Explaining the complex drivers of land abandonment of horticultural family farms in Senegal

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Extended Abstract

Introduction and method: A third of the world's food is produced by over 600 million family farms. Twelve percent of these farms are in Sub-Saharan Africa (Lowder, Sánchez, & Bertini, 2019), providing work for millions of people. However, family farms in arid and semi-arid Sub-Saharan countries are increasingly exposed to different stressors, including water scarcity (ILO, 2019). The *Niayes* area in Senegal, covering about 2795 km^2 along the northern coast, is responsible for about 60% of the country's vegetable production (Fare, 2018). The area is critical for local food security and provides livelihoods for a large part of the local population. The region has become important for vegetable production because of its favorable climatic conditions and availability of groundwater. It is thus of high interest for the governmental plan to increase food independence (Senegal, 2014). The aquifer called *nappe des sables quaternaire* (NSQ) is the only source of water for the vegetable sector. However, since a drought in the 1970s/80s, the water table has dropped significantly (Aguiar, Garneau, Lézine, & Maugis, 2010). This decline in the groundwater table leads to increasing water scarcity for family farms and a threat for the sector (DGPRE, 2014; Faye & Msangi, 2018). Over time, other factors started to reduce the water quantity and quality, which include pollutants from agriculture and industry as well as saltwater intrusion from the sea (Sall, 2010). The exponential increase in vegetable production in the area (FAO, 2019) has also led to increasing water extraction for irrigation. However, the relative importance of these factors for the development of the groundwater table remain unclear. Nevertheless, a recent model concluded that in the coming decades, farms might need to adapt to increasing water scarcity (Faye & Msangi, 2018). Weak regulations and easy access to the shallow unconfined aquifer make the groundwater a de facto common-pool resource difficult to manage (Ostrom, 1990).

The decline in the water table has created an increasing disparity between those farms that can adapt to it, by drilling deep boreholes, and those who lack access to improved irrigation equipment, namely the large number of small family farms (Boillat & Bottazzi, 2020; Fare, 2018). Together with other driving factors, this might eventually lead to more industrialized and large-scale vegetable production and an uncertain future for family farms (Camara, Bourgeois, & Jahel, 2019). Better understanding the drivers of the growing disparity between different farm types, as well as the risk of groundwater over-exploitation for the future of the vegetable sector, are the motivations of this research.

A case study conducted by Boillat and Bottazzi (2020) highlights the complex feedbacks of the interacting factors that threaten family farms in this region. The goal of this study is to develop a formal system dynamics model, based on their and other research, to quantitatively test their explanations for the development of the sector and simulate different policy scenarios for a more just and sustainable vegetable sector. Our research process was inspired by a variety of participatory system dynamics studies on complex Socio-ecological systems (SES) related to water management and agriculture (cf. Herrera & Kopainsky, 2020; Hossain et al., 2020; Inam, Adamowski, Halbe, & Prasher, 2015; Kotir, Brown, Marshall, & Johnstone, 2017). In the first step, we aimed to validate an initial CLD built from literature, which explains the growing disparity between family farms and larger industrialized farms, their interactions, as well as the feedbacks between groundwater availability and vegetable production. To this end, we conducted five group model building (GMB) workshops in March 2021 in the area of Diender and Kayar in the south of the case study region. With the help of a local farmer's organization (FAPD), we organized workshops with a group of family farms, larger more industrialized farms (henceforth called corporate farms), as well as institutional actors. Each group of participants produced a CLD, which were then merged and verified in a fourth workshop. We dedicated the fifth workshop to the discussion of policy scenarios. In the second step, we analyzed the system archetypes in the CLD supporting the identification of key underlying feedback mechanisms (cf. Bahaddin et al., 2018). In the third step, we developed an initial formal model and simulated the Business as usual (BAU) scenario.

The CLD and archetypes: We found three system archetypes that help explain the behavior of the system, namely, *Success to the Successful*, *Limits to Growth*, and *Tragedy of the Commons*. The most important feedback loops representing these archetypes are shown in the CLD in Figure 1. First, the *Success to the Successful* archetype (R1-R4) describes how larger and more industrialized farms (corporate farms, CF) successively increase their cultivated area and accumulate cash that they can reinvest. At the same time, small family farms (FF) experience the same mechanisms but as a vicious cycle, which forces them to decrease their cultivated area and to sell part of their land to CF, which can thus further expand their cultivated area. Second, *Limits to Growth* archetype (R5 plus B1-B3) describes that with the expansion of their cultivated area, CF experience negative side-effects, such as water pollution or increasing production costs, and reach limits, such as that of available fertile land. Third, the *Tragedy of the Commons* archetype (R5 plus B6-B7) describes how each farm contributes to the exploitation of the groundwater, which eventually affects all farms negatively. However, CF are more resilient to the decline in water quality and quantity than FF, which experience the negative effects sooner. Until CF start experiencing the negative effects as well, they initially benefit from the negative effects on FF, who are forced to sell their lands to them. This is also the case for R7, which is, however, not an example of the tragedy of the commons archetype, as only CF contribute to the water pollution. There are even effects of the growth of CF on FF that do not affect CF at all. For example, R6, which describes that with a decreasing water level the workload for irrigation increases. This only affects family farms with manual irrigation equipment, not CF. In addition, there are reinforcing loops that do not involve feedbacks between CF and FF. For example, R8 shows that FF struggle with access to inputs, which reduces production and in turn farm income. The same loop exists for CF as a virtuous cycle. Similarly, not included in this CLD is the reinforcing loop between cash available for transportation of the produce to the market, which defines the price they achieve and in turn their farm income. This is a virtuous cycle for CF, but a vicious cycle for FF. Finally, with the growth of CF and their increasing profits and level of mechanization, the sector attracts more and more people. Besides this endogenous structure, there are several external factors, including climate change or the expansion of the mining industry and urban areas, which threaten the vegetable sector.

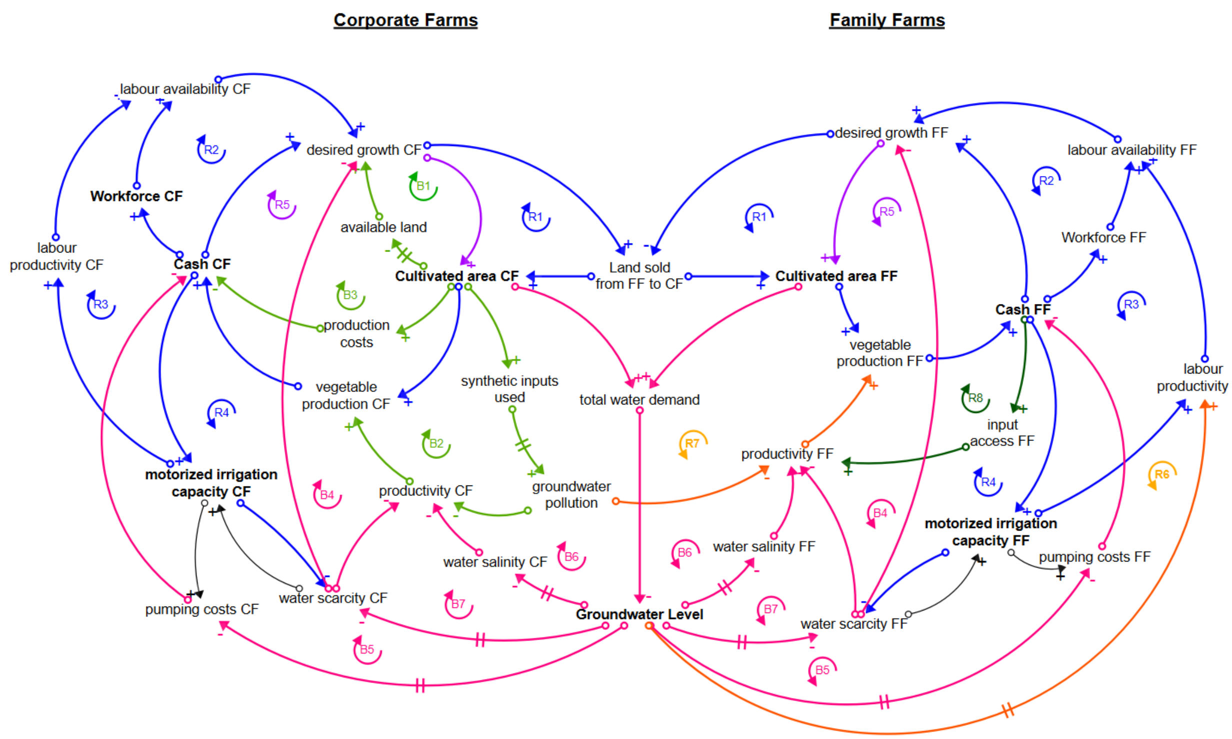

Figure 1: Causal loop diagram with largely symmetric sides representing corporate farms (CF) on the left and family farms (FF) on the right. The colours correspond to the system archetypes: tragedy of the commons (red and purple), success to the successful (blue), limits to growth (green and purple). State variables in bold.

The formal model and initial simulation results: The formal model includes five main state variables: Groundwater level, cultivated area, irrigation capacity, cash, and workforce (or jobs) for three different types of farms. To better represent the variety of farms that in reality exist, we included a third group, developing family farms, as an intermediary between FF and CF. The main differences between these farm types include the amount of initial cash, the average farm size, availability of family workforce, and the degree of mechanization (Fare, 2018). The arrayed model structure is largely the same for all farm types. We simulated the model from 1990 to 2040 and validated the vegetable production as well as the cultivated area with data from FAO (2019) (Figure 2), assuming that 60% of the total national production and cultivated area lie within the case study region. Under business as usual (BAU) assumptions, the model was able to reproduce the reference mode of increasing disparities between farm types and limits to the growth of the sector, in terms of vegetable production and cultivated area (Figure 3), as well as other indicators (such as income, workload, jobs/workforce). Total vegetable production reached a tipping point at about 750'000 tons around 2031 when also no more land was available (B1). The dominating driver for the decline of all three farm types was the declining water table and resulting pumping costs (B5) and water scarcity (B4). In addition, for FF using manual irrigation equipment, the decline in water table also strongly influenced labor productivity for irrigation and in turn cultivated area (R6). Moreover, FF were trapped in a vicious cycle between cash available for investment into the workforce, production inputs, and irrigation equipment, and resulting cultivated area, production, and farm income (R2,3,4,8). The model reproduced a relatively stable low income for FF during the first few decades, showing that they were not able to accumulate savings. The same cycles were, initially, virtuous cycles for the other types of farms, until the decline in water table was too strong, the available land used up, and balancing loops took over.

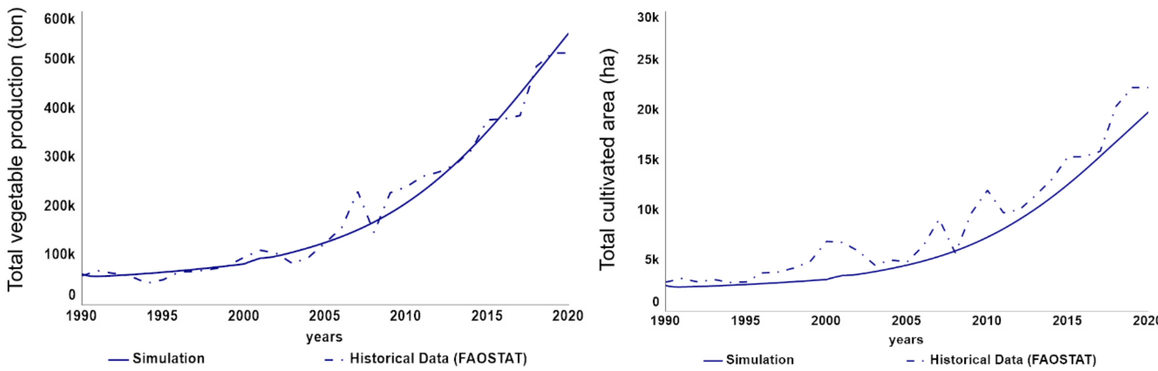

Figure 2: Validation of total vegetable production and total cultivated area.

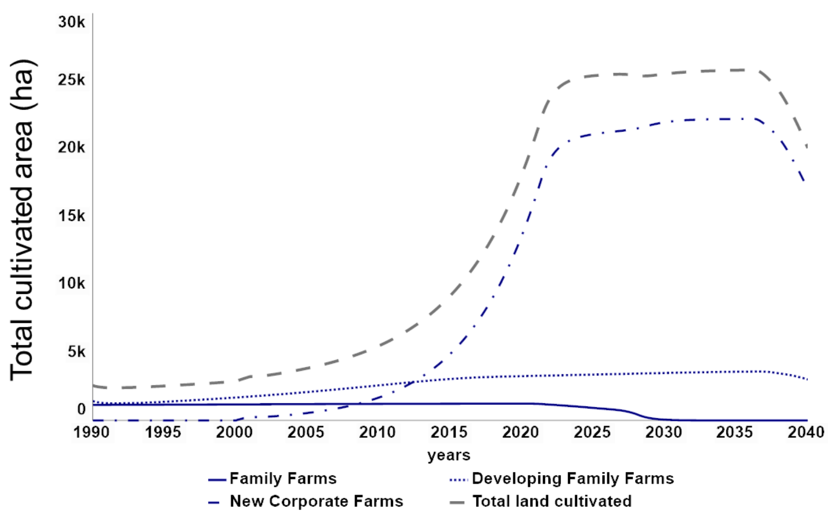

Figure 3: Total area cultivated by different farm types under business as usual.

Our initial conclusion is that without further intervention, the region is likely to observe the development towards a future without family farms, as described by Camara et al. (2019), with its implications of local food security and availability of decent and autonomous farm jobs. Further, the growing vegetable sector seems to have a critical influence on the decline of the water table and water quality in the coming decades, posing high risks to the sector. Considering the main driver of the decline in all three farm types, policy interventions should primarily focus on sustainable water management. A limitation of the cultivated area seems inevitable. However, there is also a need to improve the financial situation of family farms, and to support them with more efficient and improved irrigation equipment. The strong interactions between corporate farms and family farms suggest that cooperation and coordination between them are crucial. These insights seem in line with the policy dimensions suggested by GMB participants, namely water management (shared water infrastructure, water meters, and quotas or taxes to increase water efficiency), market and price policy (price protection, input subsidies, and creation of local markets), and land management (preserving the area for (organic) vegetable production exclusively, and access to credits for smallholders). Finally, our future work focuses on the implementation and simulation of this policy mix, as well as the inclusion of aspects that are not yet implemented in the model, including groundwater pollution and salinization, as well as on sensitivity analysis and validation of critical parameters and assumptions.

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