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The role of cropland intensification and land acquisitions across Africa

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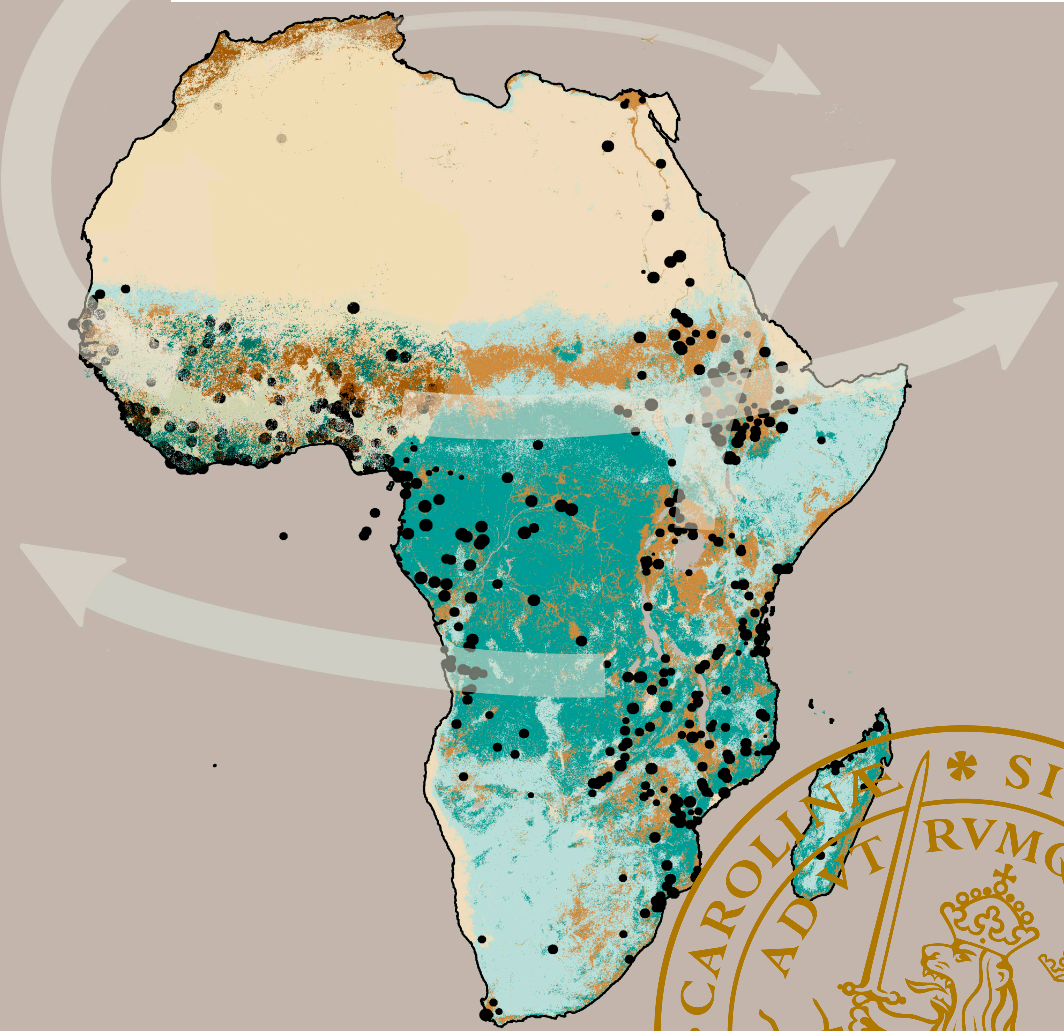
ALTAAF MECHICHE-ALAMI

DEPARTMENT OF PHYSICAL GEOGRAPHY AND ECOSYSTEM SCIENCE | LUND UNIVERSITY



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Altaaf Mechiche-Alami

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Food security in changing climate: the role of cropland intensification and land acquisitions across Africa

Abstract
Food security is one of the world's greatest challenges. The current food system shows an entanglement across the globe which means that local farmers reliant on subsistence agriculture no longer operate in isolation of larger-scale processes within the global economy or the changing biophysical system of the planet. The persistently high number of undernourished people, volatile food prices, increasing population, expected land scarcity and negative impacts of climate change on food production all contribute to a sense of urgency that future food supply in Africa will be threatened. The current global response is increasing food production by improving the productivity of smallholders in developing countries. In recent years this has been achieved through input subsidy programs aiming at agricultural intensification and to some extent Large Scale Land Acquisitions (LSLA).
This thesis investigates the challenges posed to achieving food security for all, particularly by national policies supporting LSLA and agricultural intensification programs by evaluating the local food security and environmental implications across African countries. The thesis consists of four papers framed within changes to the global food system and analyzed through the telecoupling framework. Each of the papers used separate methods, from network analysis (Paper I), GIS and probablilistic assessment (Paper II), remote sensing and residual trend analysis (Paper III) and modeling of farming systems with LPJ-GUESS (Paper IV).
Paper I assesses the evolution of global LSLA by identifying three different phases (2000-2007,2008-2010,2011-2015) related to global economic changes. It shows how African lands were consistently targeted by foreign investments based on the assumption that they could improve food security in the continent and foster economic development.
Paper II demonstrates that LSLA in Africa are in reality mostly targeting export markets and seldom tackle the food security needs of the countries where they occur. At the same time, they risk increasing land pressures and deforestation rates and fueling conflicts, further destabilizing food security.
Paper III shows that between 2000 and 2018, only 15% of croplands in West Africa witnessed significant trends in terms of productivity. These trends were mostly attributed to climatic factors in the Sahel, but increasingly to changes in cropping practices (inputs, irrigation and land rehabilitation) throughout the region.
Assuming the widespread adoption of intensification measures (elimination of fallow periods and higher fertilizer use) in North Africa, Paper IV shows that rainfed wheat yields could increase by up to 25%, but would be accompanied by dramatically higher rates of nitrogen pollution with up to a six-fold increase in leaching and seven-fold increase in N_2O emissions depending on the agro-ecological zone.
Finally, the thesis concludes with reflections on the dangers of prioritizing productivist policies, which I argue are unable to tackle the more pressing food accessibility issues across Africa and benefiting transnational corporations and national elites at the expense of the environment and the livelihoods of smallholder farmers. It also points to agroecology as a potential alternative for sustainably improving food security in the continent.

Key words: Agriculture, Land grabbing, Sustainabiliy, Network Analysis, Earth Observation, Crop Modeling

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Cover photo based on data extracted from MODIS, ESA CCI LC and Land Matrix. Methods described in Papers 1, 2 and 3. The map shows land cover classes (cropland, grasslands, forests and sparse vegetation) in 2000. The darker colors over West Africa show browning and greening trends (2000-2018) in cropland productivity. The black bubbles show locations and size of agricultural land acquisitions (until 2015). The arrows present some of the virtual exports of land from different African regions to investors in the rest of the world.

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وَأَقِيمُوا الْوَزْنَ بِالْقِسْطِ
وَلَا تُخْسِرُوا الْمِيزَانَ

And observe the weight with equity and do not make the balance deficient

(Quran, S.55, V.9 translated by Mohamad Hassan Khan)

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I. **Mechiche-Alami, A.,** Piccardi, C., Nicholas, K. A., & Seaquist, J. W. (2019). Transnational land acquisitions beyond the food and financial crises. *Environmental Research Letters*, 14(8), 084021. doi:10.1088/1748-9326/ab2e4b
II. **Mechiche-Alami, A.,** Yagoubi, J., & Nicholas, K.A. Do agricultural land acquisitions really support food security in African countries? (*Under review)*
III. **Mechiche-Alami, A.,** & Abdi, A. M. (2020). Agricultural productivity in relation to climate and cropland management in West Africa. *Scientific Reports*, 10, 3393. doi:10.1038/s41598-020-59943-y
IV. **Mechiche-Alami, A**., Olin, S., Seaquist, J. Modelling wheat-based farming systems in North Africa. (*Manuscript)*

Contributions

I. A.M-A. led the study design, performed the analysis, interpreted the results with the coauthors and led the writing
II. A.M-A. led the study design, performed the analysis, interpreted the results with the coauthors and led the writing
III. A.M.-A. designed the workflow and conducted the analysis. Both coauthors jointly conceived the study, interpreted the results and wrote the manuscript.
IV. A.M-A. led the study design, performed the analysis, interpreted the results with the coauthors and led the writing

Summary

Food security is one of the greatest challenges of the 21st century. Between the expected negative impacts of climate change on agriculture, and the predicted increase of the global population, there are concerns over our ability to provide sufficient, safe and nutritious food to all people at all times. Today, undernutrition is a reality for about 820 million people across the globe, mostly living in developing countries. In recent years, global development agendas have promoted agricultural modernization in these countries based on the assumption that increasing agricultural productivity would provide more food to the countries' populations and foster economic development at the same time. In this thesis I explore two examples of agricultural modernization in Africa; large scale land acquisitions and agricultural intensification and analyze their impacts on local food security and the environment in four different papers.

The four papers in the thesis use various methods to identify the drivers, direct and undesired impacts of land acquisitions and cropland intensification across different regions in Africa. Paper I evaluates the evolution of global land acquisitions using network analysis. It attributes changes between the three identified phases of land acquisitions to global socio-economic drivers based on the dominant investors, targeted regions and the advertized purpose of the land deals. Throughout time, the largest amount of acquired land was in Africa and was aimed at agricultural production. Paper II then looks at the details of the agricultural deals in Africa and estimates whether they are capable of addressing the identified food security needs of the 38 countries where they occur. By clearing forest areas and targeting the most productive agricultural lands in the continent, these deals often time are meant for producing high value cash crops destined for export. As such they reduce the area used by local farmers to produce food and might lead to production declines rather than gains in at least 27 countries. Paper III relates recent changes in cropland production to climatic changes in West Africa as observed from satellites. It shows that across the region recent changes in rainfall and temperature have had less of an impact than changes to farming practices on crop productivity. Paper IV explores the potential impacts of increasing fertilizer use as an intensification measure on yields and environmental degradation in North Africa using the LPJ-GUESS model. It shows that yield gains as well as associated increases of the capacity of croplands to sequester carbon are often met with larger nitrogen pollution.

In conclusion, I argue that current efforts to increase food production either through higher input farming systems or large scale acquisitions might be trading short term economic and yield gains for longer term land degradation. They might also be unsuccessful in improving food security in the many locations where the problem is lack of access to food rather than its availability. I recommend that these strategies should be re-evaluated to account for the full range of impacts on the most vulnerable peoples' livelihoods and environmental pollution in the long term. This might be the only way to achieve sustainable development goals for all.

Sammanfattning

Att trygga matförsörjningen för Jordens befolkning är en av århundradets största utmaningar. Både klimatförändringars negativa påverkan på jordbruk och befoningstillväxt väntas utmanna tillgången av näringsrik mat för alla människor. I dagsläget drabbas cirka 820 miljoner människor över världen av någon form av undernäring, främst i utvecklingsländer. På senare tid har modernisering av jordbruk stått högt upp på agendan i många utvecklingsländer med föresatsen att ökade skördar kommer att leda till mer mat och bättre ekonomisk uteveckling. I denna avhandling kommer jag att studera två sidor av denna modernisering av jordbruk i Afrika: storskaliga markförvärv och intensifiering av jorbruket, samt analysera dess påverkan på den lokala miljön och livsmedelsförsörjningen.

I de fyra artiklarna som utgör den här avhandlingen har jag använt mig av olika metoder för att studera direkta och oönskade effekter av storskaliga markförvärv och intensifiering av jordbruk över den afrikanska kontinenten, samt att identifiera de drivkrafter som orsakar dem. I artikel I använder jag mig av nätverksanalys för att studera storskaliga marförvärv på den globala skalan. Där identifierade vi tre faser som dessa förvärv har gått igenom och vilka drivkrafter som låg bakom dem samt vilket syfte som användes för att motivera dem. Över tid så har flest av dessa förvärv skett i Afrika i syfte att bedriva jordbruk. I artikel II studeras de jordbruksrelaterade markförvärv i Afrika i mer detalj för att analysera om de kan bidra till att lösa den livsmedelsförsörjningkris som råder i många av de 38 berörda länderna. Syftet i många av dessa markförvärv är att producera grödor för export. Genom att skog skövlas och att den mest produktiva marken säljs till utländska investerare så minskas utrymmet för lokalbefolkningen och deras matproduktion och i minst 27 av de länderna som ingick i studien så ledde inte dessa markförvärv till några ökade exportinkomster. Artikel III kopplar närtida förändringar i jordbruksmark till klimatförändringar i Västafrika med hjälp av fjärranalys. Här visar vi att ändringar i hur marken brukas har haft en större påverkan på grödornas produktivitet än vad förändringar i nederbörd och temperatur har haft. Artikel IV utforskar vi jordbruksintensifieringens effekter på skördar och miljön, det gör vi genom att simulera olika brukningsmetoder med ekosystemmodellen, LPJ-GUESS. I dessa simuleringar över Nordafrika så visade våra resultat att intensifiering kan leda till ökade skördar samt en potential att binda in mer kol i marken, men på bekostnad av ökat kväveläckage.

Slutligen så hävdar jag att försöken att öka matproduktionen genom intensifiering eller storskaliga markförvärv kan byta kortsiktiga vinster mot försämringar i markens bördighet på längre sikt. Dessa aktioner kan också visa sig verkningslösa som ett verktyg för att säkra livsmedelstillgången på de många platser där mat är en bristvara. Jag rekommenderar att innan man etablerar storskaliga projekt, att man bör studerar hur dessa påverkar människors försörjning och deras närmiljö. Det kan kanske vara det enda sättet som vi kan nå de globala hållbarhetsmålen, för alla.

Introduction

Context

> "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 1996).

The 1996 World Food Summit definition highlights the four main components of food security, namely: availability, accessibility, utilization, and stability. At that World Food Summit, 186 nations pledged to pursue food security through increases in food production and trade (FAO 1996).

Globally, food production has been increasing since the 1950s through agricultural expansion and intensification with the Green Revolution providing technological advances in fertilization, irrigation and genetic modification (Foley et al. 2007; Gibbs et al. 2010; Deininger 2011). These advances allowed for rapid cropland intensification whereby global food production more than doubled between 1960 and 2000 for only a 12% increase in cultivated area (Foley et al. 2007; FAO 2019). Food trade that had already increased almost three-fold between 1960 and 1990, increased by a further two-fold between 1990 and 2010, thus augmenting food availability and diversity globally (FAO 2019). These improvements have enabled 72 developing countries to meet the Millennium Development Goals food target of halving the number of undernourished people by 2015 (Alexandratos and Bruinsma 2012; FAO, IFAD and WFP 2015).

Yet over 820 million people are still undernourished today, mostly in Africa and Asia (FAO, IFAD, UNICEF, WFP, WHO 2019).

In the meantime, average global land surface temperatures have increased by over 1.3°C from 1850-1900 to 2006-2015 (IPCC 2019). As a result, the world has faced more extreme climatic events, as well as increased variability in precipitation patterns both seasonally and regionally over the past 50 years (Kovats et al. 2014). This has resulted in yield declines for maize and wheat as well as lower animal growth rates in lower latitude regions (IPCC 2019). With continued global warming, these extreme and variable events are expected to intensify and increase in the future, further destabilizing food supplies and threatening the livelihoods of increasingly vulnerable people in rural Africa and Asia (Lobell et al. 2008; Porter et al. 2014; IPCC 2019).

Paradoxically, while agriculture is suffering from climate change impacts, it is also contributing to GHG emissions. Indeed, agricultural expansion (croplands and pastures) is currently the dominant driver of global Land Use Land Cover Changes (LULCC) especially in developing countries where it occurs through intact forest clearing (Foley et al. 2005; Foley et al. 2007; Ramankutty et al. 2008; Gibbs et al. 2010; Foley et al. 2011; Lambin and Meyfroidt 2011; Alexander et al. 2015). Such changes already account for about 20% of GHG emissions from reduced carbon sinks, high nitrous oxide emissions from fertilizers, and methane from livestock (P. Smith et al. 2014; Tubiello et al. 2015; IPCC 2019). Furthermore, while uncertainties remain as to the exact amplitude of climate change impacts on food production, sustainable adaptation and mitigation strategies are undoubtedly needed and could mean a shift away from intensive agricultural practices (Lobell et al. 2008; Tilman et al. 2011; Wollenberg et al. 2016).

With the expected rise in global population to 10 billion people by 2050 (United Nations 2017), it has been estimated that 9.5 to 26.4 MHa expansion per year of global agricultural (cropland, biofuel, grazing), forested and urban areas would be required by 2030 to supply today's animal-intensive diets (Lambin and Meyfroidt 2011). At this rate, available land resources could be exhausted as early as the 2020's or up to the 2050's at the latest (Lambin and Meyfroidt 2011). For some countries already facing land scarcity problems, this means increasing imports, decreasing exports or acquiring land abroad (Lambin and Meyfroidt 2011).

The persistently high number of globally undernourished people in countries with low agricultural productivity, expected yield declines from climate change and projected increase in global population all contribute to a sense of urgency when planning to secure future food supplies. This has led to the continuation of global agendas focused on increasing food production, with a more recent focus on doing so in an environmentally and economically sustainable manner (World Bank 2007; United Nations 2016). As such, agricultural modernization (mechanized, large-scale, high input agriculture) is encouraged in developing countries as a way to foster economic development (World Bank 2007). Africa emerges as a priority intervention region with plans of an African Green Revolution to be put in place in order to increase cropland productivity through high inputs and improved seeds based on domestic and foreign investments (World Bank 2007; AGRA 2009).

For its part, the perceived land scarcity has led to the emergence of Large Scale Land Acquisitions (LSLA) as the recent practice of leasing or selling land of over 200 ha to governments or companies (Anseeuw et al. 2012). These land deals have been reported since 2000 and involve a constellation of domestic and foreign agents (governments, corporations, individual entrepreneurs) interested in a wide range of sectors from agriculture to tourism including industry, forestry and agro-fuel projects (Grain 2008; Zoomers 2010; Anseeuw et al. 2012). They target resource-rich countries (eg. in Sub-Saharan Africa, Latin America or Eastern Europe) with suitable agricultural land and large yield gaps (Fischer and Shah 2010; Lambin and Meyfroidt 2011; Coscieme et al. 2016). These target countries are also usually among developing or least developed countries and tend to welcome LSLA as Foreign Direct Investments (FDI) as they are advertised as a source of technology transfer, food security, job creation and economic development (World Bank 2007; Grain 2008; Deininger et al. 2010; Zoomers 2010; Anseeuw et al. 2012; Mittal 2014; Nolte et al. 2016).

While the Green Revolution agriculture, relying on heavy use of machinery, fertilizers, and a few hybrid crops, has successfully increased global food availability, it has also been responsible for a large array of environmental problems, including biodiversity loss, soil degradation, and a reduction in water availability and quality (Gleick 2003; Foley et al. 2005; Montgomery 2007; Gibbs et al. 2010; Foley et al. 2011). As such, "modern agricultural land use practices may be trading short-term increases in food production for long-term losses in ecosystem services, including many that are important to agriculture" (Foley et al. 2005 p.570).

Moreover, while LSLA are capable of closing yield gaps (Rulli and D'Odorico 2014), recent studies have shown that the resulting production from LSLA is oftentimes destined to be exported from the countries hosting them, that in many cases are also food insecure (Burch and Lawrence 2009; Borras and Franco 2012). This raises doubts as to whether LSLA are capable of improving food security in the countries where they occur. This is particularly troubling when considering the reported negative impacts on local populations (e.g. displacement of rural populations, loss of livelihood and human rights violations) (Anseeuw et al. 2012; Akram-Lodhi 2015; Nolte et al. 2016) and the environment (e.g. water grabbing to increased deforestation and land degradation) (Rulli et al. 2012; Clements and Fernandes 2013; Johansson et al. 2016).

Furthermore, closing yield gaps alone is not sufficient for providing food security as it only addresses its availability aspect. Indeed, "adequate global supplies do not mean that countries or households have enough food" (World Bank 2007 p.50). Yet, food security policies continue to focus on increasing food production, with the United Nation's Sustainable Development Goal (SDG) target 2.3 aiming at doubling smallholder food production by 2050 (United Nations 2016). The current proposal of an African Green Revolution (World Bank 2007; AGRA 2009), furthers the global expansion of high input agriculture with little consideration to the combination of socio-economic and environmental aspects that composes food systems and influences the accessibility, stability and utilization aspects of food security beyond production (Lang and Barling 2012).

Hence this thesis takes a holistic and critical approach for analyzing the impacts of policies and measures deriving from global production narratives on food security, farmers' livelihood and the environment in African countries.

Objectives and research questions

This thesis investigates cases where global production narratives facilitate land acquisitions and agricultural intensification (mostly through high inputs), and evaluates their impacts on the food security of African countries within the context of climate change.

This is accomplished through a compilation of articles answering four main questions:

- How did global Large-Scale Land Acquisitions emerge and evolve? (Paper I)
- To what extent are large-scale agricultural land acquisitions able to tackle the food security needs of African target countries? (Paper II)
- How do changes in climate and management influence food production in West Africa? (Paper III)
- What is the environmental cost in terms of soil carbon and nitrogen related pollution to cropland intensification in North Africa? (Paper IV)

Structure of the thesis

This thesis provides a systemic perspective to the challenges for African countries to achieve food security in this century through an interdisciplinary approach bridging social and natural sciences. This work is embedded within the field of Land System Science, concerned with understanding the processes by which humans use land resources, as well as their environmental and socio-economic consequences (Turner et al. 2007; Verburg et al. 2013b). This is an interdisciplinary field based on evaluating the drivers and impacts of changes in coupled human and environmental systems (Verburg et al. 2013a). As this thesis explores various drivers and impacts of change to the food system, I have chosen to use the telecoupling framework (Liu et al. 2013; Eakin et al. 2014) as an analytical structure to situate my articles and discuss their findings in relation to the scientific literature.

The thesis starts by an overview of the data and methods I used in each paper. Thereafter, I describe the telecoupling approach used and motivate why this approach is taken in relation to the global food system. I then take a story telling approach, in my overarching analysis of the four papers by following the framework's components of global drivers, driving agents, flows, and direct and indirect impacts on food security. This approach allows for better connection between the different aspects I want to highlight from the papers while contextualizing them within the literature. It also enables me to better negotiate the social and natural science divide to make an argument without being limited by disciplinary constraints. Finally, I discuss some system feedbacks that I have identified in through the Results section by taking a critical stance in regards to the limitations and potential dangers of pursuing the current productivist global agendas as opposed to more sustainable alternatives.

Methodologies

In order to answer the different research questions of this thesis, I have used various data sources and methods (Table 1). Data on land acquisitions from the Land Matrix dataset (The Land Matrix Global Observatory 2016) were used to assess the evolution of LSLA at a global level and the countries involved through network analysis (Paper I). A newer version of that dataset was used in order to establish a typology of land deals and evaluate their ability to improve the food security of African countries (Paper II). The trends in crop phenology, derived from satellite images (MODIS) through time series analysis, were related to trends in climate (rainfall, temperature and radiation) to evaluate the impact of recent climate change on agriculture in the different countries of the Economic Community Of West African States (ECOWAS) (Paper III). Finally, data from field-based surveys (FAO crop calendar, and own fieldwork) together with the MODIS images were used to evaluate the tradeoffs of different farming systems between improving crop yields and depleting soils in Western Africa (Paper IV).

Table 1: Overview of Data and Methods by Paper and which telecoupling elements are studied.

	Research Question	**Study Area**	**Methods**	**Data sources**	**Telecoupling elements**
Paper I	How did land acquisitions emerge and evolve between 2000 and 2015?	Global	Network analysis	Land matrix	Global drivers, agents and flows
Paper II	To what extent are large scale agricultural land acquisitions able to tackle the needs of African host countries?	Africa	Probabilistic impact assessment	Land Matrix National statistics	Global and national drivers and agents National and local impacts
Paper III	How do changes in climate and management influence food production in West Africa?	West Africa	Time series and trend analysis	Satellite-based data	National and local environmental impacts
Paper IV	Is cropland intensification improving yields in North Africa and what environmental cost?	North Africa	Crop modeling	Survey-based data National statistics	Local environmental impacts

Datasets

Land Matrix (Papers I, II)

The growing interest in the controversial consequences of LSLA has called for a greater need for monitoring these deals, which often lack transparency. The Land Matrix initiative has taken the role of gathering data on land deals from public sources, official documents, press releases, academic research, field surveys and crowd sourcing (Anseeuw et al. 2013). The Land Matrix database (The Land Matrix Global Observatory 2016) was created in an effort to increase transparency and accountability regarding land deals and encourage global citizens' active participation and involvement in global land governance issues (Anseeuw et al. 2013; The Land Matrix Global Observatory 2016).

The dataset reports on deals negotiated or concluded since 2000. It provides information on the current status of these deals as intended (or under negotiation), concluded, in production or failed. It also mentions the host country, the investors and the investors' country of origin. Details on the size of the land intended, acquired and / or in production as well as the intention of the acquisition, ranging from agriculture (including crops grown) to tourism, are also reported (The Land Matrix Global Observatory 2016).

Data were extracted for Paper I on March 9th 2016 and were limited to concluded deals with at least one foreign investor between 2000 and 2015. For Paper II, this subset was complemented by another extraction from the updated dataset on March 1st 2019 and was limited to concluded deals intended for agriculture or biofuel production in African countries between 2000 and 2015 irrespective of the origin of investors. This new version of the dataset also includes information on the intended destination of the production (local or export markets).

National statistics datasets (Papers II and IV)

The FAO and World Bank continuously monitor data on a range of indicators that are relevant to food security. In paper II, indicators on average dietary energy supply adequacy, prevalence of undernourishment, value of food import over total merchandise exports, access to improved water and sanitation were extracted from the food security suite (FAOSTAT, 2017). Domestic supply of vegetables and fruits and the average dietary energy supply adequacy without imports were calculated from the food balance sheets (FAOSTAT, 2017). The poverty headcount ratios at national poverty lines were extracted from the World Bank dataset (World Bank 2015).

The Spatial Production Allocation Model (SPAM) from the International Food Policy Research Institute (IFPRI) was used in Paper IV. It disaggregates these national statistics to the pixel level (10Km) and estimates crop distribution distinguished by four different types of management systems; irrigated, high input, low input and subsistence for the years 2000, 2005 and 2010 (You et al. 2009; You et al. 2014).

Satellite-based data (Papers II, III and IV)

In Paper II, satellite sensor-derived products were used to establish the biophysical characteristics of the location of deals circa 2000. Land cover data for the year 2000 at 1Km were taken from ESA for papers II and III (ESA 2017).

Vegetation data in Papers III and IV were derived from the Moderate Resolution Imaging Spectro-radiometer (MODIS). MOD09Q1 images from the latest Collection V6 for the red and near infrared (NIR) bands of 250m resolution for every 8 days were downloaded between 2000 and 2018. These were used to calculate, according to [1], the Normalized Difference Vegetation Index (NDVI), a spectral index of photosynthetic activity.

$$NDVI = \frac{\text{NIR}-\text{Red}}{\text{NIR}+\text{Red}} \quad [1]$$

In Paper III, the images cover the region from Senegal to Nigeria that encompasses all countries of the Economic Community of West African States (ECOWAS) except for Cabo Verde. In Paper IV, they cover the North African countries of Morocco, Algeria and Tunisia.

Climate data for Paper III were also extracted from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA for temperature and solar radiation at 10 km resolution (Dee et al. 2011) and from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) for precipitation at 5 km resolution (Funk et al. 2015).

Survey-based data (Paper IV)

Paper IV relies on results from surveys conducted by different projects as well as my own fieldwork in Morocco in April 2018. The FAO crop calendar collects information on sowing and harvesting periods as well as cropping practices for 130 crops based on country level agro-ecological zones (FAO 2010). These data were extracted for North African countries for paper IV.

During my fieldwork in Morocco, I conducted semi-structured interviews in individual meetings with researchers and policy makers from various government institutions and research institutes. I also interviewed 20 farmers in four different regions of the country based on an established questionnaire related to their farming practices (crops grown, rotations. sowing time, irrigation, fertilizers and average, minimum and maximum yields attained). Extended conversations with farmers and extension officers were used to establish assumptions for representing farming systems in paper IV.

Methods

Network analysis of transnational LSLA (Paper I)

Networks (or graphs) represent how a set of nodes or vertices are connected to each other through links or edges (Newman 2010). Edges can be directed, meaning that the connection between nodes only happens in one specific direction (Newman 2010). This can be thought of as a one-way path between an origin and a destination point. Edges can also be weighted whereby a weight representing a specific characteristic of the edge is assigned to it (Newman 2010). Network analysis tools enable the identification of patterns, communities and preferentiality within networks, and as such, have been extensively used to analyze global trade (Serrano and Boguna 2003; Garlaschelli and Loffredo 2005; Dalin et al. 2012; Piccardi and Tajoli 2012; Cingolani et al. 2015).

In paper I, global LSLAs are presented as a Land Trade Network (LTN), such that the nodes $i = 1,2, \dots, N$ represent the $N = 125$ countries participating in LSLA (bubbles in Figure 2 which size represents the total amount of land exchanged) and the L=486 edges correspond to the deals concluded between these countries (links between bubbles in Figure 1) weighted by the total amount of land transferred between countries (width of the links in Figure 1). These edges are directed as they flow from the exporting countries (or host countries providing the land) to the importing countries (investing in foreign land) as marked by the color of the link corresponding to the exporting country in Figure 1. The weights associated with each edge represent the aggregated amount of land traded between the two countries (in ha). This is exemplified in Figure 1 through the thickness of the links between countries, while the size of the bubbles represents the total amount of land exchanged (imported + exported) by each country.

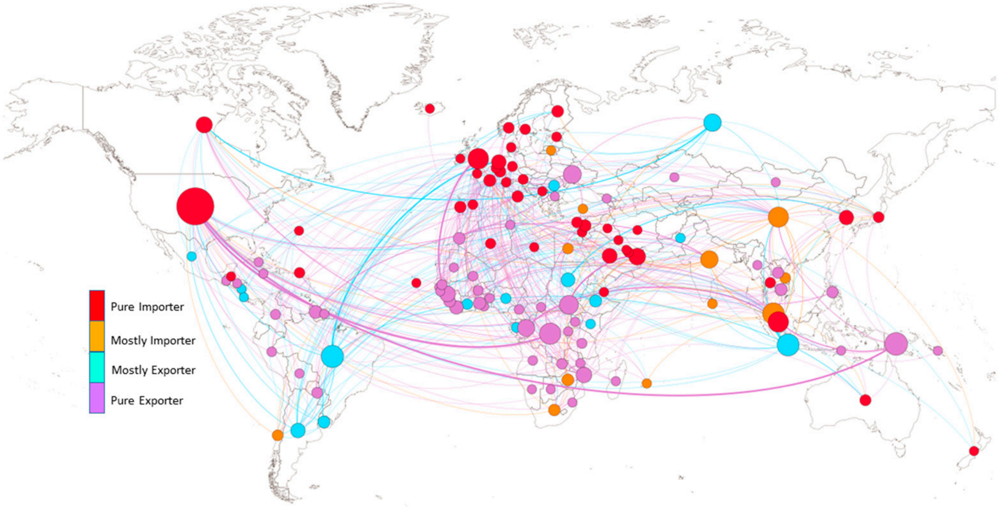

Figure 1: Network of LSLA between 2000 and 2015. The size of a node (country) represents the total amount of land exchanged (imported + exported), the color refers to the country classification from Pure Importer to Pure Exporter. The width of an edge (flow) represents the total amount of land transferred from the target to the investor country and the color refers to the target country

Network analysis tools provide information on the structure of a network, the positions of the nodes within the network, and their positions within their neighborhood. By applying basic network metrics to a weighted and directed LTN, it is possible to identify the structure of the network and its geographical patterns. This is done by assessing the global (absolute) position of each country i, based on its number of import/export partners (in-degree k_i^{in}/out-degree k_i^{out}), number of import/export deals (in-deals n_i^{in} /out-deals n_i^{out}) and amount of imported/exported land (in-strength s_i^{in}/out-strength s_i^{out}) (Newman 2010). The relative (local) positions of countries are characterized by the type of partners with which they interact (authority x_i and hub y_i centrality) (Kleinberg 1999; Newman 2010). In other words, if a country imports large amounts of land from heavily exporting countries, then it will have a large authority measure while a country exporting large tracts of land to strong importers would have a large hub centrality

Furthermore, by combining these metrics, it is possible to characterize the trading behavior of each country. This could be thought of as a multi-criteria ranking and thereby moves beyond simply accounting for the amount of land acquired or transferred. Indeed, countries' behaviors in the LTN such as how competitive they are in terms of number and types of partners, number of deals and amount of land exchanged, qualify the functional role they play in the network. These metrics can thus be combined in order to group countries using the notion of role-based community detection as proposed by Berguerisse-Diaz et al. (2014). By identifying role-based communities of countries, it is possible to classify them as competitive, preferential, diversified, and occasional, and evaluate if and how it changed over time.

Assessing food security needs: indicators and thresholds (Paper II)

Paper II estimates the food security status of African countries hosting LSLA with a baseline representing the year 2000. Two indicators were selected for each of the four dimensions of food security and thresholds were applied based on the desired outcomes of the SDGs (Table 2).Countries would then score between 0 and 2 on each dimension based on the number of thresholds fulfilled.

A ranking of dimensions was then adopted to determine the priority needs of countries starting from availability, accessibility, stability and lastly utilization. The severity of food insecurity was also assessed by considering countries where sufficient food is not available, unaffordable or where undernourishment concerns over 30% of the population as severely insecure. On the other hand, if there are sufficient supplies of affordable food in the country which is either self-sufficient or has high capacity to import food, then it is considered as relatively food secure. The cases in between are labelled as moderately food insecure.

Table 2: Selected food security indicators and thresholds to assess FAO's four dimensions of food security in 38 African countries (United Nations 2016; FAO 2018a)

Dimension	Indicator	Threshold
Availability	1.1 Average dietary energy supply adequacy (%)	≥ 95%
	1.2 Domestic supply of vegetables and fruits (g/day/capita)	≥ 400g
Accessibility	2.1 Prevalence of undernourishment (% of population)	≤ 5%
	2.2 Affordability index	>0
Utilization	3.1 Access to improved water sources (%)	≥ 95%
	3.2 Access to improved sanitation facilities (%)	≥ 95%
Stability	4.1 Self-sufficiency	≥ 95%
	4.2 Value of food import over total merchandise exports (%)	≤ 11%

A ranking of dimensions was then adopted to determine the priority needs of countries starting from availability, accessibility, stability and lastly utilization. The severity of food insecurity was also assessed by considering countries where insufficient food is available, unaffordable or where undernourishment concerns over 30% of the population as severely insecure. On the other hand, if there are sufficient supplies of affordable food in the country which is either self-sufficient or has high capacity to import food, then it is considered as relatively food secure. The cases in between are labeled as moderately food insecure.

Probabilistic assessment of LSLA impacts (Paper II)

Paper II also evaluates the ability of different land deals to address the food security needs of the countries that host them. This is done through a probabilistic assessment (eg. Table 3) of the destination (local or export) of the production from LSLA, based on the origin of investors (domestic, foreign, mixed), investing sectors (agribusiness, government, finance, etc.), types of investors (individual, investment fund, private company etc.), and intended crops (food stuffs, cash crops, biofuel, etc.).

The probability of a deal's production to be exported or sold on local markets is calculated based on the origin, type and sector of investors as well as the nature if the intended crops for those deals were this information was reported in the Land matrix dataset. It was then used to assign the destination of the production for the deals where it was not available.

Table 3: Probabilistic assessment of deals' production destination based on crops and investors in the case of foreign investors. Colors represent the most probable destination market. Numbers refer to the probability of deals to be destined for the market indicated by color (when data were available, 65% of deals).

Foreign	Agri						Finance						Gov	Others				
	Individual	Fund	NPO	Private	State	Listed	Individual	Fund	NPO	Private	State	Listed		Individual	NPO	Private	State	Listed
Cash & Flex				0.7	0.8	0.5	1	1		1			1			1		1
Cash & Food				0.7						1			1			0.6		
Flex				0.6	0.6	0.5				1		0.8		1		0.6	0.8	1
Food		0.6		0.7	0.8	0.5		0.9	1	0.8			1	1	0.5	0.8		
Livestock				0.6	1	1					1					1		
Food & Flex		0.9	0.8	0.6	1	0.8		0.7	1	0.8	0.6	0.8	0.8			0.6		

Markets: Local · Mostly local · Both · Mostly export · Export

Distinguishing between the effects of climate and management changes on crop productivity (Paper III)

When analyzing the effects of the global production narrative, it is important to distinguish between the impacts of changes in climate and shifts in cropland management on crop productivity. In paper III, this is done through residual trend (RESTREND) analysis (Wessels et al. 2007), whereby the effect of climatic trends is removed from the trends in NDVI integrated over the growing season (iNDVI) as a proxy for crop productivity, thus resulting in assessments of increased (greening) and decreased (browning) cropland production.

The TIMESAT software package was used in order to analyze the extracted NDVI time series and derive phenology parameters of start of season, length of season and integrated NDVI (iNDVI) over the growing season, used as a proxy for cropland productivity (Eklundh and Jönsson 2015). Temporal trends for each of these parameters were calculated based on the Thiel-Sen Slope method and compared to the trends in the residuals of the relationship between iNDVI and climate and LOS and iNDVI as per Figure 2.

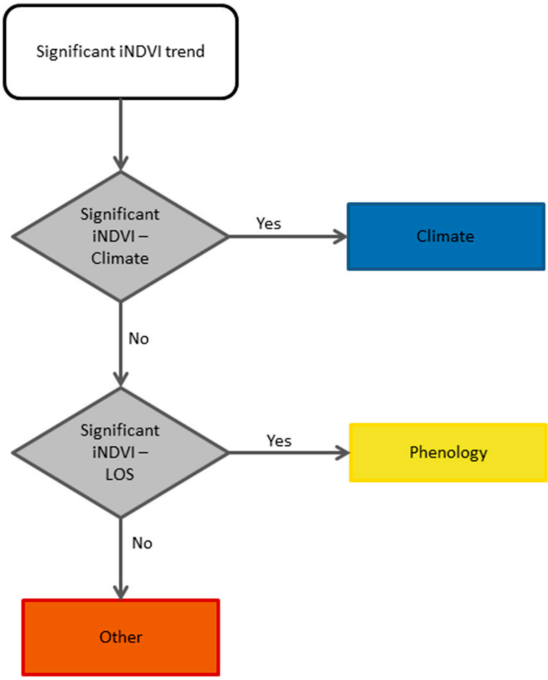

Figure 2: Attribution framework of the iNDVI (crop productivity) trends. Significance is defined at $p<0.05$ for the iNDVI trends, the iNDVI – climate relationship and the iNDVI – Length of Season relationship. Other refers to the use of inputs and irrigation or land degradation

LPJ-GUESS (Paper IV)

Crop models are process-based simulation models used to evaluate the dynamic response of crop production to climate changes by taking into account managerial conditions at a broad scale (Angulo et al. 2013; Porter et al. 2014). LPJ-GUESS is a process based Dynamic Global Vegetation Model (DGVM) designed for regional or global studies. It simulates vegetation growth and ecosystem composition based on given climatic and soil conditions as well as atmospheric carbon dioxide concentrations. (Smith et al. 2001; Smith et al. 2014). This model simulate the behavior of different plant functional types (PFTs including types of trees and grasses) both spatially and temporally as well as their ecosystem functions (primary production and evapotranspiration) by assessing the effects of environmental change (Bondeau et al. 2007). The effects considered by LPJ-GUESS are those of temperature, precipitation, radiation, CO_2 concentrations, land use, soil types and nitrogen deposition.

The version of LPJ-GUESS used in this study represents crops as crop functional types (CFTs) sharing similar growth, phenology and climatic response properties (Lindeskog et al. 2013). This version of LPJ-GUESS was further improved by Olin et al. (2015) to account for nitrogen cycling and includes nitrogen fertilization in the management practices for crops.

Assessing environmental tradeoffs to cropland intensification (Paper IV)

In paper IV, I tested the version under development that includes Nitrogen Biological Fixation (BNF) by comparing the standard simulation setting of the model (continuous mono-cropping) to more complex farming systems (rotations, fallows, multi-cropping). The resulting yields were compared to national statistics and farmer reported yields.

An intensification scenario that consisted of increased fertilizer application and reduced fallow period was established and the resulting yields, soil carbon, nitrogen fixing, emissions and leaching were compared to the current situation. This enabled to me to identify tradeoffs between yield gains and nitrogen pollution in the various agro-ecological zones of North Africa.

Telecoupled food security - Results

In this section I present the results of the four papers by taking a story telling approach based on the telecoupling framework. I start by describing the global food system and motivating the use of the telecoupling framework. I present how I modify the telecoupling framework and situate my articles in it. Thereafter, I present the results as a narrative following the structure of the components of the telecoupling framework: global drivers, driving agents, flows, direct and indirect impacts on food security.

Framing

The global food system

The food system is generally viewed as the activity chain moving foods 'from field to table' (Sobal et al. 1998; Ericksen 2008). It represents "the set of operations and processes involved in transforming raw materials into foods […], all of which functions as a system within biophysical and sociocultural contexts." (Sobal et al. 1998, p.853). As such, food systems are based on interactions between and within environmental and social systems which influence the production, processing, distribution and consumption of food (Ericksen 2008). These activities (Figure 3) then impact on food security (using the FAO definition (FAO 2018a) consisting of four dimensions: availability, accessibility, stability and utilization), biophysical (ecosystem functioning, land) and socio-economic (livelihoods, social and political capital) systems (Ericksen 2008). Trade-offs exist between the various impacts which then feedback into the biophysical and socio-economic systems (Ericksen 2008, Figure 3).

The food system, and with it, food security are tightly related to economic development and geopolitics, and are influenced by changing world orders (Friedmann 2005; Burch and Lawrence 2009; FAO, IFAD and WFP 2015). Recent transformations to the supply chain of the food system have implications for the division of labor and profits between agents and spatial regions (Friedmann and McMicheal 1989; Gereffi et al. 2005; Gibbon et al. 2008). As such, the globalization of the economy also led to the globalization of the food system and its food security impacts; as food consumed in one country is oftentimes produced and packaged in multiple others (Ericksen 2008; Burch and Lawrence 2009; Reardon et al. 2009).

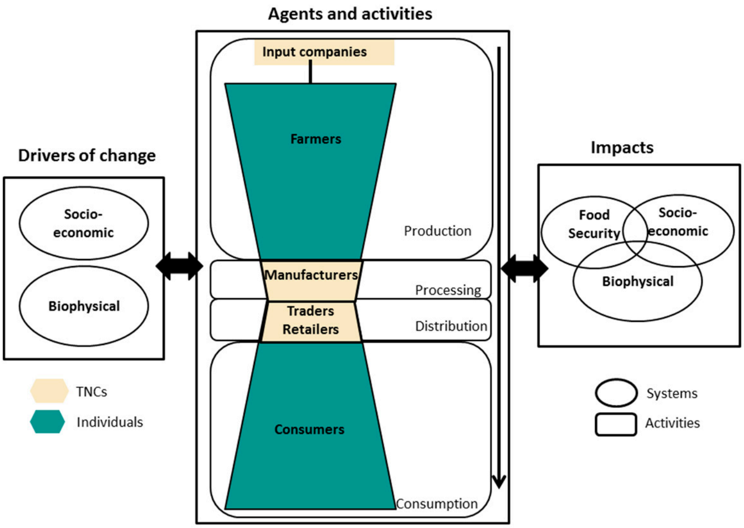

Figure 3: Conceptualization of the food system in terms of its activities (shown in curved boxes), agents (shown in the central column) and its impacts (adapted from Ericksen 2008). The system's inputs are socio-economic and biophysical drivers of change, such as population growth, economic development, land availability and climate change. Agents within the food system responsible for the activities from production to consumption respond to these drivers. These activities in turn produce impacts on food security, the socio-economic and biophysical systems such as food availability and accessibility, incomes and purchasing power and yield increase and greenhouse gases emissions. (TNCs refer to Transnational Corporations).

The agency over the system's activities are also transformed throughout time, with control over the supply chain moving from the state to the private sector (especially the food processing and retailing activities) since the 1980's (Reardon et al. 2009). This has also led to a shift of economic activity in the food system with more capital derived from processing and retailing rather than farming (Ericksen 2008). The growth of international mergers and acquisitions furthered the capital accumulation of Transnational Corporations (TNCs) through the integration of global supply chains and international competition to produce at the lowest cost in order to gain larger market shares (Gibbon et al. 2008; Burch and Lawrence 2009; Reardon et al. 2009).This led to the current hourglass-shaped food system where a large number of farmers are squeezed between a continuously shrinking number of input and trading companies (Figure 3).

Such complexity in the food system, with changes to its global structure having implications for local agents, requires a cross-scale and across disciplinary analysis of food security (Ericksen 2008), making the telecoupling framing of this thesis appropriate.

Telecoupling framework

Telecoupling is an integrated framework emerging from Land System Science, that describes distant interactions between coupled socioeconomic - environmental systems in terms of geographic and social distances (Liu et al. 2013; Eakin et al. 2014). Liu et al. (2013) define interacting coupled human-natural systems connected by flows of material, information and/or energy initiated by agents due to a change in a system (causes), and having direct or indirect impacts (effects) on another system that can in turn feed back to the initial system (Liu et al. 2013; Eakin et al. 2014; Friis et al. 2016).

The telecoupling framework can be exemplified through the soybean trade telecoupling describe in Liu et al. (2013). Through increased access to fertilizers (cause), soybean production in Brazil increased. At the same time, higher meat-based diets in China pushed for more livestock production which depends on soybean as feed (cause). China then imports soybean from Brazil (flow) which increases the demand for soybean in Brazil leading to more expansion through deforestation (effect). This telecoupling then has impacts beyond China and Brazil, as other soybean exporters lose on Chinese markets (spillover effect).

In this thesis, I combine elements from two analytical approaches to telecoupling; a structural (Liu et al. 2013) and a more heuristic approach (Eakin et al. 2014). I analyze agents initiating flows as a response to socio-economic and environmental drivers as presented in Liu et al. (2013), and their direct and indirect impacts as well as resulting feedback processes as envisioned by Eakin et al. (2014).

Story telling through the telecoupling framework

In this thesis, I focus on changes (flows of land and agricultural productivity driven by LSLA and intensification policies) to the global food system (mostly production activities). While these changes are driven by changes to the socio-economic (eg. population growth, food insecurity, poverty) and biophysical (eg. climate change, land scarcity) systems (Figure 3), I only consider these aspects as drivers and do not analyze them as systems but focus instead on their direct and indirect impacts food security in African countries (Figure 4).

To present a holistic perspective on the results from the papers using the telecoupling framework, it is central for understanding the global drivers as well as the agents responsible for the flows. As the quantitative analysis from my papers mostly tackles the flow (of land and inputs) and impact components of the framework, the discussion of global drivers and agents is mainly done based on the scientific literature (Figure 4).

Paper I identifies flows of land due to global LSLA over time and changes in the behavior of countries (agents). It also discusses potential drivers to global land acquisitions. Paper II focuses on the direct impacts of LSLA on food security (availability, accessibility, stability and to a lesser extent utilization) across Africa. It considers state institutions and companies as agents driving LSLA. It also discusses the implications of LSLA on local people' and farmers' livelihoods (socio-economic indirect impacts) and deforestation (environmental indirect impacts). Paper III investigates the relationship between farm management practice and climate change in West Africa and as such touches upon environmental drivers, direct impacts on food production and environmental indirect impacts. Finally, Paper IV examines the potential consequences (environmental indirect impacts) of agricultural intensification on the carbon and nitrogen cycles in North Africa (Figure 4).

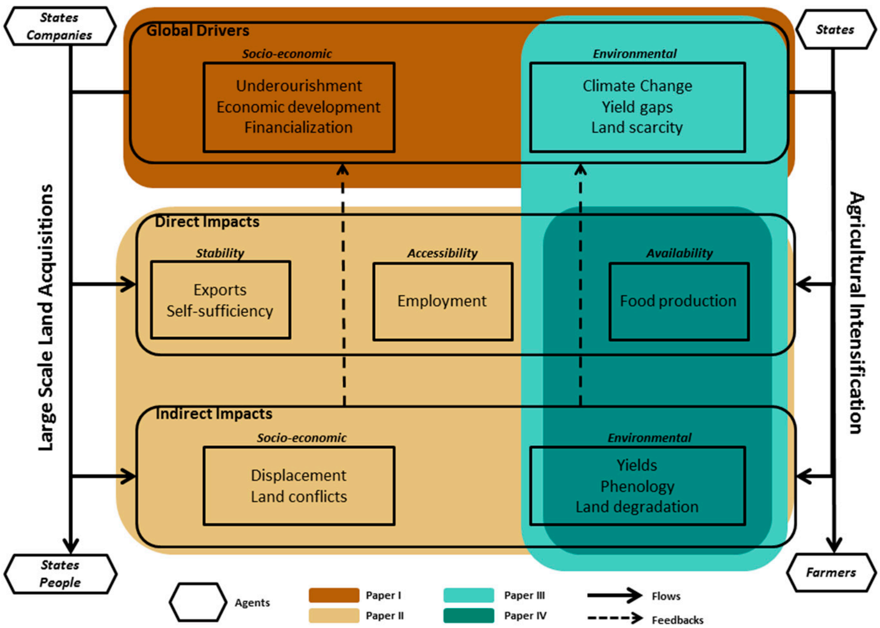

Figure 4: **Thesis structure based on the telecoupling framework.** Each paper is represented by a colored band over the telecoupling elements studied. Paper I identifies the global socio-economic and environmental drivers of LSLA by analyzing flows of land. Paper II analyses the impacts of large-scale land acquisitions (flows of land) on food security as well as the local implications for peoples' livelihoods and risks of deforestation in African countries. Paper III evaluates trends in agricultural productivity and soil degradation and distinguishes between climatic and anthropogenic (flows of inputs) drivers in West Africa. Paper IV quantifies the treadoffs between yield increase and nitrogen pollution resulting from cropland intensification (flows of inputs) in North Africa.

Global drivers

Food security narratives

From the World Food Summit of 1996, to the current Sustainable Development Goals, the importance of increasing food production is emphasized as a solution to global undernourishment (FAO 1996; United Nations 2016). In light of the expected rise in global population, and a shift to more meat-based diets, it has been estimated that global crop production would have to double by 2050 to satisfy this growing demand (Dawson et al. 2016; United Nations 2016; Zhao et al. 2017; IPCC 2019).

Publication rates of scientific literature on attaining global food security has increased 10-fold between 1970 and 2000 and boomed thereafter reaching 1500 publications in 2018 alone, most of which focused on increasing production (Tamburino et al. 2020). Older studies have pointed to the potential for agricultural expansion in Sub-Saharan Africa and Latin America to increase global food production by 20% (Alexandratos 1999). More recent studies have estimated that by closing global yield gaps, production of cereals could increase by 43% to 60% (Neumann et al. 2010; Foley et al. 2011). They have also pinpointed Africa, Eastern Europe and some parts of Asia and South America as regions with the highest yield gaps where further intensification could overcome currently low yields and enable increasing production of major crops (Licker et al. 2010; Neumann et al. 2010; Foley et al. 2011; Pradhan et al. 2015).

Yield gaps are important in African countries (Pradhan et al. 2015). Yields are constrained by biophysical and socioeconomic properties related to climate hazards (floods and droughts), pests and weeds, soil fertility and market accessibility (Pradhan et al. 2015; Tadele 2017). Market accessibility hinders the timely acquisition of inputs, extension services and selling of surplus production (Pradhan et al. 2015). Pests, which are increasing and spreading due to climate change, cause between 30 and 60% yield loss depending on the crop and region (Tadele 2017). Soil fertility is reported as a constraint across the continent (Mueller et al. 2012; Pradhan et al. 2015) but the nature of the limitation varies by region (Jalloh et al. 2011). Finally, weather shocks have considerable significance for loss of productivity especially in North and South Africa, and to a lesser extent in East Africa (Pradhan et al. 2015).

As of 2000, I found that 19 African countries were suffering from severe food insecurity either due to insufficient food supplies or high prevalence of undernourishment (Paper II, Figure 5). Moreover, of the 25 countries that depended on imports to satisfy their population’s needs, I identified that only 4 countries could afford them without it weighing heavily on their trade balance (Paper II, Figure 5).

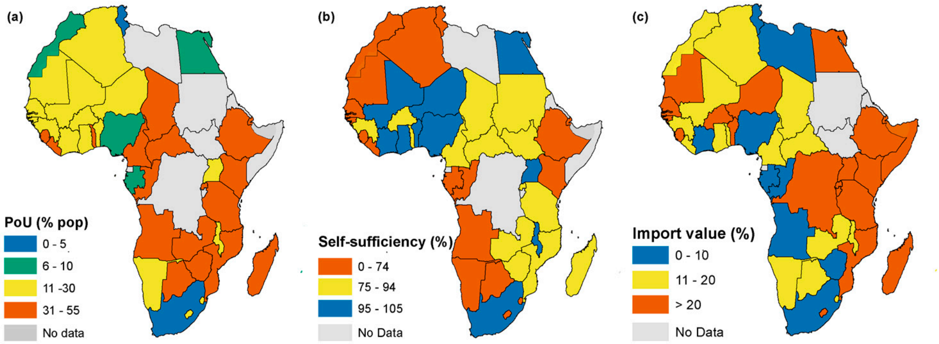

Figure 5: Food security indicators for African countries in 2000. (a) Prevalence of undernourishment (PoU) as a percentage of total population;(b) the Average Dietary Energy Supply Adequacy (ADESA) represents the ratio of available calories in the country without imports compared to the average needs per capita; (c) the value of food imports over total merchandise exports as an indicator of the financial capacity of countries to import food (adapted from Paper II)

The 2007-2008 food crisis that resulted in a doubling of wheat, rice, maize and soybean prices imposed heavy costs on food importing countries (FAO 2008). This lead to an increase in the number of undernourished people to a record high of 1 billion people fueling hunger riots in multiple developing countries and sparking a sense of global urgency in dealing with the food crisis (World Bank 2007; FAO 2008; Clapp and Helleiner 2010). Rich net food importing countries such as Korea, Japan, Singapore and the Gulf countries resolved to acquire land abroad to secure future food supplies for their populations (Friis and Reenberg 2010; Zoomers 2010; Arezki et al. 2011; De Schutter 2011b). For their parts, developing countries, more aware of the dangers of the food import dependency created by the 1980s structural adjustment policies, implemented agrarian reforms to modernize their agricultural sector and produce more food through investments (including LSLA) and trade liberalization schemes (World Bank 2007; FAO 2008; Collier and Dercon 2014). While food prices have stabilized since 2011, 53 countries in Asia and Africa still depend on food aid to feed their populations (FAO, IFAD and WFP 2015; FSIN 2019), further highlighting the urgency of increasing food production in these countries (World Bank 2007).

Agriculture-driven economic growth

The World Bank Report (2007) exemplifies the poductivist narrative that argues modernizing agriculture in Africa and moving towards a sustainable green revolution in the continent is urgent to foster economic development while working towards eradicating hunger. The main drivers of food insecurity in the continent are mostly attributed to poverty, lack of agricultural productivity due to high yield gaps or natural disasters, a lack of market integration and trade, and more recently to political instability and economic slowdowns and downturns (World Bank 2007; FAO, IFAD, UNICEF, WFP, WHO 2019; FSIN 2019). As such, international development programs continuously promote investments in agricultural inputs (mechanization, irrigation, enhanced seeds, fertilizers and pesticides) to increase yields as well as prioritize trade to achieve food availability (World Bank 2007; AGRA 2009; UNCTAD 2009; Clapp and Murphy 2013).

In theory, agricultural surplus would have a trickledown effect on national economies, increasing industrial growth and employment (World Bank 2007; De Janvry and Sadoulet 2010; Sjöström 2015). As such, the aim of agriculture for development is to move away from subsistence towards commercial farming, lifting rural populations out of poverty, scaling up modes of production and obtaining agricultural surplus to feed international markets (World Bank 2007; Sjöström 2015). This can be achieved through commercial production of previously imported crops, cash crops meant for exports or foreign direct investments (Sanchez et al. 2007; World Bank 2007; De Janvry and Sadoulet 2010).

Foreign Direct Investments (FDI) have been encouraged in countries that do not have sufficient economic capacity for modernizing their agricultural production and adaptation capacity against climate change impacts (World Bank 2007; Cotula et al. 2009; Deininger 2011; Karlsson 2014). The slow incremental process of moving smallholders from subsistence to commercial farming was jump started by LSLAs after the urgency triggered by the food crisis (Cotula et al. 2009; UNCTAD 2009; Zoomers 2010; De Schutter 2011a; Anseeuw et al. 2012; Karlsson 2014; Paper I). These acquisitions are believed to increase food production, transfer technologies to close yield gaps and offer employment opportunities, all feeding into the expected multiplier effect of agricultural growth (Deininger et al. 2010; De Schutter 2011a; Rulli and D'Odorico 2014).

Driving agents

Financialized corporations

The current hourglass shaped food system (Figure 3) is based on transnational corporations' control of the flow of food (traders, manufacturers and retailers) from farmers to consumers, as well as inputs (seeds and fertilizers) to farmers (Mascarenhas and Busch 2006; Murphy and Burch 2012; Sjöström 2015). Mergers and acquisitions over the past 20 years mean that today three companies (Dupont-Dow, Sygenta-ChemChina and Bayer-Mosanto) control 60% of the global seed and 75% of the pesticide markets (ETC Group 2017). Four companies, known as ABCD (Archer Daniels Midland, Bunge, Cargill and Louis Dreyfus Commodities) control almost all of global grain and oilseed trade - also used as biofuels (Murphy et al. 2012). By adopting product diversification, outsourcing schemes and vertical integration as business models, transnational corporations control food supply chains (Friedmann 2005; Gereffi et al. 2005; Gibbon et al. 2008; Reardon et al. 2009). These oligopolies can thus accumulate profits by imposing low purchasing prices on farmers and higher selling ones on consumers (Van Der Ploeg 2010; Murphy and Burch 2012). They also require and lobby for high yielding industrialized agriculture for the consistent supply of standardized food products and a sustained demand for improved seeds, fertilizers and pesticides (Van Der Ploeg 2010).

Transnational corporations are increasingly financialized, meaning their use of financial and investment apparatuses within their production process has considerably increased (Murphy et al. 2012). Agricultural financialization has presented new profit opportunities in agricultural systems not only for the agro-industrial sector from manufacturers to agri-food companies and supermarkets, but also to financial investors such as hedge funds, private equities and commodity traders (Burch and Lawrence 2009). The financialization of agriculture has arisen in different ways, from the introduction of commodity swap contracts for derivative agricultural markets (Burch and Lawrence 2009; Clapp and Helleiner 2010; Anseeuw et al. 2017), to the rise of flex crops (e.g. maize could be used as food, feed or fuel) as new speculation havens for commodity traders (Sorda et al. 2010; Borras et al. 2014; Hertel 2017; Genoud 2018). Investors' interest in agriculture or land comes from the expected shrinking of natural resources, the attractiveness of profits to be made by the meat industry with shifting diets in Asia, the interest from resource-poor countries in securing food supplies, and the expected incomes from potential carbon credit markets and water rights (Murphy et al. 2012; Fairhead et al. 2015; Hertel 2017; Conigliani et al. 2018; Mehrabi et al. 2018). It now means that financial institutions (banks, hedge funds and private equities) can speculate on commodity exchange markets and manage agro-industrial processes from agricultural inputs to retail, and more recently the farmland itself through LSLA (Burch and Lawrence 2009; McMichael 2012; Murphy et al. 2012; Vivero-pol 2017). LSLA also provide new opportunities for TNCs to expand their production area to developing countries where environmental regulations are less strict, labor and land cheaper and with a growing consumer base (McMichael 2012).

The state as facilitator

While the structural adjustment policies of the 1980's were based on the fundamental "hands off" approach that led to the neglect of the agricultural sector in the 1980s (World Bank 2007; De Schutter 2011b), the state is now regarded as an important actor in facilitating the modernization and liberalization of agriculture in developing countries (World Bank 2007; Sjöström 2015).

Public investments in infrastructure such as paved roads and highways are expected to facilitate the market integration of smallholders while stimulating private investments (Sanchez et al. 2007; World Bank 2007). Input subsidies that would stimulate surplus productivity, would allow smallholders to qualify for microfinance and bigger loans, thus fostering commercial farming (Sanchez et al. 2007; World Bank 2007; AGRA 2009). The adoption of investor-friendly policies would attract foreign investments in agriculture including LSLA (World Bank 2007). Through intensification and liberalization, the state can then generate surplus revenue to be reinvested in the development and the expansion of social structures (Burchardt and Dietz 2014). This goes without mentioning the rent profits that could be accumulated by the state and local elites through LSLA (Acosta 2013; Lanz et al. 2018; Ogwang and Vanclay 2019).

Flows

Large Scale Land Acquisitions (Paper I)

Modern LSLA have been reported since 2000 and covered an area of over 43MHa by 2015 (The Land Matrix Global Observatory 2016). These acquisitions have however not been consistent in time and space.

In Paper I, I found that they started with a slow phase of establishment where 19% of this area was acquired between 2000 and 2007. These first acquisitions occurred predominantly within geographically proximate regions and were characterized by some level of cautiousness whereby the majority of importing countries were investing in small amounts of land in multiple countries (diversified) or acquiring larger amounts in a selected number of countries (preferential). The exporting countries were also mostly preferential and occasional (participated in relatively few deals).

The second phase I identified, which coincides with the food and financial crises, accounted for half of the acquired area in just three years and broke with the exercised caution of Phase 1. Indeed, more countries traded land in a more competitive environment. The largest number of importers and exporters were classified as competitive (exchange large amounts of land with many countries in multiple deals). This period also marks the "rush for [African] land"; as over 10MHa in the continent (51% of trade during this phase) were acquired by Asian, European and North American investors.

The last phase I identified, between 2011 and 2015, manifested a return to intra-regional trade and more South-South exchange mostly led by Asian investments in Africa (Paper I). Competition between land exporters remained strong during this phase with 43% of exporters being classified as competitive, while importers became more occasional and targeted fewer countries, probably as a response to the publicized criticism of LSLA and the economic failure of multiple deals (Deininger et al. 2010; Committee on World Food Security 2014).

Throughout these phases, 73 countries were always active in trading land and 23 of them occupied the same roles, with the USA, UK, China, Singapore and Malaysia being competitive importers and Brazil, Argentina, Uruguay, Indonesia, Cambodia, Mozambique and Ethiopia as competitive exporters (Figure 6). This demonstrates that land acquisitions form a well-established market led by a large number of countries competing to secure the highest market shares.

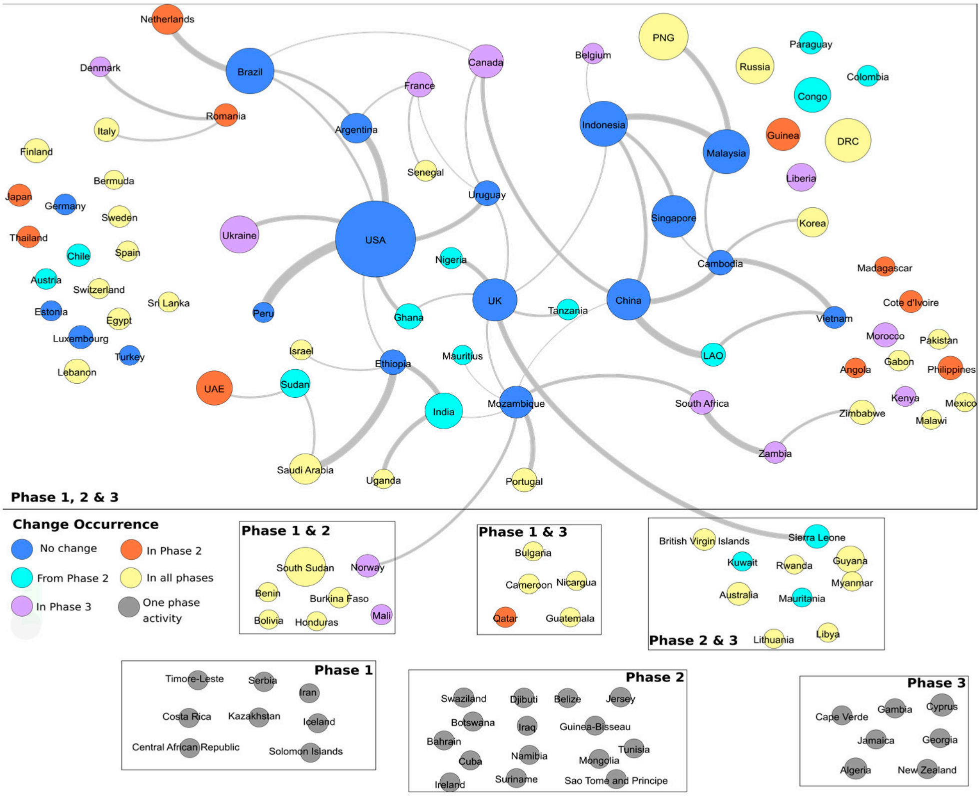

Figure 6: Summary of role changes in the Land Trade Network. Countries are grouped by phase of activity. Node size is proportional to the total amount of land exchanged; color indicates during which phase a change in countries' role occurs (eg. "In Phase 2" means that a country had the same role in phases 1 and 3 but not in Phase 2 while "From Phase 2" means that a country had one role in Phase 1 and a different one in Phase 2 which remained the same in Phase 3). Lines denote partnerships of more than 4 years between countries, and thickness represents the duration of the partnerships (Paper I).

Intensification policies in African countries

> "Intensification refers to improved productivity or output using proper agricultural inputs in optimum amount and time. Inputs that play a key role in agricultural intensification refer to direct inputs that can directly alter the outputs from the farm (e.g., fertilizer, labour, and water) and indirect inputs that facilitate or modify the direct inputs (e.g., finance, market, and knowledge)" (Tadele 2017, p.8)

The adoption of the Comprehensive Africa Agriculture Development Program (CAADP) in 2001 and the Maputo Agreement in 2003 mark a turn in the political commitment of African countries to agricultural development as a pillar of growth. African states pledged to increase investments in agriculture by assigning 10% of their annual national budget to agricultural development and to achieve a 6% annual production growth by 2015.

The African Green Revolution Alliance (AGRA) was then created in order to support African countries in their agrarian transformations. It establishes a bridge between international organizations, the private sector and civil society in order to foster an agricultural investment environment for achieving an African Green Revolution centered on smallholder farmers. The program mostly focuses on developing and disseminating improved seeds and fertilizers, but also facilitates access to loans and market-based advice for farmers to move towards commercial farming (AGRA 2009).

The largest investments as part of the African Green Revolution are so far mostly targeted towards fertilizers and pesticides and to a lesser extent improved seed varieties (AGRA 2009). Agricultural intensification has the potential to close yield gaps so that production reaches its biophysical capacity, through the use of fertilizers, pesticides, improved seeds and irrigation as well as the enhancement of market mechanisms (Nin-Pratt et al. 2009; Struik and Kuyper 2017; Tadele 2017). It has been estimated that a doubling of fertilizer use across Africa would significantly contribute to closing yield gaps (Pradhan et al. 2015). Carlson et al. (2016) estimated that by closing worldwide yield gaps at 75% through additional fertilizer, caloric production of food would increase globally by 12% for a 3% increase in GHG emissions mostly attributed to wheat, maize, barley and rice.

Finally, agrarian reforms and rural development projects were adopted by multiple countries in support of the Millennium Development Goals (United Nations 2014). These include strategies such as the Plan Maroc Vert in Morocco, the National Irrigation Development Strategy in Mali, the Food Security Strategy and the Productive Safety Net Program in Ethiopia, the Growth and Employment Strategy in Cameroon and the Livelihood Empowerment Against Poverty Program in Ghana (FAO 2015). They all aim at improving agricultural production through modernizing the sector, offering input subsidies to farmers and encouraging the development of cooperatives and agribusiness.

Direct impacts

The LSLA-based food security myth (Paper II)

Because LSLA are expected to close yield gaps, Rulli and D'Odorico (2014) estimated that they could in theory feed an additional 211.7 million people in Africa, thus completely eradicating undernourishment in the continent (FAO 2019). In reality however, even when LSLAs are aimed at agricultural production, they often prioritize cash crops and agro-fuels rather than food crops and are thus unable to increase the availability of calories for the local populations (Cotula et al. 2009; Borras and Franco 2012).

In Paper II, I found that between 2000 and 2015, LSLAs only allocated 35% of the land acquired in the continent to food production (food crops and livestock), while the remaining majority was aimed at flex (maize, soybeans, oils and sugars) and cash crops (jatropha, coffee and rubber).

Furthermore, I also found that most of the production from LSLA was destined for export in 30 countries including all the severely undernourished ones (Paper II). As such, I found that LSLAs' contribution to food security has been inappropriate in 8 countries (shown in light brown) and potentially damaging in the 14 most undernourished ones (shown in dark brown) (Figure 7).

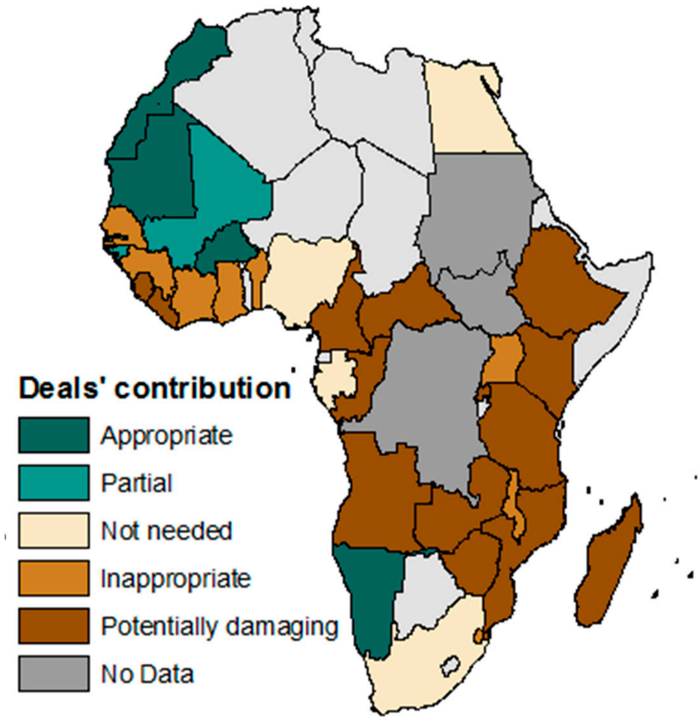

Figure 7: Ability of LSLA to contribute to the identified food security needs of countries (based on the compatibility of countries' needs and the most likely markets targeted by land deals) (Paper II)

I found that in 2017, 10 out of 46 African countries (Table 4) are severely undernourished (>30% of the population) even if half of them hosted LSLA aimed at local markets (shown in blue in Table 4). The remaining countries with LSLA targeting local markets suffer from self-sufficiency and nutritional diversity issues except for Malawi and Egypt (Table 4). As such, LSLA did not seem to improve the food security situation of the continent with countries requiring different types of intervention. Increases in production are urgent in 6 countries (shown in dark brown in the first column) and would help 6 others to achieve self-sufficiency (shown in beige in the first column). They should be targeting fruit and vegetable production in 27 countries (shown in light brown in the first column) and be accompanied by export diversification (not necessarily agricultural) in 10 (shown in dark brown in the third column) (Table 4). Finally, all but a handful of countries (shown in blue in the third column) need to prioritize improving utilization and food access.

Table 4: Food security needs of African countries based on food security scores in 2017 (according to table 2) and including targeted markets by LSLA (according to table 3). Countries in red are severely undernourished. Legend for each column is given by the label of the first appearance of the color. Dark grey represents no data and light blue in all columns means that the food security aspect is already achieved (secure) or in the case of production that self-sufficiency cannot be achieved due to biophysical constraint (Fader et al. 2013).

Country	Production	Undernourishment	Import capacity	Utilization	LSLA market
Cent. Afr. Rep.	Limited	Severe		Limited	Local
Madagascar					Export
Rwanda			Limited		
Uganda					
Zambia					
Zimbabwe					
Chad	Nutritional diversity				
Liberia					
Congo					
Tanzania					Mostly export
Benin					
Botswana					
Burkina Faso					
Cote d'Ivoire					
Djibouti					
Ethiopia					
Guinea					
Guinea-Bissau					
Kenya					
Lesotho					
Mali					
Mauritania					
Mauritius					
Mozambique					
Namibia					
Niger					
Nigeria					
Senegal					
Sierra Leone					
South Africa					
Swaziland					
The Gambia					
Togo					
Cameroon	Self-sufficiency	Moderate			
Gabon					
Sao Tome & P.					
Sudan					
Morocco					
Tunisia					
Angola					
Malawi					
Algeria					
Egypt					
Ghana					
DRC					
South Sudan					

Limited/ Export
Nutrition Diversity / Moderate
Self-sufficiency / sanitation
Secure / Local

Agricultural productivity trends in West Africa (Paper III)

Paper III analyzes current trends in cropland productivity in West Africa and derives the potential drivers responsible for them. In this paper, I find that significant improvements in productivity were only observed for 15% of croplands in West Africa between 2000 and 2018 with more areas suffering from declines rather than increases (Figure 8). I found that the sharpest increases in productivity were located in Liberia and Côte d'Ivoire, which put agricultural development at the center of their post-war recovery programs (Figure 8).

In terms of cropland area, the largest productivity gains were concentrated in Mali, Niger and Burkina Faso which are also areas that benefited from increased rainfall over the same period (Paper III, Figure 8). For their parts, declines in agricultural productivity were spread across Nigeria, Benin and the Western coast (Paper III, Figure 8).

Furthermore, the residual trend analysis I applied attributed over half of the productivity increases observed during this period to direct climatic factors in the region (Figure 8). While the climatic influence over the region is high, changes to cropping practices have a potentially stronger effect on agricultural productivity. Improved cropping practices, including the expansion of irrigation and fertilizers as well as agroforestry and other sustainable forms of soil management only covered 12% of the area with increasing trends, while land degradation occurred over 38% of the area with productivity declines (Paper III, Figure 8). Phenological changes that could be attributed to either climatic feedback or changes in farm management explain the remaining trends (Paper III, Figure 8).

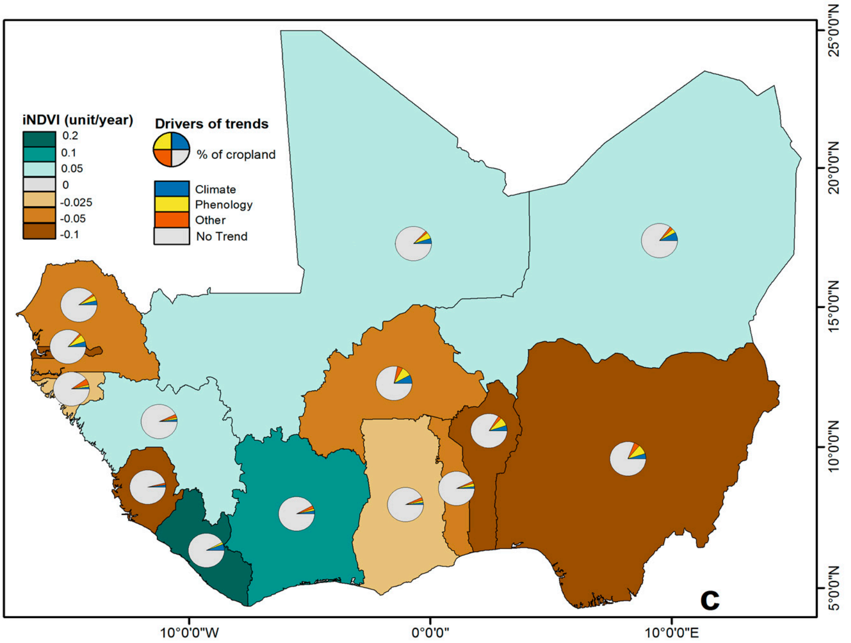

Figure 8: Statistically significant ($p<0.05$) trends and drivers of iNDVI (crop productivity) in West Africa between 2000 and 2018 aggregated by country (adapted from paper III). Most cropland exhibited no trend (grey in pie charts), while most countries that registered a change in productivity showed an overall decline (brown countries), suggesting that reported food production increases in these countries (FAOSTAT) are most likely driven by agricultural expansion.

Agricultural production was reported to have increased in all West African countries except for Cabo Verde between 2000 and 2017 (FAOSTAT) which contradicts with my findings (Figure 8, Paper III). However, it only surpassed the Maputo Agreement threshold of 6% growth per year in Sierra Leone, Mali, Niger and Ghana (FAOSTAT). For its part, the harvested area expanded in all countries except Senegal during the same time period at an average rate of 3% per year but exceeded 10% in Sierra Leone (FAOSTAT). The rate of agricultural expansion was found to be similar to that of production in Guinea, Cote d'Ivoire, Togo and Liberia (FAOSTAT) which would suggest that increases in production could largely be explained by agricultural expansion rather than intensification in these countries.

Nevertheless, according to FAOSTAT, the reported use of fertilizers (NPK and manure) between 2000 and 2017 has increased in all West African countries except Cabo Verde and The Gambia at an average rate of 36% per year with the sharpest increases reported in Burkina Faso, Guinea and Ghana (FAOSTAT). Similarly, pesticide use increased in most countries except Mali and Niger at an average rate of 20% per year (FAOSTAT). The slowest change has been in the area equipped with irrigation that only increased in The Gambia, Burkina Faso, Benin, Mali and Niger at an average rate of 5% per year (FAOSTAT).

As the trend analysis in Paper III was limited to areas that remained croplands between 2000 and 2018, this means that the reported increases in agricultural inputs in countries where large farmland areas experienced productivity declines were either mostly applied to newly cultivated areas or were not able to counter the effects of ongoing climatic changes and land degradation in the region (Paper III). As such, current intensification levels do not scale up to increases in food productions at the country level, which seems to primarily be achieved through agricultural expansion.

Indirect impacts

LSLA-induced disturbances (Paper II)

In Paper II, I found that agricultural land acquisitions in Africa have mostly targeted forests and existing croplands in densely populated areas rather than the often claimed remote sparsely populated and vegetated lands. I estimated that 90% of the land acquired in Africa could result in deforestation and high land pressures (displaced people having to share shrinking resources with their new neighbors) (Figure 9). I also estimated that 5.3 million people might have been directly impacted either through displacement or loss of productive assets (Figure 9).

While an argument in favorable of LSLA has been job creation and infrastructure building, evidence shows that oftentimes the quality and quantity of agricultural jobs decreases in acquired areas due to high mechanization and more seasonal work (Li 2011; Nolte and Ostermeier 2017). Moreover, LSLA might also be causing additional deforestation, perturbing water access (Rulli et al. 2012; Johansson et al. 2016) and fueling land conflicts through increased land competition, especially between farmers and pastoralists who already suffer from shrinking land resources (Oberlack et al. 2016; Soeters et al. 2017).

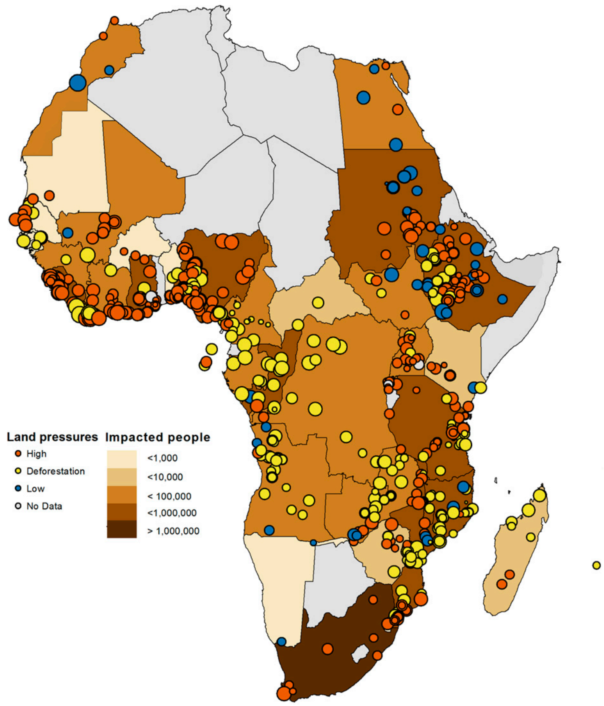

Figure 9: Potential impacts of agricultural land acquisitions in Africa between 2000 and 2015. The bubbles represent the size of the deals at their locations. Bubble colors represent the results of our assumptions on land pressures caused by the deals based on previous land cover, population density and distance to markets. The number of impacted people is estimated based on the size of the deals and the rural population density at the location of the deals (adapted from Paper II).

Intensification-based degradation (Paper IV)

Increased nitrogen fertilizer is promoted as a productivity boosting strategy, but also causes nitrogen related pollution through leaching to rivers and nitrous oxide (N_2O) emissions (Mueller et al. 2017). The current policies in North Africa however still encourage an overall increase in fertilizer use albeit based on the requirements of the soil types and crops planted.

In paper IV, I have explored the tradeoffs associated with increasing N fertilizer applications and the removal of fallow periods as the most commonly applied intensification measure in three North African countries (Morocco, Algeria and Tunisia).

In this paper, I find that across all agro-ecological zones of the study area, higher N rates are associated with 10% higher yields on average and 37% increased soil carbon stemming from the increased biomass (Figure 10).

On the other hand, the negative impacts related to nitrogen pollution are on average higher with intensification. I found that moderate yield increases generally relate to an average tripling and quadrupling of nitrogen leaching and N_2O emissions respectively (Figure 10). The impacts of intensification vary considerably by agro-ecological zone (Figure 10). For example, Figure 10 shows that a slight increase in nitrogen application (10%) could increase yields by up to 25%, reduce leaching by 5% but increase N_2O emissions by 165% in the Warm Sub-humid zones. On the other hand, a doubling of fertilizer application in the Cool Arid zones would only increase yields by 17% and lead to a six-fold and seven-fold increase in leaching and N_2O emissions respectively.

Such tradeoffs have considerable implications for these three countries that are high food importing and for which climate is becoming increasingly dry (Waha et al. 2017). With expected future precipitation variability, heavy rainfall events could considerably increase leaching and with it the pollution of scarce water resources in the region, while higher drought occurrence would further reduce yields despite intensification efforts (Waha et al. 2017).

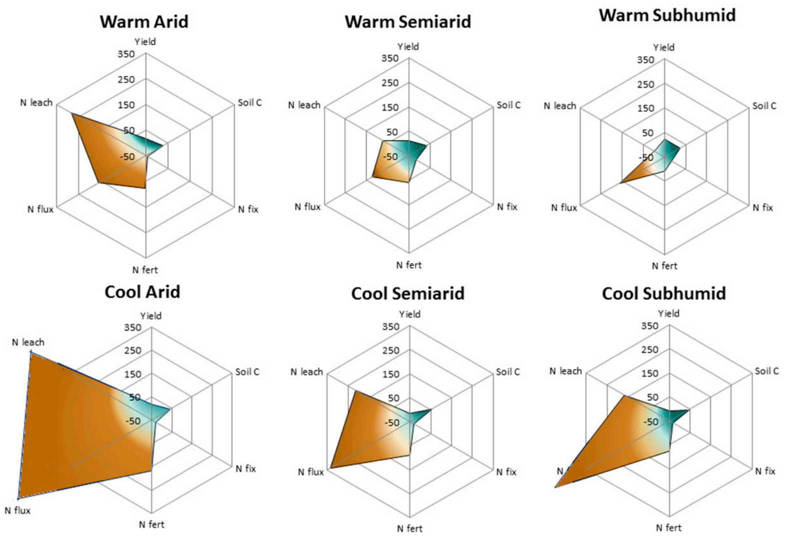

Figure 10: Modeled (with LPJ-GUESS) tradeoffs associated with intensification of farming systems in North Africa (higher N inputs and continuous cropping). Results are presented as average percentage change for yield, soil carbon, nitrogen fixing, nitrogen inputs (fertilizer application), N_2O emissions and nitrogen leaching between current and intensified (increased fertilizer and removal of fallow periods) wheat systems for all agro-ecological zones of North Africa (see Paper IV). The left side of the plots (brown) represents nitrogen pollution, the right side (green) the desired gains in terms of biophysical characteristics (yield, soil carbon and nitrogen fixing) (Paper IV).

Discussion

This thesis utilized the telecoupling framework to evaluate the impacts of Large Scale Land Acquisitions and agricultural intensification, driven by global productivist narratives, on the food security of African countries. I demonstrated how land acquisitions fail to address the food security needs of African countries. I also presented the tradeoffs in terms of nitrogen pollution and land degradation associated with increasing yields through intensification in North and West Africa.

In this section, I further reflect on the validity of the claims that increasing food production through adopting modern farming practices (large scale, high input monocultures) would improve food security and increase farmers' incomes in African countries. This is accomplished through the exploration of three arguments: agricultural production is not food security, sustainable intensification conflicts with modern farming practices, and power relations matter. I then conclude with possible alternatives to the current system that could increase production in a sustainable environmental and social manner.

Agricultural production is not food security

The current mainstream solutions to global food insecurity analyzed in this thesis include LSLA (Papers I and II) and agricultural intensification (Papers III and IV). Yet, these solutions only concern the production activities of the food system, expecting to increase global food availability, without considering the other dimensions (accessibility, stability and utilization) of food security. Changes in consumption are also not considered.

After two decades (since 2000, the start of the study period) of agricultural intensification, liberalization and agricultural investments (including land acquisitions), the number of undernourished people in the world remains high. In the case of African countries, hunger persists in all but five countries (Algeria, Egypt, Ghana, Morocco and Tunisia) and is severe (above 30% of the population) in nine (Central African Republic, Chad, Congo, Liberia, Madagascar, Rwanda, Tanzania, Zimbabwe and Zambia) (FAOSTAT). African countries clearly need major investments to eradicate hunger considering current and future population and climate changes. However, throughout this thesis, I have argued that agricultural intensification in the form of an African Green Revolution (Papers III and IV) or Large Scale Land Acquisitions (Paper II) is not able to sustainably respond to the food security needs of all African countries.

Since not all countries have the same food security needs (Table 4), the one size fits all solution of increasing production cannot yield a zero hunger outcome for the continent. Sen (1981) established 40 years ago that food availability does not equate to food security as hunger is mostly driven by the inability of people to access food due to physical, economic and social barriers (Sen 1981; FAO IFAD and WFP 2013; Clapp 2015), rather than a lack of production. This was the case in Africa in 2000 when undernourishment affected over 10% of the population in 80% of the 34 countries with sufficient food supplies (FAOSTAT). It is still the case today with undernourishment prevailing in 70% of the 40 countries with sufficient food availability from production and imports (FAOSTAT). While progress has been achieved in some countries, accessibility rather than availability still hinders food security in the continent, as income and asset inequalities increase undernourishment of the poor and marginalized (FAO 2019).

Moreover, having sufficient access to food does not mean that it is nutritious or can be consumed safely. Almost all African countries suffer from lack of access to improved water and sanitation facilities with only seven countries providing safe access to water to more than 90% of their population in 2017 (up from four in 2000) and to sanitation in four countries (up from two in 2000). In terms of diet nutrition and diversity, most countries still rely on cereals and tubers to fulfill their caloric needs and only 16 countries (up from 9 in 2000) provide a sufficient supply of fruits and vegetables for a healthy diet (FAOSTAT, Figure 5, Table 4)(WHO 2003).

Furthermore, while trade has been successful in feeding hundreds of millions of people (Wood et al. 2018), the import dependency of developing countries with limited or undiversified export revenues (UNCTAD 2019) not only incurs heavy costs on national budgets, but it also makes these countries vulnerable to price shocks as was highlighted by the 2008 food crisis (Burchardt and Dietz 2014; Clapp 2017; UNCTAD 2019). Diplomatic conflicts between countries, or production, economic or political shocks in a major exporting country could lead to food shortages in many others (Bren d'Amour et al. 2016). Bren d'Amour et al. (2016) found that if grain exports decline by 10% – either due to reduced production or export bans in some of the 12 main exporting countries – supply would decline by 5% in 58 countries. This would lead to price spikes of 10 to 17% and could impact up to 200 million poor people globally, the majority of which are located in Africa (Bren d'Amour et al. 2016). Between 2000 and 2017, 26 African countries have seen the share of available calories from their own production decline and six of them lost their self-sufficiency status (FAOSTAT). This is exemplified in the case of Uganda where the production of major food crops declined while population almost doubled, pushing the self-sufficient country in 2000 to become a severely undernourished one in 2017 (FAOSTAT).

Increasing food production in these import-dependent countries is thus necessary, but many of them are constrained by their land and water availability, meaning that they have to (or will have to) rely on imports to satisfy the needs of their population (Fader et al. 2013). In order to improve their food security status, they would need to increase and diversify their exports at the same time as they increase production (Table 4). However, the food and financial crises provide cautionary tales in regards to the reliance on primary commodities for which prices have been extremely volatile at times and steadily declining since 2011 (Pirkle et al. 2014; Clapp 2017; FAO, IFAD, UNICEF, WFP, WHO 2019; UNCTAD 2019). These crises have caused economic downturns in 23 countries and higher undernourishment levels in 67 countries globally between 2011 and 2017 (FAO, IFAD, UNICEF, WFP, WHO 2019). The continuous focus on cash crops in Africa, more recently expanding to flex crops such as soybean, palm oil and sugarcane, trades immediate profits for increased vulnerability to future price shocks. Moreover, these crops also cause large scale deforestation (Paper II), and require more water than food crops (Johansson et al. 2016).

Finally, the direct income growth from cash crops are limited to a select number of farmers that benefit from large enough land area for plantations and have access to markets (Diao et al. 2010). Due to its size and linkages, growth in export sector contributes less to a countries' GDP and poverty reduction than growth in food markets even if it has higher revenues (Diao et al. 2010).

Sustainable intensification conflicts with modern farming practices

While agricultural intensification has the potential to increase yields, to be sustainable, it must increase production on the same land area without degrading the environment (Struik and Kuyper 2017; Tadele 2017).

In Papers III and IV, I demonstrated how intensification could increase agricultural productivity in West and North Africa. However, I also highlighted the potential nitrogen pollution (Paper IV) and land degradation (Paper III) resulting from intensification practices, that could lead to declines in productivity due to the loss of soil fertility and climate feedbacks. Moreover, the use of fertilizers alone cannot circumvent the negative effects of temperature rise and unpredictable rainfall patterns as was evident in the case of Nigeria (Paper III).

Heavy fertilizer use has already been associated with soil acidification and nutrient depletion in Africa leading to land degradation as well as nitrogen leaching polluting rivers (Jalloh et al. 2011). While emissions from nitrogen fertilizer only account for 20% of cropland GHG emissions globally, the additional fertilizer required to close yield gaps would mean that Western North Africa, coastal West Africa and some areas of Eastern Africa would reach similar GHG emissions as European countries today (Carlson et al. 2017). Finally, recent evidence suggests that global nitrogen use efficiency is reducing as the trend in fertilizer use is rapidly increasing (Mueller et al. 2017), thus raising doubts as to whether a truly sustainable intensification is realizable. Moreover, in the long term, fertilizers deplete other nutrients in the soil as well as organic matter. Furthermore, pests slowly develop resistance to pesticides thus creating a dependence on inputs (pesticides and fertilizers) in order to maintain yields (Houser and Stuart 2019).

Other intensification measures that were not studied in this thesis include water management schemes and improved seeds. Irrigation schemes are necessary in areas prone to recurrent droughts but have so far been a secondary focus to fertilizer in intensification programs (Tadele 2017). There is much room for improvement in terms of irrigation expansion in the continent as only 6% of croplands are irrigated and only exceeds the global average of 20% in Libya, Eswatini, Madagascar, Egypt and Djibouti (You et al. 2010). While North African countries are near to reaching their water use limits, expansion in multiple Sub-Saharan countries has the potential to significantly increase yields (You et al. 2010; Fader et al. 2013; Tadele 2017). But, sustainable water management schemes need to be adopted as water stress already increased throughout the continent between 1990 and 2015 due to population increase and changes to streamflow (McNally et al. 2019).

Improved seeds for rice (NERICA) and maize (DTMA) have been successful in increase yields in West and East Africa but they require high levels of fertilizer inputs (Tadele 2017). Moreover, the rise of GM seeds and other hybrids under intellectual property rights causes challenges to the concept of food sovereignty and thus to the right to food (Mascarenhas and Busch 2006; Vivero-pol 2017). As DNA becomes the property of oligopolies, seed prices increase, and farmers are no longer able to save and share seeds (Mascarenhas and Busch 2006). The success of these varieties is also dependent on the use of herbicides and pesticides, sometimes provided by the same companies (Mascarenhas and Busch 2006).

While measures that increase input dependency may aim to promote sustainable intensification from an environmental and economic perspective, they ignore the social side of improved access to safe and nutritious food, and risk causing further inequalities and neglect of the poor and vulnerable smallholders which livelihood they aim to improve (Struik and Kuyper 2017).

The treadmill trap

So far I have demonstrated that LSLA (Paper II) and intensification (Papers III and IV) are not able to sustainably improve food security from an environmental perspective. Here, I argue that the created input dependence puts farmers under heavy financial pressures. On the one hand, inputs are supplied by a handful of companies setting high selling prices, and on the other few traders imposing low purchasing prices on farmers (Murphy and Burch 2012; Struik and Kuyper 2017; Houser and Stuart 2019; Luna 2019). Farmers then only have one option to maintain a livelihood in farming by increasing production, oftentimes through expansion and purchasing more inputs (Levins and Cochrane 1996; Houser and Stuart 2019). This is how they find themselves stuck in the production/technological treadmill, where they are increasingly dependent on continued purchase of ever increasing inputs to maintain high production levels (Levins and Cochrane 1996).

In the case of Africa, input subsidies form the entry point of farmers into the treadmill and enable them to sustain profits from the increased production for as long as the subsidies last. Afterwards, they are expected to bear the costs of fertilizers themselves often through credits potentially setting in motion the debt treadmill (Sjöström 2015). The other alternative is for the state to keep on subsidizing inputs, for which prices are continuously increasing, raising doubts as to whether substituting import dependence of food to that of inputs would provide any government expenditure relief necessary for investments in social structures such as healthcare and education.

Whichever choice is taken, between continuous government subsidies or farmers' debt, agriculture would transform in a way that is more damaging to the environment (Struik and Kuyper 2017), further contributing to climate change (Houser and Stuart 2019) and disrupting of the livelihoods of smallholder farmers (Sjöström 2015) that represent the bulk of undernourished people (FAO 2018b). Under these circumstances, access to food cannot be universal as it is limited to those who can afford it. As clearly stated by Vivero-pol (2017 p.185): "With the dominant no money-no food rationality, hunger still prevails in a world of abundance". The universal right to food has been opposed by powerful food corporations that benefited from subsidies and trade restrictions, appropriated knowledge, and promoted a for-profit commodification of food (Vivero-pol 2017). This, consequently restricted access to food commons and weakened the development of alternative paths to food production and consumption (Vivero-pol 2017). Today's food system thus puts farmers on the treadmill for the profit accumulation of transnational corporations and national elites by means provided by the state.

Alternatives?

The thesis has shown that the current agricultural transformation pathways of the African countries cannot sustainably respond to the food security needs of all countries. They might even cause adverse effects on the environment, the food security of the most vulnerable people and the livelihoods of smallholder farmers. Agroecology, "the application of ecological concepts and principles to the design and management of sustainable agroecosystems" (Altieri and Nicholls 2005), is viewed as more sustainable and equitable as it is rooted within social environmental justice and peasant movements, could be a better alternative (Desmarais 2002; Altieri and Nicholls 2005; Isgren 2018; FAO 2018b). It is believed to be the path to sustainable intensification that ensures that no one is left behind, as it is locally-based and accessible to all, and improves agricultural productivity and nutrition while adapting to climate change and reducing rural poverty (De Schutter 2010; Lin et al. 2011; FAO 2018b). Agroecology aims at optimizing and balancing nutrient availability, minimizing energy losses, conserving soils, maintaining agroecosystem biodiversity and enhancing biological interactions (Altieri and Nicholls 2005).

Agroecology utilizes site-specific, and agroecosystem-specific knowledge of traditional farmers and science to improve yields at low economic and environmental cost (Altieri and Nicholls 2005; De Schutter 2010; FAO 2018b). This is done through crop rotations, intercropping and cover crops that improve soil fertility through nitrogen fixing, maintaining an agrobiodiversity that improves nutritional diversity of production while reducing pest outbreaks (Altieri and Nicholls 2005; FAO 2018b). In addition to maintaining the integration of crops and livestock, the system is closed and does not require additional fertilizers or purchased feed for livestock, as manure provides sufficient input for increased yield and as crop residues and cover crops provide food for livestock at no additional cost to farmers (Altieri and Nicholls 2005; De Schutter 2010; FAO 2018b). Conservation agriculture using no-till, mulching and ridges also reduces water runoff, nitrogen leaching and soil erosion (Altieri and Nicholls 2005; Lin et al. 2011; Tadele 2017; FAO 2018b).

These agroecological practices have already proven successful in Africa (Tadele 2017). Agroforestry, through smallholders protecting and managing trees on their fields in the Sahel (Niger, Burkina Faso, Mali, Senegal and Ethiopia) helped restoring degraded lands, improving drought resilience, nitrogen fixing and providing feed and diversified fruits without additional fertilizer input (Reij and Winterbottom 2015). Push-pull systems build on natural enemies by using intercropping to repel pests and border plants to attract and neutralize them (Cook et al. 2007). This has been successfully implemented for maize in East Africa which reduced maize loss due to pests, costs related to pesticides and soil erosion while it provided additional feed crops (Midega et al. 2015).

Such easy-to-implement, cheap and successfully sustainable measures need to be scaled up and encouraged further (De Schutter 2010; Reij and Winterbottom 2015; FAO 2018b). However, such efforts are challenged by current structures as agroecology contradicts the profit accumulation of large corporations that control the food system and have considerable lobbying influence at the international scale (Murphy and Burch 2012). Now that there is political momentum towards investing in African agriculture, the principles of agroecology should be promoted if not instead of, then alongside policies favoring high inputs in order to sustainably improve smallholders' livelihoods and food security in the continent. The SDGs might never be reached if we end up with a copy/paste of the previous polluting Green Revolution in Africa.

Conclusion

This thesis evaluates the impacts of LSLA and agricultural intensification on the food security of African countries. It situates and elaborates on the findings from the different papers within the telecoupling framework by following how global productivist narratives translate into agricultural policies in African countries which then impact local populations, smallholder farmers and the environment. I conclude the analysis with reflections on the relationship between production and food security, argue for the incompatibility of modern farming practices with sustainable intensification, and explore how power relations within the food system impact on farmers and potential alternatives to the currently advertised farming practices.

In Paper I, I assessed the evolution of global LSLA between 2000 and 2015 and related three identified phases of establishment to global economic changes. I showed how global LSLA consistently targeted African agricultural lands across the three phases, based on the assumption that they could improve food security in the continent and foster economic development.

In Paper II, I demonstrated that LSLA are in reality mostly targeting the production of cash crops destined for export and seldom contribute to local food markets. Not only do LSLA not match the food security needs of most countries where they occur, but they also target densely populated areas, already cultivated or forested lands, meaning that they are likely to displace large numbers of people, fuel land conflicts and cause heavy deforestation further destabilizing food security.

In Paper III, I analyzed recent trends in cropland productivity over West Africa and found increases to mostly be attributed to climatic factors especially along the Sahel while declines were concentrated on the Western coast and across Nigeria as a result of temperature increases and land degradation. While there is a strong climatic influence on cropland productivity in the region (especially the Sahel), management practices tend to have a larger effect. This further highlights the importance of sustainable farming practices in light of future climate change challenges. Sustainable irrigation, land rehabilitation and readapted cropping calendars of selected crops have the potential to improve production in the region.

While increased fertilizer use is known to quickly increase crop yields, Paper IV shows that in the studied regions of North Africa, intensification through the removal of fallow periods and increased nitrogen fertilizer would result in considerably higher nitrogen pollution through N_2O emissions, and leaching into waterways, especially in the event of extreme climatic years. These results highlight the importance of a systems approach when considering intensification programs, as observed yield increases could hide underlying land and water degradation that risks reducing future yields.

The thesis concludes that while increasing production is necessary to improve food security in some African countries, LSLA and high input agricultural intensification cannot sustainably respond to the food security needs of all countries and risk adversely affecting the population of targeted countries. It points to the dangers of prioritizing policies benefiting transnational corporations and national elites at the expense of the livelihoods of smallholder farmers, the environment and the broader food security of the continent.

Based in these finding the thesis recommends that the need to increase food production should be accompanied by appropriate investments in structures enabling the equal distribution and the safe consumption of food in the various countries enabling the poor and marginalized to have safe access to nutritious foods. Furthermore, while shrinking land resources require intensification to occur, relying on large scale land acquisitions or repeating a Green Revolution in Africa is bound to incur environmental damage and pose threats to farmers' livelihoods through financial dependence in the case of input purchase or contract farming and loss of land in the case of LSLA. As such, if we are to achieve a "good life for all" fulfilling the Sustainable Development Goals, investments in food security should prioritize environmentally and socially just initiatives such as agro-ecology and foster food sovereignty of farmers rather than the profit accumulation of food system oligopolies and national elites.

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