When soon is already too late: How resilience and sustainability are indivisible in a country facing rapid environmental and socio-economic changes
The case of fresh tomato in Morocco

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Paper prepared for the 37th International Conference of the System Dynamics Society, Albuquerque, USA

Abstract

Farmers are increasingly exposed to various types of stresses. For horticultural growers, this is all the more striking as vegetable production, such as tomato, is input and water demanding. In Morocco, tomato is a key food crop, and also a key cash crop for the producers and it constitutes a main agri-food export commodity of the country. On the other hand, water demand for irrigation has led to an overexploitation of the groundwater table causing significant natural resource management challenges in many parts of Morocco. The combination of groundwater changes and increasing drought raises concerns about the ability of tomato producers to be sustainable and resilient to unexpected changes. To describe the interaction of environmental and socio-economic processes that influence farmers' livelihoods, we build a system dynamics model. The model allows studying the synergies and trade-offs between different goals such as productivity, resilience and sustainability under rapidly changing framework conditions. Results show the necessity for an effective and alternative water supply for irrigation, through integrated policies. The predicted increasing droughts in the future indicates that urgent action is needed to provide resilient and sustainable solutions for farmers.

Keywords: *Resilience, Sustainability, Agriculture, Water management, Tomato, Morocco*

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1. Introduction

Food system activities, ranging from production to consumption, are characterized by complex interactions that involve social, economic, political, institutional and environmental dimensions and processes (Garnett, 2013). Farmers, in particular, are increasingly exposed to climate-related shocks and stresses and operate more and more in globalised agricultural markets (Lunt, Jones, Mulhern, Lezaks, & Jahn, 2016). As more threats and shocks are foreseen in the future, there is a growing need to build and enhance resilience of farmers. Moreover, some of the disturbances, for example repetitive droughts, have direct influence on larger spatial scales (Redman, 2014) and/or longer temporal scales (Meacham, 2016), like water resources availability (Iglesias, Garrote, Flores, & Moneo, 2007). Rising temperatures and erratic precipitation patterns results in higher water demand for agricultural irrigation (Johannsen, Hengst, Goll, Höllermann, & Diekkrüger, 2016; Karmaoui, 2015; Messouli et al., n.d.). Water resource management, and general sustainability issues eventually affect farmers, jeopardizing once again their ability to face increasing pressures.

Resilience has widely been used as a key concept to understand and address the capacity of a system to deal with disturbances and shocks (Adger, 2000; Folke, 2006; Holling, 2001). In socio-ecological systems, resilience has been extensively conceptualised by focusing on non-linear dynamics, thresholds, uncertainty and surprises (Adger, 2000; Carpenter, Walker, Anderies, & Abel, 2014; Folke, 2006; Holling, 2001; Walker, Holling, Carpenter, & Kinzig, 2004). In agroecosystems, resilience thinking led to an approach based on integration of ecological and social aspects, which aims to identify measures to limit the impact of a disturbance on nature and people (Cabell & Oelofse, 2012; Darnhofer, Fairweather, & Moller, 2010; Jacobi et al., 2015). More recent studies have been discussing frameworks to enhance the resilience in food systems at a regional or a global level (Bullock et al., 2017; Tendall et al., 2015). Among a substantial amount of existing resilience frameworks, individual farm system resilience has been conceptualized by several studies (Darnhofer et al., 2010; Jacobi et al., 2015; Milestad & Darnhofer, 2003; Schuster & Colby, 2013), but the complexity of food systems and their dynamics over time and space makes it difficult to provide specific guidance on how farmers should deal with shocks (Darnhofer et al., 2010).

A resilient system is expected to deliver diversified, robust and functioning outcomes such as producing and distributing food under changing conditions(Jacobi et al., 2018). In order to assess resilience, a set of measurable indicators should be developed. Many studies suggested indicators, as well as tools and frameworks to measure farmers' resilience. Despite the growing interest and impressive amount of studies, the common agreement on how to measure farmers resilience to climate change is yet to be reached (Douxchamps, Debevec, Giordano, & Barron, 2017). Moreover, while providing an overview on static outcomes of resilience, many tools cannot capture spatial and temporal system dynamics (Douxchamps et al., 2017).

Farmers' livelihoods are considered sustainable only when farmers can cope with a shock, recover from it, maintain or even improve their capabilities and assets while not undermining natural resources (Ifejika Speranza, Wiesmann, & Rist, 2014). Under rapid complex changes in environments, societies and economies, a pathway to sustainability becomes essential for ensuring that human livelihood is sustained, social equity is ensured, and environmental integrity is protected (Fiksel, 2015; Leach, Stirling, Scoones, Stirling, & Scoones, 2010). In relation to resilience theory, sustainability is a distinct but complementary concept, crucial to deal with future challenges and disturbances of the agricultural system (Redman, 2014). Sustainability and resilience are inextricably linked to each other (Tendall et al., 2015) and need to be considered jointly (Carpenter et al., 2014), as they both have many common objectives. In this study we comprehend resilience as a component of sustainability (Marchese et al., 2018).

Within such context, there is a need to better understand what currently makes farmers resilient to droughts and how their resilience is challenged by sustainability issues in a longer-term. One way to address the long-term dynamics of a system and its effects on farmers resilience, is to use system dynamics modelling. For both resilience and sustainability, it is crucial to deeply understand the dynamics of a system, its feedback mechanisms, cross-scale linkages, cascading impacts, potential trade-offs; and system dynamics appears to be a suitable domain of action (Redman, 2014). Recent studies suggest to use System dynamics (SD) modelling as a tool to model and analyse resilience: to quantify a system's response to disturbances and to use causal analysis to identify ways to influence this response (Herrera, 2017b; Stave & Kopainsky, 2015). SD draws upon both qualitative (e.g., survey and interview methods) and quantitative techniques (e.g., computer programming and simulation) and provides a valuable framework for investigating complex agricultural and natural resource management issues (Turner et al., 2016). Although system dynamic models have been built for agricultural and natural resource management in other parts of the world, our study is one of the few applications in the MENA region and the first on tomato production in Morocco.

This study explores how the concepts of resilience and sustainability can be operationalized for an agricultural production system from a SD perspective. The case of fresh tomato production in Morocco is used to illustrate this complex interplay. To assess both sustainability and resilience issues, we address the situation of open field domestic tomato producers and greenhouse exporters who are facing repetitive droughts and gradual groundwater depletion. In a first step, we start with the description of the two different production systems (open field and greenhouse tomato production) with an SD model. In a second step, the model will be used to highlight the implications of disturbances and longer-term natural resource depletion on both production systems. Finally, we compare the situation in both systems and discuss whether they could collaboratively enhance their resilience against future droughts, with two policy tests.

2. Case study

A dual production system

In 2008, the Moroccan government launched an agricultural strategy to rehabilitate agriculture and turn it into the main engine of economic growth and the tool against poverty in Morocco. This comprehensive new strategy is based on two pillars and it is expected to reach large and small actors along the agricultural value chains. The first pillar promotes "modern agriculture, with high added value crops adapted to export markets". The second pillar develops an approach to fight against poverty by significantly increasing agricultural income for the most vulnerable farmers, particularly in disadvantaged or peripheral areas. (Plan Maroc Vert, 2008 (Akesbi, 2012)). Moroccan agriculture has essentially been shaped and divided by these pillars. On the one hand, a mechanized and well-performing production with agricultural practices evolved to meet exports-standards. On the other hand, a more traditional production has emerged to meet domestic demand. Over the last decade, the differences between these two systems became particularly visible in the fruit and vegetable sector, with 517 thousand tons of fresh tomato exported, making the country the 4th biggest exporter (FAOStat for 2017).

Tomato, in particular, is a high value crop that plays an essential role in the daily Moroccan diet (Darfour-Oduro, Buchner, Andrade, & Grigsby-Toussaint, 2018). Just as with other fruits and vegetables, there are two very different systems in tomato production in the country: open-field and greenhouse production. Tomato production for export is performed in a mechanised form under greenhouses and generates a relatively high yield (120-250 t/ha). Moreover, this system benefits from better connection to conditioning plants and cooperatives that ensure access to export markets. Around 85% of total tomatoes destined for export are produced in West Southern Morocco, in the Souss-Massa region. Considered as one of the most important agricultural poles, 55% of the exported fruits and vegetables are produced in this region to meet the European off-season demand (from September to May). This semi-arid region is characterized by the low average rainfall of 200 mm/ year in the plain and average temperature of 24 ºC (Ait Brahim et al., 2017; Malki, Bouchaou, Hirich, Ait Brahim, & Choukr-Allah, 2017). The high-water demand for the crops has led to the over-exploitation of groundwater for irrigation purposes. The Chtouka aquifer located in the region has recorded an annual deficit of 60 Million m^3 per year over the last years (Malki et al., 2017). Agricultural productivity has subsequently increased groundwater resources depletion and degradation rates over the last decades (Payen, Basset-Mens, & Perret, 2014). Due to its highly strategic economic and political importance, the region has been extensively studied over the last decades and quantitative information on the water and agricultural situation is available in the scientific and grey literature.

In contrast to large export producers, smaller producers are growing tomatoes on irrigated open-fields (from April to October) along with other vegetables throughout the year generating lower yields (40-90 t/ha) in smaller but more diversified farms. According to the ministry of agriculture, the Rabat-Sale – Kenitra region has produced most of the irrigated and open-field tomato in the recent years, 73 thousand tons in 2017. Considered as one of the most important areas of vegetable production, the region is characterized by an intensive agriculture including horticulture. Such production, using drip-irrigation has fostered inconsiderate groundwater exploitation. The cost of irrigation equipment per ha is the highest of all the investments (over €1000 ha1 on average) for all farm types, and more than twice that for large farms (Kuper, Hammani, Chohin, Garin, & Saaf, 2012).

Droughts and groundwater reliance

In Morocco, droughts have affected the country and agricultural productivity for the last decades (Ben Kabbour Brahim, Zouhri Lahcen, & Mania Jacky, 2005; Esper et al., 2007; Karaky, Arndt, & Tyner, 2016; Malki, Bouchaou, Hirich, Ait Brahim, & Choukr-Allah, 2017). Recent climate models suggest that drought risks in Morocco will increase in the future, and the country will experience the greatest climate change induced precipitation decrease among the North African countries. Increasing mean temperatures in all seasons, declining rainfall, and greater vegetation reference evapotranspiration will lead to decreased runoff, slower groundwater recharge rates and greater water stress (Babqiqi & Messouli, n.d.; Kmoch, Pagella, Palm, & Sinclair, 2018; Schilling et al., 2012). Each of the droughts in the past decades had inevitably led to a year of drastic yield reduction for rainfed crops.

As a way to overcome the reliance on rain-fed crops and to minimize water losses, the government has fostered, through intensive subsidies, drip irrigation for medium scale farmers (Kuper et al., 2012). In the last decades, horticultural production has mostly shifted to the latest irrigation systems, which made the vegetable production system relying mostly on groundwater table. As a result, during the last drought of 2016, farmers avoided heavy losses in yields, by supplying water to their fields continuously, with more pumping energy. The overexploitation of water, coupled with the intensifying droughts, inevitably leads to even greater degradation of water quality (Zouahri, Dakak, Douaik, El Khadir, & Moussadek, 2014). However, this did not solve the problem of overexploitation and depletion of groundwater table. Hence, the current research raises concerns on the substantial water availability issues foreseen in the nearest future.

3. Model structure

Modelling specificities and reference mode of behavior

The SD modelling process includes five main steps: (1) conceptualization, (2) dynamic hypothesis, (3) formulation, (4) testing and (5) policy design and evaluation. This framework in five steps, serves as a basis to support an operational analysis of systems' resilience and to identify potential policies to enhance it. Figure 2 shows the SD modelling process inspired by Herrera, 2017a) tailored for the resilience analysis.

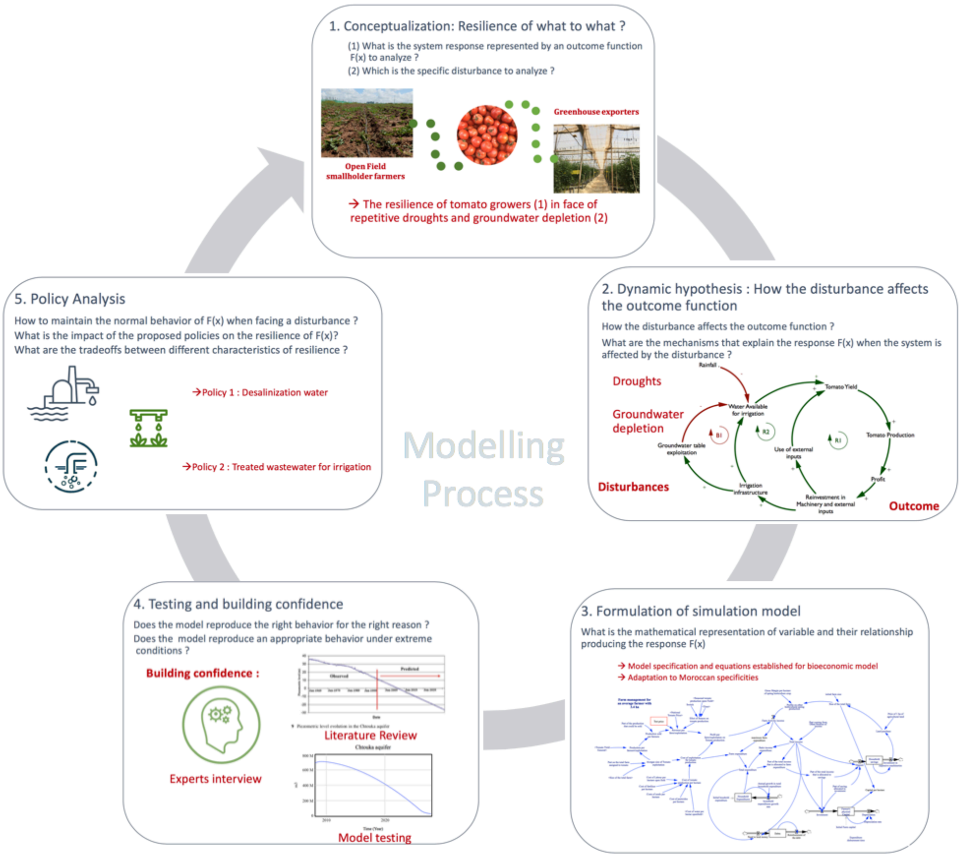

Figure 1: System Dynamics modelling process - Adaptation from Herrera, 2017a for the Moroccan Tomato case

Conceptualization – Resilience of what to what?

The conceptualization of the model is based on a series of expert interviews, field visits and an in-depth literature review. This study focuses primarily on the resilience of tomato growers to drought and groundwater depletion, with 2 case studies: open-field producers in the Rabat - Salé- Kénitra Region and greenhouse exporters in the Souss-Massa region. The financial capital of each type of producer is the outcome function of resilience. In the model, financial capital is represented as a stock that depends on revenue and various types of expenditures, including down payments of debts.

Dynamic hypothesis – How the disturbance affects the outcome function

The first hypothesis about the system concerns its behavior regarding groundwater depletion. As irrigation depends on groundwater in both case studies, tomato production is controlled by the water balancing loop (B1). This means that (1) the more water is available in the aquifer for agricultural irrigation, (2) the more water is used for agriculture, but subsequently (3) the less water is available in the reservoir. The yield function is dependent on the water uptake; hence the yield is considerably decreasing when the groundwater is depleting, generating cascading effects on the total production and the profit from it. Moreover, when the drought occurs, it affects several parts of the system such as an increasing groundwater consumption and a faster depletion, causing yield losses that appears to be faster and stronger in the long-run. An extended vision of the subsystem diagram is to be found in the appendix, stocks with their in- and outflows are explained to enable a deeper understanding of the model main flows.

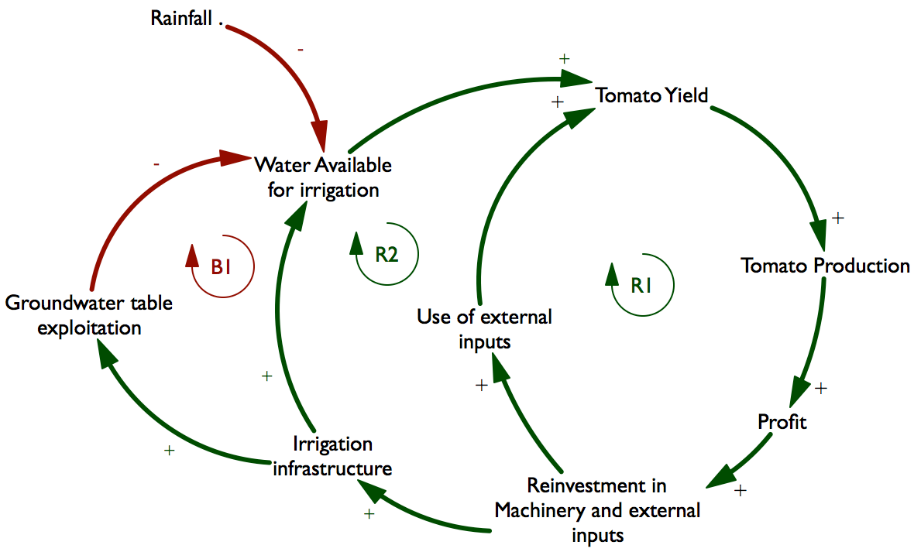

Figure 2: Main feedback loops of the production system - Linking yield and water uptake, to the water available and consumed in the groundwater table

A three-step procedure has been taken to capture the specificity of this bio-economic system, report on the causality and the feedback loops within the system and gather enough information to come up with a quantitative representation of the model. As a first step, an in-depth literature review was conducted to develop a modeling framework applying the causal loop diagramming method (Sterman, 2012) to illustrate the system's structure and feedback mechanisms. The polarity of the causality is essential in understanding system's behavior. The direction of the causal link indicates which variable is influencing the other. The perturbation of a loop may then amplify the original effect (a reinforcing loop, R) or into an equilibrating response (a balancing loop, B). This first step led to the description of the model through a causal loop diagram. It was followed in a second step by extended field visits and a series of experts' interviews, using semi-structured interview methods, to characterize the particularities of the systems and provide better insights of its key drivers and validate the causalities firstly established. Experts included agricultural consultants, to delegates of the ministry of agriculture and environment, academics and several farmers and farmers cooperatives. The framework based on causal loop diagramming is a qualitative statement about a system's structure, in this study this framework served as a base for developing and calibrating the quantitative simulation model. In addition to the interview, a data collection including a survey among 245 producers was conducted in order to adjust quantitively the model. Finally, a third step has led to model the system into a formal, mathematical simulation. The model presented in this article was calibrated for the specific case of Morocco. Once the model was robust, it served as a "virtual playground" in which to test different policy experiments.

Formulation of the model - Model development

The dynamic hypothesis was formalized by way of a simulation model that mathematically describes the dynamic interactions between tomato production, famers welfare and groundwater depletion. The simulation model focuses on a high level of aggregation and allows the identification of leverage points, strategic areas of action and fundamental mechanisms of a complex system. Such an approach allows us to understand the dynamic behavior of the system with a high degree of abstraction, yet the inability to represent phenomena on a detailed level. The dynamic complexity of a system arises though the non-linear interaction of feedback loops and the accumulation processes involved (Gerber, 2016).

In this study the differentiation between fast and slow variables plays an essential role in the analysis. Some variables operate more slowly in the system and can be called controlling or slow variables (Walker, Carpenter, Rockstrom, Crépin, & Peterson, 2012). These slow variables, such as the amount of soil organic matter, shape how a fast variable, such as crop production, responds to variation in an external driver, such as variation in rainfall during the growing season. In that sense, natural capital stocks are considered as a slow variable (Walker et al., 2012) and defined as environmental stocks that provide a flow of various goods and services such as soil, water, climate, food (Daily et al. 2011; Loon et al. 2005; OECD 2013).

For the purpose of this exercise a set of stocks will be used and analyzed as slow variables of the system. Water in aquifers will serve as a proxy for natural capital, and producers' savings (open field farmers and greenhouse exporters) will describe the financial capital. We see the analysis of the mentioned capitals as the long-term assessment needed to understand the sustainability and general behavior of the system over a long time period. The reference mode of behavior is a rapid depletion of groundwater table over the first decades, mostly because of intensive production – causing not only environmental damages but also social and economics, especially for smallholders. For more information on the model structure, please refer on the

Appendix - Model description.

Testing and building confidence

The model developed for the purpose of this exercise, still contains several assumptions (cf. Hypothesis and Data) and rely on many exogenous variables (cf. appendix). Some of those variables are defined as constants, but could be significantly more volatile in real life, such as tomato retail and wholesale prices, or rainfall. Those fluctuations imply more complex dynamics and different decision-making processes for farmers and exporter, on the short and long term. The following analysis will only focus on the 2 problematics behaviors chosen, the competition over 1 natural resource (water) and income generation inequalities. A first series of test were conducted to validate the reference mode of behavior, namely a fast groundwater depletion. Several other studies (Ait Brahim et al., 2017; Malki et al., 2017) showed the groundwater depletion patterns (Figure 3). Finally, other validation tests, such as unit consistency test, extreme value test and sensitivity test, were used for developing confidence in the model and its results.

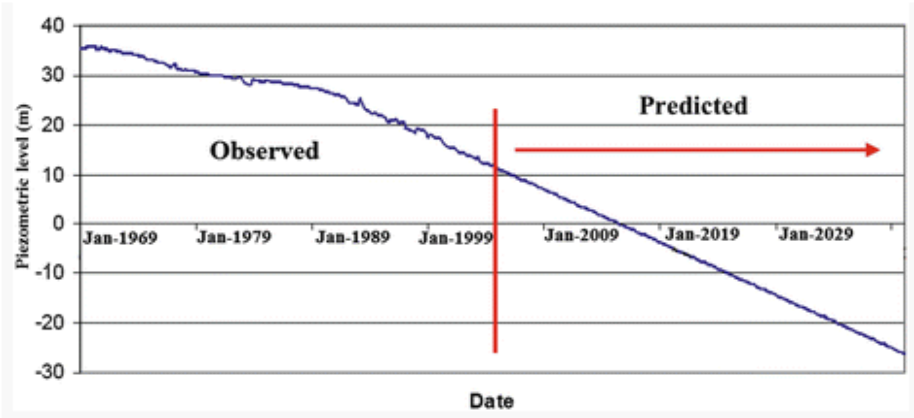

Figure 3: Piezometric level evolution in the chtouka aquifer (Ait Brahim et al., 2017)

4. Policy Description

Over the last years, many studies have highlighted the disastrous consequences of the promotion of drip irrigation on groundwater table management (Ameur, Kuper, Lejars, & Dugué, 2017; Hanjra, Ferede, & Gutta, 2009; Malki et al., 2017; Molle & Tanouti, 2017). A series of policy measures exist or are in the process of being set up to support a more sustainable use of the natural resources. Two policies have been chosen to be tested on the model.

Groundwater and agriculture conservation through desalinization

Given the urgency of the situation in the Souss-Massa region, namely the alarming decline of groundwater table, a desalinization project has emerged in 2011. The project was initiated as a result of increasing concerns of all the stakeholders (politics, economics and professionals) at local, regional and national level (farmers, elected officials, local authorities, ministerial department, etc.). Four goals have been set: the safeguarding of Chtouka aquifer, the persistence of the economic activities linked to the agricultural sector, the preservation of an essential zone for Moroccan agriculture and maintaining the possibilities of the development of agricultural activities in the region. Through a public-private partnership, aiming to build, maintain and manage the infrastructure and its exploitation, a desalinization plant (that is currently still under construction) is aiming to provide 3600 m3/ ha for all the farmers willing to subscribe to the connection of this new facility. This plant is announced as the biggest desalinization plant in the world. The project has already been launched and reinforced by the publication of a decree (N 6622-27 safar 1439 (16-11-2017)) aiming to support the protection of the water resources in Chtouka. Desalinated water should be provided to subscribers within the coming years.

This project has emerged as an adaptation measure against water depletion in that region, considered as essential for Moroccan agricultural strategy. Given the permanent water scarcity, the announced goal of alternative water sourcing is to raise the resilience of the system in the face of changing climate. In spite of these efforts, it is questioned to what extent such a project contributes in the long run to the sustainability of the system and to what extent it could also benefit the smaller farmers knowing that the price of water will double. Several other desalinization plants have been considered in the country, however none has yet been planned. An alternative option to lowering the pressure on groundwater overexploitation is wastewater reuses for irrigations purposes.

Inter-sectorial link – Wastewater reuse for agricultural use

The increasing water scarcity in the country has been induced in particular by demographic changes, water overuse for agricultural and urban purposes and sped up by climatic variability. The combination of declining renewable water resources and increasing water demand reveals a strong need for water resource management in North African regions (Droogers et al., 2012; Johannsen et al., 2016; Messouli et al., n.d.). Given the necessity to intervene, policy-makers have directed their attention towards non-conventional water resources, such as recycled wastewater (WW), to meet the demands (Hirich & Choukr-Allah, n.d.). Water recycling would be of great benefits for several purposes such as agricultural and landscape irrigation, industrial processes, and recharge of groundwater table (Jaramillo & Restrepo, 2017). On the other hand, wastewater treatment can be tailored to meet the water quality requirements of a planned reuse (Ait Brahim et al., 2017).

In Morocco, the ratio of treated WW to produced water was equal to 24% in 2017 (Frascari et al., 2018). Despite the desire to pursue efforts in this direction, the water quality requirements for irrigation purposes are high and the infrastructures to reach them costly, slowing down the process for agricultural reuse. In the Souss-Massa Region, several treatment plants are treating a total volume of 53 000 m3 /day, using the sand infiltration and lagoon system technologies, however almost less than 10% (in terms of volume) of the used water is recycled due to lack of institutional framework, landscaping and golf course irrigation. Moreover, in this region, export producers are reluctant to use treated wastewater as a precaution to compromise their markets. However, the Rabat-Sale-Kenitra Region, the study area located in a coastal zone, is dedicated to intensive land use for growing vegetables for national consumption purposes in a peri-urban agricultural zone. The potential of urban wastewater reuse is substantial and would lead to decreasing the pressure on the aquifer. This is particularly relevant as the groundwater in the Skhirat region presents a high risk of salinization (Zouahri et al., 2014)

For this purpose, the goal of this policy test is to use treated urban and industrial wastewater for agricultural purposes in order to lower the pressure on the groundwater table. This measure would be a way to contribute to a dialogue on how intersectoral management methods are crucial to tackle agricultural issues and create a bond between the agricultural sector and the urban areas, decompartmentalizing the institutional options.

Policy	Description	References
Policy 1:	An existing project that has been set in 2011 in the region of Souss-massa in order to supply the region	(Hirich, Choukr-Allah, Nrhira, Malki, &

Desalinization Plant and use desalinate water for irrigation purposes	with desalinated water. The project is in-progress and should start in few years with the heavy support of the regional institutions, the exporters associations and the ministry of agriculture.	Bouchaou, 2017; Hirich, Choukr-Allah, Rami, & El-Otmani, 2015)
Policy 2: Inter-sectorial link – Treated wastewater for agricultural use	The goal of this policy is to use treated urban and industrial wastewater for agricultural purposes in order to lower the pressure on the groundwater table.	(Ibenyassine et al., 2007) (Hirich & Choukr-Allah, n.d.) (Jaramillo & Restrepo, 2017)

Table 1: Policy Implementation summary

5. Metrics for policy evaluation

Assessing and building climate resilience for agricultural development has received a growing interest over the last decade. However, there is still no consensus on how resilience should be assessed and what indicators should be used (Douxchamps et al., 2017). In this study, resilience is understood as the systems' ability to maintain its functionality even when the system is being affected by a disturbance (Herrera, 2017b). The framework from Tendall et al. (2015) suggests four resilience elements that reflect the dynamic trajectory of changing system functionality caused by a shock. These resilience elements are: hardness, robustness, recovery and resourcefulness. In a complex and dynamic context, SD modeling is used to operationalize resilience elements and support the understanding of the long-term behavior of the system.

For a given function of the system, represented by a variable of the model, a disturbance α occurs with a magnitude δ at a time t_s. The system starts to react and lose its function at t_a until it reaches its lowest point f_1 at a time t_d. By the time it reaches its normal function again, t_f, the function gets back to its original states f_0.

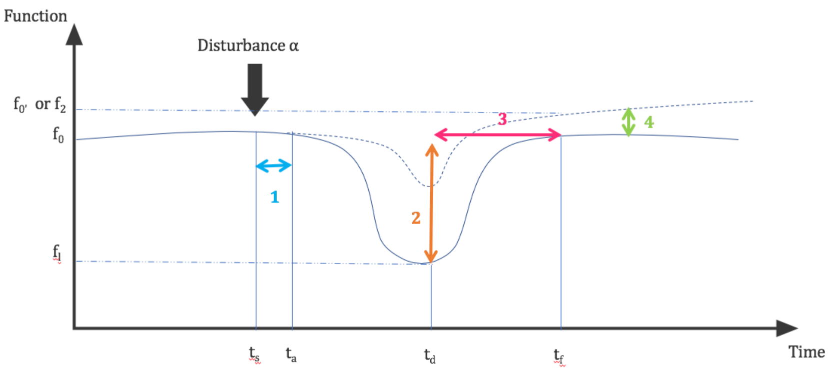

Figure 4: Resilience Framework adapted from Tendall et al., 2015

Define the elements and set the equations

1. Hardness is understood as capacity of the function to maintain its performance, despite a shock, without presenting a change in the performance of the outcome function (Herrera, 2017b). Testing the hardness of the function comes to test up to what degree the system resists shock, or more precisely what should be the amplitude of the shock before starting to feel the effects on the functions of the system.

   Hardness = α *** (t_a-t_s),**
   for $f_1 - f_0 = 0$ (+/-1%)

2. The concept of robustness has been widely developed for agricultural systems resilience (Cifdaloz, Regmi, Anderies, & Rodriguez, 2010; Napel, Bianchi, &

Bestman, 2006; Urruty, Tailliez-Lefebvre, & Huyghe, 2016). Robustness is defined as the capacity to withstand a shock without significant losses of performances, or the extent to which elements of the system are affected and loose its function. In other world, the capacity to absorb the perturbing effect of the disturbance.

Robustness = $(f_0 - f_1)/f_0$

on $\mathbf{t=t_d}$

3. Finally, rapidity or flexibility with which the function of the system is able to recover from the shock and returns to equilibrium after a disturbance σ.

Recover rapidity = $f_2 - f_1/(t_f - t_d)$

A forth element to the resilience framework is suggested by Tendall et al, 2015 – Resourcefulness. It is understood as the capacity to recover and learn from the shock. After the disturbance and its effect on the function of the system, a transformative process could be engaged, leading the system to perform potentially better than before the disturbance. Here, transformability is understood as the capacity to cross thresholds into new development trajectories (Folke, 2006). In this study, this attribute has not been quantified, however, measures to increase the resilience with different policies are tested.

6. Model results

Historic and Reference mode of behavior

The model has been analyzed and tested to a range of behavioral outcomes under varying parameter and policy assumptions. In this section we present a few experiments to highlight the most interesting outcomes. The model analysis runs from 2008 to 2050, which is long enough to study long-term social and environmental processes in this dual tomato production system.

The first objective is to capture the historical behavior of the last decade since the implementation of the GMP (Green Moroccan Plan). The causal links within the system and the identifications of the main feedback loops, enable us to validate some of the general tendencies of the model. The main ones are a growing irrigated agricultural land, an increasing water demand and thus a decreasing groundwater availability. The water availability has an impact on the yield and subsequently on the profitability of the crop.

In a second step, the model simulation is showing the behavior until 2050. With this longer time frame, observations enable to have a long-term sense of the dynamics of both production systems. Two types of outcomes are displayed: the producer's financial capital for both open-field and greenhouse farmers and groundwater availability of both aquifers. In a third step, we implement repetitive drought on both systems to observe the implication of increasing shocks and reflect on the resilience of the system.

Financial Capital

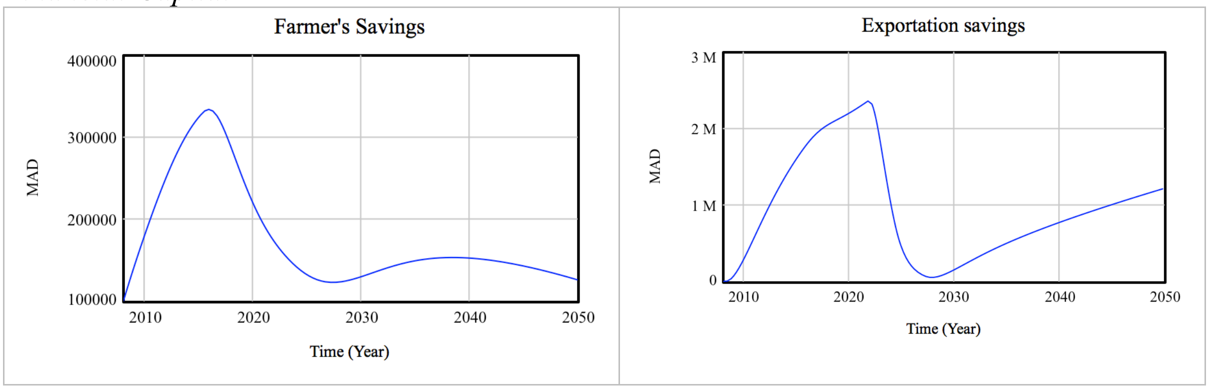

Table 2: Open Field farmers and exporters saving behavior

The dual agricultural system presents 2 different patterns in the face of the same water depletion trend. For the smaller farmers, producing open field tomato, savings increase until 2019 (Table 2 and Table 3). Then, once this tipping point is reached, the savings are continuously decreasing. This tipping point is reached when the groundwater becomes really scarce (Table 3) and the yield decrease due to this scarcity. For the exporter, a similar increase over the first 15 years is observed and is directly followed by a drastic decrease over a longer time period. However, an increase in exporters 'saving could be noticed after 2030, it is explained by the link between tomato production yield and the profit. While water adequacy decrease, producers are still using adequate nutrients to the ground and that enable a proper nutrient uptake. The nutrients used allow the yield to theoretically somewhat increase. Also, the scales of savings are not the same, while exporters are selling to both international and national markets, their profit remains much higher than the local farmers, and despite the groundwater depletion, their financial capital allows them to bear a potential increase in the cost of water.

Water management

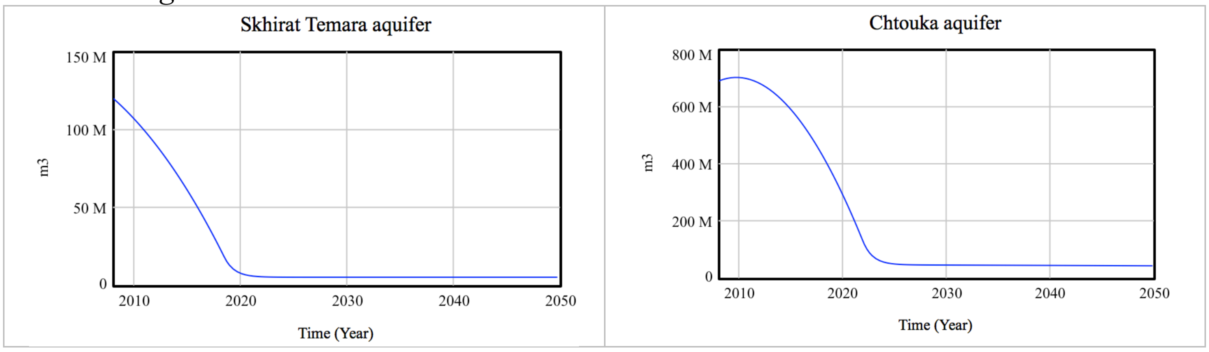

Table 3: Skhirat - Temara aquifer (in Rabat Salé Kenitra Region) and Chtouka aquifer (in Souss Massa Region) dynamics

In this model, all the water used for irrigation and for urban and industrial use comes from the groundwater table. We focused here on 2 aquifers (in the 2 studied regions) that are mostly used for agricultural irrigation. The demand for the agricultural sector depends on the type of crop produced and the total surface area of agricultural land using drip irrigation. The Green Moroccan Plan has fostered drip irrigation and thus the land using this type of irrigation has risen the first decade. The Goal of this first analysis is to show the unsustainable use of resources and the increasing competition between agricultural producers. The aquifers dynamics, shown

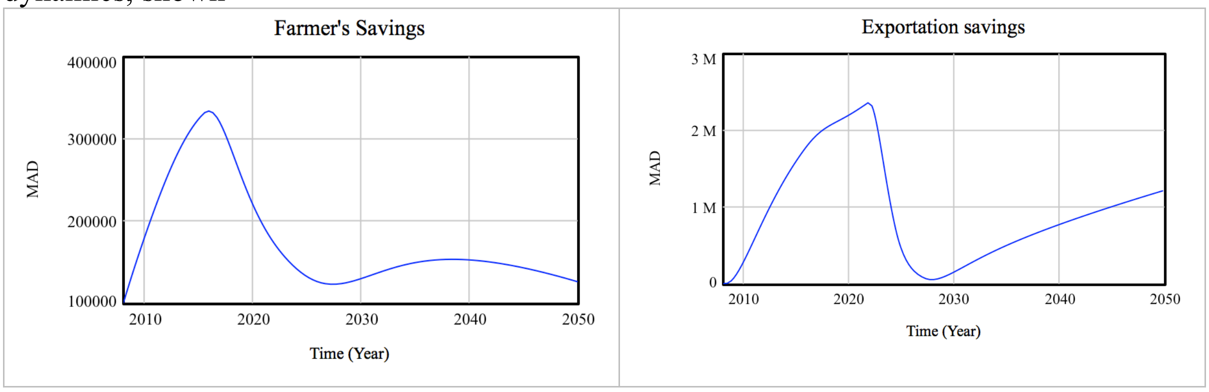

Table 2 are represented as stocks in the model. Those 2 slow variables operate as sustainability indicator for this study. They highlight the severity of water scarcity in that region. While groundwater recharge can be achieved through rainfall, Morocco has faced many cases of drought in the recent years, reinforcing subsequently the water stress in the region and the water table deficit.

Drought

Droughts are predicted to happen more frequently and to affect agriculture and food security in the Middle East North African (MENA) Region and more specifically Morocco. For this study, we decided to simulate repetitive droughts for both case study regions and played with the magnitude of the shock in order to observe the effects on both natural and economic indicators of the model. In the model, the drought is a lack of rainfall input to the groundwater table and the need for farmers to pump more groundwater to fulfill the water requirement of the agricultural crops.

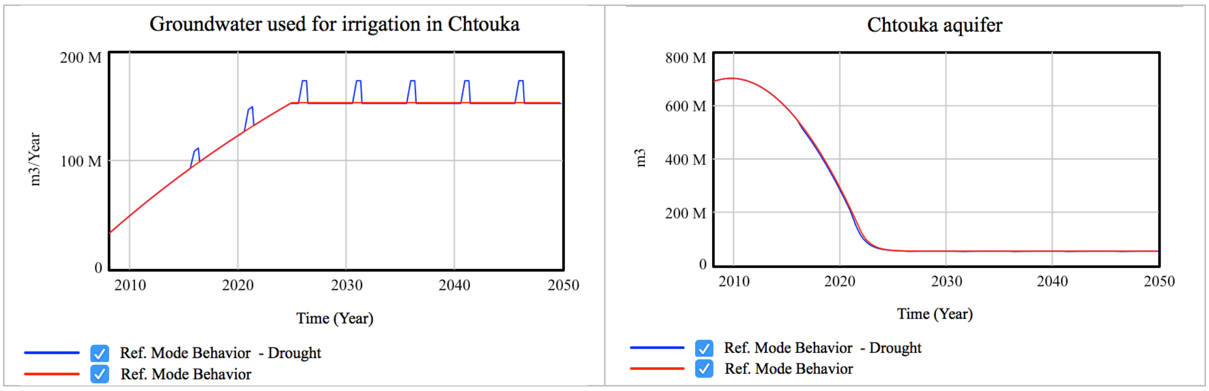

Table 4: Groundwater reaction to repetitive droughts

The repetitive drought simulations enable to observe the peaks in water consumption when the drought shock occurs. The variable "Groundwater used for irrigation in Chtouka" shows an increase in water consumption of several millions cubic meter every time a drought occurs. However, no significant changes can be noticed for the aquifer, expect a small acceleration in the depletion process. This is due to the nature of the stock in the model, that reacts more slowly and with some delays. Also, this could explain the lack of reaction from the authorities and the farmers on field that didn't notice in time the direct effects of the drought on the aquifer.

Policy scenarios

The next step of the study aims to simulate (1) how alternative water sources can decrease the pressure on the aquifer and (2) how it would influence the tomato production systems.

Desalinization

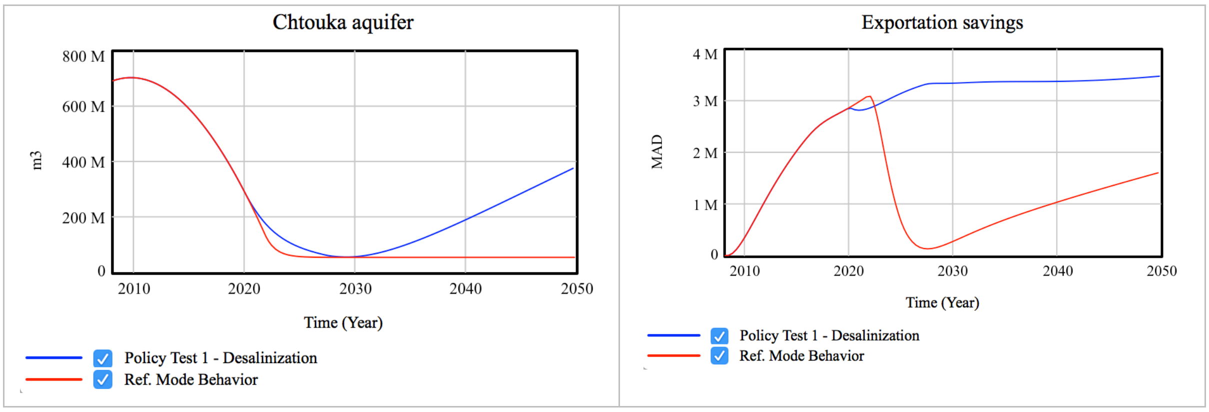

Table 5: Effects of Desalinization on Chtouka aquifer and Greenhouse exporters savings

This first simulation shows how a desalinization plant that would start in 2020 and would supply producers in irrigation water could in the long term enable the aquifer to recharge. Also, a continuous water supply would ensure a decent tomato yield. This would have the effect of maintaining the profitability of the production. However, as mentioned, this policy will only take place in the export region of Souss-Massa. Regarding the open field producers, this simulation is only a test and is not planned to be installed in the Rabat Sale Kenitra Region. For that matter, a second policy has been tested for this region that is located close to an urban center. We studied the possibility to collect wastewater from urban region to treat it and reinject it in the groundwater table.

Inter-sectorial linkage

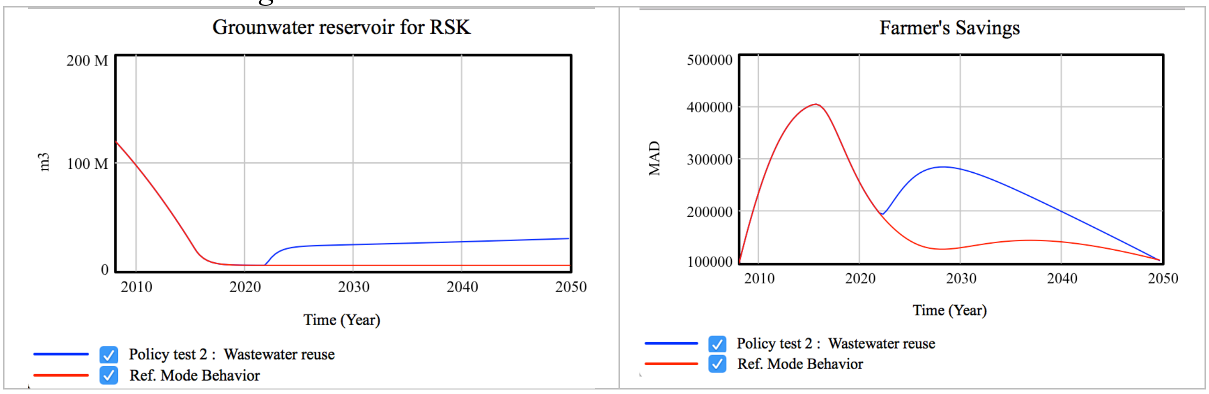

Table 6: Effect of inter-sectorial linkage on the groundwater table and farmers 'savings

This policy test uses treated urban wastewater for agricultural purposes in order to lower the pressure on the groundwater table. This measure is a way to contribute to a dialogue on how intersectoral management methods are crucial to tackle agricultural issues and create a bond between the agricultural sector and the urban areas, decompartmentalizing the institutional options. The simulation shows that the aquifer is not substantially filled, however it allows open-field farmers to increase their savings for a certain amount of time. If launched within the next few years, this policy would enable a delay in farmer's impoverishment. However, such installations take time to build and institutional authorities must take the lead on this policy before it becomes too late for the farmers and their families.

In subsequent version of the paper, we will report on the outcome of the resilience assessment. The synergies and trade-offs between sustainability and resilience will be studied. A further analysis would focus on how the system is behaving and if the policies tested are still valid under repetitive droughts.

7. Conclusion

This paper describes the development of a system dynamics model (SDM) that captures the interactions and feedbacks between two regions and two types of tomato producers in Morocco. The specific objectives of the study were to use the model as a learning tool to improve our understanding of the long-term dynamics of the different production systems and as a basis for exploring alternative policy scenarios for a sustainable and resilient water resource management and agricultural development. The model was tested using a structural and behavioral pattern tests and also sensitivity analysis. This study has demonstrated that SD is a useful tool to understand the long-term behavior of the system and its reaction to sudden changes. In addition, it constitutes an insightful decision support tool for sustainable water resources management.

The results show that the two policies could prevent aquifer depletion and enable farmers to have a long term and sustainable access to irrigation. However, only the desalination policy has been already launched and will be ready to start in 1-2 years, supporting mostly the exporters. On the other hand, despite the advantages of the inter-sectorial policy 2, no plans have been announced by the government so far to initiate it, threatening now not only the long-term but actually the short and mid-term prosperity of open-field producers. Moreover, the predicted increase of drought frequency and intensity in the future will speed up the aquifer depletion and reinforce negative effects on yield and farmers savings, leaving the farmers with no sustainable and resilient solutions for the future.

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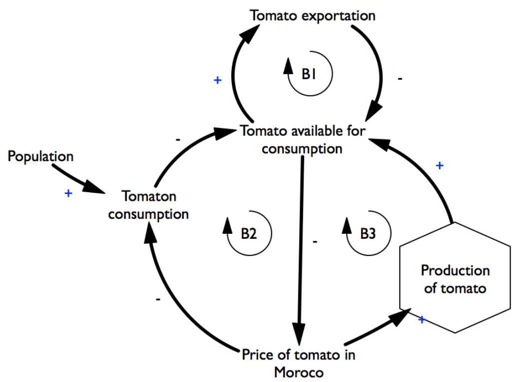
Appendix - Model description

This section presents a summarized description of the model and the key variables. This description focuses on the main dynamics included in the model but excludes some of its details. The following chapter provide a short description of each module in the model. The modules are subsections of the model that help to explain the particular dynamics of the system. For explanatory purposes, the modules in the model can be split between those exploring the economic dynamics in the system and those describing the natural resources supporting it. (Herrera, 2017).

Economic modules

Tomato Market dynamics (view 1)

This component contains the links between Tomato Production and the Supply/Demand loops. Both Greenhouse producers and smallholders are supplying the national market. The demand/supply ratio evolve in function of the population growth and the tomato consumption per capita and the tomato production. The tomato production is a function of the yield and the land used for tomato production.



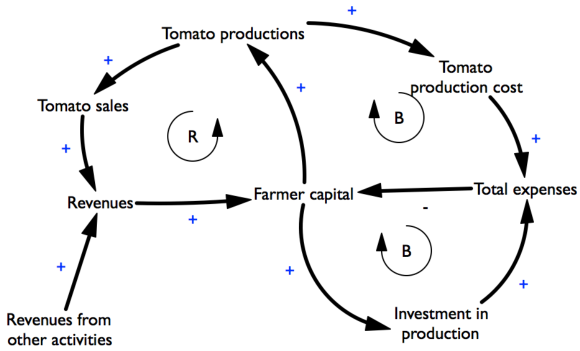
Local Farmer dynamics (view 2)

The structure of the farmers management is an aggregated way to link income and expenditures. The main stocks are:

- Farmers Financial Capital – The depends on the income (from tomato, other crops and other non-agricultural sources), the investment on inputs, the depreciation of the goods and the reimbursement of the debts.
- Household expenditures – That are growing because of a high annual growth in rural households.
- Debts that are depending on the ratio expenditure / income. The reimbursement is done with the farmers capital.

Hypothesis: We suppose that the average exploitation size for an exporter is 3.4 ha and 1/3 is used for tomato production. The other land is used for other horticultural crops. We suppose that it is a family farming activity, involving that the household expenditures are part of the total expenditure.

The investment on inputs does not influence the yield – we suppose that the farmers is irrigating his crop with the same amount of water.



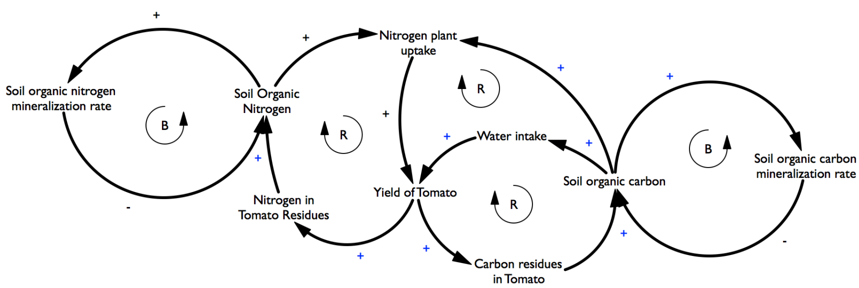
Exporter Dynamics (view 3)
On this section of the model, we described the particularities of the exporters production system. With an initial capital to start the producing activities, exporters can invest on quality inputs, labor, and mechanized tools to produce a better yield. The capital is considered as a stock and is the one enabling producers to invest in the first place on mechanized tools, building and good quality inputs. It also enables them to hire agricultural employees. The agricultural workforce is also a stock evolving in function of the number of employees hired and discharged by the exporters. Exporters' tomato has to meet certain standards of quality to be able to be exported to European and international markets – that explains the high costs of production yearly and the need to invest on mechanization and good quality inputs on a yearly basis.

Hypothesis: We suppose that the average exploitation size for an exporter is 13.7 ha.
We also suppose that the exporters yield is enhanced with the use of good quality inputs and investment on mechanized tools that appears to have a positive effect after 15 year. For that matter, exporter's yield is superior than Farmer's yield.

Natural resources modules

Soil dynamics (view 4 and 4bis)
Soil Organic Matter and Yield formation have been extracted and simplified from Andreas Gerber Model. For the moment, the equations and the structure haven't been modified or changed. In the model, the yield function depends on the Nitrogen and Water uptake of the plant – in that case Tomato. The effect of water on yield is also linked to the water availability.

Hypothesis: The effect of water on tomato yield hasn't been found on the scientific literature and an estimation had to be done.



Yield (view 5 and 5bis)
The yield for both greenhouse and open field production are dependent of the effect of water uptake and the effect of nitrogen uptake. The main difference between the 2 type of

production is the Water required per ton of crop per year and the Yield plateau (that is higher for greenhouse tomato). In general, the yield evolves between 40-60 ton/ha for open field production, 100 and 150 ton/ha for greenhouse production – which is close to the reality and the survey conducted. However, the yield function is very volatile and depend on few key variables, such as the constant effect factor of water on yield.

The main equation for the yield is:

Yield = yield plateau * effect of water uptake on yield * effect of nitrogen uptake on yield

Where,

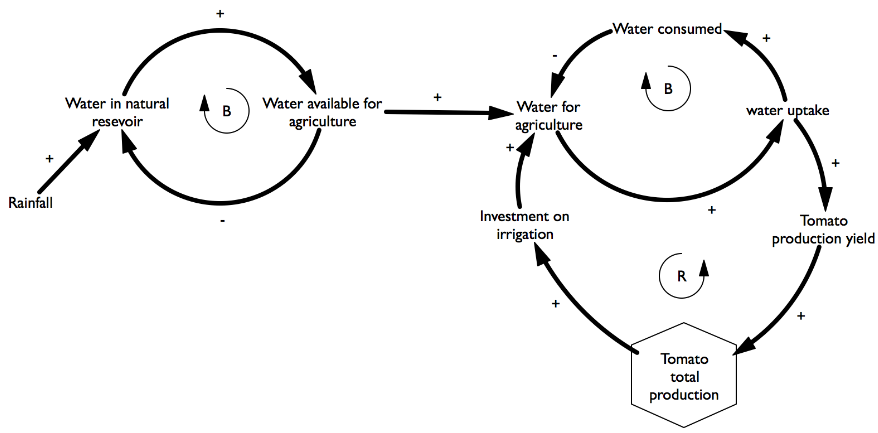
effect of water uptake on yield = 1-10^ (-Average water uptake agriculture*Effect factor of water on yield/Initial water uptake in agriculture)

effect of nitrogen uptake on yield= 1-10^ (-effect factor of nitrogen uptake on yield table*Nitrogen uptake by tomatoes)

Water and irrigation dynamics (6 and 6bis)

This last component of the model, is a simplified version of the water supply dynamics - were water is only extracted from groundwater (recharged by the infiltration of precipitation and the surroundings rivers and dam) – Groundwater withdrawal depends of domestic, industrial and agricultural use. The domestic use is growing with the population. The agricultural land stock is now a constant, that should rather be understood as the agricultural land available in the region.

Hypothesis: Over simplification of the water supply system – with only 1 source of water from the groundwater table and fixed arable areas.



Land (view 8)

This view decomposes the total irrigated land available, the conversion to drip irrigation and the part of it that is used for tomato production. The balancing loop that is described here is: The less water there is, the less agricultural land is switching to drip irrigation.

Hypothesis: The growth in use of drip irrigation depends on the water adequacy. At one point, when the water is too low, producers stop to convert their irrigation to drip. When the water adequacy is below 0.2, then there is no more implementation of drip irrigation.

List of exogenous variables

Name in the model	View	Value	Unit	Source / Note
Demand elasticity of tomato price	1	-0.2	Dmnl	TO CHECK
Price perception adjustment time	1	1	year	TO CHECK
Availability perception reference time	1	5	year	TO CHECK
Tomato consumption per capita	1	30	kg/capita	http://www.chilealimentos.com/medios/Servicios/noticiero/EstudioMercadoCoyuntura2011/Conservas/Fresh_vs_processed_tomato_consumption_study_January_2011.pdf
Part of the Greenhouse production for export	1	0.34	Dmnl	http://eumed-agpol.iamm.fr/private/wp5files/rapport_adepta_janv05.pdf
Export tomato price	1	7500	MAD/tom	Average price for Tomato in Wholesale market in France - Knowing that France is importing more than 65 % of the tomato produced for export in Morocco - https://rnm.franceagrimer.fr/prix?TOMATE&12MOIS
Open field Area harvest	1	lookup	Ha/year	FAO STAT until 2014 → Partly endogenous – including the seasonal tomato production area in the region of RSK
Part of the production that could be sold	2	1	Dmnl	It's mostly to test if the markets are too far and it generates a lot of waste for example
Average size of a farm exploitation	2	3.4	ha	According to the Survey realized in 2018, 1/3 of the total area is allocated to tomato production 4 months a year.
Cost of Labor per hectare	2	12000	MAD/(ha*year)	Estimations for 10 employees for 10 days payed 120dh/day Source: Farmers interview
Cost of fertilizer	2	12000	MAD/(ha*year)	Estimation based on the number of bags of fertilizer, liters for fertigation and manure lorry that comes to the field Source: farmer interview
Cost of seeds per hectare	2	7500	MAD/(ha*year)	5 bags of seeds per hectare - As 1 bag of seeds cost 1500 MAD Source: Farmers interview
Cost of pesticides per hectare	2	12000	MAD/(ha*year)	Source: Farmers interview
Profit on other crop production	2	23735	MAD/(ha*year)	Oates, Naomi & Jobbins, Guy & Mosello, Beatrice & Arnold, John. (2015). Pathways to irrigation development in Africa - insights from Ethiopia, Morocco, and Mozambique.
Part of the capital that is invested in equipment	2	0.2	Dmnl	TO CHECK Value should be for Maintenance of all the capital – irrigation installations, buildings, and all material
Annual Growth in rural household expenditure	2	0.045	Dmnl	http://rgphencartes.hcp.ma/
Initial household expenditure	2	55550	MAD/year	http://rgphencartes.hcp.ma/
Initial farm capital	2	100000	MAD	Test
Other sources of income in	2	40000	MAD	Estimating that the total income of agricultural origin represents 52.7% - the rest comes from mainly wages, income transfers and independent nonagricultural activities

				http://medfrol.maich.gr/documentation/view/reports/wp1-asr/Morocco.pdf
Cost of Labour	3	43850	MAD/(ha*year)	Source: Aloui O, Kenny L., (2005). The cost of compliance with SPS Standards for Moroccan Exports: A case study, he International Bank for Reconstruction and Development /The World Bank 1818 H Street, NW.
Cost of fixed charge	3	11920	MAD/(ha*year)	-
Cost of pesticides per year per hectare	3	20000	MAD/(ha*year)	-
Cost of fertilizer per year per hectare	3	20000	MAD/(ha*year)	-
Cost of of seeds per year	3	10000	MAD/(ha*year)	-
Cost of compliance for certification	3	21640	MAD/(ha*year)	Source: Aloui O, Kenny L., (2005). The cost of compliance with SPS Standards for Moroccan Exports: A case study, he International Bank for Reconstruction and Development /The World Bank 1818 H Street, NW.
Average life of capital	3	3	Year	No sources yet, could vary from 2 to 5 years depending on the "input/infrastrucure"
Share of profit invested	3	0.8	Dmnl	test
Part of the relative capital invested	3	0.15	Dmnl	test
Fraction plant residues remaining on the field / above ground	4bis	0.1	Dmnl	TO CHECK – andreas model
Organic Nitrogen from animals	4bis	0.276	Ton/year	Malkia M., Bouchaoua L. et al. (2017). Impact of agricultural practices on groundwater quality in intensive irrigated area of Chtouka-Massa, Morocco, Science of The Total Environment - Volume 574, 1 January 2017, Pages 760-770 https://doi.org/10.1016/j.scitotenv.2016.09.145
Carbon share in dry matter	4bis	0.58	Dmnl	This variable represents the carbon share in total soil organic dry matter. Scheffer/Schachtschabel (2010): Lehrbuch der Bodenkunde. p. 55. Schubert (2011). Pflanzenernährung. Grundwissen Bachelor. Ulmer UTB. p153: To convert C-content into soil organic mater (SOM), one can assume an average C-concentration of 58%. The C-concentration can vary from 40 to 60%.
Organic matter from animals	4bis	0.035	Ton/year	TO CHECK – Hugo
Organic matter in residue above grounds	4bis	0.8	1	TO CHECK – Hugo
Nitrogen content on above ground residues	4bis	0.006	1	TO CHECK – Hugo
Initial soil organic carbon	4bis	20	ton/ha	This constant represents the initial value of the soil organic carbon stock.
Initial Soil organic Nitrogen	4bis	1.6	Ton/ha	This constant represents the initial value of the soil organic nitrogen stock.
Average mineralization time	4bis	31	Year	This constant represents the average soil stock residence time for carbon and nitrogen. Parameter range: 10-50 years. Source: Scheffer and Schachtschabel (2010). Lehrbuch der Bodenkunde.
Effect of OM in water uptake	5	0.55	Dmnl	TO CHECK – Hugo

Initial water uptake in agriculture	5	0.6	Dmnl	TO CHECK – Hugo - test
Constant effect factor of water on yield	5	1.5	m3/(ha*year)	The constant effect factor of water on the maize is yield is estimated as inversely proportional to the amount of total water required.
Water Required per ton of crop per year	5	8.5	m3/(ton*year)	TO CHECK – Hugo
Yield plateau Open field tomato	5	150	ton/ha	General maximum yield reach for Daniela Variety of tomato
Initial plant uptake share of Nitrogen	5	0.5		
Effect of Organic matter in Nitrogen	5	0.25		
Nitrogen fertilizer application per hectare tomato	5	0.926	ton/(ha*yeart	Malkia M., Bouchaoua L. et al. (2017). Impact of agricultural practices on groundwater quality in intensive irrigated area of Chtouka-Massa, Morocco, Science of The Total Environment - Volume 574, 1 January 2017, Pages 760-770 https://doi.org/10.1016/j.scitotenv.2016.09.145
Effect of nitrogen uptake on yield table	5	0.15	(ha*year)/ton	TO CHECK – Hugo
Watertable input and outputs	6	All variables		Malkia M., Bouchaoua L. et al. (2017). Impact of agricultural practices on groundwater quality in intensive irrigated area of Chtouka-Massa, Morocco, Science of The Total Environment - Volume 574, 1 January 2017, Pages 760-770 https://doi.org/10.1016/j.scitotenv.2016.09.145
Watertable input and outputs	6 bis	All variables		http://81.192.102.15/images/documents/Synthese-PDAIRE-%20francais.pdf and http://www.fao.org/nr/water/aquastat/irrigationmap/MAR/MAR-gmia.pdf
Percentage of the population living in the Souss	7	0.8	Dmnl	http://rgphencartes.hcp.ma/
Percentage of population living in RSK	7	0.13	Dmnl	http://rgphencartes.hcp.ma/
Initial water use per capita per year	7	18	m3/capita/year	AQUASTAT Morocco http://www.fao.org/nr/water/aquastat/countries_regions/Profile_segments/MAR-WU_eng.stm
Part of the urban and industrial water used pumped in the groundwater table	7	0.5 and 0.7	Dmnl	Test
Part of the irrigable land installing drip irrigation	8	0.02	Dmnl	AFD, Plan BLeu (2012), GESTION DE LA DEMANDE EN EAU DANS LE BASSIN MEDITERRANEEN – EXEMPLE DU MAROC - CAS D'ETUDE DU SOUSS MASSA
Initial Irrigable agricultural land in Souss	8	100500	ha	http://www.fao.org/nr/water/aquastat/irrigationmap/MAR/MAR-gmia.pdf
Initial Drip irrigated land Souss	8	9386	ha	AFD, Plan BLeu (2012), GESTION DE LA DEMANDE EN EAU DANS LE BASSIN MEDITERRANEEN – EXEMPLE DU MAROC - CAS D'ETUDE DU SOUSS MASSA
Initial Drip irrigated land RSK	8	24690		http://www.agriculture.gov.ma/sites/default/files/rabat_sale_zemmour_zaer_2014.pdf
Part of the land allocated to vegetable production Souss	8	0.13	Dmnl	-

Part of the land allocated to tomato production Souss	8	0.57	Dmnl	-
Part of the land allocated to vegetable production RSK	8	0.4	Dmnl	http://www.agriculture.gov.ma/sites/default/files/rabat_sale_zemmour_zaer_2014.pdf
Part of the land allocated to tomato production RSK	8	0.33	Dmnl	% of surface area for tomato production per exploitation - SURVEY
Cost of pumping machine and irrigation facilities	9	20000	MAD/ha*year	http://www.sirrimed.org/catalogo/d_2_5_2014-mar-31.pdf
Price of water	9	2	MAD/m3	http://scholar.google.ch/scholar_url?url=http://www.semide.net/media_server/files/i/9/CohinRieuMontginoulWaterpolicyreformspricingwatercostrecoverywaterdemand.pdf&hl=fr&sa=X&scisig=AAGBfm0zTHVSifjQwcQG4VdPhUQRjuTgzA&nossl=1&oi=scholarr
Water used per hectare of vegetables	9	7500	m3/(ha*year)	http://medfrol.maich.gr/documentation/view/reports/wp1-asr/Morocco.pdf
Water used per hectare of other crops	9	750	m/(ha*year)	test
Part of the water used for tomato	9	1	Dmnl	test
Part of irrigation water from groundwater	9	1	Dmnl	test
Water used per hectare of vegetables openfield	9	2000	m3/ha	test
Water used in Rabat				http://81.192.102.15/images/documents/Synthese-PDAIRE-%20francais.pdf
Maximum Best irrigation use	9	0.85	Dmnl	test
Seasonal Tomato production Open Field	10	Lookup	dmnl	http://www.fao.org/land-water/databases-and-software/crop-information/tomato/en/
Seasonal Tomato production under Greenhouse	10	Lookup	Dmnl	From August to March for greenhouses – mostly dependent on the market calendar for off-season needs. http://www.cmgp.com/wp-content/uploads/2016/12/Tomate.pdf