 The historical and geographical dimensions of commodity frontiers

Frontiers have long captivated scholars of economic history, and within the social science more generally, because they represent dynamic zones of incorporation where the forces of labor, land, and capital converge, offering fertile ground to explore the expansion of markets—and capitalism more specifically, resource extraction, and the reorganization of social and economic systems. Frederick Turner’s (1994 [1920]) frontier thesis framed the expansion of agricultural frontiers as central to American development, emphasizing the role of “free land” and the frontier as a site of democratic innovation. While seminal, this perspective has been critiqued for its linear and geographically deterministic nature. Rosa Luxemburg (2003 [1913]) extended this discourse by illustrating how capitalist systems rely on the

incorporation of non-capitalist spaces to sustain accumulation, providing an early articulation of frontiers as zones of extraction and exploitation. Barbier (2010), further develops a theoretical understanding of frontiers that underscores that they are historically hinged on the availability of abundant land and resources, but as frontier lands are exploited, the deterioration of essential ecological functions creates a growing relative scarcity of natural services. This dynamic not only highlights the negative social-ecological consequences of economic growth but also positions frontier exploitation as a fundamental driver of both development and ecological crises.

Understanding these historical and theoretical foundations helps contextualize the dynamics at play in Argentine frontier expansion, particularly the ways in which capitalism appropriates and reorganizes new spaces for extraction and production, often through violent dispossession and the exploitation of ecological systems. In other contexts, such processes have been analyzed through the conceptual lens of commodity frontier expansion—first posited by Moore (2000) and later expanded upon by others (Banoub et al., 2021; Beckert et al., 2021; Berg, 2021; Findlay and O’Rourke, 2021; Langthaler, 2020; Mostern, 2021; Watts, 2021).<sup>9</sup> The concept of commodity frontiers captures the expansion of capitalist systems into new territories, where land, labor, and natural resources are integrated into global circuits of production and exchange (Beckert et al., 2021). These frontiers represent spaces where existing social and ecological relations are fundamentally reorganized to align with the logic of capital accumulation. This expansion is not limited to economic incorporation but entails widespread ecological change, including deforestation, soil degradation, and biodiversity loss; powerfully linking the concept with the theoretical logic of metabolic rifts.<sup>10</sup>

In Argentina, few studies have adopted a commodity frontier lens to analyze the expansion of commodity soybean and those that have, have only been published in recent years and span large theoretical and methodological divides (Blum et al., 2022; del Giorgio et al., 2022; le Polain de Waroux et al., 2018; Magliocca et al., 2022; Rocha et al., 2022). Largely, however, these studies subscribe to the comparative advantage narrative of agricultural expansion in Argentina and under-theorized history as an es-

---

<sup>9</sup> The Commodity Frontier Initiative is “a network of scholars, research teams, artists, and civil society organizations from all over the world” that specifically focus on commodity frontiers, “working extensively on global commodity production, rural societies, labor history, the history of capitalism, and social and ecological frictions and capitalist fixes in the global countryside”. <https://commodityfrontiers.com/>

<sup>10</sup> Despite their strong criticisms of Moore’s world-ecology, Hornborg (2023b) also finds the commodity frontier conceptually useful and well-aligned to more structural analyses.

sential factor. Moreover, the commodity frontier concept is almost exclusively applied to the expansion of soybean agriculture into the Dry Chaco ecoregion, neglecting that expansionary processes are still occurring in the Pampas. To dive deeper into these dynamics and contribute to this growing body of scholarship, I have drawn inspiration from The French Annales School which offers a critical theoretical foundation for understanding how history and geography—time and place—intersect to shape the dynamics of frontier expansion to better understand these processes as they are rooted in the expansion of global capitalism.

The French Annales School approached the study of history by rejecting narrow event-driven narratives in favor of holistic analyses that incorporate enduring structures, conjunctural shifts, and sudden events. Bloch's (2015 [1931], 1992 [1949], 1967 [1928]) nuanced understanding of historical continuity and rupture underscores that transformative moments are always embedded within deeper, long-term patterns of socio-ecological organization. Braudel (1958) expanded upon this foundation with his concept of the *longue durée*, situating historical transformations within the enduring material and ecological forces that shape human society. These insights, when applied to frontier expansion, foreground the ways in which frontiers emerge as products of long-term processes, deeply rooted in the histories of agrarian development, land tenure systems, and ecological processes. Frontiers, from this perspective, are not only sites of economic activity but historical configurations shaped by temporal rhythms that stretch far beyond immediate contexts.

For Bloch (2015 [1931], 1992 [1949], 1967 [1928]), history is not a sequence of discrete moments but a continuous interplay between long-term structures and short-term ruptures. Time is not homogenous; it moves at different speeds, with some processes operating as deep currents shaping social-ecological systems, while others are rapid and contingent, tied to political-economic or ecological ruptures. In the context of soybean frontier expansion, these temporalities are embedded in the soil itself—slow ecological rhythms of fertility and nutrient cycles intersect with medium-term patterns of agrarian development, such as technological adoption and land-use change, and with short-term fluctuations driven by global market dynamics, such as the almost universal and instantaneous adoption of the GE soybean technological package by Argentine soybean producers and movement away from mixed crop-livestock rotations after 1996 as well as annual price fluctuation for seed, inputs, and land. Time, in this sense, is not an abstract backdrop but an active force materialized in the landscape and agricultural systems in the Argentine countryside.

Place, as articulated by Bloch, is equally dynamic. It is not a static container for historical processes but a relational field shaped by the interplay of natural conditions, historical decisions, and social organization. In the

case of soybean agriculture, place is defined not only by ecological factors such as soil quality, rainfall variability, and climate, but also by the historically rooted land tenure arrangements and agrarian structures that mediate the adoption of production technologies and demands of global trade. This study draws on these insights to examine how the divergent historical trajectories of the two subnational case studies, Southern Córdoba and Eastern Santiago del Estero, have produced distinct expressions of soybean frontier expansion—deepening in the former and flexible shifting in the latter. These are not arbitrary outcomes but historically and spatially embedded processes shaped by the interplay of time and place.

By framing time and place as active, intertwined forces rather than passive backdrops, the French Annales School provides a theoretical scaffold for analyzing soybean frontier expansion in Argentina. It allows this study to move beyond simplistic narratives of technological inevitability or market determinism, instead revealing how the material conditions of the landscape, historical legacies, and global economic pressures coalesce to produce regionally specific outcomes in Southern Córdoba and Eastern Santiago del Estero. This perspective positions frontier expansion as a historically contingent and spatially differentiated process—one in which time and place are inseparable in shaping both social and ecological transformations.

### **3.3.1 The frontier dynamics of deepening, broadening, and flexibly shifting**

By integrating the insights of Bloch, this framework underscores the importance of history and place as dynamic and interwoven forces in the production of frontiers. However, Bloch never explicitly studied commodity frontiers, and therefore never articulated a means of understanding their dynamics across time and space. Commodity frontier analysis as implemented by Langthaler (2020) delineates three interrelated modalities of frontier expansion: deepening, broadening, and flexibly shifting. These modalities describe how commodity frontiers expand through the incorporation of new lands into production (broadening), the intensified exploitation of existing lands via technological and organizational changes (deepening), and the adaptive reconfiguration of production processes between broadening and deepening in response to shifting conditions and market demands (flexibly shifting).

**Papers 2 and 3** provide empirical examples of these dynamics in the context of soybean expansion in the Argentine countryside. Southern Córdoba exemplifies deepening, where technological innovations such as GE seeds and no-till practices intensify production on already commodified

land. Broadening in Eastern Santiago del Estero has involved the conversion of forests and marginal lands into soybean monocultures. This process, as detailed in **Paper 2**, aligns with Barbier's (2010) insights into scarcity-driven expansion and Turner's (2015 [1920]) notion of frontier zones as spaces of opportunity and conflict.

However, throughout time, commodity frontiers in Argentina—and according to Langthaler (2020) in the Brazilian *Cerrado*—have flexibly shifted between these modalities, which, highlighted in **Papers 2 and 3**, illustrates the adaptive strategies of agrarian capitalism. Modern interpretations of commodity frontiers reject deterministic models, emphasizing the non-linear and contingent nature of frontier dynamics. **Papers 2 and 3** demonstrate how historical legacies, global trade pressures, and regional social-ecological conditions interact in unpredictable ways. For instance, the neoliberal reforms of the 1990s catalyzed the soybean boom, yet these changes were mediated by pre-existing land use patterns and land tenure conflicts.

## 4. On mixed-methods and sources

The methodological framework developed for this research integrates diverse approaches to address the complexities of soybean commodity frontier expansion and its social-ecological consequences in Argentina, focusing largely on soil nutrient loss. By combining quantitative and qualitative analyses, the framework strives to provide a holistic understanding of the relationships between global trade dynamics, regional agrarian structures, and soil nutrient loss. Each paper included in the dissertation employs specific methods tailored to their respective research questions (see **Section 1.3**), yet all are unified by an overarching comparative framework, which facilitates the investigation of historical processes and place-based factors influencing soybean expansion—though as will be discussed in the next subsection, **Paper 1** was not a comparative study on its own. The approach taken across this dissertation, I believe, is best summed up as a mixed-method research design.

For reference, **Paper 1** uses a simple nitrogen mass balance method to analyze asymmetric nitrogen flows in the Pampas over five decades (1970–2021). It quantifies nitrogen loss and highlights the associated unaccounted-for social costs using Kapp’s (1978) theory of social costs. **Paper 2** proposes a novel comparative frontier approach, investigating historical continuities and ruptures in agrarian capitalism by contrasting the different periods of wheat and soybean expansion in both Southern Córdoba and Eastern Santiago del Estero. Finally, **Paper 3** integrates nutrient budget calculations for nitrogen, phosphorus, and sulfur with an interpretive framing rooted in political ecology to examine subnational regional disparities in soil nutrient loss and why these are difficult to resolve. Together, these studies provide complementary perspectives on the drivers and consequences of soybean expansion, elucidating the interconnectedness of biophysical, historical, and political processes.

Much like the specific theories applied and their justifications are discussed within each paper, so too are the methodological frameworks. Therefore, they are not presented nor discussed anew in this section. Instead, in the following subsections, I present the overarching “red thread” methodological approach of the dissertation, briefly discussing how the specific methods of nutrient budgets, expert interviews, and interpretive

framings were used across studies, and the benefits and challenges of integrating quantitative and qualitative data.

#### 4.1 Meso-scale comparative approach

Thinking more abstractly about a methodological “red thread” that connects the overall research design of this dissertation, I propose that the different methods, sources, and operationalizations of theory found across the three papers can be synthesized into what I call a meso-scale comparative approach. This framework serves as both an umbrella and unifier, designed to address the overarching research aim: to understand how historical processes and place-based factors influence soybean commodity frontier expansion and soil nutrient loss. This approach focuses on the meso-level, bridging macro-level global trends with micro-level local, or even farm level, variations. It highlights the historical, ecological, and political-economic dimensions of soybean agriculture, situating regional outcomes within broader systemic forces.

This dissertation holds the assumption that understanding how subnational specificities shape and are shaped by the consequences of broader global forces, like the extractive aspects of agrofood globalization and expansion of commodity frontiers, requires a meso-scale focus. Doing so, serves as a response to the pitfalls of methodological nationalism, which often compresses the diversity of local and regional histories and social-ecologies into oversimplified national narratives. As Wood et al. (2023) highlight, the dichotomy between local and global food systems often oversimplifies the complex, cross-scale interactions that define agricultural production and ecological outcomes. Their critique underscores how local production systems are often embedded within and shaped by global supply chains, challenging assumptions that local systems are inherently more sustainable or resilient. This perspective reinforces the need to analyze agrofood commodity frontier expansion, such as Argentina’s soybean frontier, through frameworks that account for both global capitalist pressures and local socio-ecological dynamics, where the regional, the meso-scale, provides a crucial lens for understanding how these forces interact and unfold. Drawing inspiration from Bloch’s (2015 [1931], 1967 [1928]) insistence on examining historical processes at regional scales, the three papers within this dissertation collectively aim to address the roles of history and place in shaping the varied consequences of *sojización*.

However, individually, only **Papers 2 and 3**, are explicitly comparative in their methodology. **Paper 1** concentrates on the Pampas, using a nitrogen mass-balance methodology to analyze five decades of nitrogen flows

and their social-ecological consequences. Though it lacks explicit comparative elements, its integration into the overarching framework lies in its focus on how global trade asymmetries manifest at the meso-scale site of production. By employing Kapp's (1978) theory of social costs, the paper elucidates the unaccounted-for and hidden consequences of nitrogen loss, differentiating between first-order costs (directly resulting from nitrogen extraction) and second-order costs (stemming from attempts to mitigate nitrogen limitations). This focus on the regional outcomes of global processes exemplifies the meso-scale framework's emphasis on connecting subnational biophysical outcomes to broader structural forces.

The limitations of **Paper 1** in addressing regional variability are counterbalanced by the explicitly comparative scope of **Paper 2** which investigates the modalities of frontier expansion in Southern Córdoba and Eastern Santiago del Estero, respectively representing the Pampas and Dry Chaco ecoregions, contrasting the historical wheat frontier (1872–1937) with the contemporary soybean frontier (1970–2019). Drawing from Langthaler's (2020) framework, the study examines how the forms of production (the seeded area of key crops and the share of land cover by crops, pastures, forests and shrublands, and other coverage) and social relations (land tenure estimates) evolved or ruptured in each region. In this framework, the modalities of frontier expansion—broadening into new lands, deepening the use of already commodified landscapes, or flexibly shifting between these processes—highlight diverse pathways that agrarian development can take as they are shaped by regional histories and social-ecological conditions. These frontier dynamics are non-linear and not historically predetermined; instead, they evolve through periods of opening, collapse, re-opening, or closure, shaped by long-term structural patterns and short-term contingencies (Bloch 2015 [1931], 1967 [1928]; Kröger and Nygren, 2020). The comparative lens of **Paper 2** extends the meso-scale framework by situating soybean expansion within a continuum of frontier dynamics, demonstrating that regional variability is critical to understanding the broader patterns identified in **Paper 1**.

**Paper 3** builds on the insights of **Paper 2** to examine regional disparities in nutrient loss between the Southern Córdoba and Eastern Santiago del Estero. Using nutrient budget calculations for nitrogen, phosphorus, and sulfur, **Paper 3** reveals how ecological conditions, global market pressures, and historical changes to the agrarian structure shape soil nutrient loss and limit replenishment. These findings underscore the importance of place-based factors in shaping biophysical outcomes, aligning with the meso-scale framework's emphasis on regional differentiation. By comparing the social-ecological consequences of soybean expansion, **Paper 3** complements the regional focus of **Paper 1** and the historical analysis of **Paper 2**, creating a more comprehensive understanding of soybean frontier

dynamics. This integrative approach not only enhances the coherence of the research design but also contributes to theoretical debates in agrarian political ecology—and commodity frontier studies more generally, offering valuable insights into the systemic challenges of sustainable agriculture and rural development in Argentina.

#### 4.1.1 Nutrient budget calculations

Nutrient budgets are central to **Papers 1 and 3**, providing a quantitative basis for understanding the biophysical outcomes of soybean expansion. These budgets estimate the balance between nutrient inputs (for example, fertilizers, atmospheric deposition, biological nitrogen fixation) and outputs (for example, nutrient removal in harvested grain, emissions, runoff) in soybean production systems. By comparing nutrient budgets for nitrogen, phosphorus, and sulfur across regions and time periods, the studies reveal critical differences in management practices, social-ecological consequences, and the structural pressures that limit their resolve.

However, while complementary, the specific method used in each study differs. **Paper 1** focuses on nitrogen dynamics in the Pampas, employing a historical perspective to examine how soybean monoculture depletes soil nitrogen. Using production data from 1970–2021, the study used di Ciocco et al.’s (2011) localized estimation of soil nitrogen loss per kilogram of harvested soybean. This was a heuristic choice—and honestly a pragmatic one, due to the large data set it would require to calculate all key inputs and outputs for the entire Pampas region and my inexperience at the time to do so.

In contrast, **Paper 3** produces nutrient budgets for nitrogen, phosphorus, and sulfur in Southern Córdoba and Dry Chaco by calculating all key inputs and outputs. This was possible due to the much smaller sample size, totaling 12 departments in total compared to the 132 studied in **Paper 1**, as well as the experience in conducting and evaluating such studies I had gained over time.<sup>11</sup> Moreover, where **Paper 1** is longitudinal in time, **Paper 3** is longitudinal in space, highlighting regional disparities between Southern Córdoba and Eastern Santiago del Estero.

While the robustness of the nutrient budget methodology in **Paper 3** might overshadow the simple mass balance for nitrogen of **Paper 1**, it is important to remember that all nutrient budgets are heuristic devices that entail considerable amounts of uncertainty due to the partitioning of nutrient losses (Galloway et al., 2003; Oenema et al., 2003; Roy et al., 2003).

---

<sup>11</sup> Of the 132 departments studied in **Paper 1**, the vast majority were in Buenos Aires province: 102 in total. For Córdoba, Santa Fe, Entre Ríos, and La Pampa, the total departments studied were 6, 9, 8, and 7, respectively.

Thus, their appropriateness depends on how well they align with the specific research aims and questions they are designed to address, rather than on their methodological complexity or comprehensiveness (Deutsch and Troell, 2021).

Also, important to consider is that nutrient budgets are inherently estimations that depend on generalized assumptions, which can lead to mismatches when compared to real-world conditions. Previous research has underscored that variability in soil properties, climatic factors, and land management practices often exceeds the assumptions embedded in standardized nutrient budget models, necessitating more site-specific estimations (Corti et al., 2023; Martinez-Feria and Basso, 2020; Roy et al., 2003). Integrating localized knowledge, history, and grounded insights from the specific regions under study is also crucial to enhancing the accuracy and contextual relevance of these estimations (Kanter et al., 2020; Schutter, 2019).

#### **4.1.2 Expert interviews**

Expert interviews served as a critical methodological tool in both **Paper 2** and **Paper 3**, although their roles differed according to the specific objectives of each study. The purpose of each interview evolved alongside the research design. So, while all interviews were ultimately semi-structured on a standardized interview guide, following Steiner Kvale (2007, pp. 60–63), new questions were formulated and introduced depending on each interviewee’s contextual knowledge and professional experience as well as the stage of the research design (**Appendix 1.3**). Such an approach closely aligns with Alexander Bogner and Wolfgang Menz’s (2009, pp. 43–44) three-fold typology for expert interviews which distinguishes between *exploratory*, *systematizing*, and *theory-generating* approaches. The exploratory interview seeks to gain initial insights into a new field of study, often used in early research stages to refine hypotheses or identify key variables. The systematizing interview focuses on collecting structured information from experts to build or validate empirical frameworks, ensuring consistency and reliability in data collection. Finally, the theory-generating interview aims to produce new theoretical insights by engaging experts in reflective discussions that go beyond their immediate expertise, fostering the co-production of knowledge. These typologies emphasize the flexibility of expert interviews in addressing diverse research aims, highlighting their capacity to bridge exploratory, empirical, and conceptual dimensions within a single methodological framework. For the purposes of these two papers, expert interviews were used for both exploratory and systematizing purposes.

In **Paper 2**, insights from interviews with predominantly agronomists and researchers were used to deepen the comparative analysis of frontier dynamics in Southern Córdoba and Eastern Santiago del Estero. These interviews contextualized quantitative data, such as agricultural censuses and land use records, by providing qualitative knowledge into how changes in production forms and social relations have unfolded during the soybean frontier period (1970–2019). For instance, interviewees highlighted the persistence of land tenure inequalities in Eastern Santiago del Estero and the role of technology in intensifying production in Southern Córdoba. These insights helped identify the modalities of frontier expansion—broadening, deepening, and flexibly shifting—and their connections to historical and ecological contexts.

In **Paper 3**, expert interviews complemented nutrient budget calculations by validating quantitative estimates of nutrient inputs and outputs while elucidating any perceived constraints on soil management. Agronomists provided region-specific knowledge, such as the adoption of cover crops and moderate fertilizer use in Southern Córdoba, contrasting with the challenges of limited inputs, deforestation, and land tenure conflicts in Eastern Santiago del Estero. These interviews bridged gaps between positivist nutrient budgets and practical realities, helping to demonstrate how structural factors like global market pressures and historical marginalization influence regional disparities in soil nutrient loss.

These interviews align with broader methodological practices in social-ecological research. As Sacha Amaruzaman et al. (2022) argued, grounding interviews in local social-ecological systems is essential for capturing the complexities of regional dynamics, particularly in contexts of rapid agricultural change. Andrew Allan et al. (2022) similarly emphasized the importance of participatory approaches that engage local expertise to enhance the validity of models and frameworks. Together, these insights highlight the value of qualitative methods in complementing quantitative analyses, particularly in research on agrarian transformations and environmental sustainability.

Despite their strengths, these expert interviews were not without limitations. The research design of both studies relied heavily on the perspectives of a small sample of individuals (in total, eight interviews), which may not fully capture the diversity of experiences within the regions studied. This limitation is compounded by potential biases, such as the professional affiliations or disciplinary backgrounds of interviewees, which can influence their interpretations of policy impacts or sustainable practices. Kvale (2007) underscores that the co-production of knowledge in interviews depends on how questions are framed, meaning that findings are shaped by the methodological design itself. Therefore, while expert interviews enrich the research, they must be triangulated with other data sources to ensure a

balanced and comprehensive understanding of the social-ecological systems under study.

### 4.1.3 Interpretative framings

I believe that the strategies employed in both **Papers 1 and 3** aimed at bridging the quantitative findings concerning soil nutrient loss with broader historical and social-ecological contexts can best be described as a form of interpretative framing. For example, the approaches taken in each study aligns with Gustav Cederlöf and Hornborg's (2021) use of qualitative interpretations to reveal systemic inequalities and resource dependencies obscured by quantitative methodologies.

In **Paper 1**, interpretative framings of nitrogen mass-balance calculations are used to discuss first-order social costs—direct consequences of soil nitrogen loss—and second-order costs—which are cascading and arise from systemic responses to solve soil nitrogen extraction. **Paper 3** similarly uses qualitative interpretations in its discussion of the social-ecological ramifications of soil nutrient loss across Southern Córdoba and Eastern Santiago del Estero as well as to identify structural barriers to resolving the issue.

However, while narratives effectively bridge data and context, their reliance on interpretive coherence may oversimplify multidimensional processes, highlighting the importance of methodological transparency and diversity—hence the myriad methods and sources used throughout the individual studies (Kvale, 2007).

## 4.2 Data selection and usage

As previously stated, the general mixed-method quality of the meso-scale comparative approach in this dissertation relies on the integration of qualitative and quantitative data (**Table 1**). All three papers rely on cross-scale and contemporary agricultural production and trade estimates that draw data from some combination of the FAOSTAT (2024), the Secretariat of Agriculture, Livestock, and Fisheries (SAGyP, 2024), the Observatory of Economic Complexity (OEC, 2024) and TRASE (Lathuillière et al., 2022) database. These sources have provided a strong foundation for understanding how changes in the forms of production have occurred over time and for calculating soil nutrient budgets and understanding the general agrarian structure of the Argentine countryside. However, these datasets, despite their methodological robustness and utility, are inherently limited by their aggregated nature, which conceals the granular variability such as land-use

practices, soil conditions, and farmer preferences. While localized agromonic studies were consulted for each paper (see each paper's respective methodology sections for more detail) to add precision, their limited geographic coverage underscores that only direct soil sampling and deep ethnographic fieldwork could eliminate the reliance on such secondary sources. Moreover, these databases only contain data for the contemporary period.

Historical sources offer depth and complement the quantitative datasets by allowing to trace long-term agricultural transformations. **Papers 2 and 3** utilize national agricultural censuses, published by different institutional variations of the contemporary National Institute of Statistics and Censuses (*Instituto Nacional de Estadística y Censos* (INDEC)), historical material, and the literature to examine transitions from the wheat frontier of the late 19th century to the contemporary soybean period. These sources were instrumental in highlighting shifts in production strategies and land tenure systems, yet they are not without their blind spots. Institutional archives often privilege dominant narratives, marginalizing the experiences of smallholders and indigenous communities, this is evidenced by historical accounts produced by intellectual elites, politicians, and diplomats that the papers make use of—not to mention that the agricultural censuses were produced by the very state that was active in the genocide of indigenous populations (Hasbrouck, 1935; Sarmiento, 2003 [1845]).

Moreover, the restricted access to archives during the COVID-19 pandemic exacerbated these limitations, narrowing the breadth of available data. The first iteration of this dissertation's research design was conceived in the spring of 2020, before the far-reaching impacts of the COVID-19 pandemic could be fully understood. As the pandemic unfolded, with restrictions limiting mobility and academic activities shifting to remote platforms, the challenges of executing field and archival visits became evident, forcing a fundamental restructuring of the project. Faced with this restriction on fieldwork opportunities and the pervasive uncertainty of the period, I adapted my research design to embrace the meso-scale approach it is today, moving beyond the originally planned micro-scale ethnography to critically engage with broader structural processes. While this shift ultimately deepened the analytical scope of the dissertation, the transition was arduous, shaped by trial, error, and the pervasive strain of pandemic-era disruptions. Instead, I have relied on the ethnographic work and bottom-up insights of others to obtain these perspectives, for example, Lapegna (2016), Leguizamón (2020, 2019), Paz et al. (2019), and Urcola et al. (2015).

**Table 1: Summary of methods and materials used in each article**

	Methods	Empirical materials
<b>Paper 1</b>	Simple mass balance for nitrogen	<ul style="list-style-type: none"> <li>▪ Production and trade data for soybeans produced in the Pampas ecoregion (1970-2021)</li> </ul>
	Social cost analysis	<ul style="list-style-type: none"> <li>▪ Localized agronomic estimations for calculating simple mass balance from di Ciocco et al. (2011)</li> </ul>
	Interpretive framing	<ul style="list-style-type: none"> <li>▪ Number of departments studied = 132</li> <li>▪ Material for primary data: FAOSTAT, OEC, and SAGyP databases</li> <li>▪ Material for secondary data: Previous studies on Argentine soybean production and trade, embedded biophysical materials in Argentine exports, and domestic and foreign agribusiness</li> </ul>
<b>Paper 2</b>	Comparative frontier analysis	<ul style="list-style-type: none"> <li>▪ Production and land tenure data for wheat produced in Southern Córdoba and Eastern Santiago del Estero (1872-1937)</li> </ul>
	Expert interviews	<ul style="list-style-type: none"> <li>▪ Production and land tenure data for soybeans produced in the Pampas ecoregion (1970-2019)</li> <li>▪ Number of departments studied = 14</li> <li>▪ Material for primary data: National censuses produced by INDEC, SAGyP database. A total of 8 expert interviews with primarily local agronomists</li> <li>▪ Material for secondary data: Previous studies on Argentine soybean production and trade, Argentine agrarian history (especially concerning forms of production and social relations), and on frontier expansion more broadly</li> </ul>
<b>Paper 3</b>	Nutrient budget calculation for nitrogen, phosphorus, and sulfur	<ul style="list-style-type: none"> <li>▪ Production, trade, and land tenure data for soybeans produced in in Southern Córdoba and Eastern Santiago del Estero (2015-2019)</li> </ul>
	Interpretive framing	<ul style="list-style-type: none"> <li>▪ Localized agronomic estimations for calculating budgets, primarily from Brihet (2015), (see <i>Paper 3</i>)</li> </ul>
	Expert interviews	<ul style="list-style-type: none"> <li>▪ Number of departments studied = 14</li> <li>▪ Material for primary data: National censuses produced by INDEC, SAGyP, OEC, and TRASE databases. A total of 8 expert interviews with primarily local agronomists</li> <li>▪ Material for secondary data: Previous studies on Argentine soybean production and trade, fertilizer prices, agroecological conditions, and both contemporary and historical Argentine agrarian studies more broadly</li> </ul>

Semi-structured interviews with several agronomists and one South Córdoba farmer, also provide valuable contemporary perspectives on soil management practices as both triangulation and qualitative data. However, the absence of more farmer perspectives represents a crucial gap, omitting the lived experiences and adaptive practices of those most directly perpetuating and impacted by soil nutrient loss. Furthermore, the integration of qualitative narratives with quantitative metrics poses methodological challenges. While interviews offer rich, contextual insights, they can be difficult to reconcile with the standardized approaches of nutrient budgets.

The theoretical frameworks applied across these studies deepen the analysis, particularly through the use of Kapp's (1978) concept of social costs, which frames soil nutrient loss as a systemic outcome of agrarian capitalism. By linking regional agricultural practices and consequences to global trade, the studies align with political-ecological perspectives and offer a critical lens for understanding the structural drivers of soil nutrient loss. Yet, there are still gaps in data representation, as the lived experiences of affected communities and gendered perspectives are not sufficiently captured.

Moreover, as a researcher from a Global North institution studying the perceived problems of the Global South, I am acutely aware of the positionality and potential biases this entails. However, being a Latin American studying Latin America, I have conducted my interviews in the language of the interviewees—Spanish—and placed significant emphasis on engaging with the literature of Argentine researchers. This approach, I hope, valorizes hispanophone research that is largely marginalized in anglophone academia.

Having discussed these important, but in many ways addressed and accounted for limitations, I have in all my capacity charted the best course between the Scylla of macro-scale structural explanations and the Charybdis of historical contingency, human agency, and micro-scale theory. Perhaps I have drifted too close to the unyielding grip of structuralism, with its rigid and overarching frameworks; but much like Odysseus, I did so to avert being swallowed by the vortex of endless variations and contingencies.

## 5. Key insights and contributions

Earlier in this kappa, I reviewed the state of the art of three separate, but overlapping areas of scholarship in which the aim of this research is situated (**Section 2**). I synthesized the identified gaps in the literature into four overall lacunae concerning the historical, regional, and structural studies of Argentine soybean agriculture and soil nutrient loss: an under-representation of diachronic historizations of soybean frontier expansion, a need to address soil nutrient loss as a systemic issue connecting it across various scales, an under-theorization and insufficient comparisons of place-based differences in soybean frontier expansion across Argentina, and a need for more integrated and rigorous methodological frameworks for bridging disciplines as well as integrating quantitative and qualitative data and sources for studying soybean expansion and soil nutrient loss. Through each paper and as a doctoral research project as a whole, this dissertation provides an interdisciplinary and integrative analysis of soybean frontier expansion in Argentina to address these lacunae. I present in the following subsections a discussion on how this dissertation has addressed each individual gap, highlighting the contributions of each paper as well as the greater synthesis of them.

### 5.1 Historicizing Argentine soybean frontier expansion

The totality of this dissertation situates soybean production within Argentina's agrarian history, emphasizing how contemporary dynamics of *sojización* build upon earlier waves of agricultural expansion. By drawing comparisons between the wheat frontier of the late 19th and early 20th centuries and the soybean frontier of the late 20th and early 21st centuries, it reveals that modern agrarian change is deeply informed by historical trajectories and structural conditions.

In the Pampas, the agriculture heartland of Argentina, soybean expansion exemplifies a process of frontier-deepening, where established agrarian systems are intensified through technological adoption and capital investment. **Paper 2** highlights how the region's stable land tenure, robust infrastructure, and long-standing integration into global markets facilitate this intensification. The Pampas, represented by the case study area of

Southern Córdoba, has evolved into a hub of highly mechanized, input-intensive production. This transformation builds upon historical patterns of land use, where mechanization and technological innovation have long played pivotal roles in maintaining agricultural productivity.

In contrast, the Dry Chaco, represented through the study of Eastern Santiago del Estero, exhibits a flexibly shifting process of frontier-broadening and deepening, characterized by the conversion of marginal and forested lands into agricultural use and the widespread adoption of the GE soybean technological package. **Paper 2** identifies deforestation and extensive land-use change as key features of this expansion, alongside persistent land tenure conflicts. While Southern Córdoba benefits from a legacy of stable agrarian structures, Eastern Santiago del Estero's agricultural development has been marked by ecological vulnerability and social (class) volatility. This differentiation underscores the significance of place-based factors in shaping regional dynamics.

Importantly, the dissertation avoids the conflation of historical events and regional processes. For instance, while the Conquest of the Desert violently displaced indigenous populations and integrated the southern Pampas into the national economy in the late 19th century, this military campaign did not directly affect Eastern Santiago del Estero. Instead, Eastern Santiago del Estero's historical marginalization stems from distinct patterns of land tenure, labor dynamics, and ecological constraints, which have rendered it more vulnerable to exploitative agricultural practices during the recent soybean boom.

**Paper 1** enriches this historical analysis by linking soybean production to long-term patterns of ecological extraction, particularly through the mobilization and export of nitrogen. The study demonstrates how Argentina's role as a net exporter of embodied nitrogen contributes to global patterns of inequality while drawing heavily on regional biophysical resources. **Paper 3** complements these insights by exploring how regional differences in soil nutrient loss reflect historical and structural conditions, revealing the layered complexity of agrarian change.

By synthesizing these findings, the dissertation historicizes soybean frontier expansion as both a continuation and reconfiguration of Argentina's agrarian past. This approach advances commodity frontier scholarship by elucidating how historical processes and regional contexts interact to shape contemporary agricultural landscapes across the subnational level, offering a nuanced perspective on the temporal and spatial dimensions of frontier dynamics.

## 5.2 (Re)Conceptualizing systemic soil nutrient loss as a social cost

A critical contribution of this dissertation is its reframing of social-ecological consequences as social costs inherent to the soybean production model. Drawing on the concept of social costs, this research argues that social-ecological crises are systemic to the productive process—such as soil nutrient loss, deforestation, and economic inequalities—and not externalities or market failures.

**Paper 1** quantifies the extraction of soil nitrogen due to export-oriented soybean production in the Pampas, showing that soybean monoculture depletes soil nutrients at unsustainable rates. By calculating nitrogen mass balances over five decades, it demonstrates how this loss erodes soil fertility and shifts the long-term ecological burden onto third-parties and future generations, away from agribusiness and producers who conduct such unsustainable practices. These findings challenge the notion that soybean production is a model of sustainable agricultural modernization and beneficial economic growth, revealing instead its dependence on cost-shifting mechanisms that externalize its social-ecological consequences.

**Paper 3** extends this analysis by examining regional disparities in soil nutrient loss. In Southern Córdoba, nutrient loss stems from the intensive practices of capitalized farming, where moderate fertilizer use fails to offset the demands of monoculture. In Eastern Santiago del Estero, nutrient loss is even more severe, driven by extensive land-use changes, minimal input use, and the ecological conditions of the region. These findings highlight how the structural pressures of global trade exacerbate regional inequalities, perpetuating unsustainable practices in both intensive and extensive agricultural systems.

By integrating these insights, the dissertation reframes soil nutrient loss as an intrinsic feature of Argentina's agrarian model, rather than a market failure or externality. This reconceptualization integrates critical social theory with a methodology typically reserved for positivist agronomic science. Additionally, it advances debates in political ecology by foregrounding the systemic nature of environmental degradation in global agricultural systems and highlighting the need for policies that address these structural inequalities.

### 5.3 Subnational regional divergences and global pressures

This research emphasizes the interplay between regional variability and global market pressures in shaping the dynamics and negative consequences of soybean frontier expansion. While both the Pampas and Dry Chaco are integrated into national and global economies, their distinct historical and social-ecological contexts lead to divergent patterns of agrarian change and social-ecological outcomes.

**Paper 2** highlights the structural contrasts between the two case study areas. In Southern Córdoba, soybean intensification builds on a stable foundation of agrarian capitalism, enabling consistent yield increases through technological innovation. In Eastern Santiago del Estero, agricultural expansion involves the rapid incorporation of new lands, often accompanied by deforestation, social-ecological disruption, and land tenure conflicts. These regional dynamics reflect the distinct historical trajectories of each region, where Southern Córdoba benefits from long-established capitalist agrarian systems while Eastern Santiago del Estero grapples with the challenges of being a relatively new frontier for agricultural commodification.

**Paper 3** situates these subnational patterns within the broader context of global trade, showing how international demand for soybeans exacerbates regional inequalities. The European Union and China, as major importers, play pivotal roles in perpetuating unsustainable production practices, prioritizing yield and export volume over long-term and sustainable land-use management. **Paper 1** complements this analysis by linking nitrogen flows to global trade systems.

By synthesizing these findings, the dissertation demonstrates that subnational disparities in soybean frontier expansion are not merely localized phenomena but are deeply intertwined with global market dynamics. This integrated perspective highlights the systemic barriers to sustainability in agrarian systems, emphasizing the need for context-specific policies that address both regional challenges and global inequalities.

### 5.4 Innovative methodologies and interdisciplinary integration

The dissertation's methodological approach combines historical, biophysical, and political-ecological analyses, offering a comprehensive framework for studying soybean frontier dynamics. By integrating quantitative methods such as nutrient budget calculations with qualitative insights from interviews, historical records, and secondary literature, the research

bridges disciplinary divides to provide a stable holistic understanding of agrarian change.

**Paper 3** exemplifies this interdisciplinary approach by quantifying soil nutrient loss through nutrient budgets and contextualizing these findings within broader structural and historical frameworks. **Paper 2** employs a comparative frontier analysis to disentangle the modalities of agricultural expansion, while **Paper 1** situates these regional dynamics within the global agrofood system, linking ecological consequences to long-term patterns of resource extraction and trade.

This methodological integration not only enriches the empirical findings but also advances theoretical innovation, demonstrating how interdisciplinary approaches can illuminate the multifaceted nature of social-ecological transformations and crises. The dissertation provides a model—or at least a point of departure—for analyzing the intersection of subnational histories, ecological impacts, and global economic pressures, offering insights that are both rigorous and actionable. Providing a unified analysis of soybean frontier expansion in Argentina, it addresses its historical, ecological, and political dimensions where the findings of the three papers highlight how historical processes, place-based factors, and global pressures converge to shape the dynamics and impacts of soybean production



## 6. Conclusions and other considerations

Sojización, as explored in this study, is emblematic of the contradictions inherent in contemporary agrofood globalization. It reveals an unsettling truth: the relentless pursuit of productivity is inseparable from insidious forms of plunder. This dialectic of abundance and poverty reflects broader tendencies within capitalist modernity, where the promise of progress is bound to a systematic destruction of ecological and social worlds. In tracing the expansion of soybean cultivation, this study uncovers the ghostly presence of historical forces that permeate the present. Making place inscribed with the legacies of past modes of exploitation, commodification, and violence. The contemporary agrofood system, in its ceaseless drive toward commodification, is ignorant in historical amnesia, forgetting that the new is often a repetition of the old under a different guise—or as I state in **Paper 2** “the story of sojización is not one of pure innovation but rather of old wine in very new bottles—where the deeper logic of capitalist exploitation remains intact, even as the landscape and technologies evolve”. The modernization of agriculture—through biotechnological innovations, market integration, and land concentration—reveals itself as a deepening of historical continuities that have tended to privilege extraction over regeneration, and profit over people. This dissertation concludes that soil nutrient loss is not external to the productive process, nor is it a technical issue that can be solved through economic incentives and technological fixes. Instead, it is a structural consequence of Argentina’s historical integration into global commodity markets. Moreover, it shows that while geographical variation and historical ruptures clearly exist, the structural patterns of Argentina’s insertion remain dominant drivers. By linking historical legacies and global economic forces to uneven agricultural development, this research offers critical insights into the long-term social and ecological consequences of global agricultural production.

This dissertation critiques the extractive logic of agrofood globalization that externalizes its costs to the peripheries of the world-system. The displaced burdens of soil nutrient loss and social disruption are not incidental but constitutive of a system that thrives on the invisibility of its own destructiveness. Future research could expand on this study by comparatively exploring the long-term ecological consequences of sojización between different subregions, particularly in relation to soil health, water resources,

and biodiversity. Moreover, comparative subnational studies across different South American countries engaged in soybean production could also offer valuable insights into the regional patterns and local specificities of agrofood globalization. Finally, since this is only a myopic investigation of a complex global commodity chain, focusing specifically on sites of production, more diachronic comparative studies along other portions of the chain are warranted.

In the end, this study is not just an indictment of agrofood globalization but a call to reimagine the relationship between history, place, and agriculture. It should challenge us to reject the fatalism of existing narratives and to seek modes of production that honor the specificity of subnational ecologies and communities. The task forward is to not only critique but to envision new possibilities, to resist the instrumental logic that reduces land to a resource and people to appendages of the market. Only by reckoning with the historical and spatial entanglements of agrofood systems can we begin to envision this future that transcends the cycle of productivity and plunder, and toward a genuinely sustainable and equitable world.

## 7. References

- Allan, A., Barbour, E., Nicholls, R.J., Hutton, C., Lim, M., Salehin, M., Rahman, Md.M., 2022. Developing socio-ecological scenarios: A participatory process for engaging stakeholders. *Science of The Total Environment* 807 (1), 150512. <https://doi.org/10.1016/j.scitotenv.2021.150512>
- Alonso-Fernández, P., Regueiro-Ferreira, R.M., 2022. Extractivism, ecologically unequal exchange and environmental impact in South America: A study using material flow analysis (1990–2017). *Ecological Economics* 194, 107351. <https://doi.org/10.1016/j.ecolecon.2022.107351>
- Álvarez, R., Berhongaray, G., de Paepe, J., Mendoza, M.R., Steinbach, H., Caride, C., Cantet, R., Álvarez, C., 2015. Sojización y productividad de los suelos pampeanos. *Ciencia Hoy* 24 (142), 35–41.
- Álvarez, R., Steinbach, H.S., de Paepe, J.L., 2016. Historical balance of nitrogen, phosphorus, and sulfur of the Argentine Pampas. *Ciencia del Suelo* 34 (2), 231–244.
- Álvarez, R., Steinbach, H.S., L. De Paepe, J., 2014. A regional audit of nitrogen fluxes in pampean agroecosystems. *Agriculture, Ecosystems & Environment* 184, 1–8. <https://doi.org/10.1016/j.agee.2013.11.003>
- Amaral, S., 1998. *The rise of capitalism on the Pampas: The estancias of Buenos Aires, 1785–1870*, Cambridge Latin American Studies. Cambridge University Press, Cambridge: UK. <https://doi.org/10.1017/CBO9780511665202>
- Amaruzaman, S., Bardsley, D.K., Stringer, R., 2022. Reflexive policies and the complex socio-ecological systems of the upland landscapes in Indonesia. *Agriculture and Human Values* 39 (2), 683–700. <https://doi.org/10.1007/s10460-021-10281-3>
- Arora, P., Bert, F., Podesta, G., Krantz, D.H., 2015. Ownership effect in the wild: Influence of land ownership on agribusiness goals and decisions in the Argentine Pampas. *Journal of Behavioral and Experimental Economics* 58, 162–170. <https://doi.org/10.1016/j.socec.2015.02.007>
- Austin, A.T., Piñeiro, G., Gonzalez-Polo, M., 2006. More is less: Agricultural impacts on the N cycle in Argentina, in: Martinelli, L.A., Howarth, R.W. (Eds.), *Nitrogen cycling in the Americas: Natural and anthropogenic influences and controls*. Springer Dordrecht: Netherlands, 45–60. [https://doi.org/10.1007/978-1-4020-5517-1\\_3](https://doi.org/10.1007/978-1-4020-5517-1_3)
- Austin, K.F., 2010. Soybean exports and deforestation from a world-systems perspective: A cross-national investigation of comparative disadvantage. *The Sociological Quarterly* 51 (3), 511–536. <https://doi.org/10.1111/j.1533-8525.2010.01180.x>
- Balsa, J., 2002. La concentración de la agricultura entre 1937 y 1988: El Corn Belt y la pampa maicera argentina. *Boletín del Instituto de Historia Argentina y Americana Dr. Emilio Ravignani* 25, 121–156.

- Banoub, D., Bridge, G., Bustos, B., Ertör, I., González-Hidalgo, M., de los Reyes, J.A., 2021. Industrial dynamics on the commodity frontier: Managing time, space and form in mining, tree plantations and intensive aquaculture. *Environment and Planning E: Nature and Space* 4 (4), 1533–1559. <https://doi.org/10.1177/2514848620963362>
- Baraibar Norberg, M., 2022. Sojización as a new first movement: A Polanyian analysis of the South American soybean ‘boom’ in: Da Silva, C.M., De Majo, C. (Eds.), *The age of the soybean: An environmental history of soy during the Great Acceleration*. The White Horse Press, Winwick: UK, 91–114. <https://www.jstor.org/stable/j.ctv309h1fx.11>
- Baraibar Norberg, M., 2020. *The political economy of agrarian change in Latin America: Argentina, Paraguay, and Uruguay, Governance, development, and social inclusion in Latin America*. Palgrave Macmillan, Cham: Switzerland.
- Baraibar Norberg, M., Deutsch, L., 2023. *The soybean through world history: Lessons for sustainable agrofood systems*. Routledge, London: UK. <https://doi.org/10.4324/9780367822866>
- Barbier, E.B., 2010. *Scarcity and frontiers: How economies have developed through natural resource exploitation*. Cambridge University Press, Cambridge: UK. <https://doi.org/10.1017/CBO9780511781131>
- Barsky, O., Gelman, J., 2009. *Historia del agro argentino: Desde la Conquista hasta comienzos del siglo XXI*. Editorial Sudamerica, Buenos Aires: Argentina.
- Beckert, S., Bosma, U., Schneider, M., Vanhaute, E., 2021. Commodity frontiers and the transformation of the global countryside: A research agenda. *Journal of Global History* 16 (3), 435–450. <https://doi.org/10.1017/S1740022820000455>
- Berg, M., 2021. Commodity frontiers: Concepts and history. *Journal of Global History* 16 (3), 451–455. <https://doi.org/10.1017/S1740022821000036>
- Berkes, F., Colding, J., Folke, C. (Eds.), 2002. *Navigating social-ecological systems: Building resilience for complexity and change*. Cambridge University Press, Cambridge: UK. <https://doi.org/10.1017/CBO9780511541957>
- Berndt, C., Werner, M., Fernández, V.R., 2020. Postneoliberalism as institutional recalibration: Reading Polanyi through Argentina’s soy boom. *Environment and Planning A: Economy and Space* 52 (1), 216–236. <https://doi.org/10.1177/0308518X19825657>
- Bernstein, H., 2016. Agrarian political economy and modern world capitalism: The contributions of food regime analysis. *The Journal of Peasant Studies* 43 (3), 611–647. <https://doi.org/10.1080/03066150.2015.1101456>
- Bértola, L., Weber, J.R., 2015. Latin American economic history: Looking backwards for the future, in: *Routledge Handbook of Global Economic History*. Routledge, London: UK.
- Bhaskar, R., 2008. *A realist theory of science*. Routledge, London: UK. <https://doi.org/10.4324/9780203090732>. *Originally published in 1975*.
- Biggs, R., Schlüter, M., Schoon, M.L. (Eds.), 2015. *Principles for building resilience: Sustaining ecosystem services in social-ecological systems*. Cambridge University Press, Cambridge: UK. <https://doi.org/10.1017/CBO9781316014240>
- Binimelis, R., Pengue, W., Monterroso, I., 2009. “Transgenic treadmill”: Responses to the emergence and spread of glyphosate-resistant johnsongrass in Argentina. *Geoforum, Themed issue: The ‘view from nowhere’? Spatial politics and cultural significance of high-resolution satellite imagery* 40 (4), 623–633. <https://doi.org/10.1016/j.geoforum.2009.03.009>

- Bloch, M., 2015. French rural history: An essay on its basic characteristics. Routledge, London: UK. *Originally published in 1931.*
- Bloch, M., 1992. The historian's craft. Manchester University Press, Manchester: UK. *Originally published in 1949.*
- Bloch, M., 1967. A contribution towards a comparative history of european societies, in: Anderson, J.E. (Tran.), Land and Work in Mediaeval Europe (Routledge Revivals). Routledge, London: UK. *Originally published in 1928.*
- Blum, D., Aguiar, S., Sun, Z., Müller, D., Alvarez, A., Aguirre, I., Domingo, S., Mastrangelo, M., 2022. Subnational institutions and power of landholders drive illegal deforestation in a major commodity production frontier. *Global Environmental Change* 74, 102511. <https://doi.org/10.1016/j.gloenvcha.2022.102511>
- Bogner, A., Menz, W., 2009. The theory-generating expert interview: Epistemological interest, forms of knowledge, interaction, in: Bogner, A., Littig, B., Menz, W. (Eds.), *Interviewing experts*. Palgrave Macmillan UK, London, 43–80. [https://doi.org/10.1057/9780230244276\\_3](https://doi.org/10.1057/9780230244276_3)
- Bourdain, A., 2006. *No Reservations: Peru*. [TV Broadcast]Travel Channel.
- Borras, S.M., Franco, J.C., Isakson, S.R., Levidow, L., Vervest, P., 2016. The rise of flex crops and commodities: Implications for research. *The Journal of Peasant Studies* 43 (1), 93–115. <https://doi.org/10.1080/03066150.2015.1036417>
- Braudel, F., 1958. *Histoire et Sciences sociales: La longue durée*. *Annales. Histoire, Sciences Sociales* 13 (4), 725–753.
- Brihet, J.M., 2015. Relevamiento de tecnología agrícola aplicada campaña 2012/2013. Bolsa de Cereales Buenos Aires, Buenos Aires: Argentina.
- Bronstein, H., 2013. Lack of crop rotation slowly turns Argentine Pampas into “sand”. *Scientific American*. URL: <https://www.scientificamerican.com/article/analysis-lack-of-crop-rotation-sl/>.
- Bulmer-Thomas, V., 2014. *The economic history of Latin America since Independence*, 3rd ed, Cambridge Latin American Studies. Cambridge University Press, Cambridge: UK. <https://doi.org/10.1017/CBO9781139208710>
- Buttel, F.H., 2001. Some reflections on late twentieth century agrarian political economy. *Sociologia Ruralis* 41 (2), 165–181. <https://doi.org/10.1111/1467-9523.00176>
- Bøhn, T., Millstone, E., 2019. The introduction of thousands of tonnes of glyphosate in the food chain—an evaluation of glyphosate tolerant soybeans. *Foods* 8 (12). <https://doi.org/10.3390/foods8120669>
- Börjeson, L., 2014. The antithesis of degraded land: Toward a greener conceptualization of landesque, in: *Landesque Capital*. Routledge, London: UK.
- Cáceres, D.M., Gras, C., 2020. A tipping point for agricultural expansion? Technological changes and capital accumulation in Argentina's rural sector. *Journal of Agrarian Change* 20 (1), 79–97. <https://doi.org/10.1111/joac.12336>
- Calzada, J., Rossi, G., 2019. 84% de la soja argentina se exporta como grano, harina, aceite y biodiesel. Bolsa de Comercio de Rosario. URL: <http://www.bcr.com.ar/es/mercados/investigacion-y-desarrollo/informativo-semanal/noticias-informativo-semanal/84-de-la-soja> (accessed 6.28.24).
- Campos, M.A., Wander, A.E., Carvalho, C.R.R., Costa Filho, B.A. da, 2017. Competitiveness of the soybean complex in Brazil: Enhancers and inhibitors. *Revista Sodebras*, 12, 70–76.

- Carlson, J.D., 2001. Broadening and deepening: Systemic expansion, incorporation and the zone of ignorance. *Journal of World-Systems Research* 7 (2), 225–263. <https://doi.org/10.5195/jwsr.2001.180>
- Cederlöf, G., Hornborg, A., 2021. System boundaries as epistemological and ethnographic problems: Assessing energy technology and socio-environmental impact. *Journal of Political Ecology* 28 (1). <https://doi.org/10.2458/jpe.2303>
- Clapp, J., Isakson, S.R., 2018. *Speculative harvests: Financialization, food, and agriculture, Agrarian Change and Peasant Studies*. Fernwood Publication, Halifax: Canada.
- Clark, B., Foster, J.B., 2009. Ecological imperialism and the global metabolic rift: Unequal exchange and the guano/nitrates trade. *International Journal of Comparative Sociology* 50 (3-4), 311–334. <https://doi.org/10.1177/0020715209105144>
- Collino, D.J., Salvaggiotti, F., Peticari, A., Piccinetti, C., Ovando, G., Urquiaga, S., Racca, R.W., 2015. Biological nitrogen fixation in soybean in Argentina: Relationships with crop, soil, and meteorological factors. *Plant and Soil* 392 (1-2), 239–252.
- Commoner, B., 1971. *The closing circle : Nature, man and technology*. New York: US.
- Corti, M., Cavalli, D., Pricca, N., Ferrè, C., Comolli, R., Marino Gallina, P., Abu El Khair, D., Cabassi, G., 2023. Site-specific recommendations of cattle manure nitrogen and urea for silage maize. *Nutrient Cycling in Agroecosystems* 127 (1), 155–169. <https://doi.org/10.1007/s10705-023-10302-z>
- Cruzate, G.A., Casas, R.R., 2017. Balance de nutrientes en los suelos agrícolas de la Argentina en la campaña 2015/16. *Informaciones Agronómicas de Hispanoamérica* 28, 14–23.
- Cruzate, G.A., Casas, R.R., 2012. Extracción y balance de nutrientes en los suelos agrícolas de la Argentina. *Informaciones Agronómicas de Hispanoamérica* 6, 14–23.
- Cruzate, G.A., Casas, R.R., 2009. Extracción de nutrientes en la agricultura argentina. *Informaciones Agronómicas de Hispanoamérica* 44, 21–26.
- del Giorgio, O., Robinson, B.E., le Polain de Waroux, Y., 2022. Impacts of agricultural commodity frontier expansion on smallholder livelihoods: An assessment through the lens of access to land and resources in the Argentine Chaco. *Journal of Rural Studies* 93, 67–80. <https://doi.org/10.1016/j.jrurstud.2022.05.014>
- Delvenne, P., Vasen, F., Vara, A.M., 2013. The “soy-ization” of Argentina: The dynamics of the “globalized” privatization regime in a peripheral context. *Technology in Society* 35, 153–162. <https://doi.org/10.1016/j.techsoc.2013.01.005>
- Deutsch, L., Troell, M., 2021. Flow and impact analysis, in: *The Routledge Handbook of Research Methods for Social-Ecological Systems*. Routledge, London: UK.
- DeVerteuil, G., Golubchikov, O., 2016. Can resilience be redeemed?: Resilience as a metaphor for change, not against change. *City* 20 (1), 143–151. <https://doi.org/10.1080/13604813.2015.1125714>
- de Vries, W., Kros, J., Kroeze, C., Seitzinger, S.P., 2013. Assessing planetary and regional nitrogen boundaries related to food security and adverse environmental impacts. *Current Opinion in Environmental Sustainability*, Open issue 5 (3), 392–402. <https://doi.org/10.1016/j.cosust.2013.07.004>

- di Ciocco, C., Penón, E., Coviella, C., López, S., Díaz-Zorita, M., Momo, F., Álvarez, R., 2011. Nitrogen fixation by soybean in the Pampas: Relationship between yield and soil nitrogen balance. *Agrochimica* 55 (6), 305–313.
- Díaz de Astarloa, D.A., Pengue, W.A., 2018. Nutrients metabolism of agricultural production in Argentina: NPK input and output flows from 1961 to 2015. *Ecological Economics* 147, 74–83. <https://doi.org/10.1016/j.ecolecon.2018.01.001>
- Dorninger, C., Eisenmenger, N., 2016. South America's biophysical involvement in international trade: the physical trade balances of Argentina, Bolivia, and Brazil in the light of ecologically unequal exchange. *Journal of Political Ecology* 23 (1). <https://doi.org/10.2458/v23i1.20240>
- Dorninger, C., Hornborg, A., Abson, D.J., von Wehrden, H., Schaffartzik, A., Giljum, S., Engler, J.-O., Feller, R.L., Hubacek, K., Wieland, H., 2021. Global patterns of ecologically unequal exchange: Implications for sustainability in the 21st century. *Ecological Economics* 179, 106824. <https://doi.org/10.1016/j.ecolecon.2020.106824>
- Ernstson, H., 2013. The social production of ecosystem services: A framework for studying environmental justice and ecological complexity in urbanized landscapes. *Landscape and Urban Planning* 109 (1), 7–17. <https://doi.org/10.1016/j.landurbplan.2012.10.005>
- Esper Neto, M., Lara, L.M., Maciel de Oliveira, S., Santos, R.F. dos, Braccini, A.L., Inoue, T.T., Batista, M.A., 2021. Nutrient removal by grain in modern soybean varieties. *Frontiers in Plant Science* 12. <https://doi.org/10.3389/fpls.2021.615019>
- Fabinyi, M., Evans, L., Foale, S.J., 2014. Social-ecological systems, social diversity, and power: Insights from anthropology and political ecology. *Ecology and Society* 19.
- Faingerch, M., Vallejos, M., Texeira, M., Mastrangelo, M.E., 2021. Land privatization and deforestation in a commodity production frontier. *Conservation Letters* 14 (4), e12794. <https://doi.org/10.1111/conl.12794>
- FAOSTAT, 2024. FAOSTAT Statistical Database [Data set]. Food and Agriculture Organization of the United Nations, Rome. URL: <https://www.fao.org/faostat/en/#data>. *Last access on 15 January, 2025.*
- Findlay, R., O'Rourke, K.H., 2021. Commodity frontiers: A view from economic history. *Journal of Global History* 16 (3), 462–465. <https://doi.org/10.1017/S1740022821000024>
- Flachs, A., 2020. Political ecology and the industrial food system. *Physiology & Behavior* 220, 112872. <https://doi.org/10.1016/j.physbeh.2020.112872>
- Fogel, R., 2015. Algunos efectos de la expansión sojera, in: Palau, M. (Ed.), *Con la soja al cuello: Informe sobre agronegocios en Paraguay 2013-2015*. BASE, Asunción: Paraguay.
- Fontana, M.B., Novelli, L.E., Sterren, M.A., Uhrich, W.G., Benintende, S.M., Barbagelata, P.A., 2021. Long-term fertilizer application and cover crops improve soil quality and soybean yield in the Northeastern Pampas region of Argentina. *Geoderma* 385, 114902. <https://doi.org/10.1016/j.geoderma.2020.114902>
- Foster, J.B., 1999. Marx's theory of metabolic rift: Classical foundations for environmental sociology. *American Journal of Sociology* 105 (2), 366–405. <https://doi.org/10.1086/210315>
- Foster, J. B., Clark, B., York, R., 2011. *The ecological rift: Capitalism's war on the Earth*. Monthly Review Press, New York: US.

- Frank, A.G., 1969. *Capitalism and underdevelopment in Latin America: Historical studies of Chile and Brazil*. Monthly Review Press, New York: US.
- Gale, F., Valdes, C., Ash, M., 2019. *Interdependence of China, United States, and Brazil in soybean trade* (No. OCS-19F-01). USDA, Economic Research Service, Washington, D.C.: US.
- Galloway, J.N., Aber, J.D., Erisman, J.W., Seitzinger, S.P., Howarth, R.W., Cowling, E.B., Cosby, B.J., 2003. The nitrogen cascade. *BioScience* 53 (4), 341–356. [https://doi.org/10.1641/0006-3568\(2003\)053\[0341:tnc\]2.0.co;2](https://doi.org/10.1641/0006-3568(2003)053[0341:tnc]2.0.co;2)
- Gorman, H.S., 2013. *The story of N: A social history of the nitrogen cycle and the challenge of sustainability*. Rutgers University Press, New Brunswick, US.
- Gras, C., Cáceres, D.M., 2020. Technology, Nature's appropriation and capital accumulation in modern agriculture. *Current Opinion in Environmental Sustainability* 45, 1–9. <https://doi.org/10.1016/j.cosust.2020.04.001>
- Gras, C., Hernández, V., 2014. Agribusiness and large-scale farming: Capitalist globalisation in Argentine agriculture. *Canadian Journal of Development Studies* 35, 339–357. <https://doi.org/10.1080/02255189.2014.933702>
- Grau, H.R., Gasparri, N.I., Aide, T.M., 2005. Agriculture expansion and deforestation in seasonally dry forests of north-west Argentina. *Environmental Conservation* 32 (2), 140–148. <https://doi.org/10.1017/S0376892905002092>
- Guan, C., Yahalom, S., Germanakos, L., Lapage, S., McKeever, B., 2019. Global soybean trade, supply chain and tariffs, in: Passerini, G., Ricci, S. (Eds.), *Maritime transport*. WIT Press, Ashurst Lodge: UK.
- Guareschi, R.F.G., Boddey, R.M., Alves, B.J.R., Sarkis, L.F., Martins, M.R., Jantalia, C.P., Cabriales, J.J.P., Núñez, J.A.V., Urquiaga, S., 2019. Balanço de nitrogênio, fósforo e potássio na agricultura da América Latina e o Caribe. *Revista Terra Latinoamericana* 37 (2), 105–119. <https://doi.org/10.28940/terra.v37i2.423>
- Hart, C., 2017. The economic evolution of the soybean industry, in: Nguyen, H.T., Bhattacharyya, M.K. (Eds.), *The soybean genome*. Springer, Cham: Switzerland, 1–9. [https://doi.org/10.1007/978-3-319-64198-0\\_1](https://doi.org/10.1007/978-3-319-64198-0_1)
- Hasbrouck, A., 1935. The Conquest of the Desert. *The Hispanic American Historical Review* 15 (2), 195–228. <https://doi.org/10.2307/2506294>
- Havlin, J.L., Tisdale, S.L., Nelson, W.L., Beaton, J.D., 2017. *Soil fertility and fertilizers*, 8th ed. Pearson Education, London: UK.
- Hecht, S.B., 2005. Soybeans, development and conservation on the Amazon frontier. *Development and Change* 36 (2), 375–404. <https://doi.org/10.1111/j.0012-155X.2005.00415.x>
- Heckscher, E., 1949. The effect of foreign trade on the distribution of income. *Readings in the theory of international trade*. Blakiston, Philadelphia: US, p. 272-300. *Originally published in 1919*.
- Hetherington, K., 2020. *The government of beans: Regulating life in the age of monocrops*. Duke University Press, Durham: US.
- Hilbert, J., Luciana, S., Manosalva, J., Geretto, P., Ponieman, K., Camardelli, A., 2021. Greenhouse gas emission from the cultivation of soybean in Argentina. *INTA, Buenos Aires: Argentina* <https://doi.org/10.13140/RG.2.2.20622.69441/1>
- Hora, R., 2001. *The landowners of the Argentine Pampas: A social and political history 1860-1945*. Clarendon Press, Oxford: UK.
- Hornborg, A., 2023a. Acknowledging materiality without fetishizing it: Some pitfalls in speaking for matter, in: Boysen, B., Rasmussen, J. (Eds.), *Against new materialisms*. Bloomsbury Academic, London: UK, 143–160.

- Hornborg, A., 2023b. Transhistorical perspectives on commodities, fetishism, and world-systems: Technologies of exploitation through five thousand years. *Locus: Revista de História* 29 (1), 14–39. <https://doi.org/10.34019/2594-8296.2023.v29.40399>
- Hornborg, A., 2019. *Nature, society, and justice in the Anthropocene: Unraveling the money-energy-technology complex*, *New Directions in Sustainability and Society*. Cambridge University Press, Cambridge: UK. <https://doi.org/10.1017/9781108554985>
- Håkansson, N.T., 2019. Criticizing resilience thinking: A political ecology analysis of droughts in nineteenth-century East Africa. *Economic Anthropology* 6 (1), 7–20. <https://doi.org/10.1002/sea2.12127>
- Håkansson, N.T., Widgren, M. (Eds.), 2016. *Landesque capital: The historical ecology of enduring landscape modifications*. Routledge, New York: US. <https://doi.org/10.4324/9781315425696>
- INDEC, 2021. *Censo Nacional Agropecuario - 2018*. Instituto Nacional de Estadística y Censos, Buenos Aires: Argentina.
- INDEC, 2003. *Censo Nacional Agropecuario - 2002*. Instituto Nacional de Estadística y Censos, Buenos Aires: Argentina.
- INDEC, 1939. *Censo Nacional Agropecuario - 1937*. Instituto Nacional de Estadística y Censos, Buenos Aires: Argentina.
- INDEC, 1909. *Censo Agropecuario Nacional - 1908*. Instituto Nacional de Estadística y Censos, Buenos Aires: Argentina.
- INDEC, 1898. *Segundo censo de la República argentina*. Instituto Nacional de Estadística y Censos, Buenos Aires: Argentina.
- INDEC, 1872. *Primer censo de la República Argentina*. Instituto Nacional de Estadística y Censos, Buenos Aires: Argentina.
- Infante-Amate, J., Mesa, A.U., Aragay, E.T., 2020. Las venas abiertas de América Latina en la era del Antropoceno: Un estudio biofísico del comercio exterior (1900-2016). *Diálogos Revista Electrónica de Historia* 21, 177–214.
- Jobbágy, E.G., Aguiar, S., Piñeiro, G., Garibaldi, L.A., 2021. Impronta ambiental de la agricultura de granos en Argentina: Revisando desafíos propios y ajenos. *Ciencia Hoy* 29 (173), 55–64.
- Jobbágy, E.G., Grau, H.R., Paruelo, J.M., Viglizzo, E.F., 2015. Farming the Chaco: Tales from both sides of the fence. *Journal of Arid Environments*, 123, 1–2. <https://doi.org/10.1016/j.jaridenv.2015.07.011>
- Kanter, D.R., Del Grosso, S., Scheer, C., Pelster, D.E., Galloway, J.N., 2020. Why future nitrogen research needs the social sciences. *Current Opinion in Environmental Sustainability, Climate Change, Reactive Nitrogen, Food Security and Sustainable Agriculture* 47, 54–60. <https://doi.org/10.1016/j.cosust.2020.07.002>
- Kapp, K.W., 1978. *The social costs of business enterprise*. Russell Press, Nottingham: UK.
- Katz, J., Kosacoff, B., 2000. Import-substituting industrialization in Argentina, 1940–80: Its achievements and shortcomings, in: Cárdenas, E., Ocampo, J.A., Thorp, R. (Eds.), *An economic history of twentieth-century Latin America: Volume 3: Industrialization and the state in Latin America: The postwar years*. Palgrave Macmillan UK: London, 282–313. [https://doi.org/10.1057/9780230595682\\_10](https://doi.org/10.1057/9780230595682_10)
- Kay, C., 1989. *Latin American theories of development and underdevelopment, Development and underdevelopment*, Routledge, London: UK.

- Kay, C., Gwynne, R.N., 2000. Relevance of structuralist and dependency theories in the neoliberal period: A Latin American perspective. *Journal of Developing Societies* 16 (1). <https://doi.org/10.1163/156852200511987>
- Koritschoner, J.J., Whitworth Hulse, J.I., Cuchietti, A., Arrieta, E.M., 2023. Spatial patterns of nutrients balance of major crops in Argentina. *Science of The Total Environment* 858, 159863. <https://doi.org/10.1016/j.scitotenv.2022.159863>
- Krausmann, F., Langthaler, E., 2019. Food regimes and their trade links: A socio-ecological perspective. *Ecological Economics* 160, 87–95. <https://doi.org/10.1016/j.ecolecon.2019.02.011>
- Kröger, M., Nygren, A., 2020. Shifting frontier dynamics in Latin America. *Journal of Agrarian Change* 20, 364–386. <https://doi.org/10.1111/joac.12354>
- Kvale, S., 2007. *Doing interviews*. SAGE Publications: London: UK. <https://doi.org/10.4135/9781849208963>
- Lander, B., DuBois, T.D., 2022. A history of soy in China: From weedy bean to global commodity, in: Da Silva, C.M., De Majo, C. (Eds.), *The age of the soybean: An environmental history of soy during the Great Acceleration*. The White Horse Press, Winwick: UK, 29–47. <https://www.jstor.org/stable/j.ctv309h1fx.8>
- Langthaler, E., 2020. Broadening and deepening: Soy expansions in a world-historical perspective. *Historia Ambiental Latinoamericana y Caribeña* 10 (1), 244–277. <https://doi.org/10.32991/2237-2717.2020v10i1.p244-277>
- Langthaler, E., Martsch, M., Tober, G., 2023. Conceptualizing historical commodity studies: The case of soy, in: Carmona-Zabala, J. (Ed.), *Commodities in history: Theoretical reflections and empirical case studies*. Institute for Mediterranean Studies, Crete: Greece. <https://doi.org/10.17613/9yrb-fq42>
- Langthaler, E., Schüßler, E., 2019. Commodity studies with Polanyi: Disembedding and re-embedding labour and land in contemporary capitalism. *Österreich Z Soziol* 44 (2), 209–223. <https://doi.org/10.1007/s11614-019-00339-2>
- Lapegna, P., 2016. *Soybeans and power: Genetically modified crops, environmental politics, and social movements in Argentina*. Oxford University Press, New York: US.
- Lassaletta, L., Billen, G., Garnier, J., Oita, A., Shibata, H., Shindo, J., Hayashi, K., 2019. Nitrogen embedded in global food trade, in: Ferranti, P., Berry, E.M., Anderson, J.R. (Eds.), *Encyclopedia of food security and sustainability*. Elsevier, Oxford: UK, 105–109. <https://doi.org/10.1016/B978-0-08-100596-5.21975-6>
- Lathuillière, M.J., Suavet, C., Biddle, H., Su, N., Carvalho, T., Ribeiro, V., Feerman, A., 2022. Argentina soy supply chain (2015-2019) (Version 1.1) [Data set]. Trase. <https://doi.org/10.48650/DY8T-0S49>. *Downloaded 19 October, 2023*.
- Lavado, R.S., Taboada, M.A., 2009. The Argentinean Pampas: A key region with a negative nutrient balance and soil degradation needs better nutrient management and conservation programs to sustain its future viability as a world agresource. *Journal of Soil and Water Conservation* 64 (5), 150-153. <https://doi.org/10.2489/jswc.64.5.150A>
- le Polain de Waroux, Y., Baumann, M., Gasparri, N.I., Gavier-Pizarro, G., Godar, J., Kuemmerle, T., Müller, R., Vázquez, F., Volante, J.N., Meyfroidt, P., 2018. Rents, actors, and the expansion of commodity frontiers in the Gran Chaco. *Annals of the American Association of Geographers* 108 (1), 204–225. <https://doi.org/10.1080/24694452.2017.1360761>
- Leguizamón, A., 2020. *Seeds of power: Environmental injustice and genetically modified soybeans in Argentina*. Duke University Press, Durham: US.

- Leguizamón, A., 2019. The gendered dimensions of resource extractivism in Argentina's soy boom. *Latin American Perspectives* 46 (2), 199–216. <https://doi.org/10.1177/0094582X18781346>
- Leguizamón, Y., Goldenberg, M.G., Jobbágy, E., Seppelt, R., Garibaldi, L.A., 2023. Environmental potential for crop production and tenure regime influence fertilizer application and soil nutrient mining in soybean and maize crops. *Agricultural Systems* 210, 103690. <https://doi.org/10.1016/j.agsy.2023.103690>
- Levin, S., Xepapadeas, T., Crépin, A.-S., Norberg, J., Zeeuw, A. de, Folke, C., Hughes, T., Arrow, K., Barrett, S., Daily, G., Ehrlich, P., Kautsky, N., Mäler, K.-G., Polasky, S., Troell, M., Vincent, J.R., Walker, B., 2013. Social-ecological systems as complex adaptive systems: Modeling and policy implications. *Environment and Development Economics* 18 (2), 111–132. <https://doi.org/10.1017/S1355770X12000460>
- Lewis, P.H., 1990. *The crisis of Argentine capitalism*. University of North Carolina Press, Chapel Hill: US.
- Luxemburg, R., 2003. *The accumulation of capital*, 1st ed. Routledge, New York: US. *Originally published in 1913*.
- Magliocca, N.R., Bremond, A.C. de, Ellicott, E.A., Seghezzo, L., Venencia, C.D., Mosciaro, M.J., Nolte, C., 2022. Two of a kind? Large-scale land acquisitions and commodity frontier expansion in Argentina's Dry Chaco. *Ecology and Society* 27 (2). <https://doi.org/10.5751/ES-13103-270225>
- Maldonado, G.I., Bustamante, M., 2019. Una tipología de los actores sociales en el agro pampeano del Sur cordobés, Argentina. *Cuadernos Geograficos* 58 (3), 234–258. <https://doi.org/10.30827/cuadgeo.v58i3.8769>
- Martínez Álvarez, D.L., 2012. Historia de la soja en la Argentina: Introducción y adopción del cultivo, in: Baigorri, H.E.J., Salado Navarro, L.R. (Eds.), *El cultivo de soja en Argentina*. Vicente López, Córdoba: Argentina, 11–31.
- Martinez-Feria, R.A., Basso, B., 2020. Unstable crop yields reveal opportunities for site-specific adaptations to climate variability. *Scientific Reports* 10 (1), 2885. <https://doi.org/10.1038/s41598-020-59494-2>
- Marx, K., 1992. *Capital, Volume I*. Penguin Classic, New York: US.
- McFarlane, I., O'Connor, E., 2014. World soybean trade: Growth and sustainability. *Modern Economy* 5 (5), 580–588.
- McMichael, P., 2014. *Food regimes and agrarian questions*. Practical Action Publishing, Rugby: UK. <https://doi.org/10.3362/9781780448787>
- McMichael, P., 2009. A food regime genealogy. *The Journal of Peasant Studies* 36 (1), 139–169. <https://doi.org/10.1080/03066150902820354>
- McNeill, J.R., Engelke, P., 2016. *The Great Acceleration, The Great Acceleration*. Harvard University Press, Cambridge: US.
- Medan, D., Torretta, J.P., Hodara, K., de la Fuente, E.B., Montaldo, N.H., 2011. Effects of agriculture expansion and intensification on the vertebrate and invertebrate diversity in the Pampas of Argentina. *Biodiversity and Conservation* 20 (13), 3077–3100. <https://doi.org/10.1007/s10531-011-0118-9>
- Medina, G. da S., 2022. The economics of agribusiness in developing countries: Areas of opportunities for a new development paradigm in the soybean supply chain in Brazil. *Frontiers in Sustainable Food Systems*. 6. <https://doi.org/10.3389/fsufs.2022.842338>
- MINREMIC, 2020. Entrevista entre el canciller Felipe Solá y el ministro de Comercio de la República Popular China Zhong Shan. Ministerio de Relaciones Exteriores,

- Comercio Internacional y Culto. URL: <https://www.cancilleria.gob.ar/es/actualidad/noticias/entrevista-entre-el-canciller-felipe-sola-y-el-ministro-de-comercio-de-la>
- Mitchell, B.R., 1993. *International historical statistics*. Palgrave Macmillan, London, UK. <https://doi.org/10.1007/978-1-349-13071-9>
- Moore, J.W., 2017. Metabolic rift or metabolic shift? Dialectics, nature, and the world-historical method. *Theory and Society* 46 (4), 285–318. <https://doi.org/10.1007/s11186-017-9290-6>
- Moore, J.W., 2015. *Capitalism in the web of life: Ecology and the accumulation of capital*. Verso, London: UK.
- Moore, J.W., 2000. Sugar and the expansion of the early modern world-economy: Commodity Frontiers, ecological transformation, and industrialization. *Review (Fernand Braudel Center)* 23 (3), 409–433.
- Moraes, M., 2008. *Assessing comparative advantage in soybean production: A global perspective* (PhD. Dissertation). University of Illinois, Urbana-Champaign, US.
- Mostern, R., 2021. Comments on time, space and method for the study of commodity frontiers and the transformation of the global countryside. *Journal of Global History* 16 (3), 456–461. <https://doi.org/10.1017/S1740022820000443>
- Muradian, R., Martinez-Alier, J., 2001. Trade and the environment: From a ‘Southern’ perspective. *Ecological Economics* 36 (2), 281–297. [https://doi.org/10.1016/S0921-8009\(00\)00229-9](https://doi.org/10.1016/S0921-8009(00)00229-9)
- Myrdal, J., 2022. *A theory kit for world history*. *Agrarhistoria* 7.
- Neiman, M., Blanco, M., 2020. Beyond the Pampas: Global capital and uneven development in Argentine soybean expansion. *Journal of Agrarian Change* 20 (4), 538–561. <https://doi.org/10.1111/joac.12370>
- Norse, D., Ju, X., 2015. Environmental costs of China’s food security. *Agriculture, Ecosystems & Environment* 209, 5–14. <https://doi.org/10.1016/j.agee.2015.02.014>
- The Observatory of Economic Complexity (OEC), 2024. Argentina (ARG) exports, imports, and trade partners. [Data set] URL: <https://oec.world/en/profile/country/arg>. *Last access on 15 January, 2025*.
- OECD, 2023. *Agricultural policy monitoring and evaluation 2023: Adapting agriculture to climate change*. Organisation for Economic Co-operation and Development, Paris: France.
- OECD, 2019. *Agricultural policies in Argentina*. Organisation for Economic Co-operation and Development, Paris: France.
- OECD, 2006. *Trade, agriculture and development: Policies working together*. Organisation for Economic Co-operation and Development, Paris: France.
- Oenema, O., Kros, H., de Vries, W., 2003. Approaches and uncertainties in nutrient budgets: Implications for nutrient management and environmental policies. *European Journal of Agronomy, Element Balances as Sustainability Tools* 20 (1), 3–16. [https://doi.org/10.1016/S1161-0301\(03\)00067-4](https://doi.org/10.1016/S1161-0301(03)00067-4)
- Ohlin, B.G., 1967. *Interregional and international trade*. Harvard University Press: Harvard: US. *Originally published in 1933*.
- Oliveira, G. de L.T., 2021. Political ecology of soybeans in South America, in: Ahmed, A., Gasparatos, A. (Eds.), *Political ecology of industrial crops*. Routledge, London: UK.

- Oliveira, G. de L.T., Hecht, S., 2016. Sacred groves, sacrifice zones and soy production: Globalization, intensification and neo-nature in South America. *The Journal of Peasant Studies* 43 (2), 251–285.  
<https://doi.org/10.1080/03066150.2016.1146705>
- Oliveira, G. de L.T., Schneider, M., 2016. The politics of flexing soybeans: China, Brazil and global agroindustrial restructuring. *The Journal of Peasant Studies* 43 (1), 167–194. <https://doi.org/10.1080/03066150.2014.993625>
- Pain, A., Marquardt, K., Khatri, D., 2021. Secondary forests and agrarian transitions: Insights from Nepal and Peru. *Human Ecology* 49 (3), 249–258.  
<https://doi.org/10.1007/s10745-021-00224-1>
- Paz, R.G., 2020. Agricultural holdings with undefined boundaries, communal systems and counter-hegemonies: The persistence of the peasantry in Argentina. *Journal of Agrarian Change* 20, 562–578. <https://doi.org/10.1111/joac.12363>
- Paz, R.G., Jara, C., Wald, N., 2019. Tensions around land tenure in Argentina’s agrarian periphery: Scales and multiple temporalities of capitalism in Santiago del Estero, Argentina. *Latin American Research Review* 54 (3), 694–705.  
<https://doi.org/10.25222/larr.483>
- Paz, R.G., Lipshitz, H., Zerda, H.R., Tiedeman, J., 2015. Estructura agraria, áreas de concentración de la agricultura familiar y procesos de expansión de la frontera agropecuaria en Santiago del Estero, Argentina. *Revista Núcleo de Estudios, Pesquisas e Projetos de Reforma Agrária* 18 (27).
- Pengue, W.A., 2009a. Cuestiones económico-ambientales de las transformaciones agrícolas en las pampas. *Problemas del desarrollo* 40 (157), 137–161.
- Pengue, W.A., 2009b. Agrofuels and agrifoods: Counting the externalities at the major crossroads of the 21st Century. *Bulletin of Science, Technology & Society* 29 (3), 167–179. <https://doi.org/10.1177/0270467609333731>
- Pengue, W.A., 2005. Transgenic crops in Argentina: The ecological and social debt. *Bulletin of Science, Technology & Society* 25 (4), 314–322.  
<https://doi.org/10.1177/0270467605277290>
- Pengue, W.A., 2004. Producción agroexportadora e (in)seguridad alimentaria: El caso de la soja en Argentina. *Revista de la Red Iberoamericana de Economía Ecológica* 1, 046–055.
- Perez Manrique, P.L., Brun, J., González-Martínez, A.C., Walter, M., Martínez-Alier, J., 2013. The biophysical performance of Argentina (1970–2009). *Journal of Industrial Ecology* 17 (4), 590–604. <https://doi.org/10.1111/jiec.12027>
- Pérez-Rincón, M.A., 2006. Colombian international trade from a physical perspective: Towards an ecological “Prebisch thesis.” *Ecological Economics* 59 (4), 519–529. <https://doi.org/10.1016/j.ecolecon.2005.11.013>
- Peterson, G., 2000. Political ecology and ecological resilience: An integration of human and ecological dynamics. *Ecological Economics* 35 (3), 323–336.  
[https://doi.org/10.1016/S0921-8009\(00\)00217-2](https://doi.org/10.1016/S0921-8009(00)00217-2)
- Phélinas, P., Choumert, J., 2017. Is GM soybean cultivation in Argentina sustainable? *World Development* 99, 452–462.  
<https://doi.org/10.1016/j.worlddev.2017.05.033>
- Piquer-Rodríguez, M., Butsic, V., Gärtner, P., Macchi, L., Baumann, M., Gavier Pizarro, G., Volante, J.N., Gasparri, I.N., Kuemmerle, T., 2018. Drivers of agricultural land-use change in the Argentine Pampas and Chaco regions. *Applied Geography* 91, 111–122. <https://doi.org/10.1016/j.apgeog.2018.01.004>
- Polanyi, K., 1944. *The great transformation*. Farrar & Rinehart, New York: US.

- Polimeni, J.M., 2008. The Jevons paradox and the myth of resource efficiency improvements. Earthscan, London: UK.
- Portela, S.I., Reixachs, C., Torti, M.J., Beribe, M.J., Giannini, A.P., 2024. Contrasting effects of soil type and use of cover crops on nitrogen and phosphorus leaching in agricultural systems of the Argentinean Pampas. *Agriculture, Ecosystems & Environment* 364, 108897. <https://doi.org/10.1016/j.agee.2024.108897>
- Prebisch, R., 1950. The economic development of Latin America and its principal problems. United Nations Economic Commission for Latin America and the Caribbean.
- Prodöhl, I., 2023. Globalizing the soybean: Fat, feed, and sometimes food, c. 1900–1950. Routledge, London: UK. <https://doi.org/10.4324/9781003255222>
- Reca, L.G., 2006. El sector agropecuario argentino: Despegue, caída y resurgimiento (1875 y 2005). *Estudios Económicos* 23 (47), 91–118.
- Ricardo, D., 2015. On the principles of political economy, and taxation, Cambridge library collection - British and Irish History, 19th Century. Cambridge University Press, Cambridge: UK. <https://doi.org/10.1017/CBO9781107589421>. *Originally published in 1817*.
- Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S.E., Donges, J.F., Drüke, M., Fetzer, I., Bala, G., von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kummu, M., Mohan, C., Nogués-Bravo, D., Petri, S., Porkka, M., Rahmstorf, S., Schaphoff, S., Thonicke, K., Tobias, A., Virkki, V., Wang-Erlandsson, L., Weber, L., Rockström, J., 2023. Earth beyond six of nine planetary boundaries. *Science Advances* 9 (37). <https://doi.org/10.1126/sciadv.adh2458>
- Ritchie, H., 2021. Drivers of deforestation. Our World in Data. URL: <https://ourworldindata.org/drivers-of-deforestation>
- Robinson, G.M., 2018. Globalization of agriculture. *Annual Review of Resource Economics* 10, 133–160.
- Rocha, C.B., Nehring, R., Silva, S.D.E., 2022. Soy without borders: The transnational dynamics of commodity frontiers in South America (1971–2019). *Global Environment* 15 (3), 423–455. <https://doi.org/10.3197/ge.2022.150301>
- Roy, R.N., Misra, R.V., Lesschen, J.P., Smaling, E.M., 2003. Assessment of soil nutrient balance: Approaches and methodologies, Fertilizer and Plant Nutrition Bulletins. FAO, Rome: Italy.
- SAGyP, 2024. Estimaciones Agrícolas. [Data set]. Secretaría de Agricultura, Ganadería y Pesca. URL: <https://datosestimaciones.magyp.gov.ar/reportes.php?reporte=Estimaciones>. *Last access on 15 January, 2025*.
- Sandström, V., Kaseva, J., Porkka, M., Kuisma, M., Sakieh, Y., Kahiluoto, H., 2023. Disparate history of transgressing planetary boundaries for nutrients. *Global Environmental Change* 78, 102628. <https://doi.org/10.1016/j.gloenvcha.2022.102628>
- Sarmiento, D.F., 2003. *Facundo: Civilization and barbarism*. University of California Press, Berkeley: US. *Originally published in 1845*.
- Schlüter, M., Haider, L.J., Lade, S.J., Lindkvist, E., Martin, R., Orach, K., Wijermans, N., Folke, C., 2019. Capturing emergent phenomena in social-ecological systems: An analytical framework. *Ecology and Society* 24 (3).
- Schneider, M., McMichael, P., 2010. Deepening, and repairing, the metabolic rift. *The Journal of Peasant Studies* 37 (3), 461–484. <https://doi.org/10.1080/03066150.2010.494371>

- Schutter, O.D., 2019. The political economy approach to food systems reform. *IDS Bulletin* 50 (2). <https://doi.org/10.19088/1968-2019.115>
- Scobie, J.R., 1964. *Revolution on the Pampas: A social history of Argentine wheat, 1860-1910*. University of Texas Press, Austin: US.
- Shurtleff, W., Aoyagi, A., 2009. *History of soybean in South America (1882-2009): Extensively annotated bibliography and sourcebook*. Soyinfo Center, Lafayette: US. URL: <https://www.soyinfocenter.com/pdf/132/LaSo.pdf>
- Singer, H.W., 1950. The distribution of gains between investing and borrowing countries. *American Economic Review* 40 (2), 473.
- Sly, M.J.H., 2017. The Argentine portion of the soybean commodity chain. *Palgrave Communications* 3 (1), 1–11. <https://doi.org/10.1057/palcomms.2017.95>
- Solberg, C., 1987. *The Prairies and the Pampas: Agrarian policy in Canada and Argentina, 1880-1930*. Stanford University Press: Stanford: US.
- Spruk, R., 2019. The rise and fall of Argentina. *Latin American Economic Review* 28 (1). <https://doi.org/10.1186/s40503-019-0076-2>
- Stojanovic, T., McNae, H.M., Tett, P., Potts, T.W., Reis, J., Smith, H.D., Dillingham, I., 2016. The “social” aspect of social-ecological systems: A critique of analytical frameworks and findings from a multisite study of coastal sustainability. *Ecology and Society* 21 (3).
- Street, J.H., James, D.D., 1982. Institutionalism, structuralism, and dependency in Latin America. *Journal of Economic Issues* 16 (3), 673–689.
- Sunkel, Osvaldo., 1973. *Past, present and future of the process of Latin-American underdevelopment*. Center for Afro-Asian Research of the Hungarian Academy of Sciences, Budapest: Hungary.
- Svampa, M., 2019. *Neo-extractivism in Latin America: Socio-environmental conflicts, the territorial turn, and new political narratives*. Cambridge University Press, Cambridge: UK.
- Trigo, E.J., Cap, E.J., 2003. The impact of the introduction of transgenic crops in Argentinean agriculture. *AgBioForum* 6 (3).
- Turner, F.J., 1994. *Rereading Frederick Jackson Turner: “The significance of the frontier in American history” and Other Essays*. Yale University Press, New Haven: US. *Originally published in 1920*.
- Turzi, M., 2017. *The political economy of agricultural booms: Managing soybean production in Argentina, Brazil, and Paraguay*. Springer, Cham: Switzerland.
- United Soybean Board, 2024. *Soybean Fertility*. Soybean Research & Information Network. URL: <https://soybeanresearchinfo.com/agronomics/soybean-fertility/>
- Urcola, H.A., de Sartre, X.A., Veiga, I., Elverdin, J., Albaladejo, C., 2015. Land tenancy, soybean, actors and transformations in the Pampas: A district balance. *Journal of Rural Studies* 39, 32–40. <https://doi.org/10.1016/j.jrurstud.2015.03.001>
- Urien, C.M., Colombo, E., 1914. *Geografía general de la República Argentina: Estudio histórico, físico, político, social y económico*, 2nd ed. Maucci Hermanos, Buenos Aires: Argentina.
- USDA PSD, 2024. [Data set] United States Department of Agriculture Production, Supply, and Distribution Online. URL: <https://apps.fas.usda.gov/psdonline/app/index.html#/app/home>. *Last access on 15 January, 2025*.

- Viglizzo, E.F., Carreño, L.V., Pereyra, H., Ricard, F., Clatt, J., Pincén, D., 2010. Dinámica de la frontera agropecuaria y cambio tecnológico, in: Viglizzo, E.F., Jobbágy, E. (Eds.), *Expansión de la frontera agropecuaria en Argentina y su impacto ecológico-ambiental*. INTA, Buenos Aires: Argentina.
- von Motz, F.H., 1916. *Markets for agricultural implements and machinery in Argentina*, Special Agents Series. Government Printing Office, Washington D.C.: US.
- Wald, N., 2016. Historical paths to current unrest: Extending the temporal lens in analysing geographies of agrarian change and conflict. *Geoforum* 76, 38–47. <https://doi.org/10.1016/j.geoforum.2016.08.010>
- Walker, P.A., 2005. Political ecology: Where is the ecology? *Progress in Human Geography* 29, 73–82. <https://doi.org/10.1191/0309132505ph530pr>
- Wallerstein, I., 1974. *The modern world-system I: Capitalist agriculture and the origins of the European world-economy in the sixteenth century*. University of California Press, Berkeley: US.
- Warman, Arturo., 2003. *Corn and capitalism: How a botanical bastard grew to global dominance*. University of North Carolina Press, Chapel Hill: US.
- Watts, M.J., 2021. Space, scale, and the global oil assemblage: Commodity frontiers in resource peripheries, in: Irarrázaval, F., Arias-Loyola, M. (Eds.), *Resource peripheries in the global economy: Networks, scales, and places of extraction*, *Economic Geography*. Springer, Cham: Switzerland, 145–182. [https://doi.org/10.1007/978-3-030-84606-0\\_8](https://doi.org/10.1007/978-3-030-84606-0_8)
- Weis, A.J., 2007. *The global food economy: The battle for the future of farming*. Zed Books, London: UK.
- Werner, M., Berndt, C., Mansfield, B., 2022. The glyphosate assemblage: Herbicides, uneven development, and chemical geographies of ubiquity. *Annals of the American Association of Geographers* 112 (1), 19–35. <https://doi.org/10.1080/24694452.2021.1898322>
- Wingeyer, A.B., Amado, T.J.C., Perez-Bidegain, M., Studdert, G.A., Perdomo Varela, C.H., Garcia, F.O., Karlen, D.L., 2015. Soil quality impacts of current South American agricultural practices. *Sustainability* 7 (2), 2213–2242. <https://doi.org/10.3390/su7022213>
- Wood, A., Queiroz, C., Deutsch, L., González-Mon, B., Jonell, M., Pereira, L., Sinare, H., Svedin, U., Wassénus, E., 2023. Reframing the local–global food systems debate through a resilience lens. *Nature Food* 4 (1), 22–29. <https://doi.org/10.1038/s43016-022-00662-0>
- Worster, D., 1990. Transformations of the Earth: Toward an agroecological perspective in history. *The Journal of American History* 76 (4), 1087–1106. <https://doi.org/10.2307/2936586>
- Yang, N., Wang, Y., Liu, X., Jin, M., Vallebuena-Estrada, M., Calfee, E., Chen, L., Dilkes, B.P., Gui, S., Fan, X., Harper, T.K., Kennett, D.J., Li, W., Lu, Y., Ding, J., Chen, Z., Luo, J., Mambakkam, S., Menon, M., Snodgrass, S., Veller, C., Wu, Shenshen, Wu, Siying, Zhuo, L., Xiao, Y., Yang, X., Stitzer, M.C., Runcie, D., Yan, J., Ross-Ibarra, J., 2023. Two teosintes made modern maize. *Science* 382 (6674). <https://doi.org/10.1126/science.adg8940>
- Zazo, F.E., Flores, C.C., Sarandon, S.J., 2011. El “costo oculto” del deterioro del suelo durante el proceso de “sojización” en la región de Arrecifes, Argentina. *Revista Brasileira de Agroecologia* 6 (3).

- Zorzoli, F.M., 2021. De la fiebre de la soja a la degradación de los suelos: Economía, ecología y política en la agricultura del centro-oeste del Chaco Seco, Argentina (1960-1990). *Quinto Sol* 25 (1), 111–132. <https://doi.org/10.19137/qs.v25i1.4355>
- Zuberman, F., 2019. Suelo virtual y deuda ecológica: Un cálculo para la expansión de la soja en Argentina. *SaberEs* 11 (1), 81–95.



## 8. Supplementary material for expert interviews

### 8.1 Anonymized list of respondents in chronological order

Researcher specializing in adaptive management of agronomic systems and forestry. [Interview] (February 1, 2024). Online via Zoom.

Researcher specializing in agroecology, biodiversity, and interactions between plants and insects. [Interview] (February 15, 2024). Over the phone via Whatsapp.

Researcher/Agronomist specializing in soil health and grasslands management. [Interview] (February 16, 2024). Online via Zoom.

Researcher/Agronomist specializing in rural sociology and demography in Santiago del Estero. [Interview] (February 21, 2024). Online via Zoom.

Researcher/Agronomist specializing in soybeans and agroecology in the Pampas. [Interview] (March 3, 2024). Online via Zoom.

Researcher/Agronomist specializing in soil nutrient cycling in the Pampas and the Dry Chaco. [Interview] (June 20, 2024). Over the phone via Whatsapp.

Local soybean and livestock producer from Southern Córdoba [Interview] (July 18, 2024). Over the phone via Whatsapp.

Researcher/Extension service provider specializing in soil conservation and hydrographic basins [Interview] (July 25, 2024). Over the phone via Whatsapp.

### 8.2 Interview guide

Below is a list of interview questions that were posed to the above list of expert interviewees that were formulated to gain more detailed insights into soil nutrient loss. During the first two interviews, I only asked the interviewees about nitrogen. It was because of the insights from these first two interviews that I expanded the scope of the research to include phosphorus and sulfur. These were semi-structured interviews; therefore, this list of questions represents the guiding framework, rather than a strict and consistent survey of questions asked. Questions were adapted during individual interviews and follow-up questions were posed. Moreover, as time went on and more insights were gained, a set of auxiliary questions were

created. These auxiliary questions are presented in the following subsection. As interviews were conducted in Spanish, I first attach the original questions posed below, with English translations following:

- ¿Existe extracción de nitrógeno, fósforo y azufre en los campos donde trabajas (en todos los campos o solamente algunos)? ¿Cómo te das cuenta de si existe extracción (haces algunas mediciones o usas algún tipo de indicadores - en tal caso, cuáles)?
- ¿Cómo reaccionan generalmente los productores de tu región a los problemas de suelo en general, y a la extracción de nitrógeno, fósforo y azufre en particular? ¿Cómo es el nivel de conciencia/conocimiento - a qué se debe la eventual variabilidad?
- ¿Qué explica la variedad de grado de extracción? ¿Cuál rol crees que podrían jugar la tecnología o los cambios en las políticas para mitigar la extracción de nitrógeno, fósforo y azufre del suelo?
- ¿Podría describir la evolución de prácticas de cultivo de soja, enfocándose en cambios en el uso del suelo, como la expansión a nuevas áreas o la intensificación del cultivo existente? Por favor, incluya cómo decide sobre prácticas como la rotación de cultivos, labranza y uso de fertilizantes, y cómo estas decisiones han sido influenciadas por el cultivo de soja.
- ¿Cómo han impactado sus prácticas de cultivo de soja en la salud del suelo, particularmente con respecto a los niveles de nitrógeno, fósforo y azufre en el suelo? ¿Ha observado cambios en la fertilidad del suelo, estructura u otros indicadores de salud a lo largo del tiempo debido a estas prácticas?
- Considerando las tendencias y prácticas actuales en el cultivo de soja, ¿cuáles son sus perspectivas sobre la agricultura sostenible y la gestión de la salud del suelo? ¿Qué desafíos enfrenta en la adopción de prácticas sostenibles y cómo visualiza el futuro del cultivo de soja en su área?

*English translation:*

- Is there extraction of nitrogen, phosphorus, and sulfur in the fields where you work (in all fields or only some)? How do you determine if there is extraction (do you conduct any measurements or use any type of indicators – if so, which ones)?
- How do producers in your region generally react to soil problems in general, and to the extraction of nitrogen, phosphorus, and sulfur in particular? What is the level of awareness/knowledge – what accounts for any variability?

- What explains the variation in the degree of extraction? What role do you think technology or policy changes could play in mitigating the extraction of nitrogen, phosphorus, and sulfur from the soil?
- Could you describe the evolution of soybean cultivation practices, focusing on changes in land use, such as the expansion into new areas or the intensification of existing cultivation? Please include how you decide on practices such as crop rotation, tillage, and fertilizer use, and how these decisions have been influenced by soybean cultivation.
- How have your soybean cultivation practices impacted soil health, particularly regarding nitrogen, phosphorus, and sulfur levels in the soil? Have you observed changes in soil fertility, structure, or other health indicators over time due to these practices?
- Considering current trends and practices in soybean cultivation, what are your perspectives on sustainable agriculture and soil health management? What challenges do you face in adopting sustainable practices, and how do you envision the future of soybean cultivation in your area?

### **8.2.1 Auxiliary interview questions**

Expert interviews were originally planned to better understand soil nutrient loss in the two case study regions. However, as time progressed and more interviews were conducted, I began asking more longitudinal questions alongside the original interview guide. Below is a list of auxiliary questions that were posed. Due to the semi-structured nature of the expert interview method used in this research, as well as the varying expertise of interviewees, this list is not comprehensive of all follow-up questions. The original questions as they were asked in Spanish are given, followed by English translations:

- ¿Cómo han evolucionado las prácticas agrícolas en esta región durante las últimas décadas, particularmente en relación con el cultivo de soja?
- ¿Qué prácticas tradicionales de manejo del suelo existían antes de la introducción de las técnicas modernas de cultivo de soja, y alguna de ellas ha persistido o ha sido adaptada?
- ¿Cómo perciben los agricultores la sostenibilidad a largo plazo de sus prácticas actuales en comparación con las de generaciones anteriores?

- ¿Qué estrategias locales, si es que existen, han surgido para enfrentar la disminución de nutrientes en el suelo sin recurrir a insumos sintéticos?
- ¿Qué factores externos (por ejemplo, cambios en las políticas, fluctuaciones del mercado, patrones de tenencia de la tierra) han influido más en las decisiones de manejo del suelo en los últimos años?

*English translation:*

- How have agricultural practices in this region evolved over the past decades, particularly in relation to soybean cultivation?
- What traditional soil management practices existed before the introduction of modern soybean farming techniques, and have any of them persisted or been adapted?
- How do farmers perceive the long-term sustainability of their current practices compared to those of previous generations?
- What local strategies, if any, have emerged to address soil nutrient depletion without relying on synthetic inputs?
- What external factors (for example, policy changes, market fluctuations, land tenure patterns) have most influenced soil management decisions in recent years?