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GM Soy in Argentina – Feeding or Eating the World?

Detecting and Explaining Land Use Changes in the Pampa Húmeda

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11-744-505

GEO 511 Master's Thesis

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September 29th, 2017

Cover image: Soybean field ready for harvest in the area of Junín [*soja de primero*] (Photograph: Franziska Moergeli, March 2017).

Acknowledgements

I would like to take the opportunity to thank all of the people who have accompanied me during this year of researching, planning, implementing, analyzing and writing and who have been very supportive of me.

First of all, I would like to thank my supervisor, Prof. Dr. Christian Berndt from the Department of Economic Geography in Zurich, for his support throughout every stage of my master thesis. For his continuous and constructive feedback and advice, I am very grateful.

Furthermore, I would like to thank Prof. Dr. Alexander Damm from the Remote Sensing Laboratories (RSL) at the Department of Geography at the University of Zürich. As my second supervisor, he provided helpful responses on which I could always rely. He also gave me much appreciated guidance and support.

I also gratefully acknowledge and thank Dominic Fawcett for his intensive support with the Google Earth Engine implementation in the early stages of my thesis. I furthermore want to thank further faculty members for helping me in various stages of the thesis: Annina Brügger, Dr. Curdin Derungs, Christin Bernhold, Dr. Karin Schwitter and Reik Leiterer.

Special thanks also go to the people with whom I interacted during my stay in Argentina. Thanks go to my interview partners, who made a sincere effort to improve my maps as well as to give me insight into Argentina's history to understand the processes "behind my maps". Thanks go to Victoria, who invited me into her home and helped me to get my field data and interviews. And finally, thanks go to Maria, who not only provided me with important training sites data but also passed on her knowledge and experience in genetically modified soy-induced land use change classification.

Last but not least, I want to thank Alessandro Hug, my family, Tobias Klee, Sondra Tjin, and Rebecca Meier, my friends and my fellow students for their continuous support, inspiring conversations and productive feedback.

Preface

This master thesis was written during the fall term of 2016 and spring term of 2017 in the Economic Geography Department at the University of Zurich.

I developed a growing interest in economic geography and remote sensing while taking master courses at the University of Zurich. Courses such as Global Economic Geographies of Agriculture and Food Systems or the fieldtrip to Australia with a group from the RSL served as inspirations for the topic of this master thesis.

I knew I would write about climate change or food security, but I was happy to finally focus on land use change resulting from genetically modified soy in Argentina. This master thesis enabled me to develop a comprehensive knowledge of various subjects. I was able to travel to Argentina myself, which not only enhanced my motivation but also was an enriching, pleasant and educational experience.

Writing this thesis not only allowed me to develop deep insight into a very interesting and important topic but also gave me great joy and taught me a lot along the way.

Zurich, 29th of September 2017 Franziska Moergeli

Abstract

Argentina’s development in soy production is rambling, rapid and has an impact on a large scale. Since 1996, Argentina has experienced a major restructuring of the agricultural sector due to genetically modified (GM) soy production. The land use change based on this restructuring features many processes and problems and is the main focus of this thesis. The research questions contain the study of the current situation of GM soy production regarding the geographic extent and social mindset. Additionally, the change of land use since the GM soy introduction in 1996 and the responsible drivers are investigated. To detect and explain the land use change in the *Pampa Húmed*a, land use cover maps were generated based on remote sensing data and verified with ground truth data collected in Argentina. Further, expert interviews were conducted in Buenos Aires and in surrounding areas to reveal the drivers of the extensive land use change. The maps illustrate a constant expansion and intensification of soy production from 1996 until 2010. The map of 2015 reveals a change in trends, with the focus of producers moving away from soy production toward rotation and growing semi natural areas. The mindset about GM soy and land use change diverges between two opinions: one that welcomes GM soy and the possibilities that land use change brings, and one where the land use change emerging from GM soy adaptation is feared. The two opposing opinions also vary regarding whether GM soy is “feeding” or “eating” the world. However, it can be said that despite being a good tool at the time for helping Argentina to escape the economic crisis, GM soy production today does not feed the world, and the resulting land use change rather “eats” the possibility of feeding the local population, not to mention the world. Therefore, questions emerge how the land use will change, regarding current political changes and global tendencies, which favor sustainable agricultural production.

Content

List of Figures

List of Tables

Abbreviations

AACREA	Asociación Argentina de Consorcios Regionales de Experimentación Agrícola
	Engl.: Argentine Association of Regional Consortia of Agricultural Experimentation
AAPRESID	Asociación Argentina de Productores en Siembra Directa
	Engl.: Argentine Association of No-Till Producers
DOY	Day of the Year
GEE	Google Earth Engine
GMO	Genetically Modified Organism
GM Soy	Genetically Modified Soy
GPS	Global Positioning System
FAO	Food and Agriculture Organization of the United Nations
INTA	Instituto Nacional de Tecnología Agropecuaria
	Engl.: National Institute of Agricultural Technologies of Argentina
ROI	Region of Interest
RR	Roundup Ready®
RSL	Remote Sensing Laboratories
TOA	Top of Atmosphere
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
PAN	Panchromatic

SPOT	Système Probatoire d'Observation de la Terre
USGS	United States Geological Survey
VI	Vegetation Index
WCED	World Commission on Environment and Development

1 Introduction

For more than 40 years, soybean literally has been on everyone's lips. Soy, which many people consume in various forms, remains an intensive, diverse and extensive topic of discussion (Suchanek 2013, p. 10).

Caused by its high proportion of protein and energy, soybean is a key part of the global food supply. The well-known products of soy milk, soy sauce and tofu are the most common direct soy products that humans consume. In addition, soy found its way as a raw material into various nourishments, such as butter, cheese, oil, chocolate, ice cream and even instant soup. However, an interesting and potentially shocking fact is the amount of soybean used as livestock feed. Worldwide, three-quarters of soy production end up as animal feed, whereas only 6% of soybeans are eaten directly (WWF 2014, p. 4). Soybean, as the most profitable agricultural product and the world's largest source of animal feed, is a key component of industrial farming. Worldwide soybean production has increased tenfold (27 to 269 million tons) in the past 50 years and covers more than one million square kilometers today. Most affected by this growth has been South America, where production grew by 123% in the first 10 years after genetically modified (GM) soybean introduction in 1996. According to the Food and Agriculture Organization of the United Nations (FAO), this expansion shows no sign of stopping, and the FAO assumes that soy production will almost double by 2050 (WWF 2014, p. 4-6).

Soybean has been the topic of discussion on many pages of newspapers, books, research papers, social media and more. Glyphosate and Monsanto; deforestation and the loss of biodiversity; the poisoning of wildlife, cattle and people; and moneymaking and job losses are terms associated with GM soy, causing the world to look at South America (Choumert and Phelinas 2015; Craviotti 2016; Gavier-Pizarro et al. 2012; Leguizamón 2014; Phelinas and Choumert 2017). Especially Brazil, Paraguay and Argentina are large-scale soy producers. However, 20 years ago, Argentina was especially famous for its cattle raising. However, at some point, soy production in Argentina became great and unapproachable with effects on a global scale (WWF 2014, p. 10ff).

Argentinean soybean production has caused tremendous land use change. Between 1996 and 2006, the nation's cultivated area increased by 45%, with half of the increase being due to GM soy (Gavier-Pizarro et al. 2012, p. 44). The increasing worldwide demand for soybean and the domestic economic crisis transformed traditional rotational cropping patterns into permanent soybean production. In addition, the agricultural frontier is expanding at the expense of natural lands (Craviotti 2016, p. 86; Delvenne et al. 2013, p. 154; Gavier-Pizarro et al. 2012, p. 45f; Leguizamón 2014, p. 154f). The land use change is causing Argentina to face various problems, such as deforestation, soil degradation, erosion and the siltation of rivers and wetlands; increasing the use of agrochemicals due to monoculture; and the displacement of other crops and cattle raising. Furthermore, the landscape's transformation has had a negative impact on natural wildlife habitats and biodiversity, nutrient depletion, ecological contamination (ground and aerial applications of pesticides), freshwater ecosystems and groundwater quality (Choumert and Phelinas 2015, p. 134f; Delvenne et al. 2013, p. 154; Milazzo et al. 2013, p. 808; Schrag et al. 2009, p. 135f; Tomei and Upham 2009, p. 3895). In addition, numerous social consequences of GM soy production in Argentina have been detected, evaluated and analyzed. The immense expansion of GM soy production has led to the violation of human rights, expropriation (expulsion of small farmers), the destruction of peasant agriculture, the concentration of land ownership and agricultural production, land grabbing, inequitable agricultural growth, the unequal distribution of benefits to society, decreasing rural employment opportunities, rural exodus, competition between food and non-food uses, the reduction of food diversity and security, health damage to communities (malnutrition, agrochemical intoxication), the loss of cultural diversity and many more issues (Borras et al. 2012, p. 405f; van Dam et al. 2009, p. 1680; Leguizamón 2014, p. 152; Milazzo et al. 2013, p. 808).

In summary, agricultural expansion stemming from GM soy production has caused many well-documented problems. It is known why the GM soy introduction in 1996 in Argentina happened and why it was thriving. However, uncertainties regarding the drivers and extent of the land use change, as well as the spatial distribution of GM soy production remain. The accurate large-scale monitoring of the land use changes in this area is lacking. What has happened since 1996 with the land, the land use, the people and the production of agricultural goods in Argentina? How did land use changes take place? Is land use change in Argentina undoubtedly linked to GM soy production? What does this change mean for the future, and what could future land use changes be?

Land use change and its triggering factors, processes and effects in the core agricultural production area of Argentina will be evaluated and analyzed. This will be accomplished by using interdisciplinary approaches. Remote sensing based land use cover maps from 1996 to 2016 and qualitative interviews for achieving a more in-depth look at social processes will help to narrow the research gap.

1.1 Research Focus and Objective

The main purpose and the guideline of this master thesis is an evaluation of the land use change due to GM soy production in Argentina, particularly in the northern part of the *Pampa Húmeda* [the humid Pampas].

More specifically, the following research questions concern the current situation, the development as well as the processes of the land use change:

I. What is the current situation of GM soy production regarding the extent and mindset in the northern part of the *Pampa Húmeda?*

The remote sensing approach was expected to reveal the present extent of GM soy production in the study area as well as illustrate today's main agricultural goods produced on these farmlands. Additionally, expert interviews were expected to support these statements and reveal current mindsets about GM soy.

II. How has the land use changed in the northern part of the *Pampa Húmeda* since the GM soy introduction in 1996, and what drivers have been responsible for this change?

Qualitative interviews and remote sensing data were used to detect changes in the Argentinean agricultural core area experienced since 1996. The following sub-questions helped with formulating the interview guidelines and analyzing the remote sensing data to finally explain the land use change process.

i. What are drivers of the GM soy adaptation in Argentina?
ii. What initiated the land use change in Argentina?
iii. Who initiated, performed and controlled the GM soy adaptation?
iv. What are the effects of the land use change due to the GM soy production?
v. How has the agricultural production in the *Pampa Húmeda* changed?
vi. How were ownership relations organized and regulated during the past 20 years?
vii. How have work relations and methods on these farmlands changed since 1996?

1.2 Structure of the Thesis

Starting with an introduction (Chapter 1) about soy's contemporary importance, the thesis begins with the development of the research questions (Chapter 1.1). Following this, Chapter 2 contains an overview of the theoretical background. First, the essential term of land use change is defined and explained (Chapter 2.1). Second, the history of agricultural change is summarized (Chapter 2.2) following a list of drivers responsible for change in agriculture (Chapter 2.3). In Chapter 2.4, the historical and theoretical backgrounds of land use change in Argentina due to GM soy will be analyzed and debated. In the next part (Chapter 3), the materials used to answer the research questions, are listed. The qualitative and quantitative method approaches are clarified in Chapter 4. In Chapter 5, the results of the qualitative and the quantitative approach are described and compared with data from the Ministry of Agroindustry. Afterwards, empirical findings from the generation of data related to the theoretical literature are described, critically analyzed and evaluated (Chapter 6). The aim of this chapter is to finally answer the research questions. In Chapter 7, interdisciplinarity is discussed, problems and limitations are stated (Chapter 7.1), possible improvements are suggested (Chapter 7.2) and finally, interdisciplinarity is critically reflected (Chapter 7.3). Finally, Chapter 8 contains an outlook and draws a comprehensive conclusion.

2 Argentina – an Example Case for Understanding Land Use Change

Land use change and its drivers in the Argentinean agricultural core area, the *Pampa Húmeda* are the main focus of this thesis. To understand the further steps of this thesis, first (Chapter 2.1), the term of land use change will be explained, and it will be argued why this process is important and the center of this master thesis. The land use change process most likely is caused by agricultural expansion and intensification. Hence, the following chapters delve into agricultural changes.

Historically, a fluctuating pattern of behavior between agriculture and political economy relations is distinguishable. The second chapter (Chapter 2.2) provides a short overview of historical changes in agriculture, following a definition of drivers of global agricultural change (Chapter 2.3). In Chapter 2.4, an overview of Argentina's history will clarify why a soy boom was possible and what it meant and still means regarding land use change. This part will conclude with a reflection of the research question (Chapter 2.5).

2.1 The Meaning of Land Use Change

Worldwide population growth and a consequently increasing demand for food, fiber, water, energy and shelter have resulted in clearing (tropical) forests, expanding urban areas or intensifying and expanding agricultural production. This process, where human activities transform the landscape, is called land use change (Foley et al. 2005, p. 570).

The change of the world's surface is shocking. In the past 300 years, a loss of 7 to 11 million km^2 of forest was caused by agricultural expansion and timber extraction (Foley et al. 2005, p. 571). Urban areas increased worldwide from 1970 to 2000 by 58,000 km^2. Expected is an increase in global urban land cover of between 430,000 km^2 and 12,568,000 km^2, with an estimate of to be most likely 1,527,000 km^2 by 2030 (Seto et al. 2011, p. 1). Agriculture now covers approximately 40% of the land surface, almost as much area as forests cover (Foley et al. 2005, p. 570; Schrag et al. 2009, p. 135; Seto et al. 2011, p. 2). According to

Gordon et al. (2017, p. 2), land use change is associated with the agricultural development that is currently being witnessed, "… as the most important factor in the recent loss of species and natural habitat across the planet."

The land use change resulting from agricultural intensification and expansion has impacts on a global as well as on a local scale. A change in land surfaces affects climate change. For example, deforestation for agricultural purposes influences a change in the albedo (the sunlight reflected by a surface). Sunlight that is not reflected is absorbed by the surface, resulting in a raise of its temperature. Therefore, snow and ice melts and sublimates faster, more water evaporates and the heat exchange between the surface and the lowest layer of the atmosphere is more energizes and turbulent, all of which, in the end, affect climate change (Coakley 2003, p. 1914). Deforestation is also responsible for almost 15% of global carbon dioxide (CO_2) emissions, which directly affects climate change (Foley et al. 2005, p. 572). On a local scale, agricultural land use change affects hydrological cycles, degrades soils, causes erosion and is responsible for many other processes in nature (Foley et al. 2005, p. 571f).

Land use, once considered a local environmental issue, is becoming a force of global importance. The land use change needed to sustain human needs has resulted in a dilemma. On the one hand, to provide humanity with the required critical natural resources and ecosystem services, such as food, fiber, water, energy and shelter, many land use practices are absolutely essential. On the other hand, many forms of land use degrade the ecosystem on which we depend so heavily (Foley et al. 2005, p. 570f).

2.2 A Short History of Agricultural Change

How to feed human beings and overcome the problems of food production has always been essential for humanity. Historically, the food needs of a growing population were met by mainly expanding the cultivated area along with taking advantage of a few technological breakthroughs, which increased the yield. An initial acquisition of the most fertile and irrigable lands followed a scarcity of these lands, resulting in the further expansion of the cultivation of poorer and lower-yielding land (Gendron and Audet 2012, p. 23-25; Hazell and Wood 2008, p. 495). Pessimism about the possibilities of feeding the world's ever-growing population was growing by the 19th century. The writings of Malthus, an economist of the late 18th century, exemplified that "… the power of population is indefinitely greater than the power in the earth to produce subsistence for man [meaning] population, when unchecked, increases in a geometrical ratio [while] subsistence increases only in an arithmetical ratio" (Stone

2001, p. 329). This would at some point result in wide-ranging famine and death. His relatively inelastic view of agricultural production went alongside an unrealistic estimation of an exponential growth of the population (Hazell and Wood 2008, p.495; Stone 2001, p.330). Nevertheless, the Malthusian perspective, in its effects on common perceptions and theories of agricultural change, has proved to be remarkably persistent. Theories of agricultural change affect and are affected by their political contexts. This is probably responsible for the survival of the Malthusian perspective rather than empirical analysis (Stone 2001, p. 330). However, not even agricultural expansion through the colonization of new continents, even though it was an important safety valve for Europe, was enough to ease the pessimism by the late 19th century (Hazell and Wood 2008, p. 459).

By the 20th century, dramatic yield breakthroughs were accomplished through public investments in modern scientific research on agriculture (Hazell and Wood 2008, p. 459). The theory of Boserup, an economist who specialized in the economics and development of agriculture, explains this with the idea that the population determined the technological change. This means that with the increasing size of the population, the more that knowledge and innovation can be created, thus resulting in improved technologies for solving the problem of limited agricultural production (Stone 2001, p. 330). Modern plant breeding, improved agronomy and the development of inorganic fertilizers and modern pesticides and irrigation fueled these advances (Hazell and Wood 2008, p. 459). With Boserup summarizing this as agricultural intensification, this change of agricultural methods features an increase in the production concentration at the cost of more work at a lower level of efficiency (Stone 2001, p. 330).

Agricultural change is, according to Stone (2001, p. 332), "… shaped by external economic systems, and most farmers have to contend with economic factors that affect the cost of inputs and value of output beyond local energetics." In general, agriculture and the production and distribution of food around the world were highly planned activities. For most of the 20th century, they were supported and coordinated through the intervention of the state. The purpose of the organization of agriculture and food is not only economic growth and the social stability of the sector but also, above all, an overall balanced development of the entire society (Bonanno and Busch 2015, p. 1). The state intervention via the political economy of agriculture featured, amongst others, the building of infrastructure, land redistribution, publicly sponsored research and price control. The targeting is an increase in production and productivity to feed the growing population through the enhanced use of chemicals, machines and improved plant varieties resulting in agricultural intensification (Bonanno and Busch 2015, p. 2; Gendron and Audet 2012, p. 25; Hazell and Wood 2008, p. 495). The increased agricultural productivity, called the Green Revolution, originated in the 1960s from the development of new varieties of crops in combination with the use of fertilizers and pesticides, as a response to the growing needs associated with the growth of the population (Gendron and Audet 2012, p. 26). Boserup's model, which is not totally negated by market involvement, may stimulate technological change through population pressure but result in degradation rather than innovation (cf. Chapter 2.1) (Stone 2001, p. 332).

In reaction to the high level of state intervention of the Fordist era[1], which caused an outflow of wealth as well as the exploitation of labor and resources, a change of paradigm took place. Neoliberalism, a wide-ranging policy program, and a set of concrete policy measures of the late 20th and early 21st centuries were aimed at reducing the role of the state in social as well as economic affairs and offered appealing solutions to global economic and social problems (Castree et al. 2013b). Neoliberalism is understood to be a "...multifaceted process, stemming from a utopian, ideational project of reorganizing international capitalism, often conjoined with a set of political projects that seek to enhance conditions for capital accumulation and restore the power of economic elites at multiple scales" (Yates and Bakker 2013, p. 2). The application of neoliberalism on a global scale facilitated, according to Bonanno and Busch (2015, p. 3), "... previously marginalized groups to benefit from the growth of neoliberal globalization." A consequence of the neoliberalism was the increasing placement of the organization and management of agricultural food production into the hands of private corporate actors (Bonanno and Busch 2015, p. 4). This process is called privatization, whereas marketization[2], deregulation[3] and re-regulation[4] were additional strategies of neoliberalism (Yates and Bakker 2013, p. 3).

Especially in Latin America, these strategies included, amongst others, cuts in public expenditure, free-trade agreements and the privatization of property rights related to land, forests, water and other formerly publicly owned resources (Yates and Bakker 2013, p. 3). The following restructuring from neoliberalism to post-neoliberalism in the early 2000s was a process that mainly happened in Latin America (Grugel and Riggirozzi 2007, p. 100). Post-neoliberalism revolves, according to Yates and Bakker (2013, p. 9), around the theme of "re-founding economic principles on social values via [firstly], re-socialization through redistrib-

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[1] The Fordist ear (1930s until late 1970s) is named after the automobile manufacturer Henry Ford. This period is characterized by accumulation and mass production as well as mass consumption are key factors of this time (Castree et al. 2013a).

[2] Marketization, also known as commercialization or commodification, is a process where the public sector is progressively exposed to market forces (Vujnovic 2012, p. 1).

[3] Deregulation refers to a supposedly lifting of controls like removing the monopoly of state utility companies (Mayhew 2009).

[4] Re-regulations are if previously abolished regulations are re-imposed (Moles and Terry 2005).

utive policy and practice [and secondly], the deepening of democracy by establishing greater autonomy and self-governance through processes of cultural self-determination at a variety of scales."

However, today's trade and transport indicate that agriculture is globally connected to market and finance. Gordon et al. (2017, p. 5) emphasized that today's agriculture is "the main polluter of the planet's water system, contributes significantly to greenhouse gas emission and degrades land through erosion, compaction and loss of soil carbon."

2.3 Drivers of Change in Global Agriculture

Different drivers facilitate the forces driving change in global agriculture (as outlined in the previous Chapter 2.2) and land use. Hazell and Wood (2008, p. 496) proposed the consideration of three scales of drivers for agricultural and land use change. They summarized global-scale, country-scale and local-scale drivers, whereas a driver is "… any natural- or human-induced factor that directly or indirectly brings about change in an agricultural production systems" (Hazell and Wood 2008, p. 501).

2.3.1 Global-Scale Drivers

According to Hazell and Wood (2008, p. 501), global-scale drivers affect all agriculture around the world but at different degrees. Value chain integration, trade expansion and climate change are included in these drivers as well as international processes established to mitigate or facilitate them. Further included is the rapid globalization of science and knowledge access, enabled by the expansion of global communication options, which facilitates the acceleration of the flow of information, products and technology relevant to agricultural development. Two of the key global-scale drivers are explained in more detail as follows:

International Trade and Globalization of Markets

Since the 1960s, international agricultural trade has increased 10-fold, due to market liberalization in many developing countries, more open trade policies and advances in transport and communications systems. As a consequence, the competition in export and domestic markets for almost all major agricultural commodities became more intense. The demand for safer food and higher quality increased along with the amounts of food traveling longer distances. This resulted in growing concerns about the energy used in "food miles"[5] (Gendron and Audet 2012, p. 28; Hazell and Wood 2008, p. 501). Countries that had opened their borders experienced significant changes in their crop mixes, which international trade and the globalization of markets facilitated (Hazell and Wood 2008, p. 501).

Low World Prices

The productivity of global agriculture achieved a remarkable increase in recent decades, which resulted in lower production costs. If markets are competitive, the lower production costs are passed on to consumers in the form of lower prices. Additionally, low-cost producers expanded, through greater opportunities for international trade, their market reaches. This resulted in a continuing decline in world prices, which is good for consumers but, on the other hand, is a discouragement for farmers. The low commodity prices favor the adaptation of agriculture (Hazell and Wood 2008, p. 501-502).

2.3.2 Country-Scale Drivers

Country-scale drivers affect all of the agriculture in a country. Major transformations within the agricultural sector are caused by growth in national per capita income as well as shifts in public policy (Hazell and Wood 2008, p. 502).

Per Capita Income and Urbanization

A transformation from small farms to larger, more commercialized and more specialized higher-value-product-farms have been displayed historically. This change was possible because, on the one hand, the per capita rise in income resulted in more expensive labor in relation to land and capital, which diminished the competitiveness of small farms. This was followed by more capital-intensive technologies, leading to the adaptation and exodus of agricultural workers. On the other hand, the per capita rise in income goes along with a consumer's interest in higher-value, higher-quality and safer products (Hazell and Wood 2008, p. 503).

Shifts in Public Policy

A fundamental shift in the internationally accepted development paradigm removed state agencies, which "... created opportunities for the private sector to take over as a more efficient supplier" (Hazell and Wood 2008, p. 504). This resulted in a transformation from public sector policies toward the agricultural sector. The withdrawal of state agencies left a gap that

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[5] Food miles are a unit of measurement for the distance travelled and amount of fuel used to transport food from the location of production to the consumer (Bender 2014).

has not been filled via the private sector, such as subsidies or price stabilization programs, resulting, again, in a diminished competitiveness of small farms and the intensification of larger and more commercially oriented farms (Hazell and Wood 2008, p. 504).

2.3.3 Local-Scale Drivers

Local-scale drivers, such as poverty, population pressure (as discussed in Chapter 2.2 according to Malthus and Boserup), technology design, property rights and infrastructure and market access "… are specific to each local geographical area and different types of agricultural production system" (Hazell and Wood 2008, p. 501). In this thesis, two relevant local-scale drivers are outlined in more detail.

Technology Design

According to Hazell and Wood (2008, p. 506), new and improved technologies have "… proven to be the most important driver of agricultural productivity growth." This increase in productivity is caused by agricultural change from traditional farming to high yield production systems. If the new technologies are designed and managed poorly or used inappropriately, they can increase production on the cost of degrading natural resources. Often new technologies have been developed with a focus on short-term profit for farmers and not considering their long-term sustainability. The development of efficient pesticides and herbicides has had negative effects on human and environmental health as well as long-term yields, even though they reduced costs and improved yields in the first place. On the contrary, well-designed technologies, such as the growing of fertilizer crops or low tillage farming, can contribute to productivity growth as well as improve environmental outcomes (Hazell and Wood 2008, p. 506).

Infrastructure and Market Access

Essential for agricultural growth is an adequate level of infrastructure. The type of land use is decided based on the access to infrastructure. For example, better road access to markets enhances opportunities for high-value agriculture, such as the production of more perishable goods. Unfortunately, the construction of new infrastructure (such as access to electricity or water) can be constructive because it might attract new settlements, and the profitability of less sustainable land uses increases (Hazell and Wood 2008, p. 507).

2.3.4 Further Simplification of Drivers

For a further simplification of the distinction of drivers, van Vliet et al.'s (2015, p. 24) definition of the underlying drivers of land use change will be added to the global-scale, country-scale and local-scale drivers of Hazell and Wood (2008, p. 501). They mentioned economic, demographic, technological, institutional and sociocultural drivers as well as local factors (van Vliet et al. 2015, p. 26).

According to van Vliet et al. (2015, p. 31), the global-scale drivers 'international trade and globalization of markets' as well as 'low world prices' can also be summarized as economic drivers. The country-scale driver 'per capita income and urbanization' is also categorized as a sociocultural and economic driver, whereas 'shifts in public policy' constitute an institutional driver. The local-scale drivers 'technology design' as well as 'infrastructure and market access' by Hazell and Wood (2008, p. 501) are described in van Vliet et al. (2015, p. 31f) as either technological drivers or location drivers. Furthermore, demographic drivers include the pressure that migration and population density apply to land use. Finally, local factors refer to soil quality, climate or topography (van Vliet et al. 2015, p. 31).

The possibility of characterizing drivers either as global-scale, country-scale and local-scale or as economic, demographic, technological, institutional and sociocultural drivers and local factors is useful for further analysis and discussion of the reasons for land use change (cf. Chapter 6). In the following Chapter (2.4) about Argentina's history of soy adaptation, many of these drivers are called into action.

2.4 Historical Review of Argentina's Soy Adaptation

By the 1950s, Argentina was already a corn and wheat producer and has developed from "the useless pampas into the socioeconomic heart and soul of Argentina" by today (Keeling 1997, p. 231). This was possible because Argentine farmers changed their focus from traditional grains and livestock production and started to grow soy in the Pampas in the summer of 1970 (Leguizamón 2014, p. 152; Schnepf et al. 2001, p. 15). The adaption of new agrarian technologies associated with the Green Revolution (hybrid seeds, mechanization, fertilization and herbicides) initiated the first boom in soy production by the end of the 1970s (growing season 1977/1978) (Leguizamón 2014, p. 152). In the 1990s, neoliberalism became Latin

America's official model of development (also known as the "Washington Consensus[6]"). The model proposed, based on the principles of free trade and comparative advantage and on the belief that economic growth will create social well-being, a re-organization of the international political economy. A "modernization" of agricultural techniques was advised to increase agricultural production, and the neoliberal economies provided the ideal framework for the introduction of GM seeds in Argentina (Delvenne et al. 2013, p. 154; Leguizamón 2014, p. 150).

Consequently, the Argentina's government approved the commercial use of Monsanto's Roundup Ready® (RR) soybeans in 1996. These soybeans were engineered to be resistant to Monsanto's bestselling herbicide, the glyphosate Roundup® (Leguizamón 2014, p. 151). The adaption of the "technological package" (direct seeding machinery, the GM seeds and the weed-control agrochemical Roundup glyphosate) first took place in the Pampas, Argentina's historic core of agro-export production (Leguizamón 2014, p. 151).

Since the introduction of GM soy in 1996, when the area under soy cultivation had a size of 6.9 million hectares, an average of almost one million hectares was added to production every year to cover 18.9 million hectares by the planting season of 2010/2011. Nowadays, soybean production accounts for more than 50% of the area cultivated with grains in Argentina, whereas more than 90% of the soybean production uses GM soy (Choumert and Phelinas 2015, p. 134; Leguizamón 2014, p. 152; Tomei and Upham 2009, p. 3890). Critics call this expansion the "soy-ization" or "Pampeanization" of Argentina, as GM soy expansion has gone well beyond the Pampa's region (Delvenne et al. 2013, p. 154).

In 1998/99, Argentina was hit with a strong recession followed by the collapse of the financial system in 2001/02. After the resignation of President Fernando de la Rúa by the end of 2001, the country faced political instability. Poverty, unemployment and government debt were consequences of the financial crisis (Agarwal et al. 2005, p. 243; Goddard 2006, p. 267).

In the early 2000s, it was under the Kirchners' administration[7], an alternative to the neoliberalism of the 1990s, that GM soy export found its ultimate expression, associated with the notion of a "post-neoliberal turn" in Latin America (Grugel and Riggirozzi 2007, p. 100; Yates and Bakker 2013, p. 2). This turn sustained the Kirchners' "National and Popular" model, which should bring economic growth and redistribute wealth to reduce poverty and pro-

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[6] According to Bonanno and Busch (2015, p. 3) "a convergence on interest in support of neoliberal views of political economy."

[7] Néstor Kirchner took office in 2003 until his death in 2007. Following, Cristina Fernández de Kirchner, Néstors wife accede his office and was President of Argentina from 2007 until 2015 (Grugel and Riggirozzi 2007, p. 88f; Leguizamón 2014, p. 155; Wylde 2011, p. 436).

mote social inclusion via strong government intervention. GM soy exports were praised as the country's savior, and the Kirchners' administration has created favorable conditions for the expansion of GM soy (Leguizamón 2014, p. 155).

Even though this GM technology ensures an economically attractive soy production, it is not the most ecologically or socially suitable crop (Phelinas and Choumert 2017, p. 2; Tomei and Upham 2009, p. 3891).

From a social perspective, the intensification of agriculture has led to a reduction in the rural labor force. Whereas small farms may create one job per 8 hectares, mechanized plantation may employ as few as one person per 200 hectares. From 1992 to 2002, an estimated number of 60,000 small producers left agriculture. In 2007, 4% of farmers produced 60% of the soy harvest, and tenants managed 60% of the farms (Leguizamón 2014, p. 105f; Tomei and Upham 2009, p. 3891f). The change in ownership and production is leading to the erosion of the rural culture and the loss of traditional knowledge and livelihoods. Rural depopulation goes hand in hand with a decrease in the number of farms as well as with an increased farm size and concentration of landholdings. The spread of soy farming in Argentina also has impacts on food sovereignty, as soybeans are cultivated at the expense of traditional livestock and crop production (Tomei and Upham 2009, p. 3896). In fact, the GM soy produced in Argentina is entirely used for export as livestock feedstuff or for soy-based biodiesel (Leguizamón 2014, p. 157; Tomei and Upham 2009, p. 2890). Additionally, the immense expansion of the GM soy production has led to violations of human rights, expropriation (expulsion of small farmers), the destruction of peasant agriculture, the concentration of land ownership and agricultural production, land grabbing, inequitable agricultural growth, the unequal distribution of benefits to society, decreasing rural employment opportunities, a rural exodus, competition between food and non-food uses, the reduction of food diversity and security, health damage to communities (malnutrition, agrochemical intoxication), the loss of cultural diversity and many more issues (Borras et al. 2012; van Dam et al. 2009; Leguizamón 2014; Milazzo et al. 2013).

Likewise, GM soy production affects the environment. GM soy adoption has led to (tropical) deforestation, the spread of urban areas, the drainage of wetlands or the displacement of other crops and cattle raising. As a consequence, Argentina is experiencing a large-scale land use change (cf. Chapter 2.1). The landscape transformation has a negative impact on natural wildlife habitats and biodiversity, freshwater ecosystems and groundwater quality and is responsible for soil degradation, erosion and the siltation of rivers and wetlands, increasing the use of agrochemicals due to monoculture, nutrient depletion and ecological contamination (ground and aerial applications of pesticides) (Choumert and Phelinas 2015; Delvenne et al. 2013; Milazzo et al. 2013; Schrag et al. 2009; Tomei and Upham 2009).

Even though the consequences of GM soy adaptation are tremendous and destructive (cf. Chapter 1 and 2.1), the economic developments and historical changes help with understanding Argentina's dependency on GM soy (Delvenne et al. 2013; Leguizamón 2014; Tomei and Upham 2009).

2.5 Research Question Reflection

The introduction and flourishing production of GM soybean in Argentina is driven by the interplay of domestic policies, international factors and the early adoption of new technology. The speed and magnitude of soybean expansion has caused extensive land use change in Argentina, which is the main subject of this thesis (amongst others; Craviotti 2016, p. 81; Gavier-Pizarro et al. 2012, p. 44; Urcola et al. 2015, p. 36).

But why and who is determined to promote ongoing and even increasing GM soy production and the so-called "soy-ization" in Argentina, even though its consequences are tremendous and destructive? What political measures have taken place for promoting agriculture in Argentina? And are additional drivers promoting GM soy and following land use change besides political measures?

The aim of this thesis is to answer these questions, which result from the discussion of the previous chapters, using Argentina as an example case for showing how political measures can influence agriculture. The research questions help with detecting and explaining land use change in Argentina.

3 Materials

To detect and explain land use change in the *Pampa Húmeda*, the aim of the research questions was to merge quantitative and qualitative approaches. For the detection and explanation of land use change, quantitative remote sensing data and qualitative expert interviews had to be acquired. Following, the data used for this master thesis are listed.

3.1 Study Area

The chosen study area (cf. Figure 1) is the northern part of the *Pampa Húmeda,* an extensive area of flat and fertile grassland in central Argentina. Agriculture has highly claimed this region, and GM soy adoption strongly affects it. More than 80% of Argentina's GM soy production takes place in the *Pampa Húmeda* (Leguizamón 2014, p. 151).

The studied area (upper left: [31°7'40'' S, 64°48' 50'' W], upper right: [31°7'40'' S, 57°10'22'' W], lower right: [35°17'16'' S, 57°10'22'' W], lower left: [35°17'16'' S, 64°48' 50'' W]) covers approximately 315,000km^2, almost half of the entire *Pampa Húmeda* (~613'532 km^2) including the provinces of Buenos Aires, Entre Ríos, Santa Fe and Córdoba (cf. Figure 1) (Aliaga et al. 2017, p. 1).

The *Pampa Húmeda* is located within the region of subtropical and mid-latitude or temperate climates. Hence, temperatures in this area are warm temperate throughout the year with an annual mean of 16.7° degrees (in summer, the temperatures lie between 19° and 25° degrees, and in winter, they are between 7° and 12° degrees). Furthermore, the *Pampa Húmeda* has, as its name suggests, characteristically humid weather without a dry season and with a mean annual precipitation of 970 mm (Aliaga et al. 2017, p. 1-2; Astoviza et al. 2016, p. 1460; Merkel 2017). These conditions are perfect for a flourishing agriculture, resulting in the *Pampa Húmeda* being the prime farming land in Argentina.

Whereas until the end of the 19th century livestock was the main agricultural product, grain production became important in the early to mid-20th century (Joensen et al. 2005, p. 6). Since the 1970's, soy production has begun to increase rapidly, resulting in Argentina being the third-largest GM soy producing country in the world (after the USA and Brazil) by

2000 (Joensen et al. 2005, p. 7; Suchanek 2013, p. 7). Nowadays, agriculture primarily consists of GM soybean production followed by grain (wheat and corn) production and cattle raising (Choumert and Phelinas 2015, p. 135).

Including the entire *Pampa Húmeda* as a study area was not possible for this master thesis, due to server and processing capacity limitations as well as possible variability in the phenological cycle resulting from spatial expansion.

Figure 1: The study area, the vast and fertile northern part of the *Pampa Húmeda*
(Illustration based on: Google Earth Engine Team 2015).

3.2 Land Cover Classes

For further understanding, land use has to be distinguished from land cover. Land cover describes the actual surface of a certain area, whereas land use indicates the socio-economic activities that take place on the surface (Zelaya et al. 2016, p. 95).

It had to be decided which and how many land cover classes should be generated to detect the agricultural extent of the land use change in the *Pampa Húmeda* and to finally illustrate this on maps.

GM soy, which many (amongst others, Choumert and Phelinas 2015; Craviotti 2016; Delvenne et al. 2013; Leguizamón 2014; Leguizamón 2016; Tomei and Upham 2009; WWF

2014) have described as the main driver of land use change, led to the first declaration of a 'single soy cultivation' class (on the maps, termed 'soy monocropping'). Four more classes were distinguished based on their agricultural relevance, with the first being the summer crop 'corn'. A 'soy-wheat double-cropping' class, whereas two crops are sequencing in a season, soy as the summer crop and wheat as the winter crop (Andrade and Satorre 2015, p. 137). Additionally, a class for 'semi natural areas' (including forests, grasslands and pastures) and 'bare soil' (including gravel and rock areas, fallow land and urban areas) were generated. Bare soil can include urban areas due to their similar reflectance (cf. Chapter 4.2.3) (Baumann et al. 2016; Craviotti 2016; Konefal and Busch 2010; Leguizamón 2014; Leguizamón 2016).

3.3 Satellite Data

A sufficient spectral, temporal and spatial resolution was acquired to adequately detect the land use change in Argentina based on the five land use classes (cf. Chapter 3.2). Why it turned out that Landsat 5 and Landsat 7 (cf. Table 1) provided appropriate data for this will be explained as follows.

An optical remote sensing tool is necessary for detecting land use change. Because different materials reflect and absorb solar radiation differently at different wavelengths, optical remote sensing can use the solar radiation reflected from targets on the ground to form images of the earth's surface. Therefore, with their spectral reflectance signatures, different objects on the ground can be distinguished (Lillesand et al. 2008, p. 262f). Landsat, SPOT, Sentinel 2 and MODIS are satellite missions that could be used as optical remote sensing tools for this study (cf. Table 1).

From early on, SPOT was excluded from the evaluation process due to the lack of available datasets on Google Earth Engine (GEE) (cf. Chapter 3.4) (Google Earth Engine Team 2015).

The Landsat program from the National Aeronautics and Space Administration (NASA) has a continuous history of providing Earth observation imagery since the early 1970s. Landsat 5 delivered data from March 1984 to May 2012, and Landsat 7 started to deliver them in April 1999. MODIS is a sensor on the relatively young Terra and Aqua satellites that were launched in November 2000 (Chuvieco and Huete 2010, p. 89, 109; Lillesand et al. 2008, p. 400; NASA 2017). However, the earliest date of data availability was not the only crucial factor for choosing Landsat 5 and 7 as data providers. The Sentinel 2 mission was excluded from further investigation due to its image availability from 2014 onward (ESA 2017c). This left Landsat and MODIS for further consideration and comparison.

Three criteria that also played an important role in the decision making process are the temporal, spatial and spectral resolution of a sensor.

Each orbit of Landsat 5 and 7 takes approximately 99 minutes. This means almost 15 orbits are completed per day. The distance between ground tracks for consecutive orbits is, due to Earth's rotation, approximately 2,752 km at the equator. This implies an available image of a certain area every 16th day (Lillesand et al. 2008, p. 406). As opposed to this, MODIS has a temporal resolution of two days (Lillesand et al. 2008, p. 473). It is preferable to have data on a daily basis for detecting accurate changes, but the changes in agriculture, such as sowing, harvesting or changing the texture of a certain field, can be detected with equally exact precision if data are available only every 16 days. Furthermore, having Landsat data is not only sufficient but also simplifies and accelerates data processing because less available data are present (Lillesand et al. 2008, p. 200).

Spatial resolution indicates how well a sensor can record a spatial detail (Lillesand et al. 2008, p. 33). The spatial resolution of MODIS is either 250, 500 or 1000 meters (depending on the wavelength) (ESA 2017b; Lillesand et al. 2008, p. 473), Landsat 5 has a 30 meter spatial resolution. Landsat 7 has a 15 meter spatial resolution but only for a panchromatic (PAN) band, i.e., resulting in a black and white image (ESA 2017a, Lillesand et al. 2008, p. 85, 401). Because farming field sizes vary greatly in Argentina (cf. Figure 2) (Choumert and Phelinas 2015, p. 136; Joensen et al. 2005, p. 6), a high spatial resolution is of great importance for the declaration of land use change. A spatial resolution of less than 250 meters is preferable. Therefore, Landsat 5 and 7 data were chosen.

The third criterion for choosing an adequate data provider is its spectral resolution. Spectral resolution refers "… to the numbers of bands provided by the sensor, as well as their spectral bandwidths" (Chuvieco and Huete 2010, p. 65). This means the more bands that are acquired, the better a sensor will provide discrimination capacities (Chuvieco and Huete 2010, p. 65). Keeping this in mind, Landsat 5 and 7 provided an adequate spectral resolution with seven bands for this study. MODIS, on the other hand, provides 36 bands, but only the first two provide a spatial resolution that is high enough (bands 1-2: 250 meters, bands 3-7: 500 meters and bands 8-36: 1000 meters) (ESA 2017b; Lillesand et al. 2008, p. 400, 473).

Figure 2: Agricultural fields outside of Buenos Aires
(Photograph: Franziska Moergeli, 11th of March 2017).

Summarizing, the higher the temporal, spatial and spectral resolution of the data, the more detail can be derived from the final image. Anyhow, Landsat 5 and 7 were more suitable for this study due to of data availability for the whole timeframe (1996 – 2016). Additionally, the necessary spatial resolution was provided with an adequate spectral resolution. Even though MODIS has a higher temporal and spectral resolution than Landsat 5 and 7 do, it was not fitting for this study due to its spatial resolution.

Table 1: Criteria for four optical remote sensing suitable as data sources
Yellow box indicates a suitable resolution for this study (Illustration based on: ESA 2017a; ESA 2017c; ESA 2017d; NASA 2017).

		Landsat	MODIS	Sentinel 2	SPOT
Resolution	Temporal	Since 1970 Every 16 days	Since 2000 Every 2 days	Since April 2014 Every 10 days	Since 1986 Every 26 days
	Spatial	Resolution: 15(PAN)/30m	Resolution: 250/500/1000m	Resolution: 10/20/60m	Resolution: 2.5&5(PAN)/10/20m
	Spectral	1-7	1-2 (250m) 3-7 (500m) 8-36 (1000m)	4 bands (10m) → 2-4,8 6 bands (20m) → 6-8, 11,12 3 bands (60m) → 1, 9, 10	1-5

3.4 Cloud-Based Processing Environment

Earth Engine is a free, cloud-based geospatial-processing platform that Google has provided since 2015 for research, education and non-profit purposes. It combines a multi-petabyte catalogue of satellite imagery and geospatial datasets with planetary-scale analysis capabilities for the analysis and visualization of geospatial datasets or for detecting changes, map trends and quantify differences on the earth's surface. Furthermore, it stores and organizes the public data archive satellite imagery. The Earth imagery, which is available on a global scale, has a more than a 40 year-old history, and new imagery is collected daily (Google Earth Engine Team 2015).

Google Earth Engine is a useful tool for this study due to of the huge amount of data that has to be processed. Using the Google Earth Engine (GEE) cloud-based computing power shortens the processing time immensely. Furthermore, it is open source and provides very up to date data (Google Earth Engine Team 2015).

3.5 Crop Calendar

To distinguish the five land cover classes (soy monocropping, soy-wheat double-cropping, corn, semi natural area and bare soil), a crop calendar (cf. Figure 3) was created based on the literature (amongst others, AMIS 2015; Geoglam 2011; Leguizamón 2014; USDA 2016), expert knowledge and fieldwork analysis. The crop calendar was used to check and implement phenology cycles into GEE.

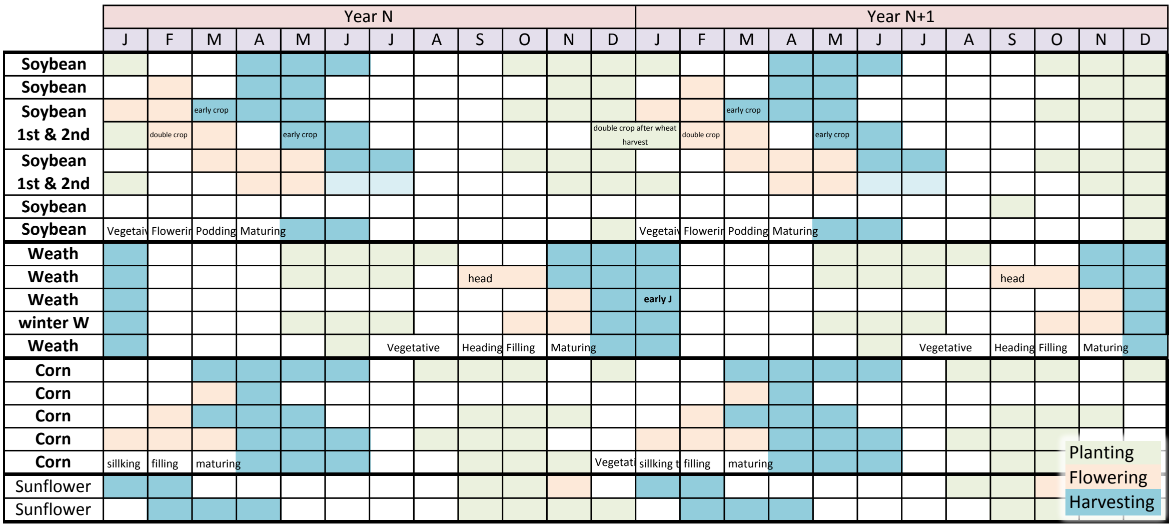

Figure 3: Crop calendar
illustrating the planting, flowering and harvesting seasons for the main agricultural goods in Argentina (Illustration based on expert knowledge, fieldwork analysis and literature (AMIS 2015; Geoglam 2011; Leguizamón 2014; USDA 2016)).

3.6 Fieldwork and Data Collection

While staying in Argentina for one month, five days were assigned to collect test sites to verify and improve the maps.

In a first step, the first drafts of the land cover maps were discussed with Maria from the *Instituto Nacional de Tecnología Agropecuaria*, Castelar (INTA). Maria is a PhD student who is currently working on generating land cover maps for detecting bird population trends resulting from land fragmentation and habitat loss due to GM soy production expansion. Checking the accuracy of the two maps from 2010 (GEE 2010 map and Maria's map generated from self-collected training sites in 2009; see Chapter 7.1.1 for limitations), a high subjective correlation was detected with QGIS (Quantum GIS Development Team 2017). However, for further improvement as well as verification, Maria's exchanged approximately 2,500 training sites for the eventually finished GEE maps in return.

Figure 4: Route of the sampling points collection
recorded with Garmin BaseCamp™, from Buenos Aires to Junín and back again (Illustration created in Garmin BaseCamp™).

In a second step, own sampling points were collected between March 24th and 27th on the route from Buenos Aires to Junín, in the area around Junín and back again to Buenos Aires (total distance approximately 550 km) (see Figure 4). Sample points were chosen depending on the accuracy with which a field could be assigned to one of the land use classes, rather than choosing them at an equal distance. This was due to high traffic, trees that covered the sight to the fields or roads located at a lower level than the fields were. When an appropriate field was assigned to a land cover class, a point in the Global Positioning System (GPS) and a picture were taken, and further details (such as the distinction of the crop, state of the crop, picture number, GPS point number, driving direction, etc.) were recorded on paper (field diary, 24th to 26th of March 2017). This resulted in a total of 63 usable GPS points for validation and correction of the map. The GPS points were also carefully chosen to avoid spatial autocorrelation. Spatial autocorrelation indicates that "(...) values for a single location tend to be more similar to those nearby than to those far away" (Chuvieco and Huete 2010, p. 331). Therefore, enough distance between sample points guarantees a variety of points.

3.7 Overview of Empirical Data Material

Choosing appropriate interview partners is very important for ensuring the quality of the provided information (Gläser and Laudel 2006, p. 113). Two initial contacts at the University of Zurich led to the collection of further contacts based on the snowball system, where one person recommends another as an additional interview partner and so on. The two initial contacts are stakeholders with different interests, minimizing the risk of heterogeneity amongst the interviewees (Kruse 2015, p. 255). One was Yann le Polain de Waroux, a postdoc from the University of Stanford studying land conversation, and the other was Santiago Goldstein, a lawyer and land owner in Argentina. After approaching 24 possible interview partners, finally, 10 people had an interest in and time for a meeting.

Between the 10th of March and the 8th of April 2017, a total of 10 semi-structured problem-centered expert interviews were conducted in and around Buenos Aires (cf. Table 2). All of them were recorded and two had complementary notes due to the amount of time spent with the interviewees. All expert interviews were held in English, two needed the assistance of a translator (Victoria). One featured the alternation of French and English due to the interviewee's lack of English knowledge. Every expert interview was literally and comprehensively transcribed and analyzed with the software MAXQDA 12 (cf. Chapter 4.3.2.1). The names of the interview partners were made anonymous (Gläser and Laudel 2006, p. 271)

A field diary was kept during all of the fieldwork and was a source of additional notes during interviews, on the remote sensing data collection and thoughts during the master thesis development.

Table 2: Overview of qualitative expert interviews.

Name (anonymous)	Profession	When	Time	Where
Santiago	Researcher (Dr.) at the INTA in the department of landscape ecology	11.03.17	01.28.32	Bar El Federal (San Telmo)
Mateo	Agricultural engineer, landowner (5th generation) and large-scale soy producer, AACREA[8] member	14.03.17	01.11.56	Cafe Liber y Liber (Retiro)
Maria	PhD student at the INTA in ecology, agro- biodiversity and environmental management	21.03.17	Entire day; Notes	INTA Castelar
Juan	Researcher and lecturer (Dr.) at the university, study land use change and agricultural production and expansion	22.03.17	00.42.18	Facultad de Ciencias Exactas y Naturales
Fernando	Researcher (Dr.) at the university in biodiversity and conversation ecology			
Emanuel	Landowner (Ing. Arg.) and cattle and soy producer	24.03.17	00.46.38	Bar Matilda (Junín)
Thiago	Agronomist	25.03.17	00.50.44	His home (Junín)
Valentino	Agronomist			
Victoria	Researcher (Dr.) at the INTA in ecology, agro-biodiversity and environmental management	24. - 26.03.17	01.04.56 Notes	Her Home (Junín)
Sofia	Coordinator of Policies for Sustainable Development and Plan Belgrano, Production Council (Ing. Arg.) - Ministry of Production of the Nation, former president of AAPRESID[9] and large-scale land owner (5th generation)	30.03.17	01.24.46	Ministry of Agroindustry (Buenos Aires)

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[8] *Asociación Argentina de Consorcios Regionales de Experimentación Agrícola* (AACREA) is an Argentinean farmer association, founded in the 1960s with the aim to share knowledge and improve the Argentinean way of farming (Mateo 2017, par. 60-66).

[9] *Asociación Argentina de Productores en Siembra Directa* (AAPRESID) is an Argentinean no-till farming association founded in 1998 (Sofia 2017, par. 16).

4 Methodological Approaches

In the context of using a qualitative approach in economic geography and a quantitative approach in remote sensing to answer the research questions, qualitative and quantitative data collection (Chapter 3), processing (Chapters 4.2 and 4.3) and analysis (Chapter 6) were performed. Therefore, method triangulation in terms of a mixed methods approach was applied.

In the first section of this chapter, the term "method triangulation in terms of a mixed methods approach" will be elucidated, whereas in the second (Chapter 4.2) and third (Chapter 4.3) sections, the quantitative and qualitative approaches, will be outlined.

4.1 Interdisciplinary Method

Triangulation means to use multiple, or at least two, research strategies in one research project (Flick 2011, p. 11). The main goal of having different perspectives on the same phenomenon can be accomplished by using, for example, different theoretical approaches, different points of view of different researchers, different data bases or, as in the case of this thesis, two different methods (e.g., qualitative and quantitative) (Flick 2011, p. 13; Schneider 2014, p. 21). Therefore, Denzin (1978 in Flick 2011, p.12) identified four basic types of triangulation: theory triangulation, investigator triangulation, data triangulation and methodological (also referred to as method) triangulation. The last one is important for the further process of this thesis.

Method triangulation means capturing the same phenomena – in this case, land use change and its driver – with different methods, not necessarily from the same method range (Kuckartz 2014, p. 46).

In using triangulation for this thesis, different aspects of the phenomenon in focus are discovered and highlighted. The strength lies within the use of different methods from qualitative interviews and quantitative remote sensing data (land use change maps) points of view to answer the research question. Due to of using triangulations, the amount of truth and objectivity generated can be assumed to be higher than with just one sort of theory, method and data (Flick 2011, p. 49; Schneider 2014, p. 18).

Mixed methods focus, more specifically as triangulation, on the adequacy of methods as well as on the adequacy of the combination of quantitative and qualitative methods (Kuckartz 2014, p. 49; Schneider 2014, p. 22).

Elwood (2010, p. 95) highlighted the ability of geographers, who have been conducting mixed methods research for decades, to answer more and more complex research questions with multi-perspective observations, interdisciplinarity or qualitative and quantitative research approaches (Kuckartz 2014, p. 52). The use of mixed methods enables a better understanding of a problem, due to the consideration of two perspectives, the quantitative of the counting and the qualitative of the sense of the meaning (Kuckartz 2014, p. 53). Strengths and possibilities of a mixed methods approach are, amongst others, a possible generalization of qualitative research results. In addition, the knowledge and the perception achieved through the project are more comprehensive and more multi-perspective and therefore more complete (Kuckartz 2014, p. 54).

As for this research, a targeted and systematic combination of qualitative interviews and quantitative analysis of remote sensing data was used for the data collection and analysis. Method triangulation in terms of mixed methods approach was applied for the detection and explanation of land use change in the *Pampa Húmeda* and the drivers causing the change.

4.2 Spectral Mixture Analysis Based Land Cover Classes

To detect land use changes in the study area since the GM soy introduction in 1996, remote sensing based maps of the past 20 years (1996 – 2016) were generated. The process of the map creation, validation and revision will be described in more detail in the following chapters.

4.2.1 Spectral Mixture Analysis

Spectral measurements made over the earth's surfaces can be described as spectral mixtures. This means the terrestrial surface is rarely spectrally pure and mostly contains complex vegetation covers. Hence, a mixture of spectral responses exists within one pixel (Chuvieco and Huete 2010, p. 265). For example, a mixed pixel might contain bare ground, vegetation and water. If a pixel contains only one feature, e.g., bare ground, it is a pure pixel.

The appearance of mixed pixels can cause problems in the traditional image classifications, such as, e.g., supervised or unsupervised classification, because the pixel belongs to more than one class but can be assigned only to a single class (Keshava and Mustard 2002, p. 44). As for the agricultural fields of this study, which can have small spatial scales and more complex spatial patterns (e.g. different corn types), the problem of a mixed pixel in the remote sensing images is prominent (Li et al. 2015, p. 1; Lobell and Asner 2004, p. 413). The goal of a spectral mixture analysis is to determine the likely composition of each image pixel and was applied for this thesis.

"Spectral unmixing is the procedure by which the measured spectrum of a mixed pixel is decomposed into a collection of constituent spectra, or endmembers" (Keshava and Mustard 2002, p. 44). The endmembers are therefore a "pure" spectrum corresponding to each of the land cover classes and serve as a reference for determining the spectral make up of mixed pixels. They are expected to represent the purest pixels in the image (Benhadj et al. 2012, p. 1326; Diao and Wang 2016, p. 467). If endmembers in a pixel appear in spatially separated patterns, similar to the squares on a checkerboard, the systematics are basically linear (Keshava and Mustard 2002, p. 45f). Therefore, to detect land cover changes based on the land cover classes (endmembers), a linear spectral unmixing algorithm (Formula 4.2) (Tseng 2000, p. 1533) was carried out on Landsat 5 and 7 time-series data (cf. Chapter 3.3). Based on the known number of endmembers (here, five) and their spectra of each pure component (cf. Chapter 4.2.2), the observed pixel value in any spectral band is modeled by using the linear combination of the spectral response of the component within the pixel (Tseng 2000, p. 1533). This linear mixture model can be described as follows:

$$P_i = \sum_{j=1}^{n} (R_{ij} \cdot F_j) + E_i \tag{4.1}$$

where:

$i = 1,\ldots,m$ (number of bands);

$j = 1,\ldots,n$ (number of endmembers);

P_i = spectral reflectance of the i^{th} spectral band of a pixel;

R_{ij} = known spectral reflectance of the j^{th} component;

F_j = the fraction coefficient of the j^{th} component within the pixel;

E_i = error for the i^{th} spectral band.

The matrix form of the linear unmixing equations requires the expansion of (4.1) to all spectral bands,

$$P = RF + E \tag{4.2}$$

where:

$$P=\begin{bmatrix}P_1\\P_2\\ \vdots\\P_m\end{bmatrix};\qquad R=\begin{bmatrix}R_{11}&R_{12}&\cdots&R_{1n}\\R_{21}&R_{22}&\cdots&R_{2n}\\ \vdots&\vdots&\vdots&\vdots\\R_{m1}&R_{m2}&\cdots&R_{mn}\end{bmatrix};\qquad F=\begin{bmatrix}F_1\\F_2\\ \vdots\\F_n\end{bmatrix};\qquad E=\begin{bmatrix}E_1\\E_2\\ \vdots\\E_m\end{bmatrix}.$$

The linear spectral unmixing of the endmembers in GEE (cf. Chapter 3.4) looks as follows:

```
// Make image with monthly NDVI values as bands
var monthNDVIseriesList = monthNDVIseries.select('fitted').toList(12);
var tounmix=ee.Image(monthNDVIseriesList.get(0))
var monthNDVIimg = ee.Image.cat(monthNDVIseriesList);
for (var i=1; i<12; i++){tounmix=tounmix.addBands(ee.Image(monthNDVIseriesList.get(i)))}
print(tounmix)

// Unmix the image
var fractions = tounmix.unmix([soy, soy_wheat, maize, shrubland, seminatural, urban],true,true).clip(roi);
Map.addLayer(fractions,{}, 'unmixed',false);

// Make image collection with an image per class, reduce by taking the maximum unmixed fraction and display it per pixel
var fractionlist = ee.List([fractions.select([0]).addBands(ee.Image(1).toInt()).rename('fractions','class')]);
var i=0;
for (i =1; i <6 ; i++) {
fractionlist = fractionlist.add(ee.Image(fractions.select([i]).addBands(ee.Image(i+1).toInt()).rename('fractions','class')))
}
```

Spectral mixture analysis has been widely used to estimate the fractional coverage of typical land covers (Drake et al. 1999, p. 13) and is applied for the quantitative method explained in Chapter 4.2.4. Beforehand, the significance of the Normalized Difference Vegetation Index (NDVI) and phenology as a provider of spectral and temporal information for the spectral mixture analysis will be outlined in the following two chapters.

4.2.2 Assessment of Spectral Information Using Vegetation Indices

An indicator for evaluating and defining land cover classes based on the Landsat 5 and 7 data (cf. Chapter 3.3) has to be defined in order to eventually detect the land use change in Argentina due to the GM soy introduction in 1996.

Satellite data provide temporal and spatial details of ecosystem properties on a regional as well as a global scale. Remote sensing tools, such as GEE (cf. Chapter 3.4) provide, amongst others, the capability of monitoring seasonal dynamics or characterizing an ecosystem structure. In return, the ecosystem structure determines a range of spectral behavior that can be monitored via satellites (Huete and Glenn 2011, p. 291). Vegetation indices (VIs) are simple techniques used to "…extract quantitative information on the amount of vegetation, or greenness for every pixel in an image" (Chuvieco and Huete 2010, p. 249). Therefore, a VI can be used to evaluate the spectral behavior of vegetation and to describe the greenness, i.e., the health and relative density of vegetation. VIs are typically used as proxies for land cover classification or land use change detection (Huete and Glenn 2011, p. 297; USGS 2016). The NDVI, one of the most widely used VIs, "… provides greenness values normalized between -1.0 and +1.0" (Huete and Glenn 2011, p. 297). Whereas a low NDVI (0.1 or less) indicates bare soil or snow, moderate NDVI values (approximately 0.2 to 0.5) result in sparse vegetation, such as grasslands or shrubs, and high NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation, like tropical and temperate forests or crops at their peak growth stages (USGS 2016). The NDVI relies on the ability of chlorophyll to differently absorb radiation in the red (visible) and near-infrared ranges (cf. Figure 5). The reflectance of chlorophyll is low in the red range due to its high absorption of radiation, and it is high in the near-infrared (NIR) range. This is because chlorophyll absorbs the radiation in the NIR only to a small extent. Based on this, the NDVI is calculated from the individual measurements of NIR and visible red band (RED) (Huete and Glenn 2011, p. 279; Yengoh et al. 2015, p. 11):

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}} \tag{4.3}$$

Hence, the healthier or more vital a plant is, the higher the spectral reflectance in the NIR is, and the lower it is in the red range. This results in a high NDVI value (Yengoh et al. 2015, p. 10–11).

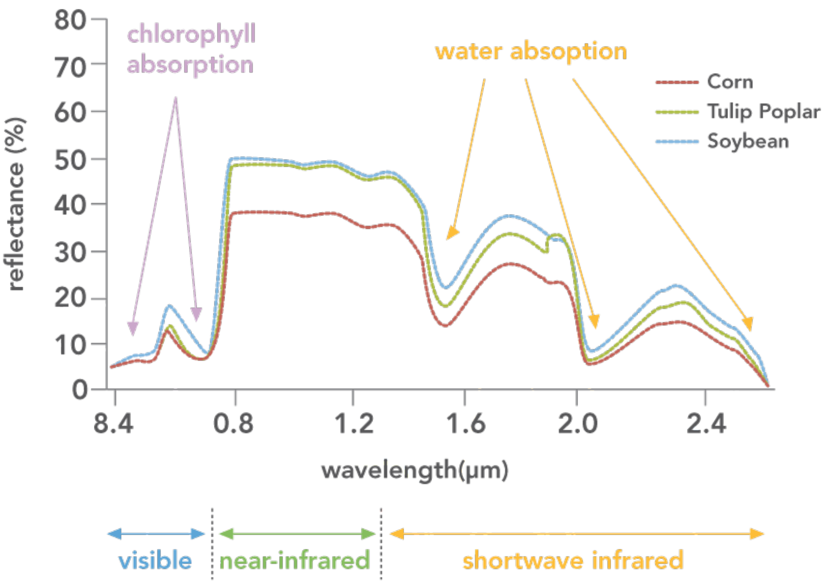

Figure 5: Spectral signatures of corn, tulip poplar and soybean
of how the plant reflects or absorbs electromagnetic energy (https://www.satshot.com/about-imagery, accessed 10th of June 2017).

Photosynthetic activity, such as growing or harvesting seasons, can be interpreted with the NDVI (USGS 2016). This is why the NDVI is used for this thesis. To study patterns of plant growth cycles in general, monitoring land surface phenology with remote sensing methods is important. For this study too, phenology based on NDVI values was used to create the land cover classes. Based on the five classes (soy monocropping, soy-wheat double-cropping, corn, semi natural area and bare soil), a land use change in Argentina should be revealed.

4.2.3 Assessment of Temporal Information Using Vegetation Phenology

Phenology is "… the study of the timing of recurring biological events…" (Leith 1974, p. 4) and not only provides important information about trends in ecology, e.g., climate change, but also detects agricultural changes. The phenological stages of crops are used to provide essential information for agricultural activities, such as flowering, maturity and harvesting (Li et al. 2015, p. 1; Zeng et al. 2016, p. 237). Phenology is a good indicator to use for land use classification due to the plant's sensitivity to climate variation and the agricultural seedtime and harvest (USGS 2016).

In having an adequate spectral resolution provided via Landsat data, it seems obvious to use the spectral reflectance to identify the land covers. However, a closer examination of the spectral reflectance curves of corn, tulip poplar and soybean (cf. Figure 5) reveals similarities between the reflectance of the crops. This could lead to differentiation problems. Hence, phenology produces more precise distinctions between land use classes and therefore was more convenient to use for the present study. Figure 6 shows the phenological cycles of five vegetation covers; it implies a clear distinction of soybean based on its peaks in December (for *soja de primero*) and January (for *soja de segunda*)[10].

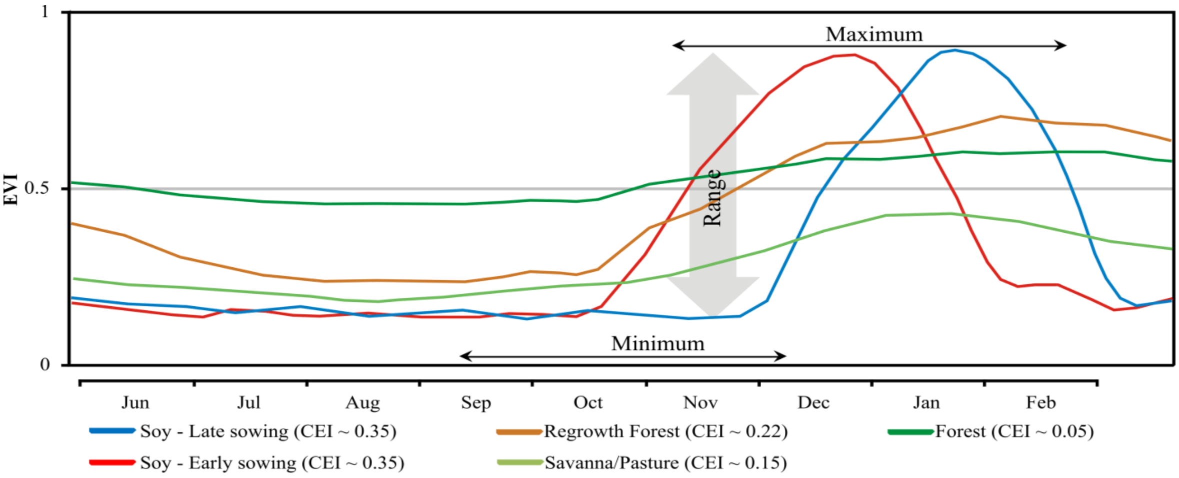

Figure 6: Example of typical temporal profiles of EVI.
Enhanced vegetation index (EVI) values for early and late sowing of soy, regenerated forest, savanna/pasture and forest (Rudorff et al. 2012, p. 1080).

4.2.4 Application of Spectral Mixture Analysis

As a foundation of the entire study, land use change maps had to be generated. The initial idea was to implement 20 maps of the study area to use as a basis for the qualitative interviews. Due to missing data in GEE (cf. Chapter 3.4, 7.1.1), six maps for the years of 1996, 2000, 2005, 2010, 2015 and 2016 were finally created and successfully used in the qualitative interviews.

For the unmixing of the linear spectral mixture model, the first step is to choose the basic types of endmembers (Li et al. 2015, p. 3), which was already accomplished in Chapter 3.2. To simplify the methods used in GEE (code in Appendix E), the further procedure will be explained based on the flowchart (Figure 7).

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[10] *Soja de segunda* [second class soybean] is sown just after the wheat harvest, therefore the yield is a little less than for *soja de primero* [first class soybean], because a lot of the nutrients from the soil where already used by the wheat. However, *soja de segunda* should not be less in quality than *soja de primero*. For this thesis, *soja de primero* refers to soy monocropping and *soja de segunda* to soy-wheat double-cropping (Emanuel 2017, par. 189).

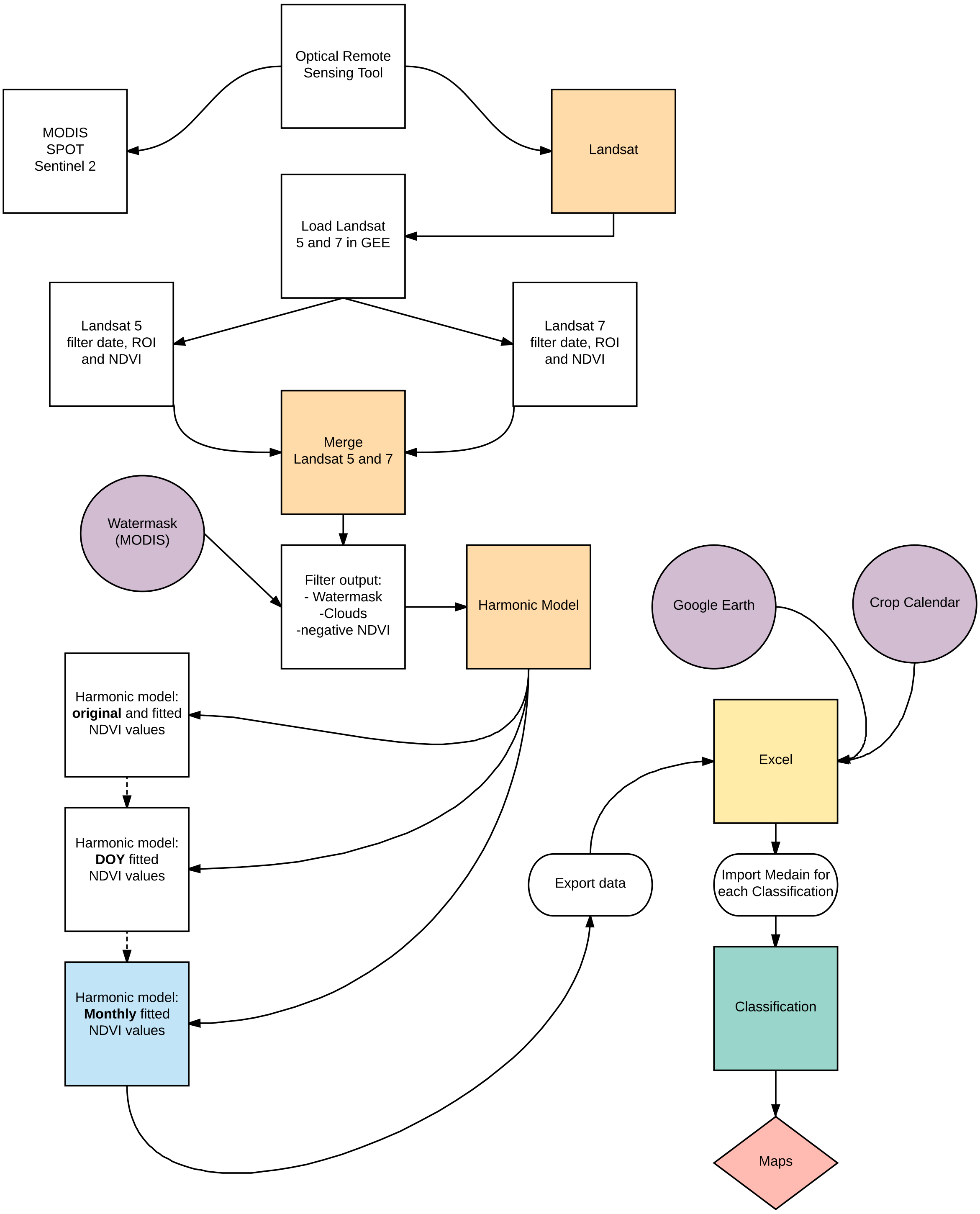


Figure 7: Flowchart of land cover classification and map creation with GEE.

The initial steps of choosing Landsat as a data source are outlined in Chapter 3.3. The standard United States Geological Survey (USGS) Landsat 5 and 7 Surface Reflectance products (Google Earth Engine Team 2015) were used as datasets. The GEE datasets are already (to some degree) free of external factors of noise (e.g., atmospheric influences, topographic shades, etc.). The Landsat 5 data was filtered for the time period from 1st of January 1996 to

31st of December 1998. For Landsat 7, GEE has data available from 1st of January 1999 to until one week from the present, i.e., no filtering was necessary. Afterwards, the datasets were coded to show spectral bands 3 and 4 to reveal the NDVI (Li et al. 2015, p. 2). Both datasets were further filtered for the study area, in the code named 'region of interest' (ROI). Negative NDVI values were eliminated, and the remaining cloud cover was removed using a masking function (cfmask flag) (Fawcett et al. 2017, p. 4). The edited datasets of Landsat 5 and 7 were then merged and pre-coded. The MODIS water mask (available as a pre-coded GEE dataset) (NASA 2014) was extracted to reduce the data volume. Figure 8 shows the available map for the ROI in the year 2005, where the colors indicate the range of the NDVI values.

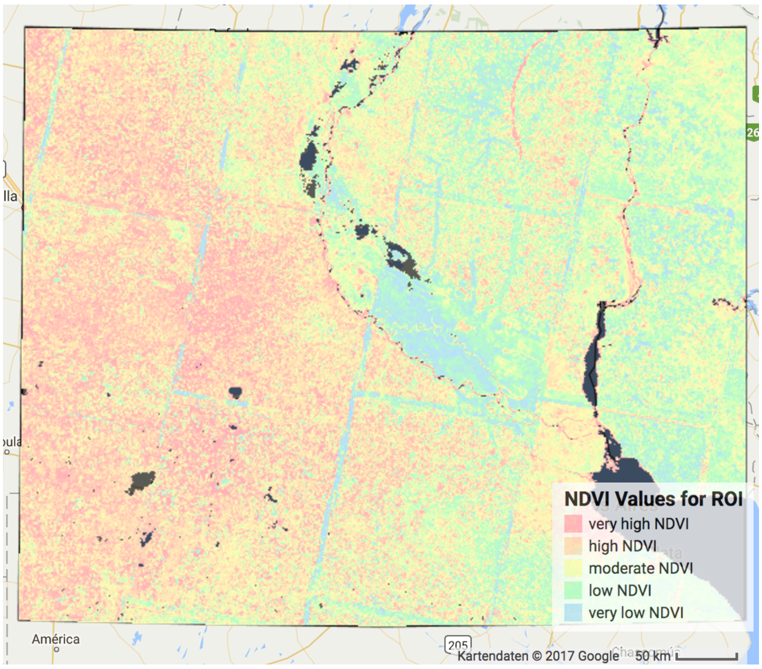


Figure 8: GEE NDVI value map of the ROI for 2005.

The area with high vegetation reflectance is in the center and left area of the map. The literature agrees that this is the core area of Argentinean agricultural production (Astoviza et al. 2016; Casa and Ovando 2014; Gavier-Pizarro et al. 2012; Leguizamón 2014). On the contrary, in the upper right corner, the yellow and green values indicate a lower NDVI reflectance, which leads to an identification of, for example, grasslands and pastures. For 2005, this is, again, correct according to the literature (Gavier-Pizarro et al. 2012, p. 46; Schrag et al. 2009, p. 137). Now, not the general reflectance of vegetation is important but rather the distinction between high and low NDVI values into land cover categories. Hence, classes had to be generated to distinguish the change of the land cover over the years. This procedure will be described below.

To properly use the NDVI values of a single pixel, a harmonic fitting had to be done. According to Fawcett et al. (2017, p. 11) harmonic fitting is "… essentially a linear regression of the independent (harmonic components, time, and constant) versus the dependent variable (NDVI)." This step is necessary because values are not available for every single day due to not eliminated cloud cover or shade or atmospheric disruption. For this reason, the available values had to be fitted into a curve (January to December). In Figure 9a), the red curve is fitted over the available NDVI values (blue). Figure 9b) shows the fitted NDVI curve calculated for every day of the year (DOY). In Figure 9c), the NDVI values separated into the monthly values are depicted.

After the harmonic fitting, the monthly fitted value curve in Figure 9c) is essential for the further steps.

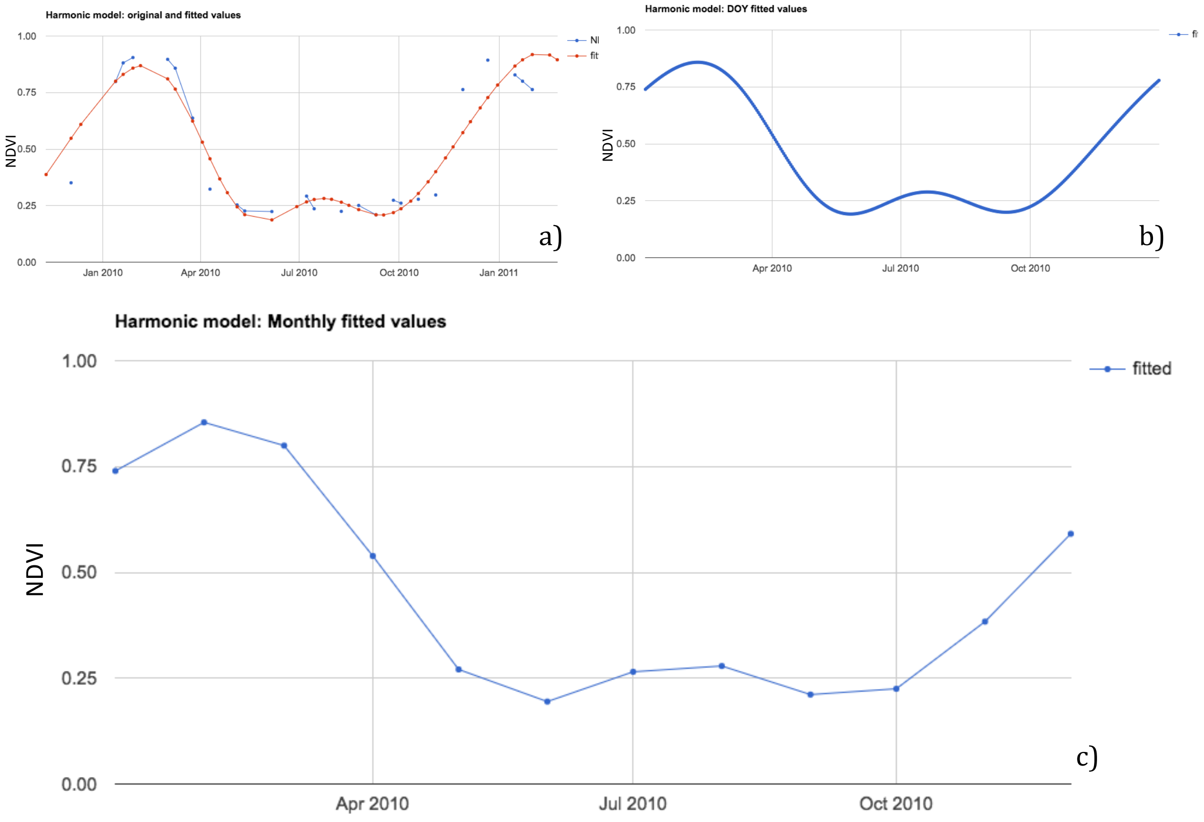


Figure 9: Harmonic fitting for one pixel
revealing it as soybean monocropping, due to the peak in February and decrease of the NDVI value until Mai, indicating the soy harvest.

Next, random pixels were selected in the ROI in GEE, i.e., all of these pixels have the same probability of being selected (Chuvieco and Huete 2010, p. 351), and their monthly fitted values were exported to Microsoft Excel. The values in Excel were analyzed based on the crop calendar, expert knowledge and Google Earth image interpretation (Google Earth 2016), and they were allocated to the five land cover classes. Having at least 25 monthly fitted pixel value samples for each class, the median was calculated. Beforehand, extremes shown in the Excel diagram were deleted. The sample size should represent the study area (Mayer 2002, p. 59), the sampling size of 25 could not be more numerous due to the time limitation. Finally, the median monthly NDVI values (calculated in Excel) were used to classify the land cover classes in GEE.

After the classification method was completed, the input and the output picture had the same spatial structure, but the output no longer represented a quantitative measure but a numeric label identifying a land use category. Hence, the quantitative method of this thesis is a mixed method approach: even though the pixel values are numeric, they are considered to be a qualitative rather than a quantitative measurement scale. However, statistical tools designed for class variables have been properly applied to classified images (Chuvieco and Huete 2010, p. 272). The classified image in this study was exported to ArcMap 10.4.1 (ESRI 2017) and transformed into a thematic map (cf. Figure 15, Figure 16 and Appendix A) that was used for the qualitative interviews. Later (cf. Chapter 5.1), the histogram of the classified image was used to create an inventory of the numbers of pixels and the area, called an area inventory, to be able to conduct a quantitative analysis.

4.2.5 Validation

Back in Switzerland, the final goal and third step of the digital classification (cf. Chapter 4.2.4) was the validation of the product and checking whether the remote sensing data results were close to the actual ground truth conditions. To complete an accuracy assignment, remote sensing results and a true representation of ground conditions are always required (Chuvieco and Huete 2010, p. 343).

Prior to completing an accuracy assignment, the data that the INTA provided had to be adapted. The training sites were provided in the form of polygons. Nevertheless, to use the polygon, information pixel values have to be available. With a random sampling strategy, five pixel values for each polygon were chosen and assigned to the polygon class (see Figure 10). This process was conducted in R (R Core Team 2015).

Approximately 2,500 training sites resulted in 12,500 pixels, each of which was assigned to a land use class and therefore ready to use for the accuracy assignment (see Chapter 5.1).

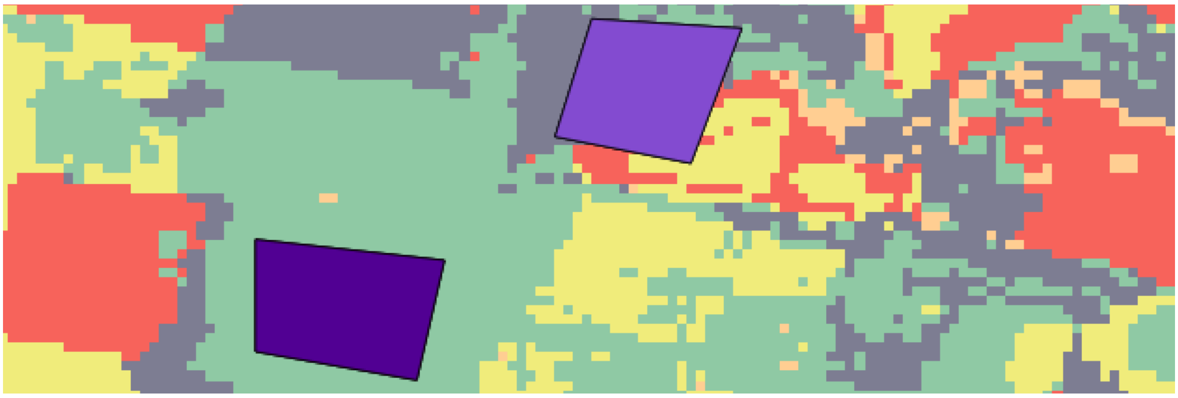


Figure 10: Training sites polygon (purple) that the INTA provided as shown in QGIS.
Correlation check with GEE generated maps is depicted. Whereas dark polygons represent fodder, the GEE classification is correctly assigned to the semi natural class. Meanwhile, bright violet polygons are not assignable.

The first accuracy assessment of the initial land cover classification reveals an overall accuracy of 27%. Using the collected field data as well as the test sites that the INTA provided, the land cover maps were improved, resulting in a better overall accuracy (cf. Chapter 5.2).

The improvement was based on a more specific distinction of the land cover classes of the summer crops of soy and corn. According to Maria (field diary, 21st of March 2017), soy and corn show a very distinct crowing behavior and therefore phenology patterns. In Figure 11, the differences of the NDVI values of soy and corn are illustrated. Soy grows steadily after the seeding, depicted in the higher NDVI value, and the vegetation canopy closes fast. On the other hand, corn grows slower, therefore its NDVI value is reduced, and the vegetation canopy closes much later in the plant growing process. This is identifiable in the increase in the NDVI value in December and January. The literature agrees with this assumption (Abendroth et al. 2011; Wright and Lenssen 2013, p. 2).

Based on the statement of Maria, the field data and the test sites from the INTA (cf. Chapter 3.6), a more precise land cover classification (cf. confusion matrix in Chapter 5.2) was possible.

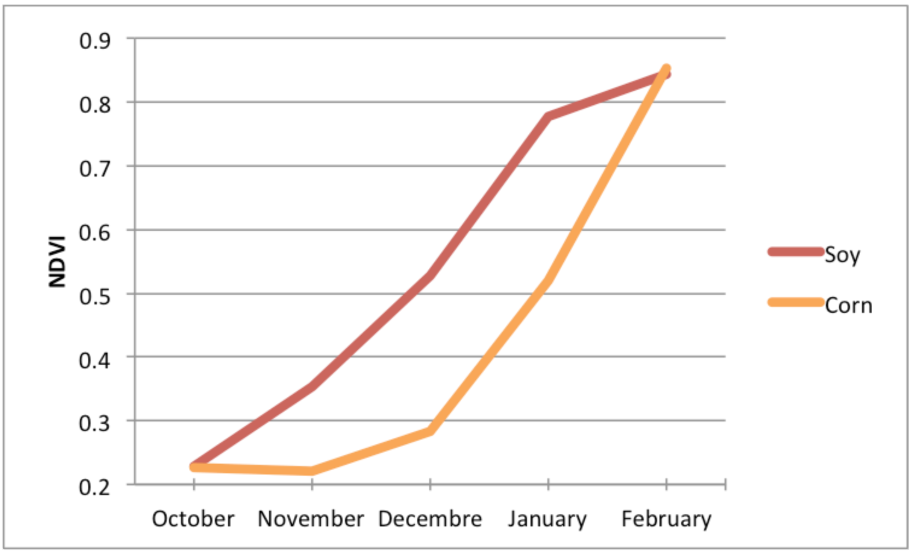


Figure 11: Growing patterns of soy and corn.
The distinction of corn and soy is possible based on their difference of the NDVI values in the early stage of their growing cycle. Depicted are the median values of soy and corn (October to February) after the INTA test site verification.

4.3 Qualitative Approach with Qualitative Interviews

In properly addressing research question II, to evaluate and explain land use change and its effect in the Argentinean agrarian heartland, qualitative semi-structured problem-centered expert interviews were held. The interview development, implementation and analysis are described as follows.

4.3.1 Acquisition of Information

To learn about land use change and its drivers in the *Pampa Húmeda*, qualitative semi-structured problem-centered interviews with experts were applied.

One possibility for retrieving information from people, besides observation, is the questioning of individuals who are involved in the phenomenon in focus. Nowadays, oral surveys are known as interviews (Gläser and Laudel 2006, p. 37). The key feature of a qualitative interview is to provide the interviewee with as much liberty as possible to answer the questions. Therefore, her or his answers can evolve freely and are not biased by the opinions of the interviewer (Kruse 2015, p. 150). The openness of this approach benefits the interviewer, as it supplies him or her with previously unfamiliar facts and opinions (Atteslander 2000, p. 77).

4.3.1.1 Expert Interviews

"An expert is someone who has special knowledge about social facts, and expert interviews are tools to get access to this knowledge" (Gläser and Laudel 2006, p. 10; own translation).

Because experts deal with specific topics on an everyday basis, they are very familiar with them. Thus, expert interviews are an excellent tool for gathering a lot of relevant and often exclusive data (Bogner and Merz 2009, p. 43). The importance of gathering exclusive knowledge from experts is the primary reason that this thesis research involved applying systematizing expert interviews. This means the focus lies on "… knowledge of action and experience which has been derived from practice, is reflexively accessible, and can be spontaneously communicated" (Bogner and Merz 2009, p. 46-47). Further, systematizing expert interviews are a significant tool for the collection of data in the framework of multi-method approaches, such as triangulation (Bogner and Merz 2009, p. 47).

Keeping in mind that an interview is an artificial situation whereby the interviewee enlightens the interviewer on "objective" matters (Bogner and Merz 2009, p. 46).

For this study, expert interviews seemed appropriate due to the interest in their expertise in the field of land use change. The interviewee as a specialist was questioned, and his interpretation, perception and mindset were in focus (Gläser and Laudel 2006, p. 38). The expert interviews were semi-structured problem-centered interviews. Semi-structured means that the degree of standardization enables the interviewee to choose how he or she answers the standardized question of the interview (Atteslander 2000, p. 143; Gläser and Laudel 2006, p. 39). Problem-centered interviews, on the one hand, elicit the gain of knowledge and perception based on an inductive-deductive interrelationship. This means, on the one hand, that the field is not entered without prior knowledge, but on the other hand, no total dependency on previously determined and verifiable operationalization exists. Foreknowledge is important, but it has to be ensured that the interviewers' views of problems do not affect those of the interviewees (Kruse 2015, p. 155-157; Witzel 2000, p. 1-2).

As supportive tools for the interview procedure Witze (1985, p. 236) lists short questionnaires, tape recordings, guideline interviews and postscripts. For this thesis, three of the four tools were applied. All interviews were recorded for a fluent interview process and later analysis. The interviews were based on a guideline (cf. Chapter 4.3.1.2 and Appendix B) that served as an orientation during the conversation and ensured the comparability of all of the interviews. Finally, all interviews were transcribed as accurately as possible (cf. Chapter 4.3.2.1 and Appendix C).

4.3.1.2 From Research Questions to Guideline Interviews

According to Gläser and Laudel (2006, p. 61), research questions have two main purposes. First, strategic considerations are developed based on the research questions. These considerations help to guide the empirical research. Everything that helps to answer the research questions has to be collected. Second, the research question guides the attention of the researcher. Expert interviews as well as qualitative content analysis require a research question (Gläser and Laudel 2006, p. 61).

To frame a research question is as difficult as it is to answer it. The aim of the research questions is to produce new and relevant knowledge based on existing knowledge. They also refer to a theory and ask for a general correlation (Gläser and Laudel 2006, p. 63). For this thesis, the research questions asked are as follows:

I. What is the current situation of GM soy production regarding extent and mindset in the northern part of the *Pampa Húmeda?*

II. How has the land use changed in the northern part of the *Pampa Húmeda* since the GM soy introduction in 1996, and what drivers have been responsible for this change?

Research question I. summarizes and illustrates existing knowledge in remote sensing maps. It can be used to answer the second research question, where the "change of land use" is in focus. Based on the state of the research and expert interviews, this change will be detected and explained. The expert interviews (based on interview guidelines) and the maps are new and relevant knowledge for the change detection and explanation.

A one-month stay in Argentina was aimed at collecting subjective perceptions of different stakeholders associated with land use change caused by the expansion of GM soy production. Insights into the past and current situations had to be acquired. According to Gläser and Laudel (2006, p. 61), only interviewers who know what they want to figure out can ask the right questions. Therefore, research questions were based on knowledge gathered before the trip. Two interview guidelines (Appendix B), one for experts working in institutions and one for producers, helped with asking the research questions adequately.

Guideline interviews are characterized by a fixed distribution of roles, whereby the interviewer leads the dialogue toward an informative purpose (Gläser and Laudel 2006, p. 107). It also contains key questions as well as sub-questions, which can be applied supportively during the interview process. The advantages of an interview guideline are first, an orientation during an interview. Second, it enables the comparability of the interviews in the analysis (Witze 1985, p. 236), and third, an interview guideline provides the interviewee with an opportunity to state personal opinions (Kruse 2015, p. 228f). The interview was designed in such a way that the interviewees feel that their problems are taken seriously, and therefore, they answer openly (Gläser and Laudel 2006, p. 60f).

In this study, the guidelines served as a basic framework for the conversation situation, whereas the questions were open, precise and neutral (Gläser and Laudel 2006, p. 138-139). Guidelines can be rewritten, adapted and modified during the research process after sample interviews but should remain relatively constant thereafter (Gläser and Laudel 2006, p. 146-147). The first interview, as discussed with the interviewee, served as a pretest. Minor textual misunderstandings were corrected. Appendix B provides the final interview guidelines used for this thesis.

4.3.2 Information Processing and Difficulties

Back in Switzerland, the 10 recorded semi-structured problem-centered expert interviews (cf. 3.7) were transcribed (cf. Chapter 4.3.2.1), coded (cf. Appendix D) and analyzed in MAXQDA 12 (MAXQDA 2017) regarding a qualitative content analysis approach.

4.3.2.1 Transcription

After the implementation and recording, the interviews have to be transcribed. The aim of the transcription is to convert an audio data in a preserved form. This means it is not bound to time and allows for a systematic and comprehensive methodical analysis anytime (Kruse 2015, p. 349).

To ensure the accuracy of the data, the interviews were transcribed in full (Kruse 2015, p. 349). Transcripts have to reach a comprehensive preservation of the linguistic-communicative information (Kruse 2015, p. 350) because the interpretation of a meaning of the phrase depends heavily on “how” something is said and not only on “what” is said (Kruse 2015, p. 351). Therefore, while transcribing, the focus lay (besides the content) upon forms of verbal data, such as pauses or intonation (emphasizing a word). Otherwise, if only the content is retained, i.e., the “what” level, the objective signification of words (Kruse 2015, p. 351f) and not focusing on “how” something is said, the meaning of the interview can get lost (Kruse

2015, p. 352). This strategy applies to the transcription of the interviews, resulting in a comprehensive transcript for a further detailed analysis.

4.3.2.2 Qualitative Content Analysis

For the analysis of the expert interviews, "what is said" is important instead of "how it is said". Thus, to analyze the context rather than the form of an interview, two main methods are available (Kruse 2015, p. 398f). The first one is the grounded theory approach by Strauss and Corbin (1996, p. 7). The aim of this method is to construct a concept or theory based on the data conducted instead of reviewing the content. It uses a specific coding system to analyze the textual data. Another interpretative-categorizing approach is the qualitative content analysis approach by Mayring (2007b). Based on a rule-following interpretation and understanding of the material, the qualitative content analysis aims to systematize and arrange content (Kuckartz 2016, p. 97f; Mayring 2007a, p. 469). The central point of qualitative content analysis, on the other hand, is a category system that groups phenomena and other patterns that appear to be similar within a certain "code" or "category" (Kuckartz 2016, p. 38). The possibility of reconstructing the ideas and perceptions of the experts (Gläser and Laudel 2006, p. 191) was the main factor in choosing a qualitative content analysis for the evaluation of this thesis. Mayring (2007b, p. 56f) differentiated the three main variations in the analysis procedure, consisting of either a summarizing, explicating or structuring qualitative content analysis. The first method involves summarizing the material, and the goal of the second one is to explain difficult and unclear parts via contextual embedding. The aim of the last one, and the method applied here, is to extract a certain structure from the material based on a preconstructed coding system.

The process for answering the research questions with a structuring qualitative content analysis follows the flow chart in Figure 12 based on Kuckartz (2016, p. 45f).

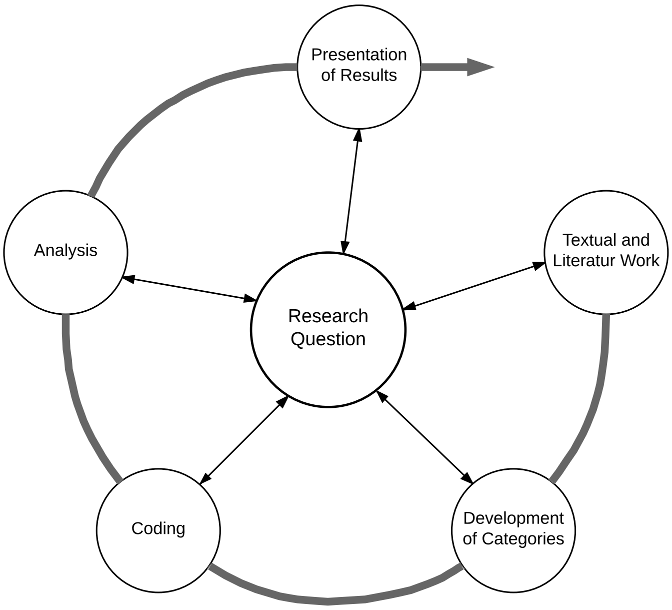


Figure 12: General strategy of a qualitative content analysis based on a flow chart
(Illustration based on Kuckartz (2016, p. 45)).

An initial planning phase with textual and literature work followed the development phase, where a category system was created with a deductive and inductive procedure. The deductive development of codes was done a priori. With a certain foreknowledge about the topic and specific research question, the first version of codes was established using the scientific literature (Kuckartz 2016, p. 63). In the third phase, test and sample coding was applied to determine the reliability of the categories (Kuckartz 2016, p. 102). Afterwards, inductive code development (including sub-codes) was created based on the empirical material from the interviews (Kuckartz 2016, p. 72, 106).

A deductive-inductive coding approach was applied for two reasons. On the one hand, the aim of this thesis research was neither to uncover a latent theory in data, which would be achieved by using an open coding system according to grounded theory (Strauss and Corbin 1996, p. 43f), nor to create abstract concepts based on the texts (Kuckartz 2016, p. 73). Rather, the detection and explanation of land use change and its drivers were in focus. Therefore, the mixed form of the deductive-inductive coding approach seemed appropriate for better revealing the phenomena of interest (Flick 2006, p. 259).

The next phase features the actual coding, making use of the fully differentiated code categories (Kuckartz 2016, p. 110). Finally, the analysis phase features the actual analysis and presentation of the results (cf. Chapter 5.3). The codes and sub-codes are in focus, and correlations have to be found with the goal of answering the research questions (Gläser and Laudel 2006, p. 240f; Kuckartz 2016, p. 117f).

4.3.2.3 Challenges of a Qualitative Content Analysis

While doing a qualitative content analysis, many challenges may emerge. For example, the codes are generated based on theoretical preliminary considerations and are therefore already an interpretation causing a loss of content nuances (Gläser and Laudel 2006, p. 196). While evaluating, it is important to keep in mind that although the interviews are individual cases, correlations can still occur, particularly in the case of the repeated occurrence of feature expressions (Gläser and Laudel 2006, p. 197).

In general, it is important to consider the limitation of a qualitative content analysis, even though it is highly regarded for its standardization, accuracy and reproducibility. These are the qualitative criteria as well as the foundation of qualitative research. In addition, a qualitative content analysis is a specific evaluation technique and therefore has to be combined with other techniques of data collection and data processing. Another point of criticism concerning a qualitative content analysis is that it is difficult to verify the intersubjectivity of a qualitative content analysis due to the randomness of the interpretations of the expert (Mayring 2007b, p. 116).

5 Detecting Land Use Change

The following sections present the results for both the quantitative and qualitative approaches obtained with the methods applied (cf. Chapter 4). The aim of this chapter is to illustrate the current situation of agricultural land use of the study area as asked in research question I., as well as to reveal land use change in the study area as asked in research question II.

5.1 Land Cover Maps Revealing Land Use Change

A result of the qualitative method approach is illustrated in Figure 15 and Figure 16. As presented here, all maps (1996, 2000, 2005, 2010, 2015, 2016) were used for the qualitative interviews. The land cover maps of 2000 and 2010 are explained more in depth because they noticeably represent land use change. The land cover maps of 1996, 2005, 2015 and 2016 can be found in Appendix A. The numbers of the land cover map of 1996 are not integrated into the statistics (Figure 13) because the remote sensing data errors would cause the results to be misleading (cf. 1996 map in Appendix A).

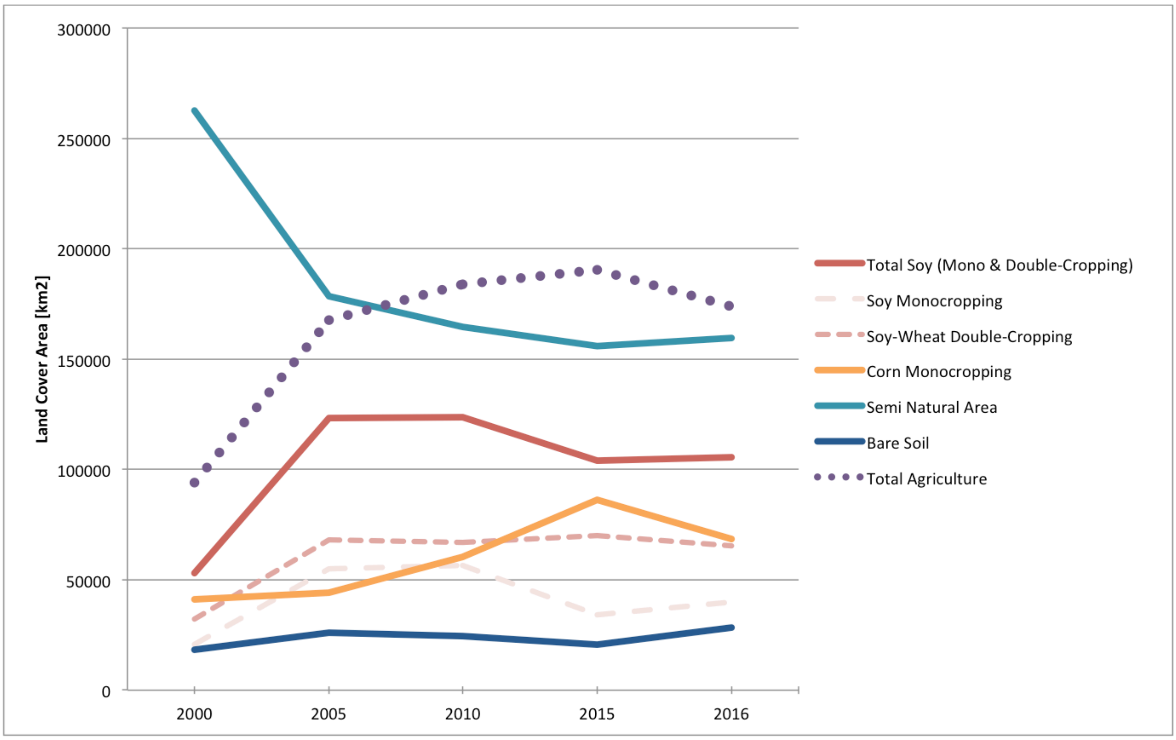


Figure 13: Proportion of land cover classes within one image of the study area illustrating land use change. A total number of pixels (444,039,300) from the land cover maps were converted into km^2 (total area of the study site is 372,489 km^2). Here, the distributed amongst the land cover classes within one image (or year) is illustrated. Per year, each class is represented with an area (km^2) and connected by a line with the following years to show a change in distribution of the size of the areas. Soy (dark red line) is a combination of soy monoculture and soy-wheat double-cropping (dashed lines) to represent the total amount of soy production.

Land Use Change

A remarkable change is detectable in agricultural use in the study area since the GM soy introduction in 1996. Figure 13 illustrates the distribution of pixels allocated to a land cover class in one year and the change from one year to another.

Most severe is the loss of semi natural areas containing forests, grasslands and fodder areas. In the early stages after the GM soy introduction, the semi natural area lost almost one-third of its proportion of the study area. The vast semi natural area east of Rosario, called the province of Entre Ríos, changed immensely into an agricultural production area over the years. In 2010 (Figure 16), in looking at semi natural areas, mainly courses of rivers can be detected east of Rosario. A close up look at the 2010 map in Figure 17 also reveals courses of rivers in between the agricultural fields. However, in 2000 (Figure 15), agricultural surfaces are still scattered visibly in the province of Entre Ríos. On a close up look, the map of 2000 (Figure 17) reveals a more varying surface of semi natural areas and agricultural use.

The Paraná Delta is not distinguishable in the map of 2000 but is clearly visible in the map of 2010. The delta, consisting of rivers, wetland areas, islands and forests (Schnepf et al. 2001, p. 27), cannot be distinguished from semi natural areas in Entre Ríos (eastern part of the map) in 2000. Meanwhile, in 2010, due to a land cover change from semi natural to agricultural areas, the delta is now easily recognizable, even though the delta itself experienced a change from semi natural to agricultural areas (cf. Figure 15 and Figure 16). A continuous decrease of the semi natural area after 2000 until 2015 can be seen in the graph of Figure 13 as well as from the maps of 2000 until 2010 (Figure 15, Figure 16 and Figure 17). After the year of 2015, the amount of semi natural area starts to increase again (cf. turquoise line in Figure 13).

The class of bare soil, representing not only gravel and rock areas but also fallow land and urban area, fluctuated over the 20 years of interest (cf. blue line in Figure 13). In the maps (Figure 15 and Figure 16), the area of bare soil is dominant in the western area of Córdoba, where the Sierras de Córdoba, a low-altitude mountain range (500 - 2800 m.a.s.l.), are (Medina et al. 2016, p. 88). Bare soil areas are mostly located along rivers or around lakes. Water body areas are depicted in white due to a watermask extraction. Other bare soil areas can be found around cities, such as Rosario (cf. upper right corners in 2000 and 2010 in Figure 17). This is due to a similarity between the reflectance of artificial surfaces (like streets or houses) and gravel, rocks or bare soil.

The production of corn steadily increased and almost doubled until 2015, and it slightly decreased the next year (cf. orange line in Figure 13). A core area of corn production is south and southeast of Córdoba (Sofia 2017, par. 46-47) visible in both maps of 2000 as well as 2010 (Figure 15 and Figure 16).

Soy production, shown as a red line (a combination of soy monocropping and soy-wheat double-cropping) in Figure 13 increased almost threefold from 2000 to 2005 and remained stable until 2010. The year of 2015 illustrates a slight decrease in soy production. This decrease is the result of soy monocropping production reduction, whereby soy-wheat double-cropping, again, shows a minor increase. The core area of soy was located west and southwest of Rosario (cf. Figure 15) and expanded as well as densified over the entire study area (cf. Figure 16).

Intensification

Not only can land use change be detected in the maps (Figure 15, Figure 16 and Figure 17) and statistics (Figure 13) but also an intensification of agriculture can be identified in the study area for the past 20 years. The total area of agricultural production (cf. violet line in Figure 13), a combination of corn, soy monocropping and double-cropping areas, almost doubled from 2000 to 2005 and increased steadily until 2015. After 2005, the total agricultural production area was bigger than the semi natural area. Despite a soy production decline, corn production increased, resulting in a totally still growing agricultural production area. In taking a closer look at Figure 17, one can see that semi natural areas vanish at the cost of agricultural production, most certainly soy monocropping or double-cropping.

The intensification of agricultural production is also recognizable in soy production. Even though soy monocropping decreased, soy-wheat double-cropping increased from 2010 to 2015 (cf. Figure 13). In general, soy-wheat double-cropping became bigger than soy monocropping did, indicating a more intensive use of the agricultural fields.

The experts also confirmed agricultural intensification (Juan 2017, par. 62; Mateo 2017, par. 123; Sofia 2017, par. 186). Described as *soja de segunda* (Figure 14), they explained intensification with an emerging double-cropping system. *Soja de primero* (cf. Cover image) is the name of soy monocropping and indicates that only soy is planted on a field within a year. And *soja de segunda* stands for soy-wheat (or any winter crop) double-cropping whereas two crops are planed within a planting season. Resulting in an intensified use of the fields.

Figure 14: Flowering soybean field in the area of Junín [*soja de segunda*]
(Photograph: Franziska Moergeli, March 2017).

Deviation of Trends

Remarkable is the deviation of the trends after 2015. Semi natural areas start to increase again, whereas the total agricultural production area decreases from 2015 into 2016. This change of trends could be because all other intervals enclose five years, whereas the last one encloses just one year. This means that by 2020, the curves would follow the trends despite the abnormal tendencies of 2016. In general, the year of 2016 was included in the statistics due to the change of government at the end of 2015, and an interest lay upon a possible, now visible change of behavior of the curves.

In the map of 2016 (cf. Appendix A), an expansion of the corn area south of Córdoba is visible. The change of interest from soy to corn will be discussed in more detail in Chapter 6.1.4 and 6.4.

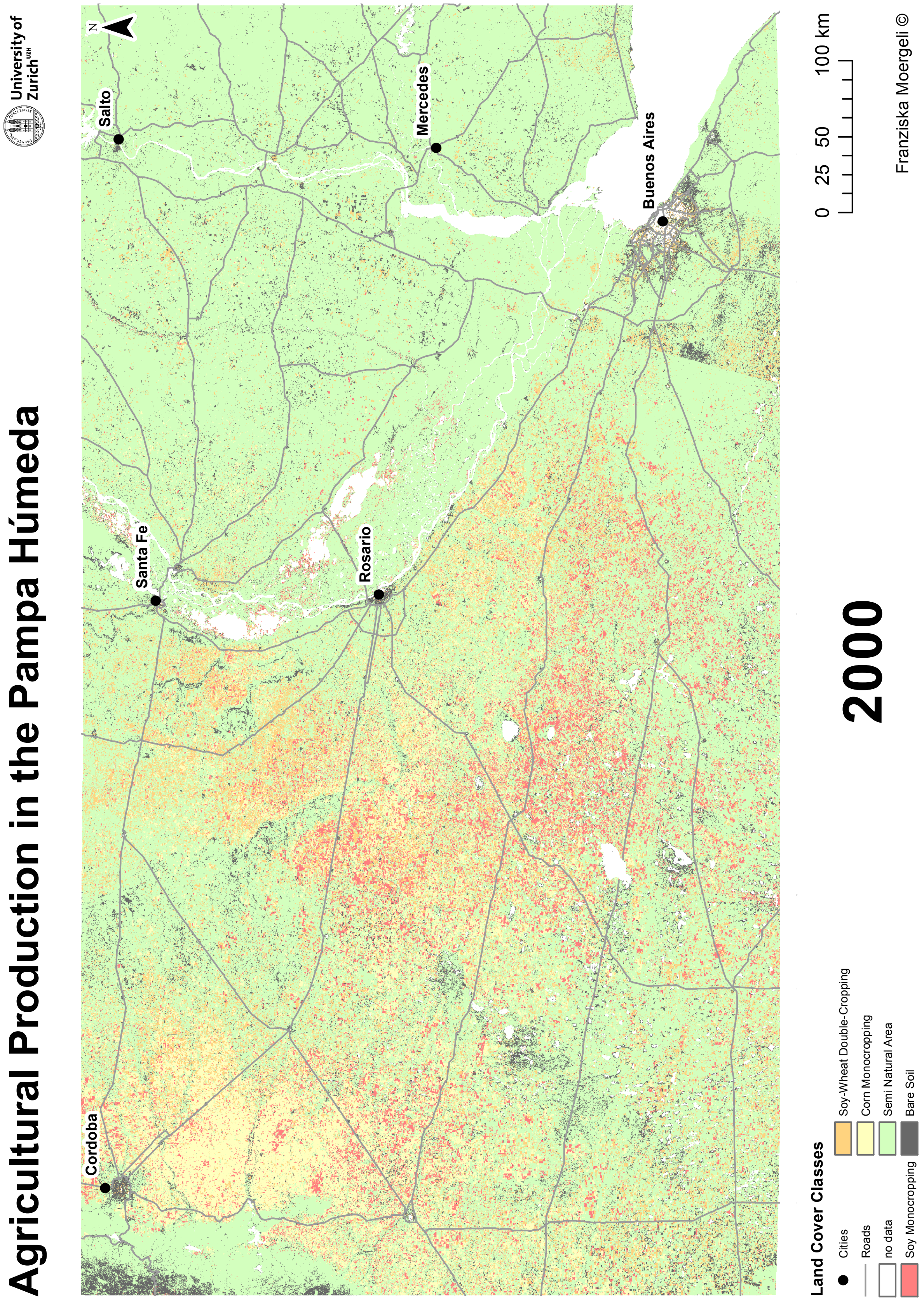


Figure 15: Final land cover map of 2000.

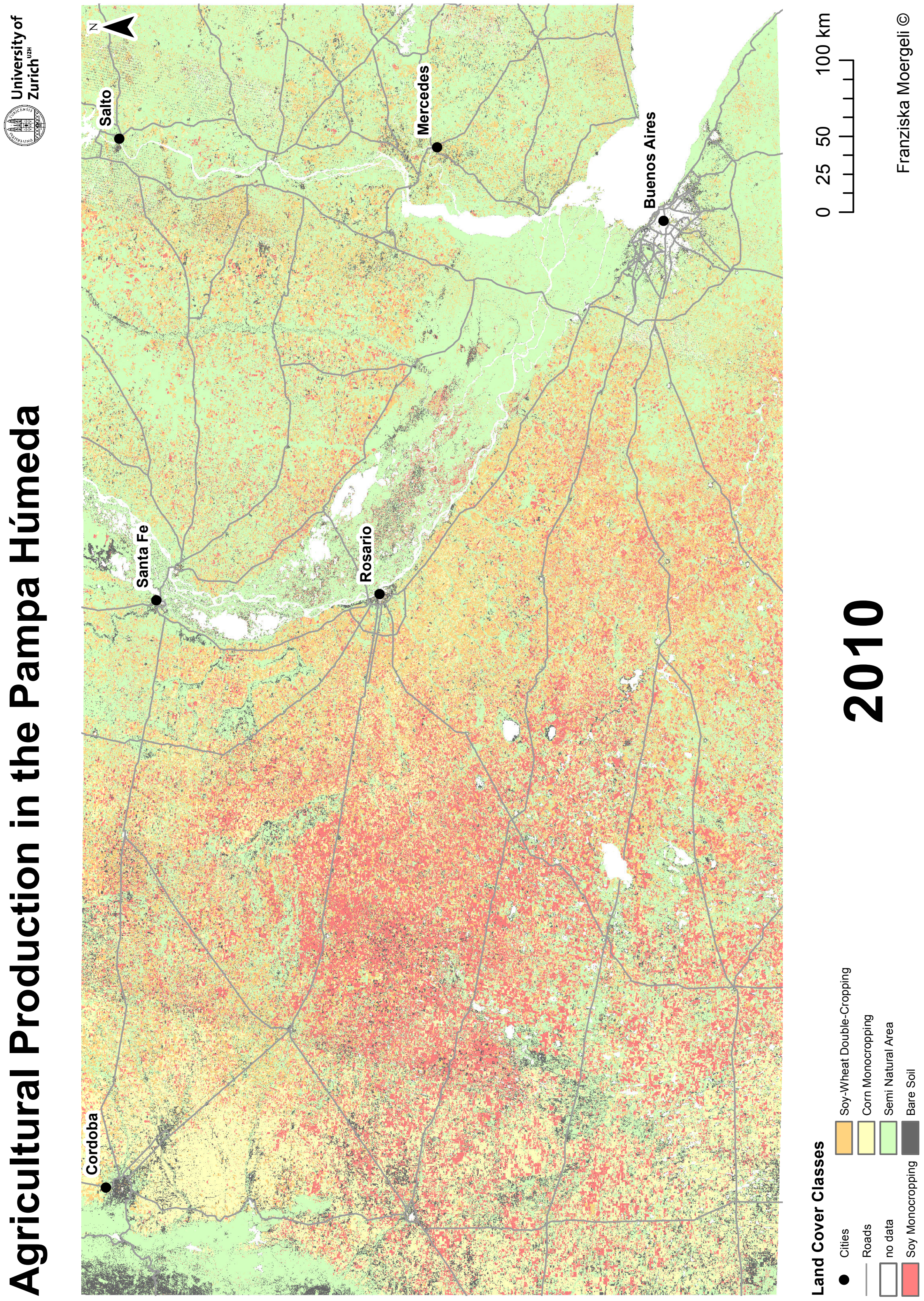


Figure 16: Final land cover map of 2010.

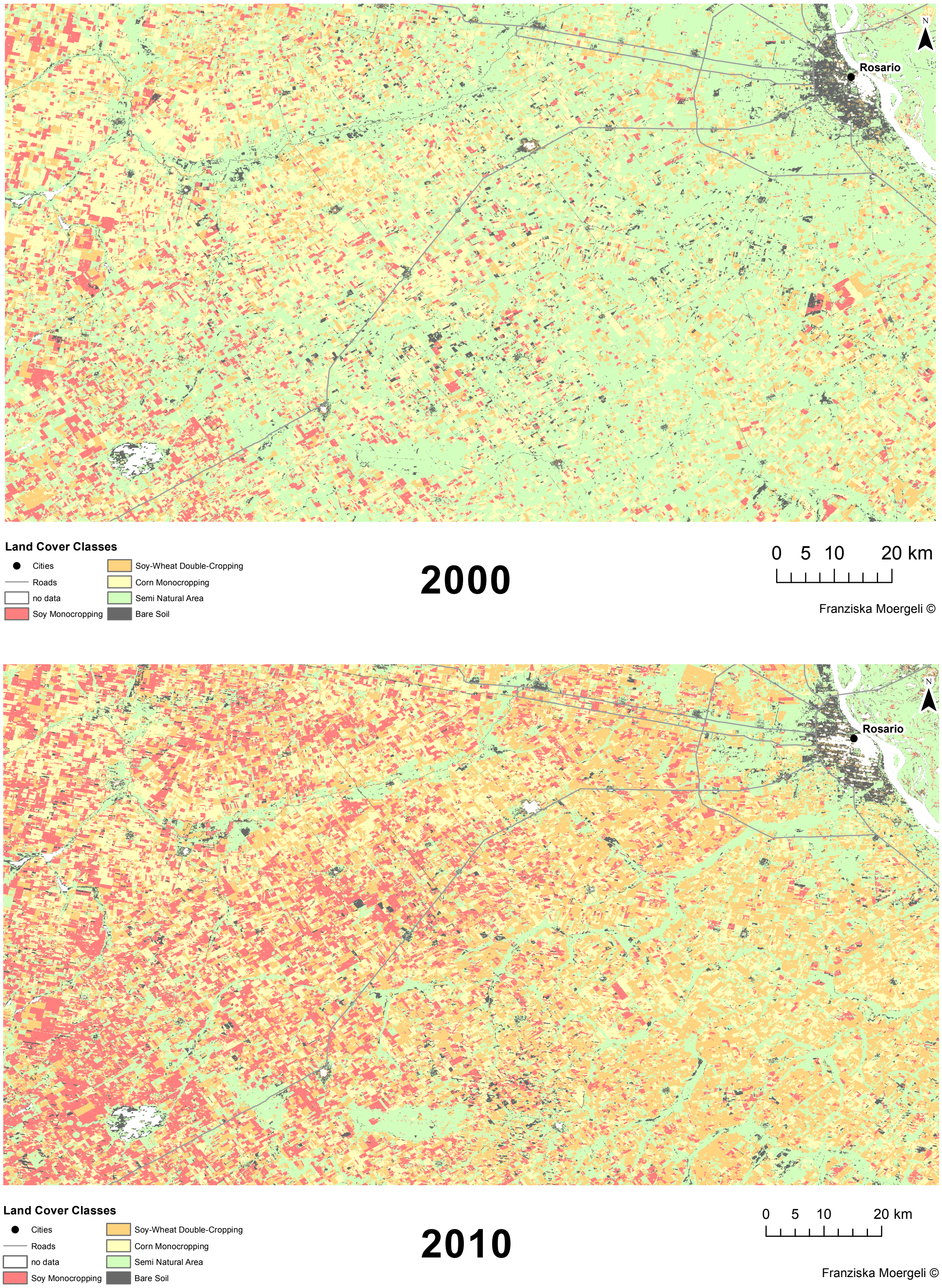


Figure 17: Close up of land cover maps of 2000 and 2010
with visible land use change from semi natural area to agricultural area.

5.2 Accuracy Assessment with Confusion Matrix

The terminal step of digital classification required a verification, whereby the probability of correct assigned classes was examined. This was done using a confusion matrix.

The samples of ground truth, which were expected to be representative of the ground conditions of the ROI, were compared with the classification results to compute different metrics of errors (Chuvieco and Huete 2010, p. 343). The error matrix is also known as the confusion matrix, which "... reflects the agreement and disagreement between the classification map and reality" (Chuvieco and Huete 2010, p. 356).

The matrix lists the trainings sites that the INTA provided (columns) versus the pixel actually classified into each land cover class (rows) and reveals various classification errors of omission (exclusion) and commission (inclusion). It reflects the disagreement and agreement between the classification map and reality (Chuvieco and Huete 2010, p. 356, Lillesand et al. 2008, p. 585).

Confusion Matrix with INTA Data

This confusion matrix validation is compounded from four instead of five classes because the INTA data do not entirely overlap with the land use class generated for this study. Therefore, no verification of the 'soy-wheat double-cropping' class was possible. The land use class of the 'semi natural area' was tested with a training site category containing fodder, forests and grasslands, and the land use class of 'bare soil' was tested with a training site category including fallow, bare soil. The result is as follows.

Table 3: Confusion matrix for the land use class verification.

		Training Set Data				
		Soy	**Corn**	**Semi Natural**	**Bare Soil**	**Row Total**
Classification Data	**Soy**	182	71	18	0	271
	Corn	174	64	24	0	262
	Semi Natural	103	49	292	0	444
	Bare Soil	34	15	15	17	81
	Column Total	493	199	349	17	1058

Training sites that are properly classified into the land use classification are shown in the major diagonal of the error matrix (highlighted in yellow). The overall accuracy – here, 52% – is calculated from the sum of the correctly classified pixels divided by the total pixel count (highlighted in orange) ((182+64+292+17)/1058). This means that 52% of all classified pixels match the reference data.

The three numbers (174, 103, 34) in the blue outlined section in Table 3 indicate the number of pixels that in spite of belonging to a certain category (in this case soy) were not assigned to it. For example, 174 pixels were classified as corn and not assigned to soy even though they should have been. This is called an error of omission and can be read from every column for each class minus the yellow underlined and properly assigned number. The commission errors are marked in a green outline and indicate the wrong labeling of the category soy. This means 89 pixels (sum of green outlined boxes) were included in the class although they should not have been. Although an omission error refers to an underestimation of a particular category, a commission error indicates an overestimation (Chuvieco and Huete 2010, p. 356f; Lillesand et al. 2008, p. 586f).

Table 4: Producer's and user's accuracy.

Producer's Accuracy	
Soy	37%
Corn	32%
Semi Natural	84%
Bare Soil	100%

User's Accuracy	
Soy	67%
Corn	24%
Semi Natural	66%
Bare Soil	21%

Both the error of omission and error of commission are inversely related to the producer and user accuracy (cf. Table 4) (Chuvieco and Huete 2010, p. 361). The user's accuracy describes the ratio of correctly assigned pixels (yellow box in Table 3) with the total number of that certain class. The user's accuracy is a measure of probability with which a pixel belongs to its reference data – in other words, how well a class matches reality. For example, the user's accuracy for soy is 67% as calculated from 182/271. The producer's accuracy is a measure of how well the classes match the reference data. For example, bare soil has a very high producer's accuracy at 100% (17/17). Therefore, the classification of bare soil fits the reality perfectly (Lillesand et al. 2008, p. 588).

Concluding from this short introduction to the land use class verification with a confusion matrix, it can be said, that the applied GEE classification has to be used with caution when analyzing land use change for such a large study area in Argentina. An overall accuracy of 52% is not sufficient for approving the land cover classification. In general, the value of the overall accuracy depends on what is of interest. In this case, the detection of land use change is rather difficult. Meaning, a pixel has a 50-50 chance of actually representing the assigned land cover class. However, the producer's and user's accuracy for semi natural areas are, with 84% and 66% respectively, representatively classified. The same applies to the user's accuracy for soy and the producer's accuracy for bare soil. Even though the remaining values seem very low and are therefore not representatively classified for the classes, it has to be kept in mind that this procedure only indicates how well the statistics extracted from the study area can be used to categorize the same area (Lillesand et al. 2008, p. 586f).

5.3 Expert Interview Reflection

An expert interview is an artificial situation as such, and the response or reaction is provided based on stimuli. According to Atteslander (2000, p. 178), each interview contains statements about social reality but only captures fragments of even this social reality. Additionally, it is important to keep in mind that the different interviewees can have different (cultural) contexts. Therefore, they can understand and interpret terms and concepts differently (Gläser and Laudel 2006, p. 109). Generally, the results have to be used with caution. The empirical material is an example case, whereas the experts hardly represent overall opinions. Thus, generalizations have to be made carefully (Kuckartz 2014, p. 24f).

To document the results of the expert interviews is neither common nor easy. A risk of only summarizing conclusions and not stating the results exists (Gläser and Laudel 2006, p. 265). Therefore, an extract of all of the results will be explained in an example as follows, whereas the interpretation of the results can be found in Chapter 6.

In Figure 18, a part of the code system is represented. The code system (cf. Appendix D) was established to focus on detecting land use change, drivers of land use change and the effects of the land use change. Based on the code system, the expert interviews were coded and analyzed (cf. Chapter 4.3.2.2). From the diagram as represented in Figure 18, interpretations can be generated supported by the scientific literature, and the research question can be answered.

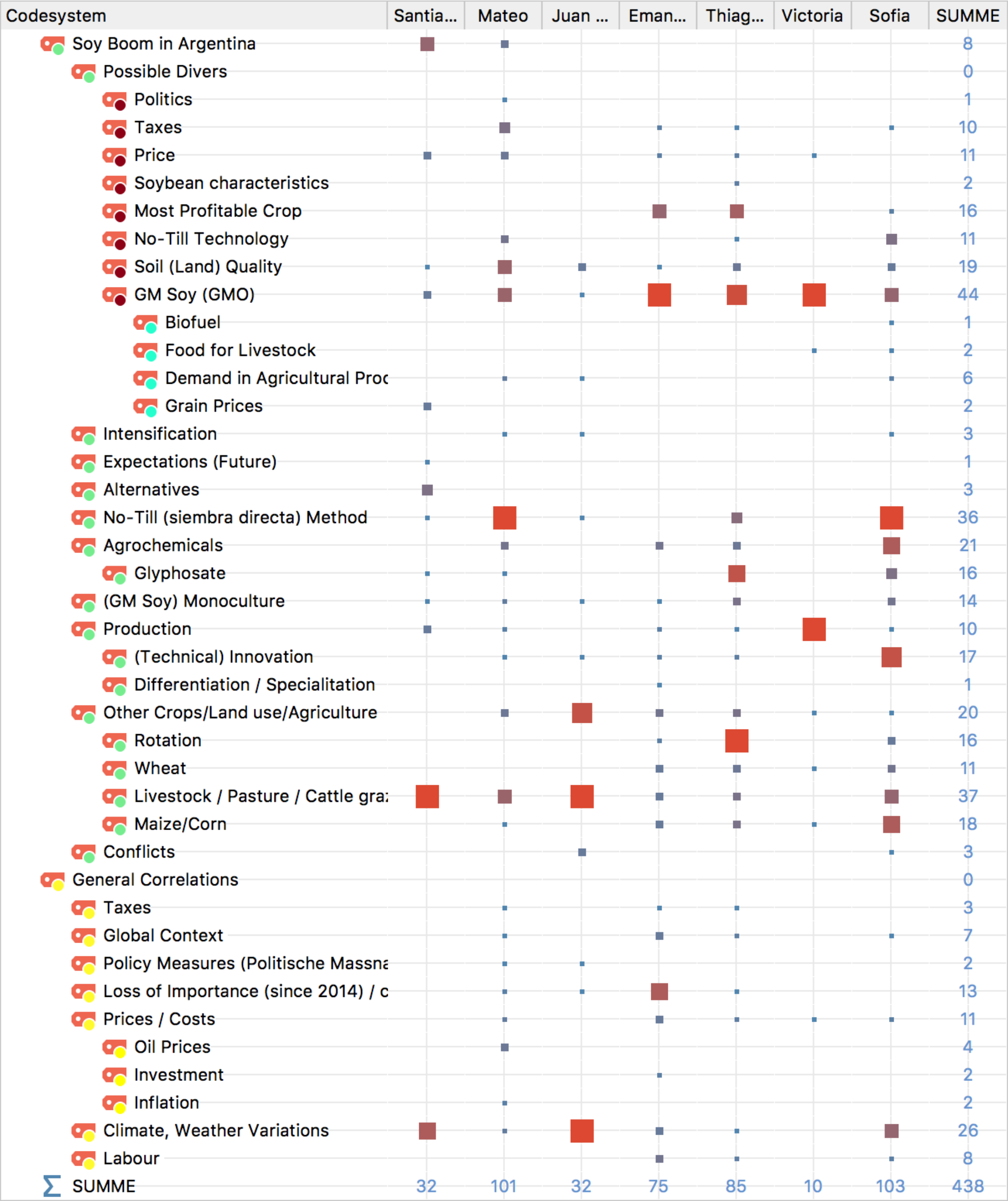
Having a closer look at the interview with Victoria, she stated that the development of genetically modified organisms (GMOs) as well as the change in production are the main drivers of the land use change in the study area. Meanwhile, for Mateo (2017, par. 24), the main driver is by far the no-till technology, which in his opinion enables a more productive and efficient way of producing agricultural goods and thus caused the agricultural expansion and land use change. Interestingly, livestock production regarding Figure 18 is also frequently mentioned in the discussion of land use change resulting from the soy boom in Argentina. It is not directly listed as a sub-code of drivers but as a sub-code of the soy boom in Argentina. This means the change in livestock production is something that occurs alongside the soy boom in Argentina. Santiago (2017, par. 35) emphasized the following:

> *"… the Pampas till there, in the middle of the 90,s was a mixture of agriculture and cattle production. We have great pastures, natural pastures, semi natural pastures with the famous argentine beef…"*

and with the GM soybean introduction, cattle ranging was moved to the peripheries. Hence, the change in livestock production is a consequence of the GM soy introduction but also is a driver of the land use change in a broader sense for.

Finally, an often mentioned cause of the land use change in Argentina is the availability of GMOs. Associated with GMOs is the emergence of the no-till technology, which according to two experts also advances land use change.

This short overview of the expert interview results emphasizes the many complex statements that could be made from this part of the codes only (Figure 18). In conclusion, the results will be embedded in the discussion of the explanation of land use change (cf. Chapter 6).



Codesystem	Santia...	Mateo	Juan ...	Eman...	Thiag...	Victoria	Sofia	SUMME
Soy Boom in Argentina	■	▪						8
Possible Divers								0
Politics		▪						1
Taxes		■		▪	▪		▪	10
Price	▪	▪		▪	▪	▪		11
Soybean characteristics					▪			2
Most Profitable Crop				■	■		▪	16
No-Till Technology		▪			▪		■	11
Soil (Land) Quality	▪	■	▪	▪	▪		▪	19
GM Soy (GMO)	▪	■	▪	🟥	🟥	🟥	■	44
Biofuel							▪	1
Food for Livestock						▪	▪	2
Demand in Agricultural Proc		▪	▪				▪	6
Grain Prices	▪							2
Intensification		▪	▪				▪	3
Expectations (Future)	▪							1
Alternatives	■							3
No-Till (siembra directa) Method	▪	🟥	▪		■		🟥	36
Agrochemicals		▪		▪	▪		■	21
Glyphosate	▪	▪			■		▪	16
(GM Soy) Monoculture	▪	▪	▪	▪	▪		▪	14
Production	▪	▪		▪	▪	🟥	▪	10
(Technical) Innovation		▪	▪	▪	▪		🟥	17
Differentiation / Specialitation				▪				1
Other Crops/Land use/Agriculture		▪	🟥	▪	▪	▪	▪	20
Rotation				▪	🟥		▪	16
Wheat				▪	▪	▪	▪	11
Livestock / Pasture / Cattle gra:	🟥	■	🟥	▪	▪		■	37
Maize/Corn		▪		▪	▪	▪	■	18
Conflicts			▪				▪	3
General Correlations								0
Taxes		▪		▪	▪			3
Global Context		▪		▪	▪		▪	7
Policy Measures (Politische Massna		▪	▪					2
Loss of Importance (since 2014) / c		▪	▪	■	▪			13
Prices / Costs		▪		▪	▪	▪	▪	11
Oil Prices		▪						4
Investment				▪				2
Inflation		▪						2
Climate, Weather Variations	■	▪	🟥	▪	▪		■	26
Labour				▪	▪		▪	8
∑ SUMME	32	101	32	75	85	10	103	438

Figure 18: Extraction of the code system.
The codes for detecting drivers of land use change are listed in the rows and the interviewees in the columns. The size of the square represents which interviewee stated which driver as the most important. For example, GMO is seen as an important driver for land use change to three interviewees.

5.4 Results versus Reality

By now, it is a certainty that the GM soy introduction caused a change in land use. As Leguizamón (2014, p. 152) stated, the cultivated soy area had a size of 6.9 million hectares in 1996 and almost tripled by 2011. Figure 19 additionally visualizes the increase or decrease of sowing areas starting in the planting season of 1969/70 until 2015/16 in four different provinces. Buenos Aires, Córdoba, Santa Fe and Entre Ríos are all part of the study area. The data were accessed via the open data portal of the Ministry of Agroindustry (Datos Abiertos Agroindustria 2017).

At first sight, the rapid and intense increase of soy sowing areas (in 1,000 hectares) can be recognized in Figure 19. Not surprisingly, the rise started in 1996. In 20 years, the sowing area of soy multiplied (in average) by three. The soy sowing area in the province of Buenos Aires increased in the past 20 year by fivefold, tripled in Córdoba and in Entre Ríos, even though a proportionally small area, increased almost by ten. However, Santa Fe has also experienced a doubling of the sowing area from the GM soybean introduction until today. Summarizing covered soybean sowing areas in 1996 about 2% of the total area of Argentina[11] and tripped by 2016 to cover 6,2%. At about the same time that the numbers of soy fields increased, the sowing areas for wheat started to decrease in Buenos Aires. Although corn sowing areas experienced a slight decrease at first, they then remained stable over the next 30 years and started to increase again by 2009/2010, and almost doubling until 2015/16.

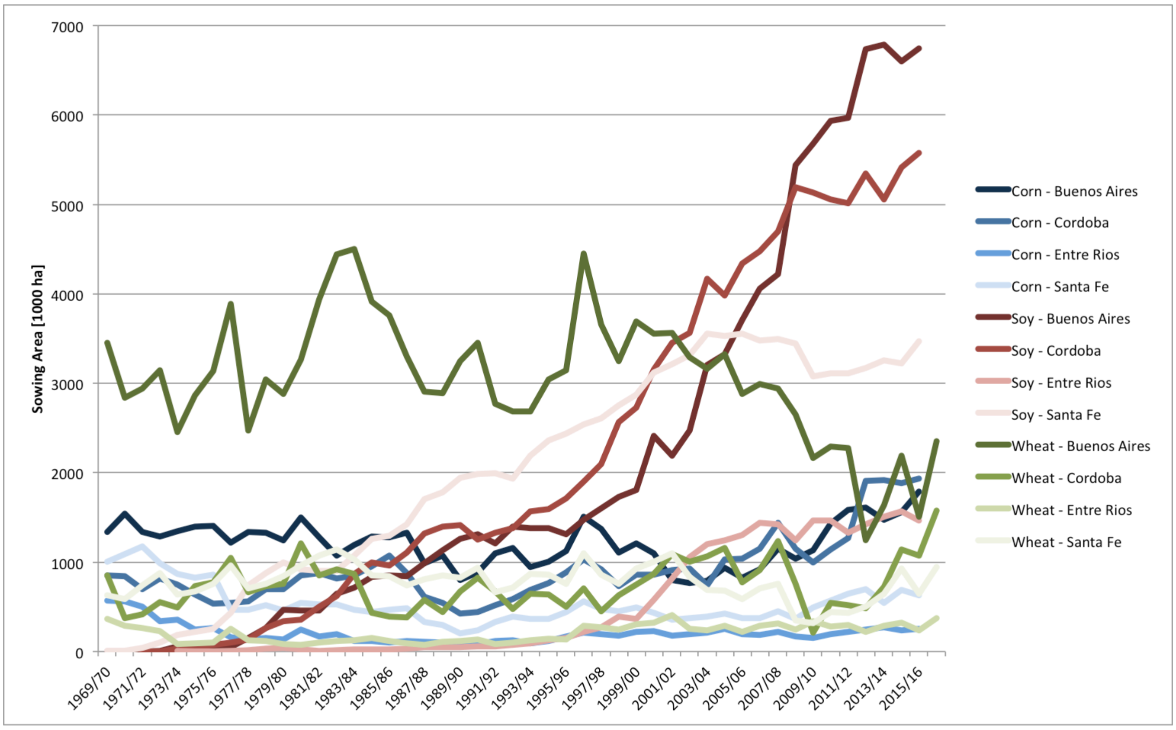


Figure 19: Change in size of sowing areas for soy, wheat and corn in four different provinces since 1969 until 2016 (Graph based on data by Datos Abiertos Agroindustria 2017, accessed 22nd of March 2017).

The land use map statistics (Figure 13) and the sowing area statistics have a soy field increase in common. Both show an intensive increase of soy fields after 1996. Although the map statistics emphasize a constant soy production area from 2005 until 2015, the data from

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[11] Argentina has a total area of 2’780’400 km^2 according to Central Intelligence Agency (2017).

the Ministry of Agroindustry illustrate a continuous increase in soy sowing areas. Additionally, the revealed decrease in soy production areas on the land cover maps is not evident in the statistics of Figure 19. Interestingly, the reduction of the soy field area is identifiable in Figure 20, where the change of production in tones is illustrated. In three out of four provinces, soy production was reduced after 2015 as it was detected with the land cover maps (cf. Figure 13). In addition, the numbers of Figure 20 reveal a fluctuating increase in corn production (blue lines) also depicted by the land cover map statistic (cf. Figure 13).

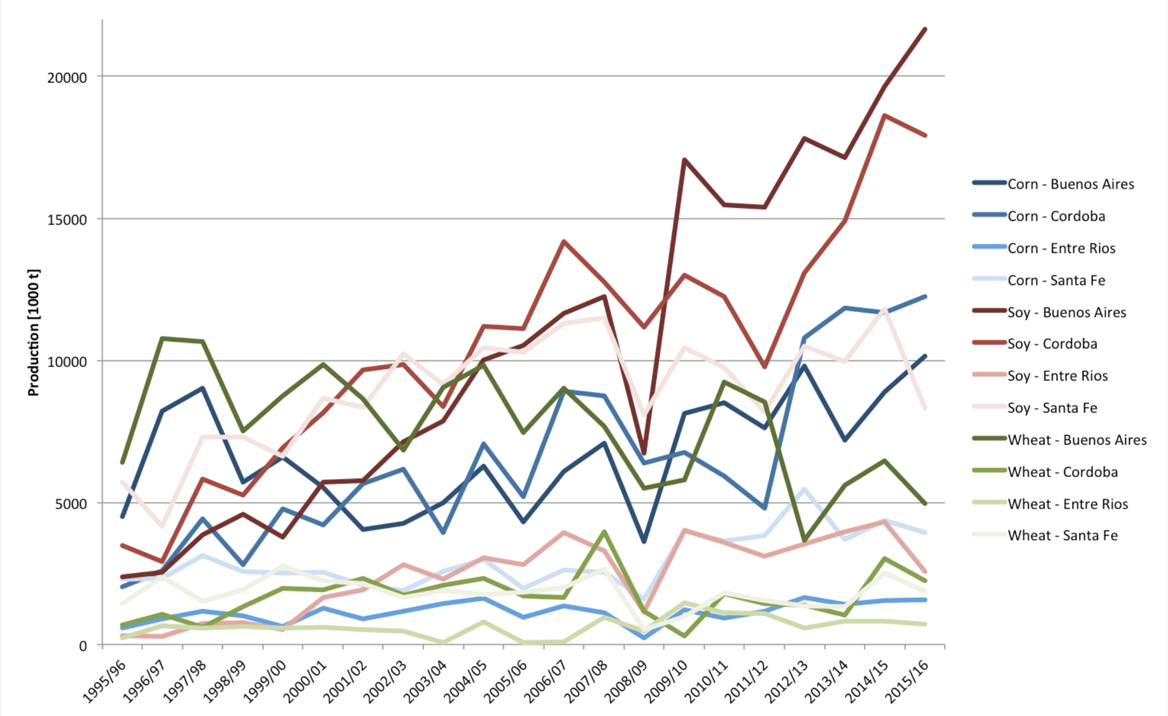

Figure 20: Change in production of soy, wheat and corn in four different provinces since 1996 until 2016 (Graph based on data by Datos Abiertos Agroindustria 2017, accessed 22nd of March 2017).

The many statements based on maps, data and statistics are valuable but not finally approved. Method triangulation in terms of the mixed methods approach applied for this thesis also requires the consideration of the qualitative expert interview results for a verification of the results and to finally answer the research questions. This will be accomplished in the next Chapter (6).

5.5 Today's Agricultural Situation in the Pampa Húmeda

The first research question concerns the current situation of the GM soy production extent in the northern part of the *Pampa Húmeda.*

Based on the materials in Chapter 3 and the methods applied according to Chapter 4, an estimation of today's soy production extent is possible. The remote sensing approach revealed the present extent of the GM soy production in the study area (cf. Figure 22). According to Figure 21, the agricultural extent occupies 48% (consisting of 11% of soy, 18% of soy-wheat and 19% of corn) more of the study area than the semi natural areas (44%). The main agricultural good produced on the farmlands in the study area is still soy (29%). This is due to soy monocropping (11%) and soy-wheat double-cropping (18%).

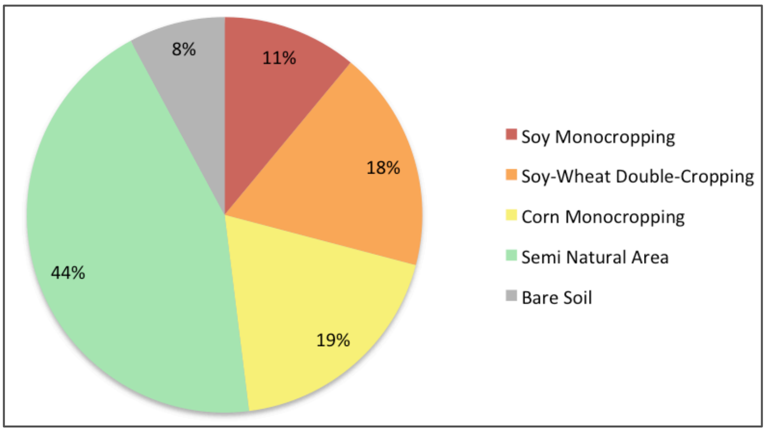

Figure 21: Percentage of the land cover class distribution in 2016.

In Figure 22, the core area of soy production is (still) in the center of the study area. The region west of Rosario has been and still is a fertile land that is used for cultivation (Schnepf et al. 2001, p. 27). According to Mateo (2017, par. 28), Valentino (2017, par. 204) and Sofia (2017, par. 229), only the best lands are used for agriculture. Therefore, the cultivation of soy in this area is not surprising. The core area of agriculture is a heterogeneous mixture of soy monocropping, soy-wheat double-cropping and corn cultivation. Nicely visible are semi natural areas, revealing courses of rivers. The core area of corn production is located south of Córdoba along the mountain range Sierras de Córdoba (Medina et al. 2016, p. 88). Sofia (2017, par. 144) emphasized an early importance of this area for corn production but questioned whether it is a soy production area today. However, the area east of Rosario, the province of Entre Ríos as well as Uruguay, is widely and heterogeneous used for agriculture, illustrating the far reaching extent of agriculture in 2016.

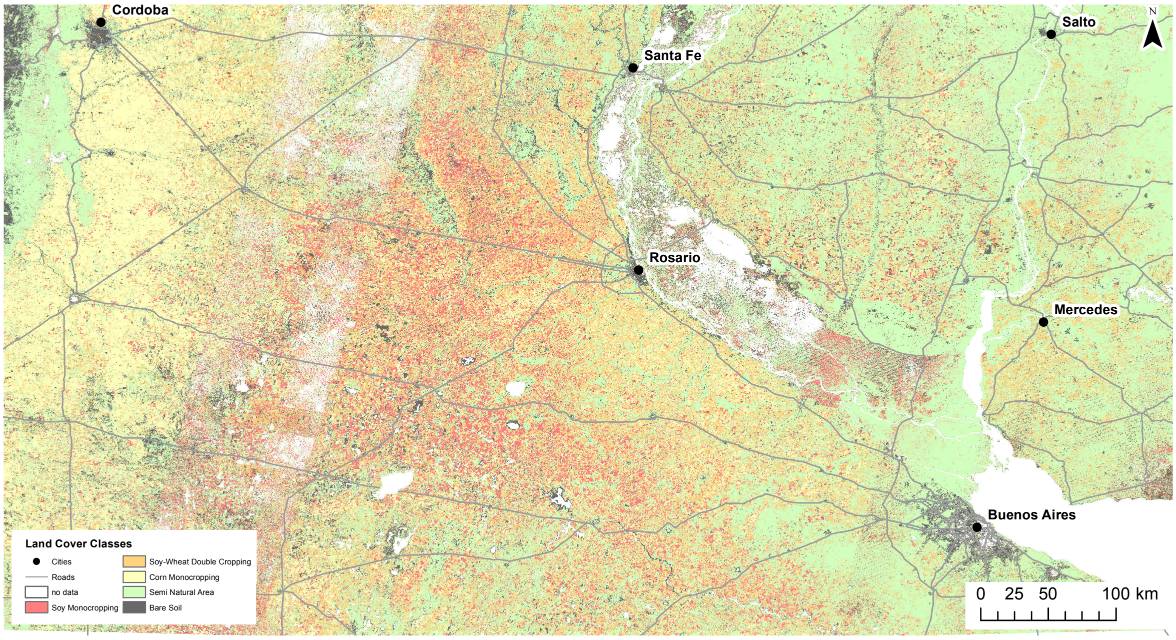

Figure 22: Land cover map of 2016
illustrating the current situation of the agricultural extent of the land cover classes.

Keep in mind the accuracy assessment calculated in 5.2, which revealed an overall accuracy of 52%. In other words, the statement of today's distribution of land cover classes has to be used with caution.

The change in trends depicted from 2015 to 2016 is very interesting. Not only did semi natural areas begin to increase again but also a decrease in corn production is recognizable (cf. Figure 13). In the map of 2016 (Figure 22), the fields are more heterogeneous compared with the map of 2010 (Figure 16). This is due to the new government policies promoting rotation (cf. Chapter 6.1.4).

> *"Finalement, l'année passé (2015) le gouvernement a changé, puis le nouveaux gouvernement a une nouvelle politique. Toute l'argentine fait du maize, soya, wheat. C'est génial." (Emanuel 2017, 87)*

> *"Until 2015 the people didn't rotate crops because the only thing profitable was soybean. So they did soybean all the time. ... From last year on they were starting to think about the soil and about the natural resources of the soil so from last year onwards [the crops] are being rotated." (Emanuel 2017, par. 159, 163)*

The discussion of past and current distribution as well as the rotation of cultivation cycles will be continued in Chapters 6.1.1, 6.1.4 and 6.3.

6 Explaining Land Use Change

This part focuses on answering research question II. Its aim is to explain land use change based on the results illustrated in Chapter 5 as well as using the analysis of the expert interviews. Potential drivers of land use change are listed and discussed in the following Chapter (6.1). Subsequently, these drivers are critically reflected in Chapter 6.2 and brought into a global context in Chapter 6.3. Finally, an outlook of prospective land use change is summarized in Chapter 6.4.

6.1 Land Use Change Driver Assessment

After detecting land use change in the northern part of the *Pampa Húmeda* since the GM soy introduction in 1996 (cf. Chapter 5), the aim was to explain this change. To do so, this thesis research involved examining the "how" of how this change of the land use took place. The qualitative research through expert interviews was outlined to detect drivers initiating and amplifying land use change.

As listed in Chapter 2.3, many drivers stimulate a change in agriculture all around the world. According to the interviewed experts, four main drivers are responsible for Argentina's change in agricultural production: (1) the introduction of GMOs (cf. Chapter 6.1.1); (2) the adaptation of no-till technology (cf. Chapter 6.1.2); (3) the quality of the soil (cf. Chapter 6.1.3); and (4) the profitability of GM soy (cf. Chapter 6.1.4).

6.1.1 Introduction of GMOs

The literature (Leguizamón 2014, p. 149; Schleifer 2016, p. 9; WWF 2014, p. 66; Zelaya et al. 2016, p. 100) and interviewees agreed on the introduction of GMOs as the main driver for land use change in all of Argentina.

> *"In 1995, more or less, where the soybean boom expansion started, with the introduction of the Roundup resistant genetically modified organisms."*
> *(Santiago 2017, par. 33)*

"When the GMO appeared, the spread was incredible." (Sofia 2017, par. 62)

Initially, GM soy, which was legalized in 1996 by Carlos Menem (Berndt et al. 2017, p. 11), was aimed at making soy crops resistant to herbicides. In Latin America, soy is genetically modified to tolerate Monsanto's herbicide glyphosate. This implies that soy can be sprayed (cf. Figure 23) with this herbicide several times during the growing season, whereby all other plants are killed and the soy plant will be the only one to survive (WWF 2014, p. 67). Nowadays, 100% of soy planted in Argentina is Monsanto's RR (Leguizamón 2016, p. 2).

Figure 23: Sprayer in Junín, spraying glyphosate in a soy field.
Sprayer company name was erased (Photograph: Victoria, March 2017).

The GMO introduction in Argentina is classified as a technological driver. The expansion of GM soy production, causing extensive land use change, was possible because, on the one hand, farmers were able to produce more GM soy at a lower cost. On the other hand, the productive and profitable new crop encouraged the acquisition of new lands for further increasing GM soy production (Norton et al. 2013, p. 6).

The production of more GM soy at a lower cost is possible for two reasons. First, GM soy production requires fewer workers than traditional farming does. Before 1996, many people worked on the fields because they had to prepare the soil mechanically and not use chemicals to do so. The same applied to the harvest (Victoria 2017, par. 11 and field diary 25th of March

2017). In contrast, the use of GMOs requires only a few people to operate machinery, such as tractors or sprayers (cf. Figure 23) for the seeding, applying chemicals and harvesting. Mateo (2017, par. 20), for example, employs only 12 workers for his farm, which covers 2,500 hectares. This transformation of a former labor-intensive type into a machine-, chemical- and fossil fuel-dependent agricultural production changed rural life dramatically (Leguizamón 2014, p. 152). Second, GM soy production is very profitable.

> *"With the introduction of the GMO soybean, you had like the soy and then you use the herbicides to kill the weeds and the only remaining thing in the fields was the soy. So it was very profitable and very easy to manage." (Thiago 2017, par. 134)*

> *"And also because you need less investment to sow soybeans than to sow corn or any other crop, it's easier." (Emanuel 2017, par. 66)*

Emanuel (2017, par. 66-67) further elucidated that the price the producers had to pay per hectare for corn was 400 US dollars, whereas for soy, it was only 250 US dollars. Hence, less money had to be invested for sowing soybeans compared with corn. According to Thiago (2017 par. 76), GM soy production was the most profitable, even if the conditions of the crop were bad, the profit of the crop was relatively low or the harvest was less than expected.

> *"You invest less and earn more! It was until 2016, then it changed![12]" (Emanuel 2017, par. 71)*

Not only was the GM soy production very profitable but also the output increased rapidly (cf. Chapters 5.1 and 5.4) with the new disease resistance and increased productivity of the plant. This encouraged farmers to start a huge transformation in all of the productive systems. Agricultural systems became more homogenous, dominated by GM soybean production. The loss of heterogeneity was caused by the loss of former great grasslands that were transformed into agricultural land. Grasslands were no longer important because soybean production generated higher financial profit than cattle raising did. The stocks for cattle were incredibly low, whereas the GM soy production was incredibly lucrative. This triggered a huge change in the agricultural system, starting in the Pampas region, and had consequences all over the country. For example, the cattle moving from the Pampas to the north into the Chaco region caused destructive land use change, such as deforestation (Santiago 2017, par.

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[12] The change mentioned by Emanuel will be discussed in Chapter 6.1.4.

39-41; Fernando 2017, par. 77). However, a change in land use was not the only consequence of the GMO introduction in Argentina.

Due to the extended use of glyphosate, weeds became stronger and more resistant to the glyphosate, resulting in a selection of surviving super weed resistant to glyphosate. As a consequence, the fields are sprayed with higher doses of the herbicide year by year (Thiago 2017, par. 145; WWF 2014, p. 66). Argentina's use of glyphosate increased from 1996 from 10 million liters to 180 million liters in 2013 and still counting (Suchanek 2013, p. 18). However, the increased use of glyphosate has impacts on human and environmental health. For example, studies link the spraying of agrochemicals, especially glyphosate, to increasing cases of cancer, miscarriages and birth defects (Leguizamon 2014, p. 155). Environmental health suffers from the spraying with regard to diminishing soil fertility, the intoxication of water systems and severe effects on biodiversity (Milazzo et al. 2013, p. 814). Thiago (2017, par. 145) mentioned that a solution for addressing the intensified spraying is the rotation of crops. Even though the super weed is resistant to glyphosate, rotation might manage the weeds because for each crop, a different agrochemical is used (Thiago 2017, par. 145-146).

However, a negative attitude toward agrochemical spraying was not widely spread among the interviewed producers. If applied in a correct way, Valentino (2017, par. 176), Mateo (2017, par. 140) and Sofia (2017, par. 40) did not see a problem with using agrochemicals.

> *"The problem with the glyphosate is not the toxicity but the dose you use, the amount of the product you use." (Valentino 2017, par. 176)*

> *"We don't have to be afraid about chemical products, if you use them in a responsible way." (Sofia 2017, par. 237)*

Sofia (2017, par. 20, 237) further expressed her concern about the reputation of glyphosate. In her opinion, the agrochemical is a solution for battling famine.

> *"It's a real pity that most of the civil society all around the world is against glyphosate. Because nowadays, it is the best product that we have and it has the least toxicity of all the products that we can use in our farms. Not only in Argentina, but also all around the world." (Sofia 2017, par. 40)*

Thiago (2017, par. 157) explained that the agrochemicals are classified into different colors representative of their toxicity (from the lowest toxicity to the highest toxicity is blue, green, yellow and red). He assured that glyphosate is categorized in the green category, hence, it is not bad for either humans or the environment. Some agrochemicals categorized in yellow and red have been used in the past but are prohibited in the meantime.

Opinions on the benefits of the GM soy adaptation vary greatly. Whereas Leguizamón (2014, p. 158) emphasized outstanding economic growth, Victoria (2017, par. 24) stated that the only advantage of soy production is the revenue associated with exports and criticized:

> *"The environmental cost, the degradation and loss of the environment, together with the natural resources like water, soil that we give away cannot be compared to the economic benefit. The difference is that the environmental consequences are or will be suffered by all the people equally." (Victoria 2017, par. 27)*

However, the change in agricultural production in Argentina, according to Mateo (2017, par. 34, 43) and Sofia (2017, par. 40), is not only the GM soy but also the new no-tillage (also known as no-till or direct drilling) method used for preparing the fields (cf. Chapter 6.1.2). Juan (2017, par.122) felt certain that only the adaption of the no-till method enabled GMO cultivation.

> *"No-tillage is the first step of the success in [the agricultural] revolution."*
> *(Sofia 2017, par. 40)*

In the context of the neoliberal economic restructuring in the late 1990s (cf. Chapter 6.1.4), the adoption of the "technological package", including planting RR soybeans, using a no-tillage method (cf. Chapter 6.1.2) and spraying the herbicide glyphosate resulted in Argentinean farmers' becoming a key global food producer (Leguizamón 2016, p. 2, 4) and allowed for the impressive expansion of agricultural soy production (Leguizamón 2014, p. 154). Hence, GM soy introduction is, as experts have emphasized, a key driver of land use change in Argentina.

6.1.2 Adoption of No-Till Method

The idea of the modern no-till technique arrived in Argentina in the 1970s. The method averts conventional plowing of the fields. With this new technique, the old crop residues are incorporated into the upper layer of the soil, the seeds are drilled in and the soil is pressed down again (cf. Figure 24) (Joensen et al. 2005, p. 17). According to Mateo (2017, par. 23-26), only with the GMO introduction was the no-till method successfully incorporated into the production procedure. He proudly claimed to be one of the first in Argentina to successfully use no-till technology himself since the early 1990s (2017, par. 22). Modern machinery developed only for this purpose immensely accelerated the no-till method, whereby one person in a single operation can complete the process. Even though the method was originally not developed to be used in combination with agrochemicals, the no-till method has become widely associated with the use of the herbicide glyphosate and Monsanto's RR crops (Joensen et al. 2005, p. 17). Nowadays, according to Sofia (2017, par. 62), more than 90% of the cultivated area in Argentina is cultivated with the no-till system.

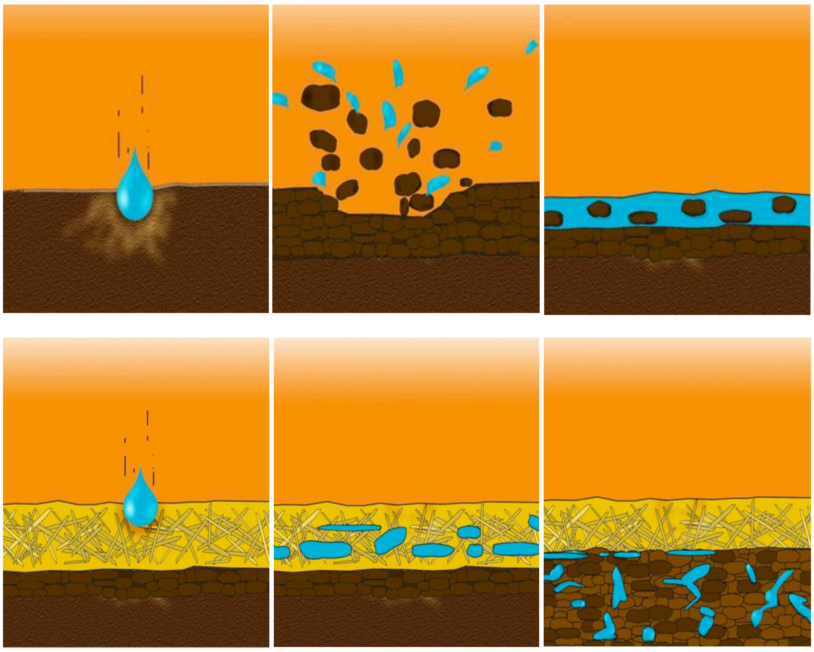

Figure 24: The effect of conventional plowing and the no-till method on the soil quality
Upper row: Using conventional plowing, soils were not able to absorb all of the rainwater. Therefore, the upper layer of the soil is washed away each time it rains. Bottom row: With the no-till method, a barrier layer is created, which can sufficiently absorb rainwater, it is incorporated into the lower layers and does not erode the soil (Illustration provided by Sofia, 30th of March 2017, AAPRESID).

Although not new to human beings, no-till technology is seen as a technological driver, same as GMO (Norton et al. 2013, p. 6; van Vliet et al. 2015, p. 30). Mateo (2017, par. 53), Juan (2017, par. 122), and Sofia (2017, par. 62) emphasized the opportunities Argentina obtained due to no-tillage. According to them, the soils were in a very bad condition and degraded from years of conventional soy production (before 1996). The farmers faced widespread soil erosion due to the loss of organic matter in the soils (cf. Figure 24) (WWF 2014, p. 62).

> *"No-tillage technology come and help to improve that situation and enhance the soil condition and was very important in the region." (Juan 2017, par. 122)*

Furthermore, they promoted no-till farming for sustainable development. No-till farming in combination with GMO and glyphosate is considered a very nice tool for ecologic production (Sofia 2017, par. 62).

> *"No-till farming as a sustainable agriculture production system, it's a very nice tool, not only for Argentinean people but also all around the world, for food security and climate change." (Sofia 2017, par. 20)*

> *"The best thing about no-till system is that you emulate nature. You know? So that's the great thing, you can, it allows you to product and taking care of the environment at the same time." (Sofia 2017, par. 47)*

> *"Is 100% more dangerous continuing plowing the soil than use herbicides is, because if you continue to plough, it is going to be a desert." (Mateo 2017, par. 131)*

Additionally, the no-till technology helped with producing agriculture in areas that used to be too dry and thus created a huge expansion of soybean in Argentina (Santiago 2017, par. 35). This is possible due to the composed material in the soil, which works as a barrier for the water, thus, the water will not evaporate as quickly as it would from soil that is plowed (cf. Figure 24) (Mateo 2017, par. 40). In addition, no-tillage increased the profitability of GM soy due to the reduction of "man hours". Mateo (2017, par. 38) is five to six times faster using the no-till method than conventional plowing. He also uses 70% less machinery but needs to spray more herbicides as well as fertilizers with the no-till method. However, Mateo (2017, par. 40-44) stated that the increased entry of glyphosate in the soil is negligible compared with the improvement of the condition and soil quality using the no-till method.

Another disadvantage of the no-till method, besides agrochemical input in the soil, is the stubbles of GM soy monoculture that degrade quickly and do not incorporate many nutrients into the soil. Therefore, crop rotation is required to maintain a good soil quality. This was not the case with the GM soy production up to 2016 (Thiago 2017, par. 85, 92; Valentino 2017, par. 79-85).

> *"No-till technology was like a very big thing that changed the system here. But because of the economic situation, rotation was not the best to do, so this tool and this technique of no-till was badly use, was badly used. That is why the environment suffered." (Thiago 2017, par. 127)*

To summarize, as stated in Chapter 6.1.1, the combination of GMOs and the no-till method was a main driver of land use change. These two drivers of land use change are contained in the "technological package", which is also according to the literature the key driver of the GM soy expansion in Argentina (Delvenne et al. 2013, p. 157; Leguizamón 2016, p. 4; Tomei and Upham 2009, p. 3891). Interestingly, neither agrochemicals nor specialized machinery (both part of the "technological package") were mentioned among experts as drivers of land use change.

6.1.3 Importance of Soil Quality

The quality of soil, according to many experts, is a determining driver of the land use change in the *Pampa Húmeda*. However, soil quality is not a driver but rather a local factor affecting agricultural decisions on a local scale (Hazell and Wood 2008, p. 501; van Vliet et al. 2015, p. 31).

GM soy introduction in combination with no-tillage farming made soy the most profitable crop. Therefore, everyone was interested in producing soy. At the beginning of the GM soy adaptation, *pools de siembra* [sowing pools] boomed (Thiago 2017, par. 241).

> *"Pools de siembra is like a group of people that make an investment, right, they hire an agronomist like me, and they hire fields, and they rent the land, they don't own the land but they rent land that is available to be rented. And then they say to me: I have this area, make me profit!" (Thiago 2017, par. 231)*

The increased interest in GM soy production is indicated in the maps (cf. Chapter 5.1). The core area of GM soy production is west of Rosario (cf. Chapter 5.1, Figure 15 and Figure 16). These lands represent the most fertile soils in Argentina and have been used for production for a long time (Victoria 2017, par. 4, and field diary 24th of March 2017).

> *"It's the most fertile soils, most productive lands in terms of good management and technologies inputs you can get crops that are records, out of your mind. Tons you can get from hectares." (Santiago 2017, par. 35)*

Land use change mainly occurred at the cost of losing semi natural areas for agricultural purposes (cf. statistics in Figure 13 and the maps in Figure 15 and Figure 16). Until the mid - 990s, the Pampas was a mixture of agriculture and cattle production. Santiago (2017, par. 35) emphasized that Argentina had great natural pastures and semi natural pastures used for the famous Argentine beef. However, with the arrival of the GMOs and the no-tillage system, the expansion of soybean production flourished due to better soil quality, facilitated production systems and low investments for production. This explains why the cattle moved out of the *Pampa Húmeda* to the marginal areas or to the Chaco (Thiago 2017, par. 203).

> *"So the factor that decides whether you do agriculture or cattle is the quality of the soil! If the soil is good to do agriculture, agriculture will be there!"*
> *(Valentino 2017, par. 204)*

> *"The best soil is [used] in agriculture, always!" (Mateo 2017, par. 66)*

In conclusion, soil quality, according to the experts, is a driver that favored land use change in Argentina. The statement that agriculture always uses the best soils implicates that cattle raising and other crops had to give way, with GM soy becoming more and more profitable (cf. Chapter 6.1.4), resulting in extensive land use change.

6.1.4 Profitability of GM Soy Production

Prices, taxes and revenues are important economic drivers of agricultural land use change, operating on a global scale, and are well applied in the context of GM soy adaptation (Hazell and Wood 2008, p. 501; Norton et al. 2013, p. 5). However, the financial incentives for soybean production in Argentina are complex and highly linked to politics. Figure 25 aims to illustrate this complex relation, which is explained in the following section.

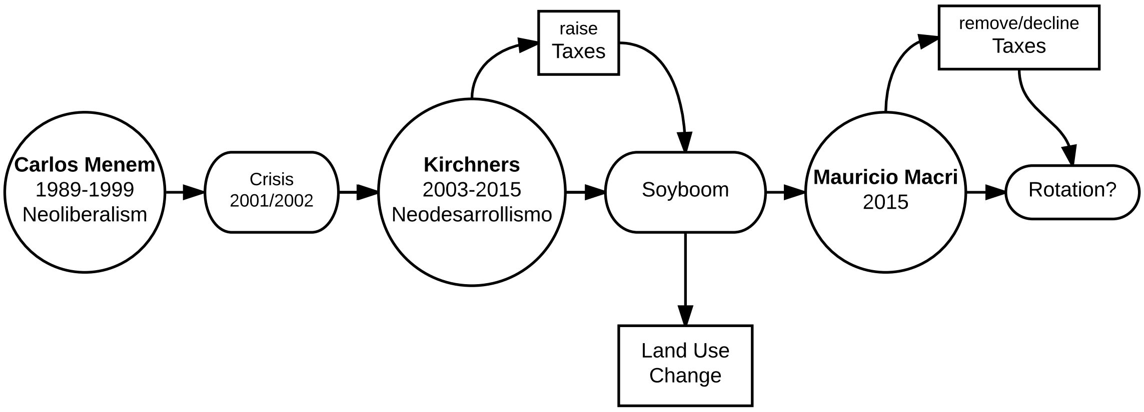

Figure 25: Land use change in the context of Argentina's political and economical development. (Illustration based on expert interviews and Goddard 2006; Grugel and Riggirozzi 2007; Leguizamón 2014; Wylde 2011).

The neoliberal government of President Carlos Menem followed the financial and economic crisis of 2001 and 2002, leaving the country in devastating debt (Craviotti 2016, p. 80; Wylde 2011, p. 437). The post-crisis administration of Néstor Kirchner took office in 2003, followed by his wife, Cristina Fernández de Kirchner, in 2007 (Wylde 2011, p. 436). This type of government, called *neodesarrollismo* [new development government], was

> *"... still a capital system but more socially oriented and with more presence of the state. It worked great for some time until things started to get really bad. I like some things that that government did, and I dislike other. But they put a lot of money in science, (...) to the state institutions, (give us) the power to do things."*
> *(Santiago 2017, par. 35)*

According to Leguizamón (2014, p. 155), the model is rooted in "strong government intervention, based on the principle that it is the government's role to promote economic growth and redistribute wealth to reduce poverty and promote social inclusion." Social inclusion has been accomplished via redistribution, whereas agricultural profits were absorbed to fund social programs, subsidies to basic services (especially electricity and transportation) or expansion of public employment. Over both Kirchner administrations employment grew by 65% (Berndt et al. 2017, p. 7-8). The key feature of this success was the strong taxation of the export commodity soy (Berndt et al. 2017, p. 7, 13). In contrast to Santiago (2017, par. 35), other interviewees expressed a more critical opinion of the Kirchners' administration politics.

> *"The worst problem we have, you know, that we have 12 years ago, a government that don't like the farmers, it was against us, we have the very high taxes."*
> *(Mateo 2017, par. 47)*

> *"More or less 10 years ago, with the other government [Kirchners'] we began to have a lot of problems, with inadequate policies, you know, so we realized we have strong conflicts during 2008*[13] *and I don't know if anybody told you about that problem with the government?" (Sofia 2017, par. 10)*

Under the Kirchners' administration, taxes were raised on the export of crops in order to diminish government debt (Leguizamón 2014, p. 155-156). According to Mateo (2017, par. 49), taxes for exporting soy were 25-35%. He emphasized that farmers were 20-25% more pressed compared with the rest of the economy. However, in 2003, export taxes represented 11% of the total government revenues, whereas in 2011, they were 61% (Leguizamón 2014, p. 156). This enabled the return of a state intervention model with social spending or investing in infrastructure, which resulted in the government's heavily promoting the expansion of GM soy production (Berndt et al. 2017, p. 7ff; Leguizamón 2014, p. 156).

Therefore, since 1996, already rapidly increasing GM soy production experienced a boom in terms of production and export with the political strategy of Néstor Kirchner (Leguizamón 2014, p. 155). Interestingly, despite high taxes for soy exports, soy was still the main agricultural good produced.

> *"The taxes on the soybean were very high, was the highest of all the crops, but even though in that case they were more profitable than other staples."*
> *(Emanuel 2017, par. 64)*

This was because, on the one hand, exports generated high revenues because the international price paid abroad was high (Emanuel 2017, 58; Valentino 2017, par. 63). On the other hand, as already outlined, the investment in soybean production was very low, whereas the price per ton of soybean was 600 US dollars (Santiago 2017, par. 37). Meanwhile, the investment to sow other crops, such as corn, was very high, in addition to the high taxes for exports

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[13] Sofia refers to the conflict between government and soy producers in March 2008, where Cristina Fernández de Kirchner announced a tax raise of soy export. Producers already felt disadvantaged with the existing soy export tax of 30% and demonstrated backed with a significant share of rural and urban population, following three-month strike (*el conflict del campo*). In June 2008, the government's grain exports tax was rejected by the Argentine Senate (Leguizamón 2014, p. 157).

(Valentino 2017, par. 65). The high profit gained from GM soy production triggered the extensive land use change in Argentina. However, the immense profitability of GM soy production further attracted investors (*pools de siembra*). According to Mateo (2017, par. 78), 60-80% of the cultivated area of *Pampa Húmeda* is cultivated under renting. The main interest of these investors is profit and not the condition or degradation of the soil. Therefore, soybean is grown year after year, yielding high revenues but degrading the soil.

In December 2015, Mauricio Macri took office as the new president of Argentina. His election led to big changes in the agricultural sector (Emanuel 2017, par. 73).

> *"Mauricio Macri, he complete withdrawn the taxes for corn and wheat. So know people investing in those because it is profitable, before they weren't doing the rotations because it wasn't profitable." (Thiago 2017, par. 107)*

> *"And now, Macri, the first thing he did, he is ok, I take all the taxes, but no soybean. So all the export taxes, we call 'redenciónes' (the redemption), export taxes are in zero, but soybean is in 30%, it's high!" (Mateo 2017, par. 79)*

Emanuel (2017, par. 87) summarized that before the Kirchners' administration, a heterogeneous distribution of produced goods in Argentina took place. During their tenure, soy was the main and dominant agricultural good, whereas since Macri has been president, all of Argentina has begun to cultivate corn and wheat again, competing with GM soy.

In the maps (cf. map statistics in Figure 13), a decline in soy production and an increase in corn production are already visible in 2015, even though Macri became president at the end of 2015. Therefore, the change in trend should first be recognizable in 2016. This (too early) change in trends was surprising to experts, who assured that soybean was still the most profitable crop in 2015 (Emanuel 2017, par. 58).

> *"I think this is the first time in our country that we have a government that recognize the agroindustry like first engine of the country and they are dedicated to give us the right policies in order to work in the right way." (Sofia 2017, par. 170)*

To conclude, land use change in Argentina was and still is heavily linked to political turns in government. It is expected that with the new government of Macri, a rotation in crop cultivation will intensify and consequently change the land use again. The rotation, however, is emphasized as bringing benefits not only in the short term but also in the long term in terms of revenues, the soil condition and environmental degradation (Sofia 2017, par. 169; Thiago 2017, par. 112). It will, for example, diminish a spread in crop diseases due to diversity in the neighborly fields. If one field is soy and the adjacent field corn, the disease of one crop will (most certainly) not be transferred to the other crop. This will result in a reduction of the need for spraying pesticides (Victoria, field diary 25th of March 2017).

6.2 Reflection on Land Use Change Drivers

Most striking were the different opinions of the experts. With the ongoing analysis, two different sides emerged amongst the interviewees. One tendency favored the opportunities that GM soy production enabled. Land use change was neither seen as a pressing nor feared phenomenon occurring alongside GM soy production. The other part of the interviewees feared land use change, and GM soy production was blamed for the comprehensive and devastating change affecting not only Argentina but also the entire world.

Argumentations for praising GM soy production are the possible sustainable production with the no-till method and the possibility of producing sufficient food to meet the global demand. In opposition to this, GMO critics emphasize that GM soy production is neither sustainable nor results in food products but rather yields food for livestock or biodiesel.

6.2.1 No-Till – A Sustainable Method?

The term "sustainable production" occurred several times during the interviews. At first, the use of this term in relation to GM soy and land use change was confusing. However, during the analysis, the meaning and interpretation became clearer.

The no-till method was associated in a positive way with the term "sustainability" among some interviewees (Emanuel 2017, par. 130; Mateo 2017, par. 133; Sofia 2017, par. 18, 20).

> *"The way you crop, years ago, maybe in 1984, 1986, 1990 we ploughed and we turn over the soil, you know, and in the 1991, 1992, 1993 we had a great change in our culture, it was amazing! Argentina was the first to change so quickly to pass from plowing to no-till, that we brought from the United States, and it was amazing because in ten years the agriculture changed a lot! So without the no-till all this area (depicting the center of the maps, the core area of GM soy production, west of Rosario) it's very degraded and with no-till we are changing and we are going to leave*

> *better soils to our sons then we received from our parents."*
> *(Mateo 2017, par. 24-26)*

> *"When the GMO appeared the spread [of GM soy production] was incredible. Because GMO and glyphosate are very nice tools for us for an ecologic production."*
> *(Sofia 2017, par. 62)*

Sofia (2017, par. 62-64) further emphasized that the innovation of the new technologies (GMOs, no-till method and agrochemicals) improved the use of the soils, implicating an increase in production due to more productive soils. The ecological production refers to the ability of the no-till method to emulate nature, despite the usage of agrochemicals.

> *"So that's the great thing, it (the no-till technology) allows you to product and take care of the environment at the same time." (Sofia 2017, par. 47)*

The term "sustainability", as used by the interviewees, refers to the ability to produce enough food. According to their points of view, the question of whether the food or agricultural production is sustainable is a question regarding the ability of the soil to produce sufficient food for everyone. Therefore, as soon as the soil quality allows for an adequate production of food, the agricultural production is seen as sustainable. Mateo (2017, par. 133) and Sofia (2017, par. 223) criticized the Kirchners' administration for promoting unsustainable agricultural development. Their interest in producing more and more soy to fund their "National and Popular" model (Leguizamón 2014, p. 155) caused an ongoing degradation of the soil (cf. Chapter 6.1.2). This resulted, according to Sofia (2017, par. 223), in the inability to produce enough due to the decreasing quality of soil, with the government of Macri being the hope to change this.

> *"We know that we developed a revolution in agriculture, in the way of achieve sustainability (…) but we had the wrong policies. So, we lost sustainability. This is the first government that we share the vision with farmers and with private sector and we totally agree to work together and farmers recognize that we made mistakes because of having the wrong policies in order to survive, you know, and to reach an economic result, so it's not a problem to convince farmers to work in the right way. No it's only to give them the right policies, the adequate policies. So that's what we are working in sustainability." (Sofia 2017, par. 223)*

However, the World Commission on Environment and Development (WCED) defined sustainable development as a pressing matter of society to "… balance the desire to maximize the benefits of economic and industrial growth with a need to maintain the quality of, and services from, natural resources and ecosystems" (Aoyama et al. 2011, p. 217). In other words, sustainability is achieved if the interlinked aspects of the economy, environment and social well-being are simultaneously addressed (Johnston et al. 2007, p. 1). This more comprising definition of the concept of sustainability supports the opinion of critics of GM soy production. They doubt that the no-till method associated with GM soy production is sustainable in any way. It is stated that the sustainability of no-till technology is used as an excuse for the further increase of GM soy production (Valentino 2017, par. 127; Victoria, field diary 24th of March 2017). Additionally, the consequences of GM soy spread, like deforestation in the Chaco region and the land use change, are by no means sustainable (Fernando 2017, par. 124).

In conclusion, using the concept of "sustainability" is correct if referring to the GM soy production in Argentina because it promotes economic growth (Phelinas and Choumert 2017, p. 2). However, neither social nor environmental (cf. Chapter 6.2.2) well-being is taken care of in terms of extensive GM soy production despite using no-till technology.

6.2.2 Argentinean GM Soy – Feed the World?

Resuming the concept of "sustainability", the argument was made that GMOs, glyphosate and no-till technology ensure food sovereignty. The fact that the introduction of this "technological package" in Argentina drastically increased soy yields is, besides in a lot of the literature (amongst others, Delvenne et al. 2013; Leguizamón 2014; Tomei and Upham 2009), depicted in Figure 13, Figure 19 and Figure 20. This rise in production is seen as a successful model for feeding the world.

> *"Sustainable agriculture production system, it's a very nice tool, not only for Argentinean people but also all around the world, for food security and climate change."*
> *Sofia (2017, par. 20)*

The secret lies within the no-till production as stated by Mateo (2017, par. 41). He pointed out that in the 1980s, around 35 million tons of soy were produced, and this amount grew to 130 million tons by today. His logical conclusion is that no-till technology in association with agrochemicals and GMOs is the solution to world hunger. Furthermore, he assured that GM soy produced in Argentina is eaten all around the world (Mateo 2017, par. 153).

The worldwide critic on glyphosate is unintelligible to Sofia (2017, par. 237). She rejected this criticism and emphasized that only privileged people make this kind of criticism.

> *"They (the privileged) have a lot of resources, but we have most of the human population on our planet and they can't decide, and they are hungry, and they live under poverty and we have to help them! We think that we have a very strong tool ("technological package") to begin working and it is a very very very necessary tool for Africa for Asia, you know?" (Sofia 2017, par. 237)*

These statements are neither congruent with the literature nor with other experts. Argentina produced more than 10% of the world's biodiesel by 2008, and in 2012, 40% of the national cultivated soy was used for biodiesel production (Leguizamón 2014, p. 157; Milazzo et al. 2013, p. 825; Tomei and Upham 2009, p. 3893; WWF 2014, p. 15). However, more pressing is the great amount of soybean produced in Argentina to feed livestock. In 2014, around three-quarters of soy produced worldwide was used as animal feed (WWF 2014, p. 14). Even though increasing soy production is needed to meet the pressing demand for meat, using soy to feed livestock is not a solution to world hunger. For example, the production of one kilogram of beef requires 173 grams of soy, one kilogram of pork requires 236 grams and one kilogram of chicken requires 575 grams of soy (WWF 2014, p. 15). A vast amount of food is therefore wasted if human beings consume meat instead of soy itself (Suchanek 2013, p. 94). In conclusion, the soybean produced in Argentina is not used to feed human beings around the world and is not a tool for fighting world hunger. Therefore, GM soy production is not socially sustainable (Phelinas and Choumert 2017, p. 5).

Additionally, Victoria emphasized that Argentina lost its food sovereignty.

> *"Because we pass from cultivating crops that we used to feed the people, mainly corn for oil and flour, or cattle for meat, to cultivating a staple crop that we export. Currently, it is less important what we eat than making the most of what we can sell abroad. The problem is that the money coming from those crops sold abroad goes only to a small part of the population." (Victoria 2017, par. 26)*

In 2011, only 5.4% of soy was destined for the local market, whereas the remaining 94.6% was exported (Leguizamón 2014, p. 152).

> *"We do not consume soy, we do not feed soy to the cattle, and we do not use it for biofuel." (Victoria 2017, par. 17)*

6.3 GM Soy – Feeding or Eating the World?

As GM soy produced in Argentina is not eaten locally or abroad but rather is sold to feed livestock and transformed into biodiesel, it is questionable whether GM soy is a successful model to be copied all around the world, or at all a solution to world hunger. With regard to land use change, the success of GM soy production is further diminished.

The land use change illustrated on the maps (cf. Chapter 5) did not surprise or shock the interviewees.

> *"On the other hand we have in this year (2000) many semi natural areas and there is a constant trend in decreasing natural areas, this is not surprising, and is nice to see it in the map because it is something all people say and all people know. (Juan 2017, par. 77)*

GMO critics have emphasized that land use change in the *Pampa Húmeda*, due to a transformation from cattle to crops, from traditional agriculture to intensified and lucrative GM soy production, is no longer their main concern anymore. This is because the *Pampa Húmeda* is beyond remedy in terms of environmental conservation. At least the possibility of rotation, since Macri's tax easing, enables a decrease in soil degradation (Victoria, field diary 26th of March 2017). Their current concern rather lies in the continuous deforestation of the Chaco region.

> *"Well it's insane now we have here in Argentina, also in Paraguay, the largest deforestation rates in the world. The Chaco, you have much more expansion of pastures for cattle production than soybeans. Soybeans now are getting secondary in the process of land use change, forest loss." (Santiago 2017, par. 45)*

With the focus in the *Pampa Húmeda* lying on crops, everyone has sold his or her cattle. This change of "the continuing and growing use of land for large-scale cultivation, in the detriment of the other main production alternative, cattle production" is called "agriculturization" (Urcola et al. 2015, p. 32). Cattle raising moved in a first step into the marginal areas of the Pampa Húmeda and in a second step north into the Gran Chaco area (Mateo 2017, par.

45). The Grand Chaco is a very fertile plain of approximately 100 million ha with a high level of biodiversity (WWF 2014, p. 51). With the again increasing interest in cattle and the still profitable GM soy production, the only outcome is a continuous deforestation rate in the Chaco. Deforestation is one reason why GM soy production is not environmentally sustainable (Phelinas and Choumert 2017, p. 4-5).

> *"Now we have serious problems in deforestation. In first instance, for soy, but now the main driver in deforestation in the region in the Chaco is for pasture for cattle."*
> *(Juan 2017, par. 77)*

> *"The only reason that Argentine land owners produce it is because it is economically worthy. They get dollar price for this crop. The rest of the people, we, that do not own lands, benefit only by the tax charged to the exports. Those taxes are supposed to be destined to infrastructure and development." (Victoria 2017, par. 24)*

This thesis concludes that GM soy cannot be a model of success: it does not feed the poor and hungry but rather feeds the ones in charge of GM soy regulation and production. Proponents use the merits of GMOs, the tool for fighting famine and malnourishment in developing countries, to justify GMO technology. This can be criticized in terms of the Malthusian perspective on agricultural change (cf. Chapter 2.2) despite the lack of evidence pointing to an "… inadequacy of current crop plants or even the likelihood of GM plants offering higher levels of production" (Stone 2001, p. 330).

Additionally, the consequences of the land use change (e.g., deforestation, examinable in an entirely different thesis) affect and marginalize the ones who do not profit from the GM soy production (Victoria 2017, par. 24, 26 and field diary 25th of March 2017).

6.4 Prospective Land Use Changes

The future of Argentina's agriculture can already be estimated in relation to the change in government in 2015.

> *"Everything is quite linked to politics." (Emanuel 2017, par. 171)*

Summarized by most experts, rotation in the cultivation cycles will be future actions in agriculture. Due to political and economical reasons, the percentage of wheat and corn will rise compared with soy (Emanuel 2017, par. 169). Additionally, it is expected that cattle raising will move back in to the *Pampa Húmeda* to further bring change to the cultivation cycles (Mateo 2017, par.123). However, the location of cattle raising will very much depend on the revenues of cattle. As long as soy production is that profitable, cattle will be grazing only in low quality soils (Emanuel 2017, par. 91).

However, alternative trends show growing interest in sustainable and organic food production. For example, consumers in Switzerland value and require GM-free soy. This is because, on the one hand, GM soy is allowed to be fed only to animals, and, on the other hand, Swiss consumers increasingly require sustainably grown agricultural products. Today, one-fifth of imported GM-free soy is produced in Europe, whereas five years ago, 100% of GM soy was imported from Latin America. Compared with the global scale, Switzerland's needs in 2016 for GM-free soy is equivalent to 0.1% (270,000 tons) of the global share, but this trend will presumably increase (Echo der Zeit 2017).

To resume sustainability as indicated in Chapters 6.2.1, 6.2.2, and 6.3, agriculture needs to equally value economic, ecologic and social well-being to be sustainable (Johnston et al. 2007, p. 60; Phelinas and Choumert 2017, p. 2). In summary, GM soy production in Argentina does not entirely fit this definition. The "technological package", containing GMOs; agrochemicals, such as glyphosate and fertilizers, the no-till method, and state-of-the-art machinery, allows Argentina to be economically sustainable in terms of growing tax revenues. These, again, were used for investing in infrastructure and social spending (Berndt et al. 2017, p. 7ff; Leguizamón 2014, p. 156; Mateo 2017, par. 113), emphasizing a social sustainability (Johnston et al. 2007, p. 62). However, with the current political tax withdrawals, these expenses are no longer possible (Victoria 2017, par. 24 and field diary 26th of March 2017). Hence, GM soy production is filling neither the pockets of the state nor the stomachs of the hungry. Therefore, GM soy production is not socially sustainable. Soy production, to that extent, is heavily criticized with regard to ecological sustainability (Juan 2017, par. 77; Phelinas and Choumert 2017, p. 4; Santiago 2017, par. 45). Especially, GM soy production (cf. Chapters 1 and 2.1) generates a wide range of environmental externalities and has devastating short- as well as long-term consequences on the environment (Delvenne et al. 2013, p. 154; Leguizamón 2016, p. 3; Phelinas and Choumert 2017, p. 3).

Even if the request for GM-free soy does not increase, it can be assumed that tendencies towards sustainable soy production will intensify. Hence, Argentina faces either the loss of its most profitable export good or has to change its way of soy production. Both outcomes will affect prospective land use change in the *Pampa Húmeda*.

However, not just requests concerning sustainability or GM-free soy could possibly lead to a future land use change in the *Pampa Húmeda*. Besides the "technological package", perfect conditions, such as excellent soil quality or a favorable climate, made the GM soy production to this extent possible (Phelinas and Choumert 2017, p. 8). Mateo (2017, par. 45) already realized an intensified change in climate affecting his lands.

> *"The climate change, on my farm, I see everything, every day. The storms are more aggressive, you have a very high dry season, drought, or you have a lot of rain, how you say, high water [flood]. You have much water and it is a mess!"*
>
> *(Mateo 2017, par. 45)*

Nevertheless, he does not fear the change of climate, he is confident that the no-till technology will withstand these changes. Furthermore, he emphasized that the quality of the soil is continuously increasing due to the no-till technology (Mateo 2017, par. 46, 123).

If the conditions of either the soil or climate (or both) change, Argentina will face an involuntary change in land use. This is due to the great dependence on the favorable local driver to produce soy, which would limit future production by far if climate or soil quality change. This might result in a restructuring of the agricultural sector.

7 Discussing Interdisciplinarity

This chapter contains a reflection on the methodology of the interdisciplinary approach (Chapter 7.1) as well as some suggestions for the improvement of the methods (Chapter 7.2) and is finalized with a critical reflection on the interdisciplinarity used for this thesis as well as on the subject geography as a whole (Chapter 7.3).

7.1 Reflection on Methodology

Being confronted with limitations and several problems during the process of the map creation and expert interview implementation, for the detection and explanation of land use change. They are outlined and discussed in the following Chapters (7.1.1 and 7.1.2).

7.1.1 Quantitative Method Limitations and Problems

Several limitations affected the process of map production as well as the success of the final product. Beginning with the harmonic fitting, uncertainty was implemented in the first step of the classification due to the interpolation of the phenology based curves on some NDVI values. Furthermore, the summarizing of the interpolated phenology curve led to 12 values (one for the first day of each month) and therefore to additional uncertainty in the following steps. The final classification based on these 12 points in GEE was therefore just an approximation of the reality.

The distinction between soy and corn is very difficult because both are summer crops that blossom in February and are harvested around April (cf. Chapter 4.2.5). The curves illustrating phenology were manipulated, based on their growth behaviors, to show a steeper curve (meaning higher NDVI values) in December for the faster growing soy compared with the slowly growing corn (Abendroth et al. 2011; Wright and Lenssen 2013, p. 2). This led to additional uncertainty in class distinction in the final maps. Sofia (2017, par. 125-127) criticized the wide distribution of corn in 2015 (cf. Appendix A) and supported this uncertainty. According to her, soy monocropping should be dominant.

For the validation and correction of the maps, the collected data from March 2017 should be checked with data on GEE in 2017. Unfortunately, no USGS Landsat 7 surface reflectance data have been available on GEE since 1st of May 2017 (see Figure 26). GEE stopped producing old-style (pre-collection) scenes (cf. Google Earth Engine Team 2015: https://developers.google.com/earth-engine/landsat, accessed 10th of July 2017). The first idea to correct this error by merging Landsat 8 surface reflectance data with the initial USGS Landsat 5 and 7 surface reflectance data is not possible, also due to a lack of available data after 1st of November 2015 (cf. Google Earth Engine Team 2015: https://explorer.earthengine.google.com/#detail/LANDSAT%2FLC8_SR, accessed 10th of July 2017).

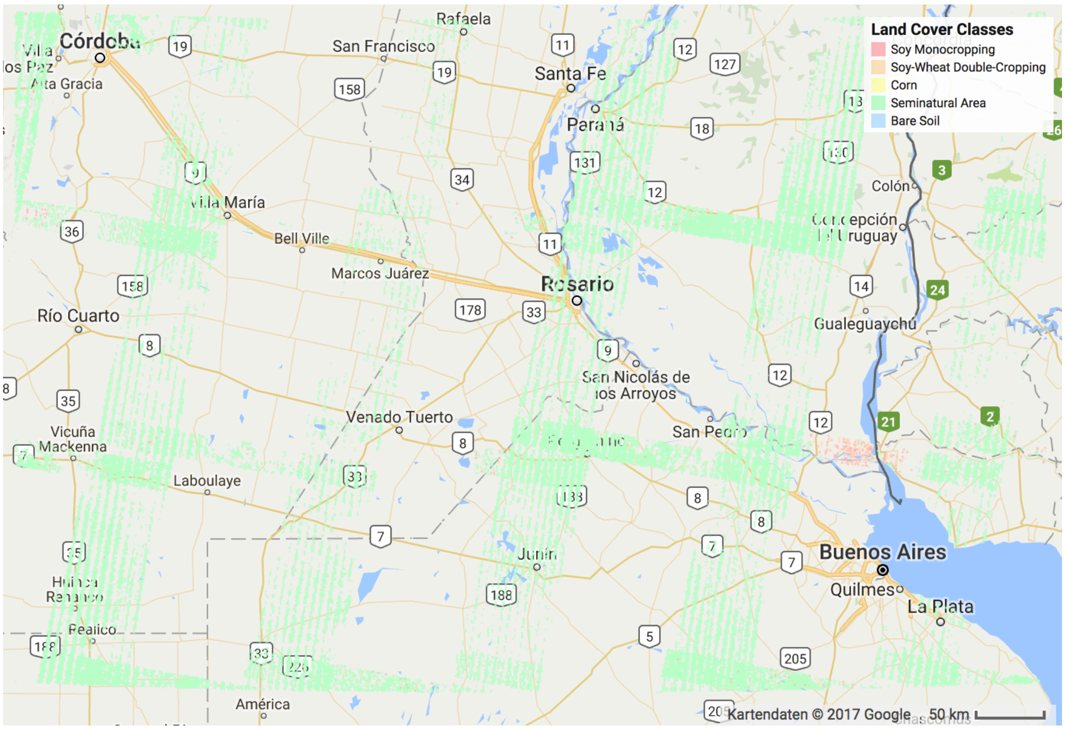

Figure 26: Classification error in 2017
resulting from missing Landsat 7 surface reflectance data.

To solve the problem of missing data, GEE developers suggest using top-of-atmosphere (TOA) reflectance from Landsat 8. After trying and checking the data with the GEE Explorer Workspace (cf. Figure 27), it turned out that the data are unusable due to heavy cloud cover in the time period of the GPS point collection in March 2017. Later, it was clear that not even after cloud cover editing would a TOA Landsat 8 dataset be available (cf. Google Earth Engine Team 2015: https://explorer.earthengine.google.com/#detail/LANDSAT%2FLC8_L1T_TOA, accessed 15th of June 2017).

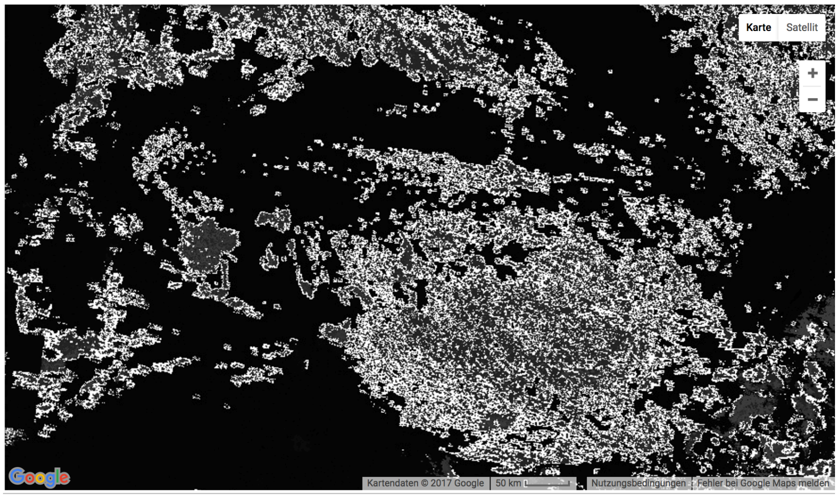

Figure 27: Average cloud cover over the ROI in March 2017
shown in the GEE explorer workspace.

To use the collected data anyhow, the maps of 2016 were used for the validation of the data collected in March 2017. The formation of errors was assumed to be minor because the kinds of crops detected in March 2017 were sown in the last trimester of 2016 and were therefore already detectable in the 2016 phenology of the crops, but still, uncertainty was incorporated.

A similar problem occurred with the INTA data. Although the training sites were collected in 2009, the map used for the validation was the one from 2010, as the 2009 GEE map (cf. Figure 28) had too many errors, such as missing data or the wrong allocation of classes.

Finally, the success of the linear spectral unmixing approach relies on an appropriate selection of endmembers. Having only five land cover classes could lead to an insufficient contrast between the endmembers, resulting in noisy and inaccurate fraction images. Therefore, the five endmembers could fail to correctly model the pixel reflectance, resulting in the failure to correctly assign the pixels (Lobell and Asner 2004, p. 415).

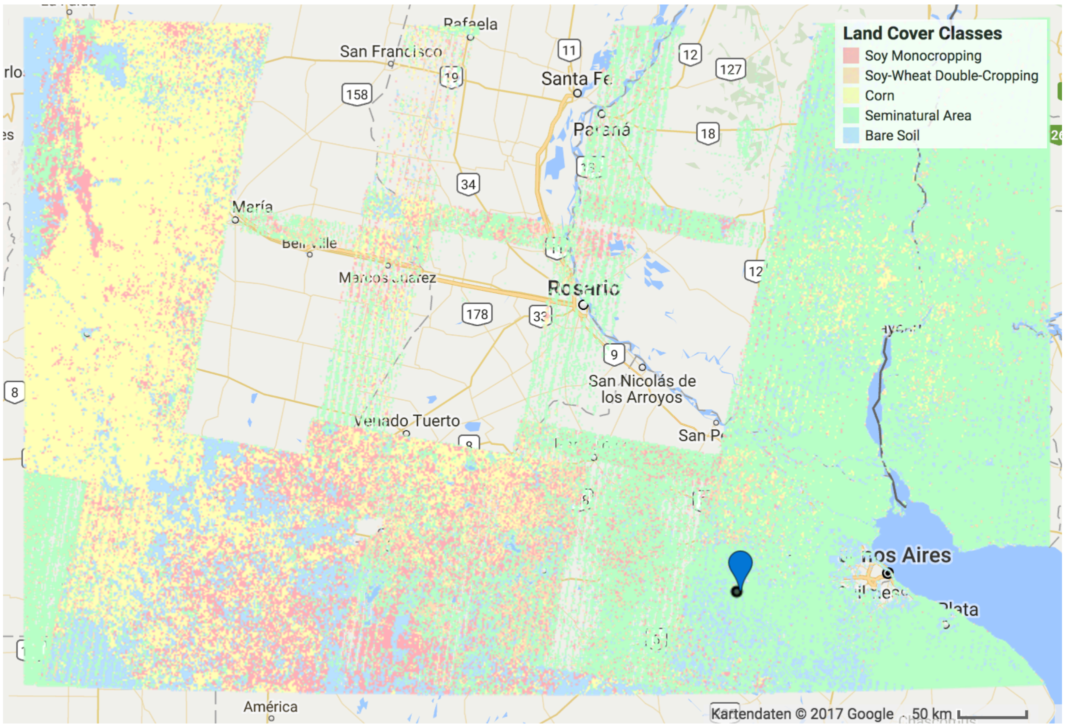

Figure 28: GEE errors for the land use classification of 2009.

7.1.2 Qualitative Method Limitations and Problems

Most difficulties in the qualitative method approach occurred while conducting the expert interview. For example, English, being neither the interviewer nor the interviewee's native language, caused many difficulties during the conversation. It can be expected that a lot of information was lost in translation. It also often occurred that an expert did not know a certain word in English and when failing to describe something just went on with the conversation. To eliminate these problems, Kruse (2015, p. 321) determined that the interview language should be the one of the interviewee. However, this was not possible due to the lack of Spanish skills of the interviewer. Besides the difficulties occurring in language variation, the differences in the cultural context of communication should not be underestimated (Kruse 2015, p. 319). The basic rules of communication are (mostly) different in different languages, are not common to everyone and lead to a lack of understanding or misunderstanding (Kruse 2015, p. 324). However, Kruse (2015, p. 323) emphasizes that statements from an interviewee could be more detailed and better explained in a foreign language because the expert has to really think about what to say. Therefore, statements could be even more ingenious and better explained than in the expert's native language.

Differences in the cultural context were also experienced in the arrangement of the interviews. While having a clear idea of the timetable of the stay in Argentina, experts were available only on very short notice; some cancelled at the last minute, and one did not show up. Additionally, the new environment was more difficult to get used to than assumed. This resulted in the time-consuming planning of single steps, such as the organization of transportation or the arrangement of accommodations.

Another experience conducted with the interviewees was the question of being taken seriously as a researcher. Often confronted with being a foreigner, young and female rather resulted in a more friendly relation than a professional one. The majority of the experts expressed their concerns about the researcher's not speaking the local language and being a young blonde female from Switzerland. As a result, they had the strong urge to provide help and to accompany the researcher at all times, which led, on the one hand, to unauthentic situations, and, on the other hand, enabled more insight into the expert's personal environment and facilitated getting in contact with further experts. The resulting difficulty for the researcher was finding a balance between being a professional and a friendly colleague to the expert.

The difficulties occurring due to language uncertainties extended to the transcription and further analysis. While transcribing, tendencies to correct the grammar or the English occurred, such as defining the not finished or mumbled sentences of Sofia and replacing the many "this", "that" and "there" that she used instead of defining the meanings of the words. This is neither required nor is it the correct way of obtaining a complete transcription (Kruse 2015, p. 353). In addition, the transcription of English interviews was more time consuming than expected. Kruse (2015, p. 354) expected the transcription of a one-hour interview to take about eight to ten hours, whereas it took 12 hours instead. In the end, it was questioned whether such a comprehensive transcription of the interviews was necessary for the kind of analysis needed for this research. However, the transcription should never be trusted completely and unquestioned, as it is not an objective data source, but rather is prone to failure and the subjective reconstruction of complex linguistic communication (Kruse 2015, p. 355). Each transcription itself is a secondary material and is therefore already a construction rather than an objective reproduction of the verbal primary material (Kruse 2015, p. 354). Writing down intonations or pauses is already an interpretation, and a reason not to transcribe the entire interview. Additionally, no transcription is able to entirely reproduce the prosodic, melodic and paraverbal characteristics of the human language. Transcriptions are rather constructions than written images of verbal data (Hammersley 2010, p. 555; Kruse 2015, p. 355).

In conclusion, the empirical data materials are samples and are regarded critically to be representative of a generality. Therefore, generalizations were used carefully in the analysis (Kuckartz 2016, p. 23).

7.2 Suggestions for Improvement

Having stated many limitations in the last Chapter (7.1), some suggestions for improvement are listed as follows.

For the quantitative method approach, more time should have been allocated to get used to the new program GEE. Problems, mostly occurring during the validation of the maps, could have probably been eliminated or at least minimized had a broader understanding of the program and the programing language (JavaScript and Python) existed. The validation process and map improvement would have also been facilitated if the data from the available test sites, which were compared with the map, had come from the same year. This step of improvement would also have required more time prior to the visit to Argentina. Checking in advance whether data on GEE for 2017 was available (and realizing they were not) would have generated time available in Argentina to acquire different validation data instead of sampling test sites in 2017 that were not entirely useful for the validation and correction of the map. The check in advance was done because a change of focus on the expert interviews happened as soon as the maps were finished. However, the validation and map correction could have also resulted in a better result than an overall accuracy of 52%, had more test sites been included in the correction process. Again, this was not done due to time limitations.

As for the qualitative approach, the quality of the statement of the analysis is dependent on the representativity of the experts (Kruse 2015, p. 242). If more experts would have been available, the result might have either strengthened or diversified. More diverse experts would not only have been beneficial but also very interesting. For example, an expert from the GM soybean producing company Don Mario intended to come to a meeting but cancelled at the last minute.

7.3 Interdisciplinary Reflection

Geography, as described by Kotlyakov and Komarova (2006, p. vii), is a multidisciplinary science and is one of the oldest sciences in the world, similar to mathematics, philosophy or history. Early attempts to discover and describe “new” lands have led to finding and explaining differences and similarities between geographical phenomena, and they later developed into a number of disciplines[14], such as human and physical geography and subdivisions, such as social geography or soil science (Gebhardt et al. 2011, p. x; Kotlyakov and Komarova 2006, p. ix). All of them always keep in mind the main idea of geography, "the studying [of] phenomena which make up the Earth's physical environment together with people and human economic activities, their spatial distribution, relationships and change over time" (Kotlyakov and Komarova 2006, p. 289). The ongoing process of specialization in sciences is both unstoppable as well as necessary. The growing isolation of individual disciplines and sub-disciplines, especially in geography, is critical and counterproductive for society as a whole (Frey et al. 1996, p. 159). However, current geographic disciplines, despite being very different, share common tools of investigation, such as maps, geographic information systems, a comparative method of exploration and remote sensing (Kotlyakov and Komarova 2006, p. ix).

Geography has a broad overview of the world but struggles exactly with this kind of wide-ranging knowledge and the accusation of not being very precise, revealing only "the tip of the iceberg". Hence, the specialization into different disciplines within geography should eliminate the problem of universality but loses simultaneously its special, holistic understanding of the world, which is also the major strength of geography (Gebhardt et al. 2011, p. 79; Kotlyakov and Komarova 2006, p. ix).

This thesis research was based on an interdisciplinary approach, which diminished the issue of focusing on only one perspective while examining a problem. According to Defila and Di Guilio (2007, p. 26) interdisciplinarity indicates the integration-oriented collaboration of people from at least two different disciplines, with regard to a common goal, while they assemble disciplinary perceptions into one synthesis. For this thesis, two researchers from different disciplines did not collaborated; rather, the concepts of two geographic disciplines were integrated to examine the research questions. However, the aim of interdisciplinarity involves "… occupying the spaces between disciplines …" (Petts et al. 2008, p. 596) and "… seeking coherence between different forms of knowledge produced by different disciplines" (Ramadier 2004, p. 425). This results in a synthesis, whereas its final objective is a single form of knowledge (Ramadier 2004, p. 425; Petts et al. 2008, p. 596).

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[14] A discipline is construct that is born out of historical processes. It involves objects and methods of a study which provide "the frame of reference, methodological approaches, topics of study, theoretical canons and technologies." (Petts et al. 2008, p. 596)

The geographic discipline economic geography is “the study of the spatial distribution and territorial organization of economy which includes the use of resources, industrial and agricultural production, consumption of goods and services, transport and other types of infrastructure” (Kotlyakov and Komarova 2006, p. 217) and was the basis for the qualitative approach of this thesis research. The quantitative approach, on the other hand, was based on the geographic discipline of remote sensing, where “the process of getting information of the Earth’s surface and other celestial bodies and objects situated on the from the distance, by non-contact methods [like] artificial satellites, planes, etc. …” (Kotlyakov and Komarova 2006, p. 601) are in focus.

The aim of qualitative research is the understanding of a phenomenon from within. The view of a subject, the course of social processes or the rules applying to a certain situation need to be understood and explained (Flick 2006, p. 46). On the contrary, quantitative research permits an exact quantification of the results, enlightens statistical correlations and enables greater objectivity and comparability of results (Flick 2006, p. 380f).

The combination of economic geography and remote sensing resulted, one the on hand, in many advantages for this thesis, but on the other hand, some unpredicted difficulties appeared during the research process.

Examining the research question with these two perspectives was very beneficial. The experts appreciated the maps generated with remote sensing data, which encouraged the detailed description of land use change processes, political statements and personal stories. Vice versa, the expert interviews facilitated a broader understanding of the land use change processes illustrated on the maps. The understandings of land use change are a territorial organization concept of economic geography. Additionally, the map statistics were a useful tool for quantifying the qualitative analysis of land use change. Combined, both approaches were useful tools for facilitating the understanding of the complexity of the large-scale issue of land use change.

The personal gain experienced by combining different research approaches was both, a very interesting research and an opportunity to acquire a broad overview of two different research disciplines. The dilemma of geographers, to choose a specialization was diminished, because of this combination of the favored disciplines. The combination also allowed a more objective and probably more accurate result what benefits this thesis. Additionally, the experience in the field was educational, diverse and a lot of fun. However, despite this benefits, a limiting factor was time. During the thesis procedure, an ongoing realization occurred that each step was way more time consuming than expected because the focus had to be split between two different approaches. The initial idea of the interdisciplinarity of two specialized researchers working together on one subject was here replaced with one researcher integrating two disciplines to answer the research question (Defila and Di Guilio 2007, p. 27). To gather a specialized knowledge, a lot of time was necessary. This resulted in cutbacks in various steps and not satisfying extent of the single approaches. Moreover, a constant consideration of not fulfilling everyone's expectations as well as being clear enough, so both experts from the disciplines comprehend the single steps, accompanied the master thesis process. Additionally, the procedure of an interdisciplinary research requires adequate organization of the project (Petts et al. 2008, p. 599), particularly due to the 'cultural differences' of the disciplines what required an adequate idea of the structure of the master thesis. However, these challenges enabled further personal output in adequately acquiring organization skills and balancing the challenge of time restrictions. Therefore, the main suggestion for improvement would either be a more extended timeframe or a stronger, more limited framework for the extent of the research.

However, the combination of economic geography and remote sensing in general can be seen as a huge advantage in research. This so-called "interface research" proved to be of great importance for emerging problems of any kind of environmental issues. Interdisciplinarity enables a more holistic perception with a high problem-solving competence. The benefit lies within the "common center" of "the interface of human and nature" (Gebhardt et al. 2011, p. 1086). Interdisciplinary studies such as this one are required to deal with prospective problems in agriculture, such as ongoing population growth, people who favor more diverse, sustainable and high-value (food) products or the climate change induced inability to produce food at all (Gendron and Audet 2012, p. 33f). The ability to collect information repeatedly over remote or dangerous regions and even the entire globe without gaining direct access is one of remote sensing's major advantages (Sheng 2011, p. 171). This multi-temporal monitoring quality of remote sensing is especially beneficial for capturing issues (such as the extent and growth of agricultural fields) examined in economic geography in a quantitative way. Remote sensing in general is a widely used tool in interdisciplinary studies since its first appearance in the 1960s (Sheng 2011, p. 172). On the other hand economic geography concepts and methods (either qualitative or quantitative) can be very useful in explaining processes or phenomena captured via remote sensing methods (Aoyama et al. 2011, p. 217f).

As for the discipline geography, Frey et al. (1996, p.159) emphasized the importance of a case-by-case (ad hoc) conceptualized "internal-disciplinary" cooperation while acknowledging significant theoretical as well as methodological approaches. "Internal-disciplinary interdisciplinarity" is seen as the connecting link in future geography (Frey et al. 1996, p. 167).

Furthermore, Wardenga (2005, p.7) indicated that the survival of geography in general is possible only if the subject can manage a transition into integrative environmental science with a focus on special human and nature interactions.

In conclusion, it can be said that even though the extent of an interdisciplinary research is comprehensive, its benefits are promising as well as encouraging. And that an initial impression of scratching only the surface of both disciplines eventually can lead to tackling new and unexplored research question.

8 Conclusion and Outlook

Land use change maps illustrated 20 years of constant expansion and intensification in agricultural soy production, and expert interviews summarized the mindset regarding past, current and future soy production development. However, on whether GM soy is feeding or eating the world, current opinions diverge.

On the one hand, GM soy production is praised as the solution to famine and malnutrition. Land use change, occurring alongside the increase in GM soy production, and the consequences resulting from the change, are mitigated or even seen as a necessity for further opportunities to produce soy. On the other hand, even though appreciated as a tool for getting out of the crisis, increasing GM soy production is considered critically. The opportunity to use the Argentinean GM soy to feed the world is denied, and it is critically stated that its main purpose is to feed livestock all around the world instead (Leguizamón 2014, p. 157). The land use change promoted by this constant increase of soy production and the shift of cattle raising to the north is feared, and future change intensifies uncertainties about the consequences. The change from tropical rainforests, forests, grasslands and pastures to agriculture bares unpredictable consequences.

However, land use change, the main focus of this thesis, is unmistakably linked to the GM soy introduction in 1996 (Chapter 6.1.1), which was possible due to political regulations (cf. driver in Chapter 6.1.4) in Argentina. The adaptation of GM soy occurred smoothly due to the "technological package" (cf. driver in Chapter 6.1.2). A traditional way of farming, involving rotation of the cultivation cycles and cattle raising, was replaced with an extensive GM soy monoculture. This was followed by intensification, where soy-wheat (or any winter crop) double-cropping increased. Simultaneously, semi natural areas in the *Pampa Húmeda* dodged agricultural areas (Zelaya et al. 2016, p. 95). Although the quality of the soil is not a driver of GM soy introduction, it is very much a driver of extensive land use change. Even though experts agreed on the same drivers of land use change, the evaluation varied. GM soy proponents emphasized that the drivers made land use change possible and therefore the intensification and expansion of the GM soy production. Meanwhile, opponents emphasized that the land use change drivers facilitated GM soy production, resulting in devastating large-scale land use change. Broadly speaking, proponents of the GM soy production welcome the advantages of land use change, whereas opponents fear and emphasize the disadvantages.

Nevertheless, after 20 years of constant intensification and expansion in agricultural soy production, Argentina faces a current phase of change. On the one hand, a change in government reduced the profitability of GM soy production compared to corn and wheat, resulting in more rotation of crop cycles and therefore more heterogeneity amongst the fields. On the other hand, agricultural changes were and are very much linked to political changes. Therefore, future changes in agriculture are very much assumed, but how these changes will affect the land use change is uncertain. Additionally, current tendencies of mindset, such as the growing interest and importance of sustainable production in agriculture, could affect the way of production in Argentina, which further affects land use and creates changes on a large scale.

However, these are estimations and require further research. For example, how will the politics of the current government affect land use change? What if interest in sustainable production, such as that in Switzerland, increases? How will Argentina’s GM soy production adapt to be economically, ecologically and socially sustainable, and how will this affect prospective land use change?

In conclusion, the promise that GM soy is a means to feed the hungry has turned out to be wrong. Instead, GM soy production and resulting land use change has tremendous consequences. This leaves the suspicion that GM soy production diminishes – or “eats” – the possibility of feeding the world at devastating rates.

Literature

Abendroth, L. J., Elmore, R. W., Boyer, M. J., and Marlay, S. K. (2011): *Corn growth and development*, PMR 1009, Iowa State University Extension, Ames, Iowa, p. 1–49.

Agarwal, S., Chomsisengphet, S., and Hassler, O. (2005): *The impact of the 2001 financial crisis and the economic policy responses on the Argentine mortgage market*, in: Journal of Housing Economics, 14(3), p. 242–270.

Aliaga, V. S., Ferrelli, F., and Piccolo, M. C. (2017): *Regionalization of climate over the Argentine Pampas*, in: International Journal of Climatology, p. 1–11.

AMIS (2015): *Agricultural Market Information System*. Available at: http://www.amis-outlook.org/amis-about/calendars/en/ (Accessed: 09th of October 2017).

Andrade, J. F. and Satorre, E. H. (2015): *Single and double crop systems in the Argentine Pampas: Environmental determinants of annual grain yield*, in: Field Crops Research. Elsevier B.V., 177, p. 137–147.

Aoyama, Y., Murphy, J. T., and Hanson, S. (2011): *Key Concepts in Economic Geography*. London: SAGE Publications Ltd.

Astoviza, M. J., Cappelletti, N., Bilos, C., Migoya, M. C., and Colombo, J. C. (2016): *Chemosphere Massive airborne Endosulfan inputs related to intensive agriculture in Argentina*'s *Pampa*, in: Chemosphere. Elsevier Ltd, 144, p. 1459–1466.

Atteslander, P. (2000): *Methoden der empirischen Sozialforschung*. 9. Auflage. Edited by Cromm, J., Grabow, B., Klein, H., Maurer, A., and Siegert, G. Berlin: Walter de Gruyert.

Baumann, M., Gavier-Pizarro, G. I., Piquer-Rodriguez, M., and Kuemmerle, T. (2016): *Land-Use Competition in the South American Chaco*, in: Land Use Competition. Springer International Publishing, p. 215–229.

Bender, D. A. (2014): *Food Miles*, in: A Dictionary of Food and Nutrition. 4th Edition. Oxford: Oxford University Press. Available at: http://www.oxfordreference.com/view/10.1093/acref/9780191752391.001.0001/acref-9780191752391-e-6178?rskey=NiriEX&result=3 (Accessed: 13th of May 2017).

Benhadj, I., Duchemin, B., Maisongrande, P., Simonneaux, V., Khabba, S., and Chehbouni, A. (2012): *Automatic unmixing of MODIS multi-temporal data for inter-annual monitoring of land use at a regional scale (Tensift, Morocco),* in: International Journal of Remote Sensing, 33(5), p. 1325–1348.

Berndt, C., Fernández, V. R., and Werner, M. (2017): *From neoliberalism to neodesarrollismo and back? Reading Karl Polanyi in Latin America*, (Working paper), p. 1-18.

Bogner, A. and Merz, W. (2009): *The Theory-Generating Expert Interview: Epistemological Interest, Forms of Knowledge, Interaction,* in: Bogner, A., Littig, B., and Merz, W. (eds): Interviewing Experts. Basingstoke: Palgrave Macmillan, p. 43–80.

Bonanno, A. and Busch, L. (2015): *The international political economy of agriculture and food: An introduction*, in: Bonanno, A. and Busch, L. (eds): Handbook of the International political economy of Agriculture and Food. Cheltenham: Edward Elgar Publishing, p. 1–15.

Borras, S., Kay, C., Gomez, S., and Wilkinson, J. (2012): *Land grabbing and global capitalist accumulation: key features in Latin America*, in: Canadian Journal of Development Studies / Revue canadienne d'études du développement, 33(4), p. 402–416.

Casa, A. C. de and Ovando, G. G. (2014): *Agricultural and Forest Meteorology Climate change and its impact on agricultural potential in the central region of Argentina between 1941 and 2010*, in: Agricultural and Forest Meteorology. Elsevier B.V., 195–196, p. 1–11.

Castree, N., Kitchin, R., and Rogers, A. (2013a): *Fordism,* in: A Dictionary of human geography. Oxford University Press, Oxford. Available at: http://www.oxfordreference.com/view/10.1093/acref/9780199599868.001.0001/acref-9780199599868-e-639?rskey=hXk892&result=640 (Accessed: 10th of August 2017).

Castree, N., Kitchin, R., and Rogers, A. (2013b): *Neoliberalism*, in: A Dictionary of human geography. Oxford University Press, Oxford. Available at: http://www.oxfordreference.com/view/10.1093/acref/9780199599868.001.0001/acref-9780199599868-e-1269?rskey=AEJkBU&result=1270 (Accessed: 10th of August 2017).

Central Intelligence Agency (2017): *The World Factbook - South America*. Available at: https://www.cia.gov/library/publications/the-world-factbook/geos/ar.html (Accessed: 19th of September 2017).

Choumert, J. and Phelinas, P. (2015): *Determinants of agricultural land values in Argentina*, in: Ecological Economics journal, 110, p. 134–140.

Chuvieco, E. and Huete, A. (2010): *Fundamentals of Satellite Remote Sensing*. CRC Press.

Coakley, J. A. (2003): *Reflectance and Albedo, Surface*, in: Curry, J. H. J. (ed): Encyclopedia of Atmospheric Sciences. Elsevier, p. 1914–1923.

Craviotti, C. (2016): *Argentina's agri-food transformations in the context of globalization: Changing ways of farming*, in: Bonanno, A. and Busch, L. (eds): Handbook of the International Political Economy of Agriculture and Food. Edward Elgar Publishing, p. 79–96.

van Dam, J., Faaij, A. P. C., Hilbert, J., Petruzzi, H., and Turkenburg, W. C. (2009): *Large-scale bioenergy production from soybeans and switchgrass in Argentina - Part B. Environmental and socio-economic impacts on a regional level*, in: Renewable and Sustainable Energy Reviews, 13(8), p. 1679–1709.

Datos Abiertos Agroindustria (2017): *Datos Abiertos Agroindustria - Ministerio de Agroindustria Presidencia de la Nación*. Available at: https://datos.magyp.gob.ar/reportes.php?reporte=Estimaciones (Accessed: 22nd of July 2017).

Defila, R. and Di Guilio, A. (2007): *Institutionalisierung und Charakteristika der Allgemeinen Ökologie an der Universität Bern*, in: Di Giulio, A. et al. (eds): Allgemeine Ökologie - Innovationen in Wissenschaft und Gesellschaft. Bern: Haupt Verlag, p. 19–50.

Delvenne, P., Vasen, F., and Vara, A. M. (2013): *The "soy-ization" of Argentina: The dynamics of the "globalized" privatization regime in a peripheral context,* in: Technology in Society, 35(2), p. 153–162.

Diao, C. and Wang, L. (2016): *Temporal partial unmixing of exotic salt cedar using Landsat time series*, in: Remote Sensing Letters. Taylor & Francis, 7(5), p. 466–475.

Drake, N. A., Mackin, S., and Settle, J. J. (1999): *Mapping vegetation, soils, and geology in semiarid shrublands using spectral matching and mixture modeling of SWIR AVIRIS imagery*, in: Remote Sensing of Environment, 68(1), p. 12–25.

Echo der Zeit (2017): *Steigende Sojaproduktion in Europa,* Radio SRF4, Podcast. Available at: https://www.srf.ch/play/radio/echo-der-zeit/audio/steigende-sojaproduktion-in-europa?id=3dc70c50-663b-4f29-a071-a80a1916fcb1&station=69e8ac16-4327-4af4-b873-fd5cd6e895a7 (Accessed: 05th of September 2017).

Elwood, S. (2010): *Mixed Methods: Thinking, Doing, and Asking in Multiple Ways,* in: DeLyser, D., Herbert, S., Aitken, S., Crang, M., and McDowell, L. (eds): The SAGE Handbook of Qualitative Geography. SAGE Publications, p. 94–113.

ESRI (2017): *ArcMap: Release 10.4.1 Redlands,* CA: Environmental Systems Research Institute. Available at: http://desktop.arcgis.com/de/arcmap (Accessed: 24th of February 2017).

ESA (2017a): *Landsat 5 and 7*. European Space Agency, Available at: https://earth.esa.int/web/guest/missions/3rd-party-missions/historical-missions/landsat-tmetm (Accessed: 07th of July 2017).

ESA (2017b): *MODIS*. European Space Agency, Available at: https://earth.esa.int/web/guest/missions/3rd-party-missions/current-missions/terraaqua-modis (Accessed: 07th of July 2017).

ESA (2017c): *Sentinel 2*. European Space Agency, Available at: https://sentinel.esa.int/web/sentinel/missions/sentinel-2 (Accessed: 07th of July 2017).

Fawcett, D., Leiterer, R., Heisig, H., Wulf, H., Kellenberger, T., and Joerg, P. C. (2017): *Google Earth Engine Product Prototypes - Google Earth Engine - Guide*. Zurich.

Flick, U. (2006): *Qualitative Sozialforschung - Eine Einführung*. 4. Auflage. Edited by König, B. Hamburg: Rowohlt Taschenbuch Verlag GmbH.

Flick, U. (2011): *Triangulation - Eine Einführung*. 3. Auflage. Edited by Bohnsack, R., Flick, U., Lüders, C., and Reichertz, J. VS Verlag für Sozialwissenschaft.

Foley, J. A., Defries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharik, C. J., Monfreda, C., Patz, J. a, Prentice, I. C., Ramankutty, N., and Snyder, P. K. (2005): *Global Consequences of Land Use*, in: Science, 309(5734), p. 570–574.

Frey, J., Glasze, G., Pütz, R., and Schürmann, H. (1996): *"Innerdisziplinäre Interdisziplinarität" und "Geographie für alle" - Elemente einer Zukünftigen Geographie*, in: Heinritz, G., Sandner, G., and Wiessmer, R. (eds): Der Weg der deutschen Geographie. Rückblick und Ausblick. Stuttgard: Franz Steiner Verlag, p. 159–168.

Gavier-Pizarro, G. I., Thompson, J. J., Goijman, A., and Zaccagnini, M. E. (2012): *Expansion and intensification of row crop agriculture in the Pampas and Espinal of Argentina can reduce ecosystem service provision by changing avian density*, in: Agriculture, Ecosystems and Environment. Elsevier B.V., 154, p. 44–55.

Gebhardt, H., Glaser, R., Radtke, U., and Reuber, P. (2011): *Geographie - Physische Geographie und Humangeographie*. 2. Auflage. Heidelberg: Spektrum Akademischer Verlag.

Gendron, C. and Audet, R. (2012): *Key drivers of the food chain*, in: Boye, J. I. and Arcand, Y. (eds): Green Technologies in Food Production and Processing. Springer, p. 23–40.

Geoglam (2011): *Global Agricultural Monitoring*, *Earth Observations Global Agricultural Monitoring Initiative*. Available at: https://www.earthobservations.org/geoglam.php (Accessed: 09th of October 2016).

Gläser, J. and Laudel, G. (2006): *Experteninterviews und qualitative Inhaltsanalyse*. 2. Auflage. Wiesbaden: VS Verlag für Sozialwissenschaft.

Goddard, V. (2006): *"This Is History": Nation and Experience in Times of Crisis - Argentina 2001*, in: History and Anthropology, 17(3), p. 267–286.

Google Earth (2016): *Google Earth Pro V.7.3.0.3830*. Available at: http://www.earth.google.com (Accessed: 20th of June 2017).

Google Earth Engine Team (2015): *Google Earth Engine: A planetary-scale geospatial analysis platform*. Available at: https://earthengine.google.com.

Gordon, I. J., Squire, G. R., and Prins, H. H. T. (2017): *Intoduction: Food Production and Natural Conserbation: Conflicts and Solutions*, in: Gordon, I. J., Squire, G. R., and Prins, H. H. T. (eds): Food Production and Natural Conserbation: Conflicts and Solutions. New York: Routhledge, p. 1–12.

Grugel, J. and Riggirozzi, M. P. (2007): *The return of the state in Argentina*, in: International Affairs, 83(1), p. 87–107.

Hammersley, M. (2010): *Reproducing or Constructing? Some questions about transcription in social research*, in: Qualitative Research, 10(5), p. 553–569.

Hazell, P. and Wood, S. (2008): *Drivers of change in global agriculture*, in: Philosophical Transactions of the Royal Society B: Biological Sciences, 363, p. 495–515.

Huete, A. R. and Glenn, E. P. (2011): *Remote Sensing of Ecosystem Structure and Function,* in: Weng, Q. (ed): Advances in Environmental Remote Sensing - Sensors, Algorithms, and Applications. CRC Press, p. 291–320.

Joensen, L., Semino, S., and Paul, H. (2005): *Argentina: A Case Study on the Impact of Genetically Engineered Soya*, in: The Gaia Foundation, p. 1–30.

Johnston, P., Everard, M., Santillo, D., and Robèrt, K.-H. (2007): *Reclaiming the definition of* *sustainability*, in: Environmental science and pollution research international, 14(1), p. 60–66.

Keeling, D. J. (1997): *Contemporary Argentina - A Geograohical Perspective*. Westview Press.

Keshava, N. and Mustard, J. F. (2002): *Spectral unmixing*, in: IEEE Signal Processing Magazine, 19(1), p. 44–57.

Konefal, J. and Busch, L. (2010): *Markets of Multitudes: How Biotechnologies are Standardising and Differentiating Corn and Soybeans*, in: European Society for Rural Sociology, 50(4), p. 409–427.

Kotlyakov, V. and Komarova, A. (2006): *Elsevier's Dictionary of Geography*. 1st Edition. Elsevier.

Kruse, J. (2015): *Qualitative Interviewforschung - Ein integrativer Ansatz*. Beltz Juventa Verlag.

Kuckartz, U. (2014): *Mixed Methods - Methodologie, Forschungsdesigns and Anaylseverfahren*. Springer VS.

Kuckartz, U. (2016): *Qualitative Inhaltsanalyse. Methoden, Praxis, Computerunterstützung*. 3. Auflage. Beltz Juventa Verlag.

Leguizamón, A. (2014): *Modifying Argentina: GM soy and socio-environmental change*, in: Geoforum, 53, p. 149–160.

Leguizamón, A. (2016): *Disappearing nature? Agribusiness, biotechnology and distance in Argentine soybean production*, in: The Journal of Peasant Studies, p. 1–18.

Leith, H. (1974): *Phenology and Seasonality Modeling*. New York: Springer.

Li, F., Liujun, Z., Han, L., Yinyou, H., Peijun, D., and Adaku, E. (2015): *Urban Vegetation Classification Based on Phenology using HJ-IA / B time series imagery*, in: Urban Remote Sensing Event (JURSE), p. 1–4.

Lillesand, T. M., Kiefer, R. W., and Chipman, J. W. (2008): *Remote Sensing and Image Interpretation*. 6th Edition. John Wiley & Sons.

Lobell, D. B. and Asner, G. P. (2004): *Cropland distributions from temporal unmixing of MODIS data*, in: Remote Sensing of Environment, 93(3), p. 412–422.

MAXQDA (2017): *MAXQDA - Software für qualitative Datenanalyse*. VERBI Software. Consult. Sozialforschung GmbH. Available at: http://www.maxqda.de/ (Accessed: 05th of

October 2016).

Mayer, H. O. (2002): *Interview und schriftliche Befragung: Entwicklung, Durchführung und Auswertung*. Oldenbourg Verlag.

Mayhew, S. (2009): *Deregulation,* in: A Dictionary of Geography. 4th Edition. Oxford: Oxford University Press. Available at: http://www.oxfordreference.com/view/10.1093/acref/9780199231805.001.0001/acref-9780199231805-e-848 (Accessed: 13th of May 2017).

Mayring, P. (2007a): *Qualitative Inhaltsanalyse*, in: Flick, U., Kardorff, E. von, and Steinke, I. (eds): Qualitative Forschung. Ein Handbuch. 5th Edition. Reinbek bei Hamburg: Rowohlt Taschenbuch Verlag GmbH, p. 468–485.

Mayring, P. (2007b): *Qualitative Inhaltsanalyse - Grundlagen und Techniken*. 9. Auflage. Weinheim und Basel: Beltz.

Medina, M. E., Pastor, S., and Recalde, A. (2016): *The archaeological landscape of Late Prehispanic mixed foraging and cultivation economy (Sierras of Córdoba, Argentina)*, in: Journal of Anthropological Archaeology, 42, p. 88–104.

Merkel, A. (2017): *climate-data.org*, *AM Online Projects*. Available at: https://de.climate-data.org/ (Accessed: 09th of August 2017).

Milazzo, M. F., Spina, F., Cavallaro, S., and Bart, J. C. J. (2013): *Sustainable soy biodiesel*, in: Renewable and Sustainable Energy Reviews, 27, p. 806–852.

Moles, P. and Terry, N. (2005): *Re-regulation*, in: The Handbook of International Financial Terms. Oxford: Oxford University Press. Available at: http://www.oxfordreference.com/view/10.1093/acref/9780198294818.001.0001/acref-9780198294818-e-6476 (Accessed: 13th of May 2017).

NASA (2014): *MODIS Water Mask*. National Aeronautics and Space Administration, Available at: https://modis.gsfc.nasa.gov/data/dataprod/mod44w.php (Accessed: 14th of November 2016).

NASA (2017): *MODIS Specifications*. National Aeronautics and Space Administration, Available at: https://modis.gsfc.nasa.gov/about/specifications.php (Accessed: 07th of July 2017).

Norton, D. A., Reid, N., and Young, L. (2013): *Ultimate drivers of native biodiversity change in agricultural systems*, in: F1000 Research, 214(2), p. 1–15.

Petts, J., Owens, S., and Bulkeley, H. (2008): *Crossing boundaries: Interdisciplinarity in the context of urban environments*, in: Geoforum, 39(2), p. 593–601.

Phelinas, P. and Choumert, J. (2017): *Is GM Soybean Cultivation in Argentina Sustainable?*, in: World Development, p. 1–11.

Quantum GIS Development Team (2017): *Quantum GIS Geographic Information System. Open Source Geospatial Foundation Project.* Available at: http://qgis.osgeo.org/de/site/ (Accessed: 27th of April 2017).

R Core Team (2015): *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. Available at: www.R-project.org/ (Accessed: 19th of April 2017).

Ramadier, T. (2004): *Transdisciplinarity and its challenges: The case of urban studies*, in: Futures, 36(4), p. 423–439.

Rudorff, B. F. T., Adami, M., Risso, J., Alves de Aguiar, D., Pires, B., Amaral, D., Fabiani, L., and Cecarelli, I. (2012): *Remote Sensing Images to Detect Soy Plantations in the Amazon Biome — The Soy Moratorium Initiative*, in: Sustainability, 4, p. 1074–1088.

Schleifer, P. (2016): P*rivate regulation and global economic change: The drivers of sustainable agriculture in Brazil*, in: Governance, p. 1–18.

Schneider, A. (2014): *Triangulation und Integration von qualitativer und quantitativer Forschung in der Sozialen Arbeit*, in: Mührel, E. and Birgmeier, B. (eds): Perspektiven sozialpädagogischer Forschung. Springer, p. 15–25.

Schnepf, R., Dohlman, E., and Bolling, C. (2001): *Soybeans, Agriculture, and Policy in Argentina*, in: Agriculture in Brazil and Argentina: Developments and Prospects for Major Crop Fields, p. 15–34.

Schrag, A. M., Zaccagnini, M. E., Calamari, N., and Canavelli, S. (2009): *Climate and land-use influences on avifauna in central Argentina: Broad-scale patterns and implications of agricultural conversion for biodiversity*, in: Agriculture, Ecosystems and Environment, 132(1–2), p. 135–142.

Seto, K. C., Fragkias, M., Güneralp, B., and Reilly, M. K. (2011): *A Meta-Analysis of Global Urban Land Expansion*, in: PLoS ONE. Public Library of Science, 6(8), p. 1–9.

Sheng, Y. (2011): *Remote Sensing*, in: Agnew, J. A. and Livingstone, D. N. (eds): The SAGE Handbook of Geographical Knowledge. SAGE Publications, p. 171–184.

Stone, G. D. (2001): *Agricultural Change Theory*, in: Smelser, N. J. and Baltes, P. B. (eds): International Encyclopedia of the Social & Behavioral Sciences. Elsevier Science, p. 329–333.

Strauss, A. and Corbin, J. (1996): *Grounded Theoriy: Grundlagen Qualitativer Soizialforschung*. Weinheim: Beltz.

Suchanek, N. (2013): *Argentinine im Soja-Fieber*, in: Forum Umwelt und Entwicklung. Rio de Janeiro, p. 1–39.

Tomei, J. and Upham, P. (2009): *Argentinean soy-based biodiesel: An introduction to production and impacts*, in: Energy Policy, 37(10), p. 3890–3898.

Tseng, Y. (2000): *Spectral Unmixing for the Classification of Hyperspectral Images*, in: International Archives of Photogrammetry and Remote Sensing, XXXIII(Part B7), p. 1532–1538.

USGS (2016): *Remote Sensing Phenology*. U.S. Geological Survey, Available at: https://phenology.cr.usgs.gov/index.php (Accessed: 10th of January 2017).

Urcola, H. A., de Sartre, X. A., Veiga, I., Elverdin, J., and Albaladejo, C. (2015): *Land tenancy, soybean, actors and transformations in the pampas: A district balance*, in: Journal of Rural Studies, 39, p. 32–40.

USDA (2016): *U.S. DEPARTMENT OF AGRICULTURE*. Available at: https://www.usda.gov/ (Accessed: 09th of October 2016).

van Vliet, J., de Groot, H. L. F., Rietveld, P., and Verburg, P. H. (2015): *Manifestations and underlying drivers of agricultural land use change in Europe*, in: Landscape and Urban Planning. Elsevier B.V., 133, p. 24–36.

Vujnovic, M. (2012): *The Wiley-Blackwell Encyclopedia of Globalization*, in: Ritzer, G. (ed.): The Wiley-Blackwell Encyclopedia of Globalization. Blackwell Publishing Ltd, p. 1–2.

Wardenga, U. (2005): *Wozu Erinnerung? Über die Rolle von Fachgeschichtsbildern in der Debatte um integrative Forschungsansätze in der Geographie*, in: Müller-Mahn, D. and Wardenga, U. (eds): Möglichkeiten und Grenzen integrativer Forschungsansätze in Physischer Geographie und Humangeographie. Leibniz: Leibniz Institut für Länderkunde, p. 7–24.

Witze, A. (1985): *Das problemzentrierte Interview*, in: Jüttemann, G. (ed): Qualitative Forschung in der Psychologie : Grundfragen, Verfahrensweisen, Anwendungsfelder.

Weinheim: Beltz: Beltz, p. 227–255.

Witzel, A. (2000): *Das problemzentrierte Interview*, in: Forum Qualitative Sozialforschung, 1(1), p. 1–9.

Wright, D. and Lenssen, A. W. (2013): *Staging Soybean Development*, in: Agriculture and Evirenment Extension Publications. Iowa State University, p. 1-4.

WWF (2014): *The Growth of Soy - Impacts and Solutions*, In: WWF Report. Edited by Jeffries, B. Gland, Switzerland: WWF International, p. 1-90.

Wylde, C. (2011): *State, society and markets in Argentina: The political economy of neodesarrollismo under Néstor Kirchner, 2003-2007*, in: Bulletin of Latin American Research, 30(4), p. 436–452.

Yates, J. S. and Bakker, K. (2013): *Debating the "post-neoliberal turn" in Latin America*, in: Progress in Human Geography, 38, p. 1–29.

Yengoh, G. T., Dent, D., Olsson, L., Tengberg, A. A., and Tucker III, C. J. (2015): *Use of the Normalized Difference Vegetation Index (NDVI) to Assess Land Degradation at Multiple Scales - Current Status, Future Trends, and Practical Considerations*. Springer VS, p. 1-110.

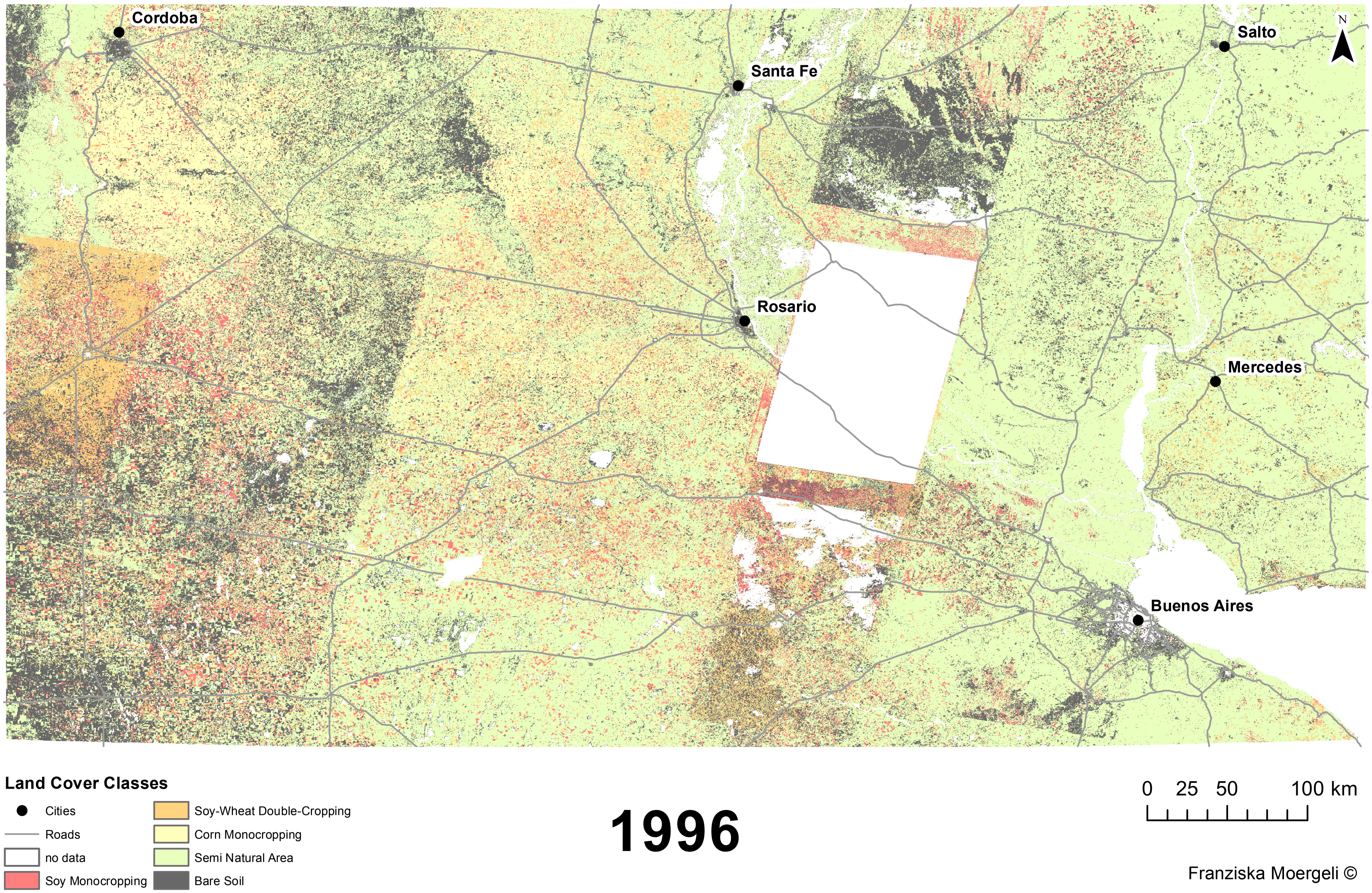
Zelaya, K., van Vliet, J., and Verburg, P. H. (2016): *Characterization and analysis of farm system changes in the Mar Chiquita basin, Argentina*, in: Applied Geography. Elsevier Ltd, 68, p. 95–103.

Zeng, L., Wardlow, B. D., Wang, R., Shan, J., Tadesse, T., Hayes, M. J., and Li, D. (2016*): A hybrid approach for detecting corn and soybean phenology with time-series MODIS data*, in: Remote Sensing of Environment, 181, p. 237–250.

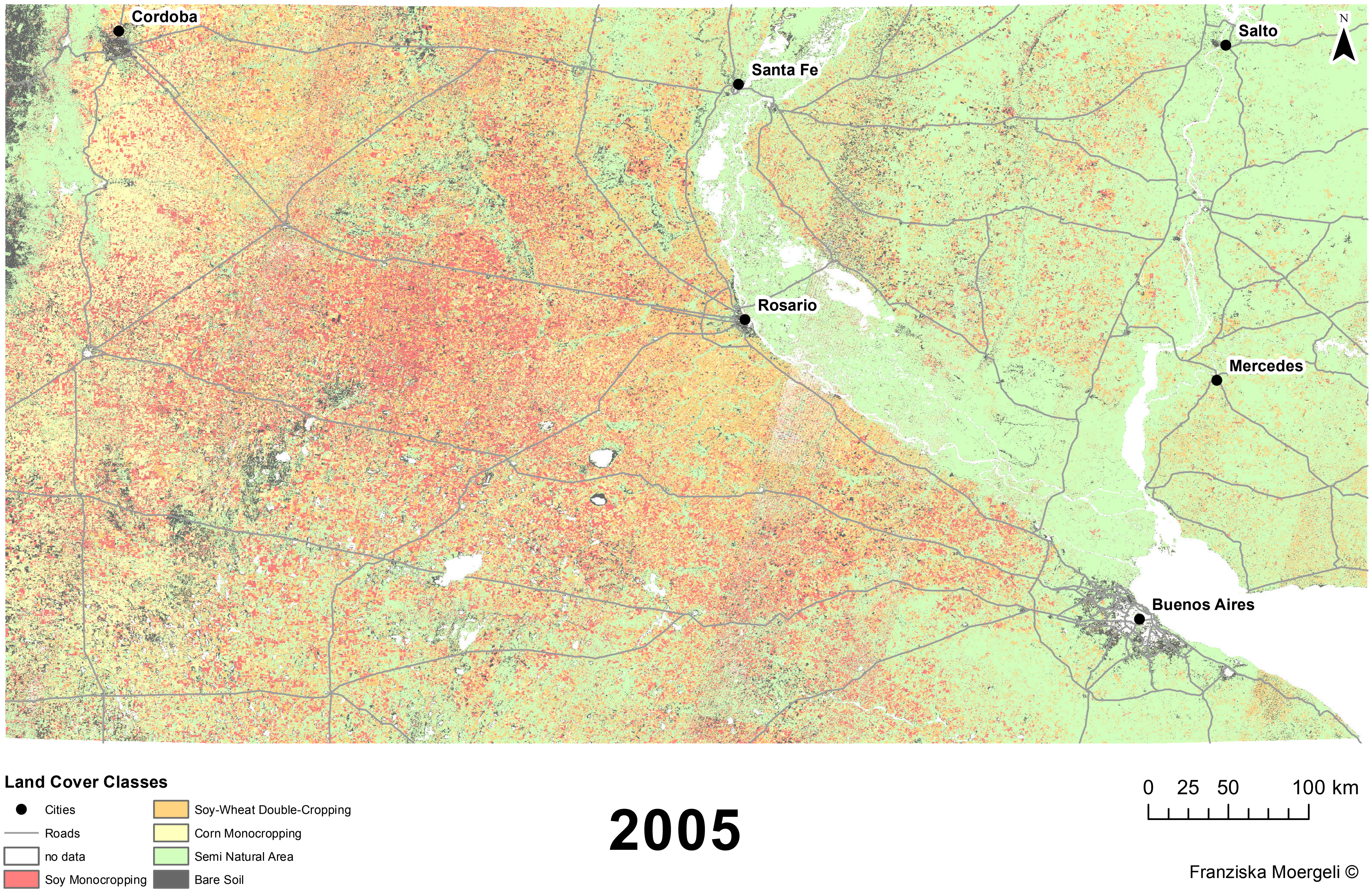
Appendix

A. Land Cover Maps

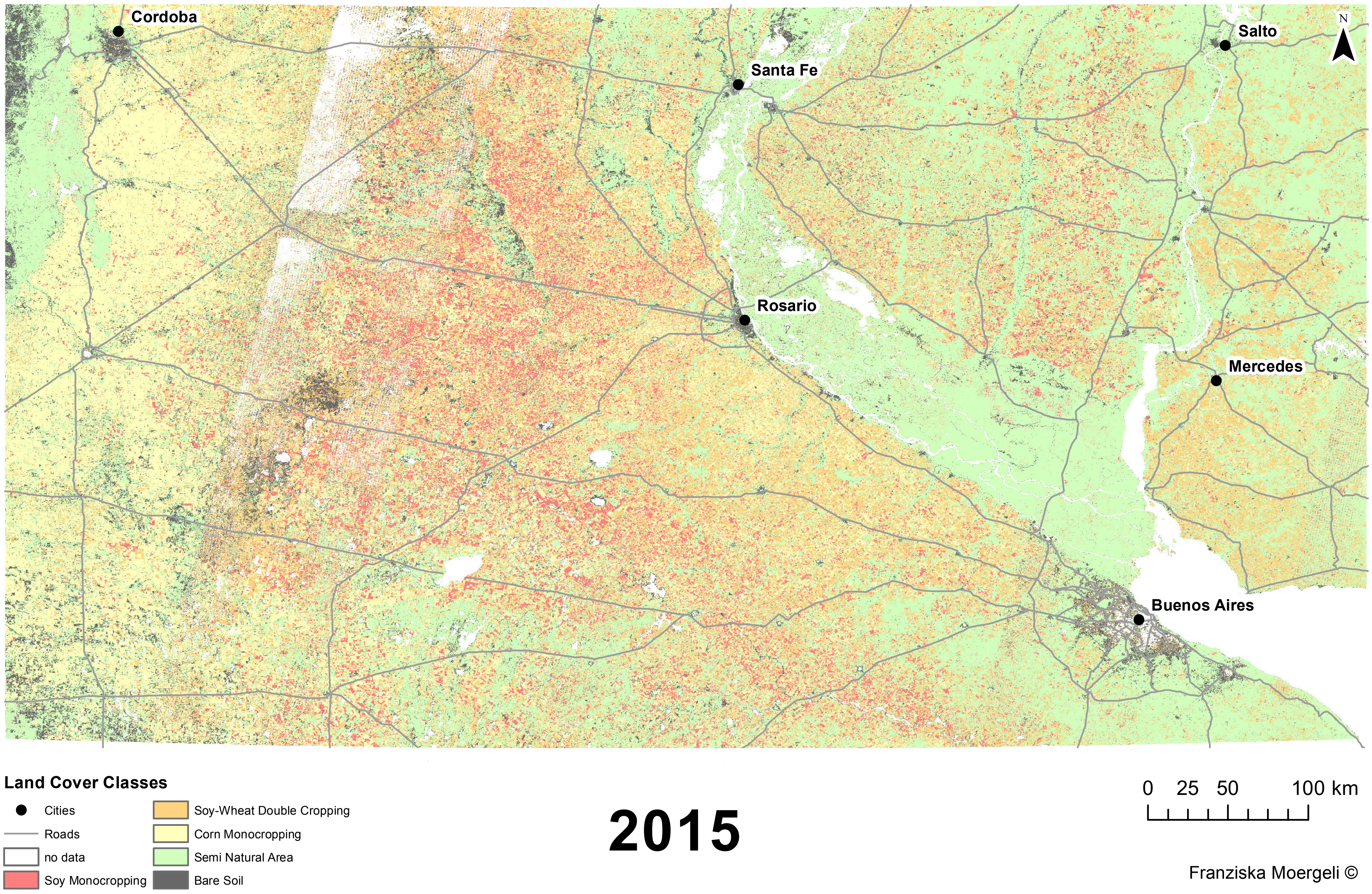
Agricultural Production in the Pampa Húmeda



Agricultural Production in the Pampa Húmeda



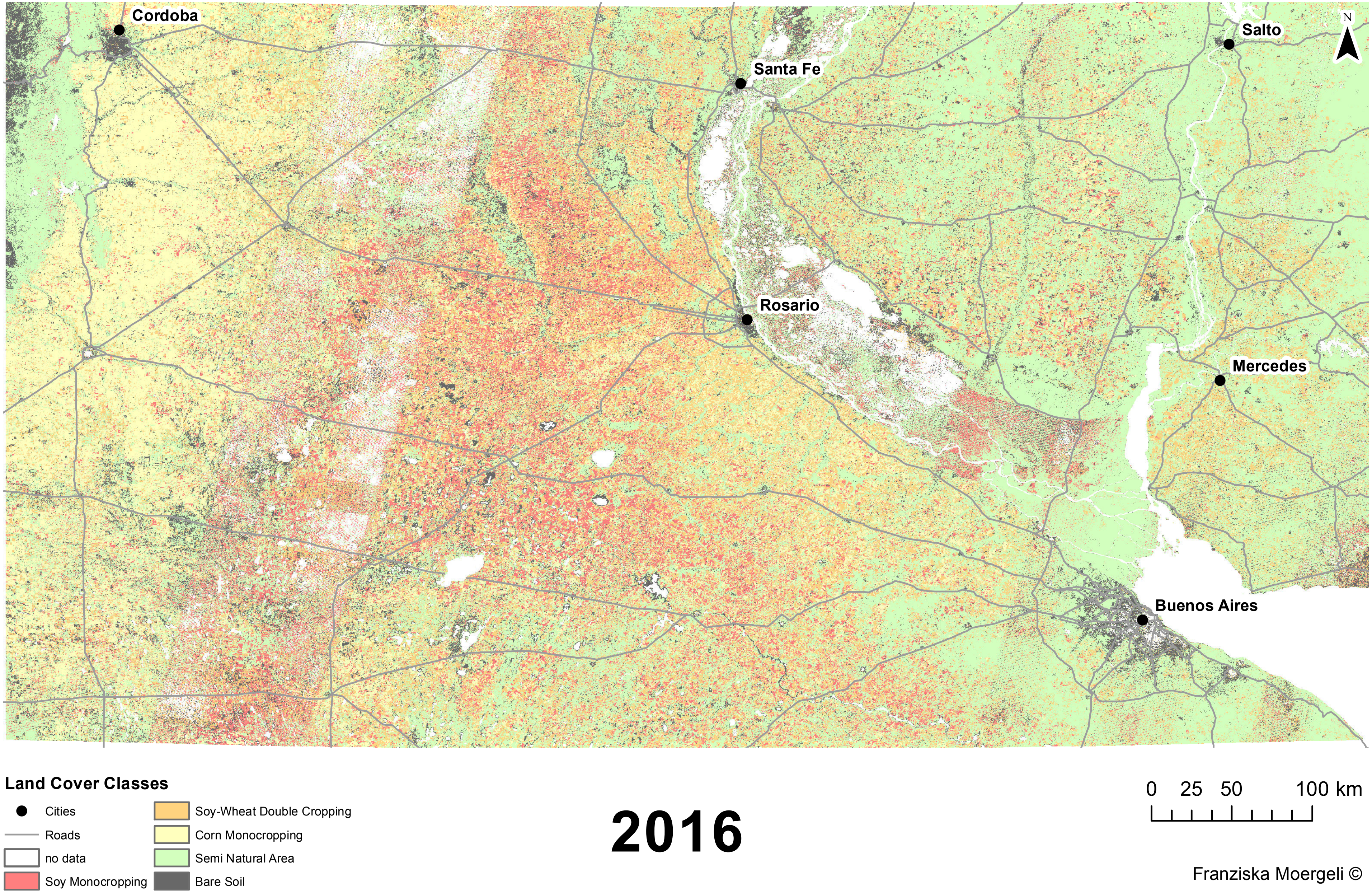
Agricultural Production in the Pampa Húmeda



2015

Franziska Moergeli ©

Agricultural Production in the Pampa Húmeda



2016

Franziska Moergeli ©

B. Interview guide

Institutions

Information about interview context:

Date: ____

Place: ____

Beginning time of the interview: ______________________________

Ending time of the interview: ________________________________

Information about interview partner:

Name: ____

Profession: ____

Name of the institution: ________________________________

Residence: ____

Starting with a few minutes where I introduce myself and explain what the interview is about, followed by the interview questions.

Introduction

- Welcome and thank your for your time
- The interview is about land use change due to GM soy in Argentina
- What's the interview/my work about → Master thesis
- Personal information will be handled with confidence and anonymity is guaranteed
- Ask the interviewee if he / she agrees if the interview is recorded for further evaluation

About the interviewee	1. Can you tell me a bit about your Institution and about your work in it?		☐
	- What does your job involve?		☐
	2. Can you tell me about the current situation of your institution?		
	- What were the (great) changes your institution was facing in the past 20 years? - What are the challenges your institution is facing? - How is your institution related to the agricultural sector and soy		☐ ☐ ☐

	production?		
	Show **maps** and explain quickly how to look at it.		
About the maps	3. What do you see on these maps?		☐
	- How would you interpret… • occurring changes? • agricultural situations on these maps? • social situations on these maps? - What do you think about this map?	→ land-use change what it shows/the change	☐ ☐ ☐ ☐ ☐
	4. Do you know **why** this area underwent such changes in the past 20 years?		
	- What were reasons to cultivate soy? • Was the change price related? • Was the change based on political reasons • Because of climate changes - How would you evaluate/assess this change of production? • Positive → Why? • Negative →Why? - Who did benefit from this change? - How was (and is) your institution affected by these changes?		☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	5. **What** happened in this region since the GM soy introduction in 1996…		
	- regarding agricultural extent? - regarding social restructuring? - regarding the political situation? - regarding land property?	Land-use change! Job loss? Relocation? To whom belongs the land?	☐ ☐ ☐ ☐
	6. How do you think this map will look like in 10 years?		
	- What do you think will happen… • regarding agricultural extent? • regarding social restructuring? • regarding the political situation? • regarding land property? - And why will the map look like you described? - What will be the consequences? - How will you be affected? - How will your institution be affected?		☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

			☐
Close up	7. Is there anything you want to add?		☐
	- Any additional Information about GM soy production? - Do you have any interesting contacts for me?		☐ ☐
	8. Short questions for the end:		
	- Since when are your working for this institution? - How much land do you own?	name the institution question depending on interviewee	☐ ☐

Ending

- Give thanks and small present
- Ask whether the interviewee is interested in my results

Producers

Information about interview context:

Date: ______________________________

Place: ______________________________

Beginning time of the interview: ______________________________

Ending time of the interview: ______________________________

Information about interview partner:

Name: ______________________________

Profession: ______________________________

Residence: ______________________________

Starting with a few minutes where I introduce myself and explain what the interview is about, followed by the interview questions.

Introduction

- Welcome and thank your for your time
- The interview is about land use change due to GM soy in Argentina
- What's the interview/my work about → Master thesis
- Personal information will be handled with confidence and anonymity is guaranteed
- Ask the interviewee if he / she agrees if the interview is recorded for further evaluation

About the interviewee	1. Can you tell me a bit about your history as a producer?		
	- What does your job involve?		☐
	2. What is your professional background?		
	- What kind of education do you have?		☐
	- Was your family always working in agriculture?	If not, what did they do?	☐
	- What is the property situation of the land you produce on?		☐
	- What do you produce?		☐
	- Do you have cattle/livestock?	Single/double-cropping	☐
	- How do they fit in the agricultural production process?	Single cropping & grazing	☐
	Show **maps** and explain quickly how to look at it.		
About the maps	3. What do you see on these maps?		☐
	- How would you interpret…		☐
	• occurring changes?	→ land-use change	☐
	• agricultural situations on these maps?		☐
	• social situations on these maps?		☐
	- What do you think about this map?	what it shows/the change	☐
	4. Do you know why this area underwent such an extensive change in the past 20 years?		
	- What were reasons to cultivate soy?	Political reasons, price/ climate related? …	☐
	- How would you evaluate/assess this change of production?		☐
	• Positive → Why?		☐
	• Negative →Why?		☐
	- Who did benefit from this change?		☐
	- How were (and are) you affected by these changes?		☐
	- Did you change your sowing production?		☐
	• Why yes? / Why no?		☐
	5. What happened in this region since the GM soy introduction in 1996…		
	• regarding agricultural extent?	Land-use change!	☐
	• regarding social restructuring?	Job loss? Relocation?	☐
	• regarding the political situation?		☐
	• regarding land property?	To whom belongs the land?	☐
	6. How do you think this map will look like in 10 years?		

	- What do you think will happen… • regarding agricultural extent? • regarding social restructuring? • regarding the political situation? • regarding land property? - And why will the map look like you described? - What will be the consequences? - How will you be affected?		☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
Close up	7. Is there anything you want to add?		
	- Any additional Information about GM soy production? - Do you have any interesting contacts for me?		☐ ☐
	8. Short questions for the end:		
	- How much land do you own? Or → How big is the area you cultivate on? • Who owns the land you produce on - How many people work for you/with you? - Since when do you work in the agricultural sector?		☐ ☐ ☐ ☐ ☐

Ending

- Give thanks
- Ask whether the interviewee is interested in my results

C. Transcriptions of the interviews

All the transcriptions can be found on the CD enclosed.

D. Category tree of the interview codes

Liste der Codes	**#**
Codesystem	1228
Study Area	**18**
Chaco	21
Historical Context Argentina (Argentinean Transformation)	**5**
Government	3
Traditional Farming	17
Politics	17
Menem Carlos	1
Macri	13
Kirchners	27
Neoliberalism	13
Economy	11
Crisis	17
Soy Adaptation	17
Mechanization	7
Agricultural Policy	**0**
Agricultural Expansion	19
Modernization	7
Export	22
Export Regulations	5
Promoting Biotechnology	9
(Forest) Laws	3
Land / Property	**0**
Private Owners	5
Land Rentals / Partnership	8
Agricultural use	4
Large Scale Farming	5
Small Scale Framing	4
uneven degree of power	3
Tenure / Property Relations	11
Land Use Change	20
Dispossession, Grabbing, Acquisition	6
Soy Boom in Argentina	**14**
Possible Divers	21
Politics	1
Taxes	11
Price	12
Soybean characteristics	2
Most Profitable Crop	16
No-Till Technology	11
Soil (Land) Quality	20
GM Soy (GMO)	85
Biofuel	4
Food for Livestock	7
Certificates	2
Demand in Agricultural Products	7
Grain Prices	4
Intensification	3
Expectations (Future)	4
Alternatives	3
No-Till (siembra directa) Method	36
Agrochemicals	29
Glyphosate	24
(GM Soy) Monoculture	24
Production	41
(Technical) Innovation	19
Standardisation	2
Differentiation / Specialitation	4
Other Crops/Land use/Agriculture	30
Rotation	16
Wheat	12
Livestock / Pasture / Cattle grazing	49
Corn	19
Conflicts	6
General Correlations	**0**
Making Profit	12
Taxes	4
Global Context	10
Policy Measures	4
Loss of Importance / Change in 2015	13
Oil Prices	4
Prices / Costs	18
Investment	2
Inflation	2
Speculation	1
Labour	20
Stakeholders (Affected / Involved)	**0**
INTA	9
Role of the State	4
AACREA	5
AAPRESID	10
Pools de Siembra	23
Agribusinesses	6
Global Corporations	3
Investors	3
Monsanto	7
Roundup Ready	5
Farmer / Producer	11
Family Farming	9
Consequences (diskursives)	**0**
Romantizising Soy, Agriculture & no-till	18
Dependence on Soy	5
Conflicts / Violence / Protest	9
Political Problems	1
Social Problems	7
Job Loss	5
Food Sovereignty	11
Illness / Health	10
Indigenous	8
Depopultation / Displacement	6
Environmental Problems	15
Fragmentation / Habitat Loss	2
Soil Degradation	5
Loss of Biodiversity	7
Deforestation	18
Connotation	0
positiv	26
negative	34

E. GEE Code

The implementation of the maps with GEE has been done in supportive collaboration with Dominic Fawcett. The structure and definition of the single steps had been done by myself using and adapting codes provided and explained by GEE Tutorials and the information guideline (Google Earth Engine Team 2015). The coding is to 60% appreciating credited towards Dominic Fawcett. The code can also be found on the CD enclosed.

```
var roi = /* color: 98ff00 */ee.Geometry.Polygon(
   [[[-64.814, -31.128],
    [-57.173, -31.128],
    [-57.173, -35.288],
    [-64.814, -35.288]]]);


// roi filter for region of interest (roi)


var geometry_moving = /* color: #4260f9 */ee.Geometry.Point([-63.3059950534906,-35.1993437124390]);


var targetyear= 2010 //adjust the year to look at here


// USGS Landsat 7 Surface Reflectance, Jan 1, 1999 - April 30, 2017
// // https://explorer.earthengine.google.com/#detail/LANDSAT%2FLE7_SR
var l7sr = ee.ImageCollection('LANDSAT/LE7_SR').filterBounds(roi);


var addNDVIbandls7 = function(image) {
 // Add an NDVI band.
 return image.addBands(image.normalizedDifference(['B4', 'B3']).rename('NDVI'))
};


var l7srndvi=l7sr.map(addNDVIbandls7)


// USGS Landsat 5 Surface Reflectance, Jan 1, 1996 - Dez 31, 1998
// // https://explorer.earthengine.google.com/#detail/LANDSAT%2FLT5_SR
var l5sr = ee.ImageCollection('LANDSAT/LT5_SR')
.filterDate('1996-01-01', '1998-12-31')
.filterBounds(roi);


var addNDVIbandls5 = function(image) {
 // Add an NDVI band.
 return image.addBands(image.normalizedDifference(['B4', 'B3']).rename('NDVI'))
};


var l5srndvi=l5sr.map(addNDVIbandls5)


// How to merge two collections -> für L7 & L5
var mergedCollection = ee.ImageCollection(l7srndvi.merge(l5srndvi));



// Watermask
var modiswater = ee.Image('MODIS/MOD44W/MOD44W_005_2000_02_24');


print(modiswater)
```

```
// function for masking water, clouds and regions with negative NDVI

var maskImg = function(img){

 var cloudmask = ee.Image(img).select('cfmask').eq(4).not()

var NDVImask = ee.Image(img).select('NDVI').gte(0)

var watermask=modiswater.select('water_mask').not()

 return ee.Image(img).updateMask(watermask.and(NDVImask.and(cloudmask)));

}


var maskedCollection = mergedCollection.map(maskImg);

//print(maskedCollection)



var harmonics = 3; //increase number of harmonics for a better fit.

//But runs into memory issues for too many harmonics.


//generate names for the harmonic components

var sincoefnames=ee.List.sequence(1, harmonics)

  .map(function(n) { return ee.Number(n).int().format("sin%d")});

var coscoefnames=ee.List.sequence(1, harmonics)

  .map(function(n) { return ee.Number(n).int().format("cos%d")});
```

```
//names of the non-harmonic independ variables.

var timevar=ee.String('t');

var constant=ee.String('constant');

//name of the dependent variable

var dependent = ee.String('NDVI');


// This field contains UNIX time in milliseconds.

var timeField = 'system:time_start';


//function to add variables for a constant, time, and harmonic components (independents)

// to Landsat 8 imagery.

var addIndVar = function(image) {

 // Compute time in fractional years since the epoch.

 var date = ee.Date(image.get(timeField));

 var years = date.difference(ee.Date('1970-01-01'), 'year');

 var timeRadians = ee.Image.constant(ee.List.sequence(1, harmonics)).multiply(years).multiply(2*Math.PI).float();//figure this out


 // Return the image with the added bands.

 return ee.Image(image)

  // Add a constant band.

  .addBands({srcImg: ee.Image.constant(1),overwrite: true})

  // Add a time band.
```

```
.addBands(ee.Image.constant(years).float().rename('t'))
 // Add harmonic terms.

.addBands(ee.Image(timeRadians).cos().rename(coscoefnames))

.addBands(ee.Image(timeRadians).sin().rename(sincoefnames))
};


var filteredLandsat = maskedCollection//l8sr //
 .filterBounds(roi)
 .filterDate(ee.Number(targetyear-1).format('%d').cat(ee.String('-11-01')), ee.Number(targetyear+1).format('%d').cat(ee.String('-03-01')))
 //year to look at with values before and after
 .map(addIndVar);



 print(filteredLandsat)
 // Map.addLayer(filteredLandsat, {}, "filteredLandsat")


// Use these independent variables in the harmonic regression.
var harmonicIndependents = ee.List([constant]).add(timevar).add(coscoefnames).add(sincoefnames).flatten();//ee.List(['constant', 't', 'cos', 'sin']);
```

```
// Regression of independent variables (constant, time, sin and cos coefficients) versus dependent (NDVI)


var harmonicTrend = filteredLandsat
.select(harmonicIndependents.add(dependent))
.reduce(ee.Reducer.linearRegression(2 + harmonics*2, 1));
//print(harmonicTrend);



// Turn the array image into a multi-band image of coefficients.
var harmonicTrendCoefficients = harmonicTrend.select('coefficients')
 .arrayProject([0])
 .arrayFlatten([harmonicIndependents]);
print(harmonicTrendCoefficients)
//print(harmonicTrendCoefficients);



var applyModel = function(image) {
 return image.addBands(
  image.select(harmonicIndependents)
   .multiply(harmonicTrendCoefficients)
   .reduce('sum')
   .rename('fitted'));
};


// Apply the model to get fitted values
var fittedHarmonic = filteredLandsat.map(applyModel);
 print(fittedHarmonic);
```

```
// Map.addLayer(fittedHarmonic.select('fitted'))



// Plot the fitted model and the original data at the ROI.

print(Chart.image.series(fittedHarmonic.select(['NDVI','fitted']), geometry, ee.Reducer.mean(), 30)

  .setSeriesNames(['NDVI', 'fitted'])

  .setOptions({

   title: 'Harmonic model: original and fitted values',

   lineWidth: 1,

   pointSize: 3,

}));


//make a list of empty images with dates for every day of a DOY range to get NDVI for (only one year can be specified as of now)


//DOY range to look at. Adjust to contain only the range with plausible SOS / EOS dates

var startdoy=1;

var enddoy=365;


var DOYs= ee.List.sequence(startdoy,enddoy,1); //adjust the step here (last parameter) if there are memory issues.

var months=ee.List.sequence(1,12,1)

//adjust the year string here to look at a different year

function makeMonthImgsWithDates(month){

 var newimg=ee.Image().set("system:time_start", ee.Date.parse('yyyy, MM,dd',ee.Number(targetyear).format('%d').cat(ee.String(', ').cat(ee.Number(month).format('%02d')).cat(',01'))).millis())

 return newimg;

}


//adjust the year string here to look at a different year

function makeDOYImgsWithDates(doy){

 var newimg=ee.Image().set("system:time_start", ee.Date.parse('yyyy, D',ee.Number(targetyear).format('%d').cat(ee.String(', ').cat(ee.Number(doy).format('%d')))).millis())

 return newimg;

}


var emptyimgsmonths = ee.ImageCollection(months.map(makeMonthImgsWithDates));

//print(emptyimgs)


var monthNDVIseries = emptyimgsmonths.map(addIndVar).map(applyModel);


var emptyimgsdoy = ee.ImageCollection(DOYs.map(makeDOYImgsWithDates));

//print(emptyimgs)
```

```
var doyNDVIseries = emptyimgsdoy.map(addIndVar).map(applyModel);



//display chart with fitted values for every DOY
print(Chart.image.series(doyNDVIseries.select('fitted'), geometry, ee.Reducer.mean(), 30)
 .setSeriesNames(['fitted'])
 .setOptions({
  title: 'Harmonic model: DOY fitted values',
  lineWidth: 1,
  pointSize: 3,
}));


//display chart with fitted values for first day of every month
print(Chart.image.series(monthNDVIseries.select('fitted'), geometry, ee.Reducer.mean(), 30)
 .setSeriesNames(['fitted'])
 .setOptions({
  title: 'Harmonic model: Monthly fitted values',
  lineWidth: 1,
  pointSize: 3,
}));



//Map.addLayer(roi)
```

```
Map.setCenter(-60.65, -32.96, 7); //Rosario
Map.addLayer(maskedCollection.select('NDVI').map(function(img) {return img.clip(roi);}),
 {palette: 'ffb3ba, ffdfba, ffffba, baffc9, bae1ff', min: 0.2, max: 0.8},'NDVI',false);
    //rot, orange, gelb, grün, blau
  //hex color palette rainbow color http://www.color-hex.com/color-palette/5361
////Map.addLayer(fittedHarmonic.select('fitted'));



// Define spectral endmembers.
var soy = [0.777, 0.844, 0.704, 0.483, 0.215, 0.196, 0.217, 0.299, 0.265, 0.228, 0.303, 0.528];
var soy_wheat = [0.652, 0.893, 0.819, 0.477, 0.36, 0.499, 0.586, 0.581, 0.644, 0.517, 0.374, 0.416];
var maize = [0.560, 0.853, 0.826, 0.542, 0.276, 0.212, 0.248, 0.264, 0.234, 0.267, 0.221, 0.283];
var shrubland = [0.555, 0.6345, 0.645, 0.527, 0.4585, 0.424, 0.406, 0.317, 0.368, 0.4345, 0.564, 0.511];
//shrubland (Forrest) zusammengeschlossen mit seminatural (Grassland) -> Zeile 268/269
var seminatural = [0.608, 0.6825, 0.69, 0.649, 0.587, 0.561, 0.473, 0.3875, 0.411, 0.545, 0.59, 0.5495];
var urban = [0.295, 0.309, 0.325, 0.288, 0.275, 0.248, 0.205, 0.215, 0.219, 0.257, 0.275, 0.275];
```

```
//make image with monthly NDVI values as bands

var monthNDVIseriesList = monthNDVIseries.select('fitted').toList(12);

var tounmix=ee.Image(monthNDVIseriesList.get(0))

var monthNDVIimg = ee.Image.cat(monthNDVIseriesList);

 //print(monthNDVIimg)

for (var i=1; i<12; i++){

 tounmix=tounmix.addBands(ee.Image(monthNDVIseriesList.get(i)))

}

print(tounmix)


// Unmix the image.

var fractions = tounmix.unmix([soy, soy_wheat, maize, shrubland, seminatural, urban],true,true).clip(roi);

Map.addLayer(fractions,{}, 'unmixed',false);


//make image collection with an image per class, reduce by taking the maximum unmixed fraction and display it per pixel

var fractionlist=ee.List([fractions.select([0]).addBands(ee.Image(1).toInt()).rename('fractions','class')]);//.addBands(NDVIbandlist.get(0))]);

//fractionlist=SMRIbandlist.add(SMRI.select([1]))

var i=0;

for (i =1; i <6 ; i++) {

 fractionlist=fractionlist.add(ee.Image(fractions.select([i]).addBands(ee.Image(i+1).toInt()).rename('fractions','class')))//.set('system:index',ee.Number.parse(SMRI8dayaggregated.select([i]).get('system:index')).toInt()));//.addBands(NDVIbandlist.get(i-1)));

}

var maxfracs = ee.Image(ee.ImageCollection(fractionlist).reduce(ee.Reducer.max(2))).select(1);

print(maxfracs)

maxfracs = maxfracs.where(maxfracs.eq(5),4) //shrubland zu seminatural

maxfracs = maxfracs.where(maxfracs.eq(6),5)

var palette=['ffb3ba', 'ffdfba', 'ffffba', 'baffc9', 'bae1ff']

 // erstes violett 'f1bdff', 'ffb3ba', 'ffdfba', 'baffc9', 'bae1ff'

Map.addLayer(maxfracs.rename('class'), {palette:palette,min:1, max:5}, 'maximum fraction class');



// Display a legend explaining the colors

// classification image.

var BAND_NAME = 'class';


var image = maxfracs.select(1).rename('class');


// Create the panel for the legend items.

var legend = ui.Panel({
```

```
 style: {
  position: 'bottom-left',
  padding: '8px 15px'
 }
});

// Create and add the legend title.
var legendTitle = ui.Label({
 value: 'Land Cover Classes',
 style: {
  fontWeight: 'bold',
  fontSize: '18px',
  margin: '0 0 4px 0',
  padding: '0'
 }
});
legend.add(legendTitle);

// Creates and styles 1 row of the legend.
var makeRow = function(color, name) {
 // Create the label that is actually the colored box.
 var colorBox = ui.Label({
  style: {
   backgroundColor: '#' + color,
   // Use padding to give the box height and width.
   padding: '8px',
   margin: '0 0 4px 0'
  }
 });
 // Create the label filled with the description text.
 var description = ui.Label({
  value: name,
  style: {margin: '0 0 4px 6px'}
 });

 return ui.Panel({
  widgets: [colorBox, description],
  layout: ui.Panel.Layout.Flow('horizontal')
 });
};



var classnames=['Soy Monocropping', 'Soy-Wheat Double-Cropping', 'Corn Monocropping', 'Semi-Natural Area', 'Bare Soil']

 for (var i = 0; i < classnames.length; i++) {
  legend.add(makeRow(palette[i],classnames[i]));
 }

// Add the legend to the map.
Map.add(legend);

Map.addLayer(geometry_moving)
print(maxfracs)

// Export the image, specifying scale and region.
Export.image.toDrive({
```

```
 image:maxfracs, //name of the image I
want to export
 description: 'imageToDriveExample',
 scale: 30,
 region: roi,
 maxPixels: 450000000
});
```

Personal declaration

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

Franziska Moergeli   Place, Date

....