An empirical evaluation of policy options for inclusive dairy value chain development in Nicaragua: A system dynamics approach

Abstract

Achieving inclusive value chain development is a challenging task due to the complex and dynamic nature of interconnected value chains and their social, economic, and ecological dimensions. While many policies and intervention options exist to upgrade value chains, there are fewer methods that can be used to understand and quantify the multidimensional impacts that value chain policies and interventions may have throughout the value chain. This paper addresses this methodological gap by employing a system dynamics (SD) modeling approach. SD models allow us to model and quantify the processes and relationships inherent in the value chain through simulations, serving as a policy laboratory for the empirical assessment of intervention options. An SD model of the Matiguás dairy value chain in Nicaragua was developed and tested through a participatory modeling process. Our research tested and evaluated the short-, medium-, and long-term impacts of specific interventions and policies in the Matiguás dairy value chain with the goal of strengthening the competitiveness and inclusion of small- and medium-scale producers. These interventions centered on improving the feeding system, which was identified by stakeholders as the critical constraint to competitiveness. The policy analysis reveals that both improved pastures and increased use of concentrates raise producer milk productivity by 5% and 11%, respectively in the long run, but are also expensive strategies for smallholder producers, leading to a reduction in profits relative to the baseline by 1% and 3%, respectively. Consequently, policymakers should identify strategies that help to reduce concentrate costs and support producers with investments in improved pasture, while also promoting training in pasture management skills. Indeed, in the long-run, model results reveal that investment and training in pasture management results in a 30% and 35% increase in milk production during the wet and dry season, respectively. Simulation results further highlighted that intensifying the feeding system to improve cow milk yields is mainly profitable in the long term, and thus requires a longer-term perspective by policymakers. The model provides a deeper understanding of the complex and dynamic nature of the Matiguás dairy value chain and the interactions between markets, coordination aspects, biophysical phenomena, and income. The system dynamics approach to value chain analysis further addresses a major analytical shortcoming in value chain analysis and provides decision makers with an improved platform for planning and policy formulation.

Key words: System dynamics; value chain analysis; inclusive development; policy analysis; smallholders; dairy

1. Introduction

The transformation of the global agrifood system offers opportunities, and poses challenges, for the integration of smallholder farmers into remunerative local, regional, and global markets. The demand for higher-value agricultural products is growing, in both domestic and foreign markets in developing countries due to a constellation of interrelated trends associated with urbanization, higher incomes, and changing food preferences away from staple goods and towards value-added, and protein-rich foods (Arias et al. 2013; IFPRI 2017). Connecting smallholders to such markets, whether local or global, could be an effective way of reducing poverty and improving food security in developing countries. However, particularly poor rural farmers are often excluded from these increasingly complex and dynamic markets (IFPRI 2017). Commercial markets are highly competitive, with high quality standards and requirements of consistent, timely deliveries (CFS 2015; Devaux et al. 2016). Due to limited access to land, capital and information, often exacerbated by poor infrastructure, many smallholder farmers have limited contacts with commercial markets and hence a poor ability to react to market forces (Devaux et al. 2016).

In Nicaragua, the cattle sector, including dairy, is economically and culturally important, with 90% of farmers being small- and medium-scale. With the rapid commercialization of the dairy sector involving a doubling of processing capacity during the last 10 years and an increase of the share of the formal sector from 26% to 50%, their inclusion is an important policy issue (MAGFOR 2013) and ensuring their competitiveness is vital. In the municipality of Matiguás, located in central Nicaragua, 80% of households keep cattle, the most important source of household income. Through cooperatives, some farmers have access to formal markets, but ensuring steady milk quality and quantity, especially in the dry season, poses challenges for successful market participation (Alcaldía Municipal de Matiguás 2011; Velásquez &

Manzanarez 2014). Policy and intervention options include promoting investment in improved pastures and improved breeds, increasing the use of concentrates, or improving integration of value chain components. However, given the complexity of these value chains, the dynamic effects of intervention options, and their resultant financial returns, are not obvious, limiting the investing ability of value chain actors, donors, and policy decision makers.

In this paper, we seek to address these identified research gaps more generally and in the context of dairy in Matiguás by employing a methodological perspective that allows us to model and quantify the processes and relationships inherent in the value chain. Using a simulation approach, this perspective serves as a policy laboratory for the assessment of intervention options. Our research specifically aims to test and evaluate the short-, medium-, and long-term impacts of specific interventions and policies in the Matiguás dairy value chain to strengthen the competitiveness and inclusion of small- and medium-scale producers. We employ system dynamics (SD) modeling to explicitly map the information and material flows, processes, decision rules, and relationships between actors that operate within a complex value chain system (Sterman 2000). Recent research has revealed the utility of this approach in agricultural and livestock systems to *ex-ante* test the dynamic impacts of feedbacks from different policy and technical interventions within value chains (Dizyee et al. 2017; Naziri et al. 2015; Rich et al. 2011). A major advantage of SD modeling is its ability to employ participatory processes in the design, construction, parameterization, and application of value chain models, improving modeling transparency and validity, and engaging value chain actors together in a process of joint learning (Lie et al. 2017). This approach thus addresses a major analytical shortcoming in traditional VCA and provides decision makers with an improved platform for planning and policy formulation.

2. Background: Dairy production in Nicaragua and Matiguás

In Nicaragua, cattle production represents 45% of national agricultural GDP and 32% of exports by commodity value. Daily milk production averages 2-2.5 million kg, of which half is processed by the formal sector, and the remainder absorbed via informal channels. The sector's size and potential (e.g., for export of dairy products to other Central American countries and the USA) is important for the Nicaraguan government in terms of its contribution to food and nutritional security, income generation, economic development, and ecosystem restoration (Holmann 2014; MAGFOR 2013).

Of the 80% of the households in Matiguás keeping cattle, 60% are small-scale producers owning less than 20 mz[1] of land, two to 20 cows and each cow producing about 3-4 kg of milk per day. Medium-scale producers make up 20% of the cattle-owning population, own between 20 and 100 mz of land and produce about 50 kg of milk per day per household (Polvorosa & Flores 2015). The growing commercialized dairy industry threatens the participation of small- and medium-scale producers in formal markets, increasing their dependency on the informal dairy sector with unstable milk prices (INIDE-MAGFOR 2013). The formal sector milk price ranges between 11 and 12 Nicaraguan Cordobas (NIO) per kilogram, while the informal milk price ranges between 8 and 13 NIO/kg, depending on the season.[2] Therefore, small- and medium-scale producers need to find ways to ensure their competitiveness alongside larger producers.

[1] In Nicaragua land is measured in manzanas. 1 mz = 0.7 ha. Small-scale farmers own less than 14 ha, medium-scale farmers between 14 and 70 ha, and large-scale more than 70 ha of land.
[2] 100 NIO = 3.4 USD (09.03.2017 XE.com)

Dairy cooperatives collect milk and provide support to producers in the form of access to inputs, credit, and extension services. In Matiguás, the dairy value chain includes five cooperatives that collect milk from over 1,000 producers (Polvorosa 2013). About 20,000 dual-purpose cows[3] produce every day 100,000 kg of milk, 60% collected by cooperatives. The dairy industry based in the capital Managua controls the conditions of participation in the formal dairy value chain (Polvorosa 2013). See Lie and Rich (2016) for a value chain map for the Matiguás dairy sector.

The value chain faces challenges in the seasonality of milk production, difficulties in securing high quality milk, and the variation in milk prices and demand for milk (Alcaldía Municipal de Matiguás 2011). Several institutions aim to support and promote inclusive development in the dairy value chain in Matiguás and have suggested a number of policies and interventions to mitigate the challenges after conducting value chain analyses (e.g., see Alcaldía Municipal de Matiguás 2011; Johan Bastiaensen et al. 2015; Velásquez & Manzanarez 2014). These include improving coordination among the actors in the chain through better information and communication regarding the newly introduced quality-based pricing system for milk; improving cattle breeds; and promoting the use of improved pastures and concentrates that reduce seasonal variations among small- and medium-scale producers. However, none of these value chain analyses and plans have included any *ex-ante* economic assessment of the potential impact of these interventions.

[3] Mostly cross-breeds of varying proportions of mainly Brown Swiss (dual purpose), Holstein Frisian, Jersey (both dairy) and Brahman (beef), with a genetic potential for milk production that is generally not reached due to suboptimal feed availability and management. Beef production would only suffer if there is a genetic shift towards "pure" dairy types, which is not the case in this model. In fact, with the current herd, the scenarios leading to higher milk production would also lead to higher beef production.

3. Methods of analysis

3.1 System dynamics modeling in value chain analysis

Value chain analysis (VCA) is a useful framework to diagnose ways to improve agricultural value chains and facilitate the inclusion of smallholders. It is an interdisciplinary, structured, yet flexible framework that provides context to the inner workings of complex value chains. VCA provides a narrative of value chain characteristics, mapping chain actors and processes, assessing governance and coordination mechanisms, identifying possibilities for upgrading in the chain, and addressing distributional issues. The implementation of VCA by practitioners has been facilitated by the development of various handbooks that guide the value chain development process (e.g. see GIZ 2008; M4P 2008; Kaplinsky & Morris 2001; Terrillon & Smet 2011; World Vision 2016).

Despite the utility of value chain analysis, a number of drawbacks remain (Rich et al. 2011). First, while VCA identifies bottlenecks in the chain and suggests ways to address them, it offers little empirical guidance to quantify the intended and unintended up- and downstream effects associated with the implementation of recommended policies or interventions. Likewise, conventional methods make it difficult to evaluate the impacts of different policies on different actors in the chain, and over the short- or long-run. Indeed, each node in the chain itself represents a complex and dynamic sub-system that needs to be mapped, analyzed, and quantified individually and in relation to the rest of the chain to capture the dynamic effects associated with policy change.

SD modeling combines the visualization aspect of VCA with a modeling platform to conduct scenario analysis. SD is a computer-aided approach to policy analysis and design. SD models can be qualitative or quantitative. As a modeling tool, SD is interdisciplinary and captures the evolution and interactions between complex economic, social, and ecological systems over time. Its graphical modeling canvas, further improves communication across disciplines. A particular benefit with SD modeling is that it can be conducted jointly with key stakeholders in the value chain. A participatory process called group model building (GMB) provides a methodology through which value chain actors and enablers can participate in all or some of the steps in the modeling process (Hovmand 2014; Vennix 1996). This process facilitates learning and shared understanding about the system among the participants, develops a more useful model, and enhances the commitment to selected strategies and their implementation, which potentially strengthens the sustainability of value chain interventions and policies (Lie et al. 2017). This process is briefly discussed in the next section.

3.2 Data collection and model development

Data collection and model construction were completed through a GMB process with key stakeholders in the Matiguás dairy value chain through four meetings held between March and June 2015, and a follow-up meeting in April 2016. Each session was carefully planned using scripts that included goals, the agenda, timings, and chosen group methods (Andersen & Richardson 1997; Luna-Reyes et al. 2006). On average, 13 participants contributed during each session. They included four small- and medium-scale farmers, three cooperative managers, one local processor, three municipal government representatives, and seven participants from research and development organizations, i.e., Heifer International, International Center for Tropical Agriculture (CIAT), Tropical Agricultural Research and Higher Education Center (CATIE) and the Nicaraguan research and development institute Nitlapan. The GMB meetings were supplemented by meetings with a reference group consisting of experts on various aspects of the dairy value chain. Additionally, key informant interviews to validate parameters and obtain background information were conducted with cooperative leadership, credit institutions, an industry actor in Managua, the Nicaraguan Chamber of the Dairy Sector (Canislac), and several informal processors and dairy sales outlets in the town of Matiguás.

The GMB stakeholders provided information about the flows, processes, and relationships between the different nodes and actors in the chain. They also provided detailed information on milk production in Matiguás and per cow, effects of feed on milk and cattle production, delays in the system (both biophysical and those associated with decision making), and information about costs and revenues. Data from the national census (INIDE-MAGFOR 2013), such as the number of cattle and amount of land used for cattle production, was also used. For additional information about participatory modeling and the GMB process of the Matiguás dairy value chain, see Lie et al. (2017).

The model was constructed using the software program iThink from isee systems.[4] The model is publicly accessible online[5] to GMB participants, the reference group, and others interested in running scenarios using the model themselves. The time step 'weeks' was chosen for the model because milk production has large seasonal fluctuations that are best captured using weeks. The model utilizes the local currency, Nicaraguan Cordoba, and the local land measure, manzana, to make the data and analysis as relevant and accessible as possible to the value chain stakeholders, policymakers, and others who have an interest in better understanding the Matiguás dairy value chain. The following section describes the development of the model.

[4] https://www.iseesystems.com/
[5] https://sims.iseesystems.com/helene-lie/dairy-value-chain-development-in-nicaragua

3.3 The system dynamics model of the Matiguás dairy value chain

The top policy goals identified by the stakeholders in the first modeling session were to increase the production of milk, both in terms of quality and quantity, and for value chain actors to achieve higher income. During the same session, a deficient feeding system was identified as the main constraint. The feeding system in Matiguás is pasture based, with traditional, improved and cut- and-carry grasses, some crop residues, and the use of concentrates, each impacting milk productivity differently. The seasonal rainfall pattern (seven months rainy season, five months dry season) and the strong effect of water availability on pasture production (Sraïri et al. 2016) lead to marked differences in milk production between the rainy and dry seasons, at 6 kg and 3 kg per cow per day respectively. In the past, milk production has increased mainly as a result of land expansion, but increasing land area for pasture is no longer an option. Since most pastures consist of traditional species,[6] with poor nutritional quality, particularly during the dry season, possibilities are limited to significantly increase milk yields without technical intervention. Therefore, GMB participants concluded that the main focus of the model should be on policies and interventions that could enhance feeding systems to improve milk quantity, especially during the dry season, as a means of increasing small- and medium-scale farmer profits.

To conduct what-if-scenarios for identified policy options (more details on this in section 3.5), we constructed a quantitative SD model. The SD model of the Matiguás dairy value chain consists of four modules that each focus on a separate sub-system of the value chain: herd dynamics, milk production and sales, feed dynamics, and financial aspects. The herd module represents the development of animals from birth to mature cows. This is a crucial input for the

[6] Predominantly *Hyparrhenia rufa* and *Ischaemum indicum*, both with sharply declining biomass and Nitrogen content (under 1%, below maintenance level) during the dry season.

milk module, which covers the production of milk that can be collected and processed before marketing and consumption. Feed is the key input in animal and milk production. The feed module differentiates between improved and traditional pastures and the use of concentrate. All three modules generate costs, while the herd and milk modules also produce revenues. Both aspects are summarized in the finance module, which is divided into two submodules, one that assembles costs and revenues, while the other highlights investment dynamics that relates profitability into investment decisions that feed back to other modules. Figure 1 presents a high-level map of the model and illustrates how the modules are interconnected. The lines indicate bundled flows (black) and bundled connectors (green). Bundled flows represent material flows between modules or sectors. The bundled connectors capture the high-level information connections between them. See appendix A for a stock and flow structure, and description, of each module and see Lie & Rich (2016) for a detailed description of main feedback loops of the model. All baseline data can be found in appendix B and equations in appendix C.

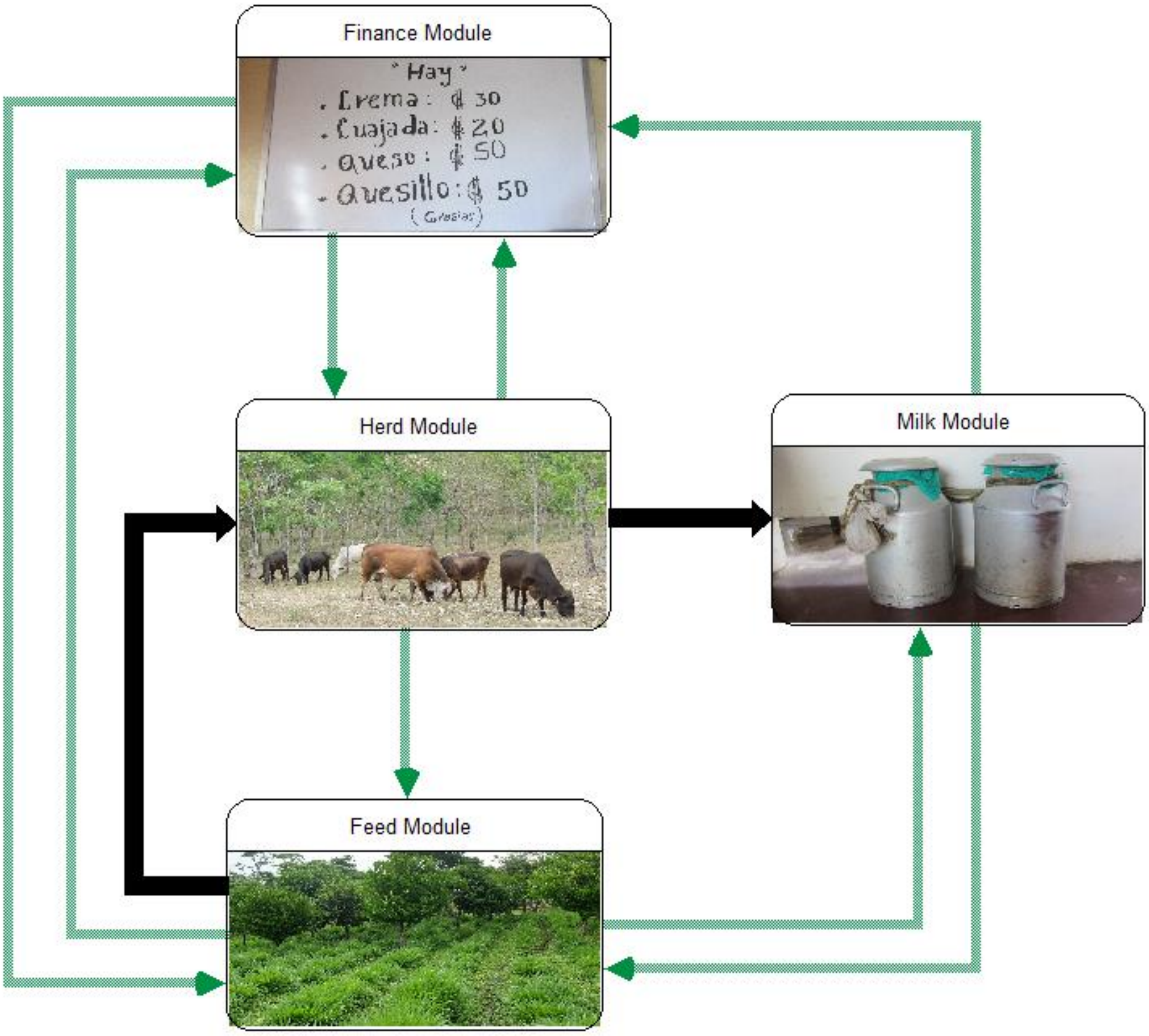

Figure 1: High-level map of the Matiguás dairy value chain model (See Appendix A for detailed modules descriptions). Source: Developed by the authors

3.4 Model validation

Model validation is about building confidence in the model (Forrester & Senge 1980). The GMB process validated the structure of the SD model of the Matiguás dairy value chain in various ways. The group itself sketched the structure of the model after receiving an introduction to SD modeling, its language, and procedures. The group also chose which problem to focus on, discussed and agreed on the boundary of the model, and provided data.

Behavior reproduction tests focusing on milk production were completed with the GMB group – i.e., GMB participants created a reference mode due to lack of historic time series data (Forrester & Senge 1980; Sterman 2000). The timing of the low and high seasons for milk production was also confirmed, with the dry season occurring from the beginning of the year until mid-May. On average, in the model each farmer owns 23 mz, which is in accordance with the census data in the area. The GMB process was duly documented to ensure recoverability of the progression and choices made during the model building process, which strengthens its reliability.

In addition to the thorough model evaluation throughout the GMB process, parameters have been extreme condition tested to make sure the model behaves realistically. All graphical effects were also thoroughly tested for sensitivity as these are variables that drive the dynamic behavior in the model (Forrester & Senge 1980; Sterman 2000). The model has dimensional and parameter consistency and does not contain parameters without real world meaning. Details about equations and parameters can be found in appendices A and B.

3.5 Scenarios for policy analysis

The GMB group identified several possible policies to achieve their value chain goals (see Lie & Rich 2016). The selected policies to test were: (1) increasing the use of concentrates during the dry months; (2) increasing the amount of land used for improved pasture; (3) increasing the number of dairy cows; and (4) a combination of policies (1) and (2). In addition to these four policy interventions, we simulate a baseline run based on collected data to establish a benchmark to compare policy interventions relative to the status quo. We also conducted different types of sensitivity analysis associated with the occurrence of drought and simulated changes in prices for concentrates. In model runs, short run was considered to be two years, medium term five years and long term eight years after the intervention started.

Baseline: The baseline was parametrized based on data provided during the GMB sessions. In the baseline, 20% of the cows are fed concentrate and 42% of land is used for improved pasture, with 53% devoted to traditional pasture, and 5% to cut-and-carry grasses. The baseline was also run with a drought simulation where we simulate a drought occurring from week 104 and lasting for two years. Droughts have occurred in Matiguás more frequently during the past ten years, with the last one occurring from 2014 to 2016 as a result of a strong “El Niño”. Under these conditions, we assumed that during the dry season (week 1-23) the productivity of traditional pasture falls by 50%. Based on earlier research results, we further assumed that the productivity of improved pasture and cut- and-carry grasses only falls by 30% under drought conditions (Miles et al. 2004; Peters M et al. 2011), which is an incentive to invest in these technologies since drought is becoming more common and many improved grass species are drought adapted.

Scenario 1: Concentrates can complement dry season grazing when the amount of dry matter availability and quality of feed in terms of the Nitrogen content decline sharply. Concentrates are expensive, and thus they must yield a quick positive return on investment to make it feasible for producers. They are typically only given to lactating cows to boost milk production, usually 2 kg per animal per day[7]. In Scenario 1, we considered improvements to concentrate use in two ways. First, we boosted the impact that profitability has on farmer decisions to use concentrates by modelling a 20% increase to the total effect that short-term

[7] Equivalent to 3-4 kg of milk (if maintenance requirements are met by other feed sources).

profits have on investment decisions. In other words, for a given change in short-term profits, farmers will invest 20% more in concentrates than in the baseline. We selected the level of 20%, a fairly high percentage, because investing in concentrates only applies to some months of the year so that any potential losses can be recovered during the same season. This level could be further facilitated by policies that promote better access to short term credit (e.g., microcredit facilities). Access to concentrates in general is also a precondition for this scenario. As we do not precisely know how sensitive farmer investments in concentrates are for a given change in profitability, we conducted sensitivity analysis on the investment percentage that ranges from 5% to 25% in intervals of five percentage points (see Appendix D).

Second, we assumed that the fraction of cows consuming concentrates increased by 50% to 70%. This is not an unrealistic assumption that if concentrate prices go down, interventions are put into place that promote local production, and milk prices remain more or less constant. The advantage of concentrates is that they are very easy to administer and greatly and directly increase milk production. This scenario could be brought about by a combination of policy measures: subsidies, training on (artisanal) production of concentrates,[8] and even certification schemes that stimulate planting or conserving leguminous trees that produce concentrate ingredients. The level of concentrates given to lactating cows is driven by the gap between the desired amount of protein per animal and the level of feed produced (measured in kg of protein[9]). Both of these shocks were assumed to take place from week 104 (year two) in the simulation. Similar to the baseline, we also ran a drought simulation, with a two-year drought

[8] Based on mainly locally available ingredients, like pods of leguminous trees, sorghum and molasses.

[9] Protein is used as the metric of measurement for feed since protein is the most limiting factor for milk production. Many types or large quantities of dry matter of feed could be available, but if their quality is low (in protein terms) it will not lead to higher levels of milk production. This is also the reason for complementing grazing with concentrates, which has a high level of protein (see more information in Appendix A).

commencing in year 2. In scenario 1, we also ran several simulations to analyze the effects of changing the price for concentrate.

Scenario 2: In the model, we assume that moving between traditional and improved[10] pasture is influenced by the level of expected profit over the medium-term. If farmers experience higher profits than expected over the medium run, we assume that they will make investments to transform their land use from traditional into improved pasture. The total amount of land is constant since land availability is limited, and hence the focus is on intensification. In scenario 2, we assume that higher medium-term expected profits will lead to 10% more investment in improved pasture relative to the baseline. We chose a lower investment percentage in this scenario since it applies to the entire year and most likely requires several years to be successful. From a policy standpoint, this would require access to longer term and larger amounts of credit, and an enhanced rural financial market to facilitate. Access to seeds, equipment, and information about pasture management are also preconditions for this scenario. As with scenario 1, since we do not precisely know how sensitive farmer investments in pastures are for a given change in profitability, we conducted sensitivity analysis on the investment percentage that ranges from 5% to 25% in intervals of five percentage points (see Appendix D).

As before, drought simulations similar to the baseline were also implemented here. In this scenario, an additional source of sensitivity analysis was to consider the role that farmer knowledge plays in improved pasture management. Here, we considered the impact of improved learning (through participatory training) on pasture management, productivity and farmer profitability. We ran simulations that introduce training to improve farmer pasture

[10] Improved pastures are based on grasses of the genus Brachiaria: *B. brizantha* and the hybrid "Mulato". These are more drought adapted than the traditional grasses and increase, without irrigation, the dry season availability of dry matter, energy and protein by 80%, 90%, and 130%, respectively.

management skills starting in week 104. These simulations last for three years and eventually reach 50% of farmers over time.

Scenario 3: The decision to buy or sell dairy cows depends on long-term profitability. In the model, we assume that farmers will invest in dairy cows if expected profits over a three-year time horizon are greater than expected. Similarly, dairy cows will be sold if farmers experience sustained long-term losses or if there is not enough feed for all animals. In scenario 3, we assume that changes in long-term profits will change investments in dairy cows by 10% more than the baseline from week 104. We use 10% in this scenario as well since investing in dairy cows and enlarging the herd is a major decision for a smallholder farmer, requiring a larger amount. Similar to scenario 2, access to formal credit and the development of strong rural financial markets are important policy levers. As with scenarios 1 and 2, this scenario also includes a drought simulation. Furthermore, similar to scenario 1, since we do not precisely know how sensitive farmer investments in dairy cows are for a given change in profitability, we conducted sensitivity analysis on the investment percentage that ranges from 5% to 25% in intervals of five percentage points (see Appendix D).

Scenario 4: Scenario 4 combines scenario 1 and scenario 2, since investments in improved pasture to increase feed quality in the medium and long term are often combined with using concentrates in the dry season for a short term feed quality increase.

The online model includes additional versions of the scenarios. As the GMB sessions were primarily held in 2015, the model starts in January 2015 and runs for ten years (520 weeks) until 2025. Each scenario was evaluated over different lengths of run (short, medium and long term). Any policy introduced in a given scenario starts in 2017, which is year two (week 104) in the model. We define short-term as the two years following the implemented policy (until week 208). Examples of short term strategies are feed-related interventions such as adopting the use of concentrates and farm management related interventions such as improving hygiene and milk practices. We define medium-term to be the third to fifth year after intervention (until week 364), including strategies that introduce the use of improved pastures and silvopastoral systems, and product development and diversification. Long-term is defined as the sixth to eighth year after a policy is implemented (until week 520), which could be associated with breeding related interventions.

The policy analysis primarily focuses on producer milk inventory and small- and medium-scale farmer profitability (on a weekly basis and cumulatively in the short (4-year)-, medium (7-year)-, and long (10-year)- term). Where relevant, we also report the total cattle population and land distribution between improved and traditional pastures (feed availability) to understand the drivers of milk production and profit.

In the next section, we present a summary of cumulative farmer profit and milk production over the short-, medium-, and long-run. We then present dynamic weekly results, which provide details on the numerous feedbacks between and within the modules and their intended and unintended consequences due to policy changes.

4. Results

4.1 Cumulative results

Table 1 summarizes the results for cumulative discounted farmer profits over the short-, medium-, and long- term using an annual discount rate of 5% that is adjusted weekly. Table 1 also reports changes in cumulative profit in policy scenarios relative to the baseline. Similarly, table 2 presents values and percentage change figures (relative to the baseline) of cumulative milk production over the different time scales.

Increasing the use of concentrates (scenario 1), increases milk yield by 6% to 11% over the simulated time horizon (see table 2), but is less profitable (-3%) relative to the baseline. This suggests that the current price of concentrates is too high to make it viable for producers. However, a 20% discount in the concentrate price (see Scenario 2 + 20% discount in the concentrate price) does increase profit relative to the baseline by 4% to 9% and milk yield by 7% to 12%. A sensitivity analysis of the concentrate price (see Appendix E) reveals that a 20% decrease is required for concentrate use to be more profitable compared to the baseline when milk production is lowest. Buying in bulk, e.g., through cooperatives, would reduce prices but likely only up to 20%. Another option would be local production of concentrates, using locally produced ingredients. This could arise, for instance, from the use of high protein legumes produced on-farm and agricultural byproducts (brans). Initial investments (equipment) could be supported by the local government or development organizations.

Investments in improving pasture quality (scenario 2) result in an increase in milk yield by 1% (short term) to 5% (long term), but similar to scenario 1, they are not as profitable as the baseline, due to high initial investment costs, in the short (-3%), medium (-2%), and long run (-1%). Other investments along with pasture improvement are thus needed to increase farmer profitability. Indeed, by investing in farmer training (scenario 2 plus training) in pasture management, long-term milk yields and profits relative to the baseline increase by 10% and 7%, respectively. However, due to high investment costs, scenario 2 plus training is not as profitable in the short term (3% lower profits compared to the baseline) and only equivalent to the baseline in the medium term. This is due to high investment costs in improved pasture.

Training in pasture management could be paid externally and would thus not impact farmer costs, while improving profitability. Training can be provided in different ways. One way is through the government and mainly paid through soft loans from the World Bank, Inter-American Development Bank (IADB), the International Fund for Agricultural Development (IFAD) (already on-going), and development organizations such as Heifer International. They could also be funded directly by cooperatives, either through members or in combination with development organizations.

Investing in additional dairy cows is less profitable (-1%) than the baseline in the short term and yields equivalent results in the medium- and long-term. It also does not lead to any change in milk production, and hence should be discouraged by policy-makers until higher quality and quantity feed is available (see scenario 3 in tables 1 and 2).

On the other hand, scenario 4 (combining scenarios 1 and 2 – i.e., using concentrates and improving pasture simultaneously) increases milk yields by 7 to 16% relative to the baseline, but has negative consequences on relative profitability compared to the baseline (-5% in the short term to -4% in the long term), again due to high investment costs. However, similar to scenario 2, applying scenario 4 along with training producers to manage improved pastures generates positive results in the long term (+5%) relative to the baseline. However, profitability in the short- and medium-term is lower (-5% and -2%, respectively) relative to the baseline.

These results suggest that policy-makers should acknowledge that intensifying feeding systems to improve milk yields is only profitable in the long term and requires support in the interim to induce and sustain these investments. This means that during the first phase (initial five years) of investment, producers may need to be supported by government, development organizations, and/or the private sector. Alternatively, policymakers could consider strategies that reduce input costs to obtain positive returns in the short-term. Similarly, an aggressive policy strategy (i.e., simultaneously applying all scenarios – improved pastures plus concentrates plus training plus lower concentrate prices) generates significantly higher profits in the short and long term (from +1% in the short term to + 16% in the long term) relative to the baseline. In general, these results suggest that there is no single intervention that can improve producer incomes, particularly in the short-term. Instead, a suite of policies will be needed to consider the dynamic impacts that different options may have on farmers.

It is important to note that while we have focused our attention on the gains associated with producers in our scenarios, we have not considered the costs to external parties that might facilitate their implementation (government, NGOs, and/or private sector). Indeed, while the aggressive policy strategy noted above has the strongest effects on producer profitability, it may come at a high cost to achieve. Data limitations prevented us from computing the returns on the investment scenarios given here, as information on the costs of achieving these scenarios was unavailable. Having said that, our model still provides useful information and a platform for policy dialogue for decision makers to understand the potential impacts that policies could have on the value chain, and to provide guidance on the need to shape policies – and their costs – to achieve desired outcomes.

Table 1: Cumulative farmer profits from the simulation analysis

	Short term		Medium term		Long term	
	NIO (*1000)	Change (%)[a]	NIO (*1000)	Change (%)[a]	NIO (*1000)	Change (%)[a]
Baseline	146	-	228	-	301	-
Scenario 1	142	-3	222	-3	292	-3
Scenario 1 + 20% decrease in concentrates price	152	+4	245	+7	328	+9
Scenario 2	142	-3	223	-2	303	-1
Scenario 2 + training	142	-3	229	0	324	+7
Scenario 3	145	-1	227	0	300	0
Scenario 4	138	-5	216	-5	288	-4
Scenario 4 + training	139	-5	223	-2	315	+5
Scenario 4 + training and 20% decrease in concentrate prices	148	+1	244	+7	348	+16

a Percentage change relative to baseline

Source: Simulation results

Table 2: Cumulative milk production from the simulation analysis

	Short term		Medium term		Long term	
	Million kg	Change (%)[a]	Million Kg	Change (%)[a]	Million kg	Change (%)[a]
Baseline	93	-	160	-	230	-
Scenario 1	98	+6	176	+9	255	+11
Scenario 1 + 20% decrease in concentrates price	99	+7	177	+10	257	+12
Scenario 2	93	+1	166	+3	243	+5
Scenario 2 + training	93	+1	168	+5	254	+10
Scenario 3	93	0	161	0	230	0
Scenario 4	99	+7	181	+13	268	+16
Scenario 4 + training	99	+7	182	+14	277	+20
Scenario 4 + training and 20% decrease in concentrate prices	99	+7	183	+14	279	+21

a Percentage change relative to baseline

Source: Simulation results

As mentioned earlier, water availability is a major limiting factor of livestock production. In addition to the effect of seasonal rainfall patterns, the increased occurrence of droughts is a principal source of inter-annual fluctuations in feed availability. Table 3 and 4 summarize scenarios in which droughts take place. Scenarios 1, 2, and 4 all result in higher cumulative milk production in the short-, medium-, and long-term relative to the baseline, but are only more profitable relative to the baseline plus drought scenario in the long run, with the exception of scenario 1. An increase in off-farm feed resources such as concentrate is less profitable than the baseline unless there is a reduction in the price of concentrates. Hence, to support farmers to deal with drought, policymakers could support farmers with investment in improved drought adapted pastures combined with training in pasture management to increase the resilience of the farm. When drought occurs, farmers start selling cows to deal with the lower feed availability and limit losses (see scenario 2 and 4 in table 4). In this case, drought lasts for two years, which in the medium run results in farmers selling fewer cows to recover their herd to the size before the drought. This leads to an increase in milk production, but profitability lags behind compared to the baseline.

Policymakers could advise farmers to use a higher amount of concentrates during the dry season through policies that improve farmer access to credit. This would boost the level of milk production during the dry season and enable farmers to supply a larger amount of milk to cooperatives, which would strengthen their position in the dairy value chain. On the other hand, policymakers could subsidize concentrates when droughts occur as a temporary policy that can be put in place quickly. This would result in higher milk yields, and secure farmer ability to supply cooperatives. On the other hand, such subsidies would be quite expensive, and suggest a need to think of institutional mechanisms that could deliver similar outcomes at lower cost.

Table 3: Cumulative milk production in drought scenarios

	Short term		Medium term		Long term	
	Million kg	Change (%) [a]	Million kg	Change (%) [a]	Million kg	Change (%) [a]
Baseline + drought	86	-	144	-	213	-
Scenario 1 + drought	93	+7	157	+9	234	+10
Scenario 2 + drought	87	+1	151	+5	228	+7
Scenario 2 + drought + training	87	+1	152	+5	241	**+13**
Scenario 4 + drought + training	93	**+8**	163	**+14**	262	**+23**

a Percentage change relative to baseline

Source: Model simulations

Table 4: Cumulative farmer profit in drought scenarios

	Short term		Medium term		Long term	
	NIO (*1000)	Change (%)[a]	NIO (*1000)	Change (%)[a]	NIO (*1000)	Change (%)[a]
Baseline + drought	170	-	229	-	290	-
Scenario 1 + drought	168	-2	224	-2	283	-3
Scenario 2 + drought	169	-1	220	-4	295	**+2**
Scenario 2 + drought + training	169	**-1**	221	-3	303	**+5**
Scenario 4 + drought + training	166	**-2**	216	-5	395	+2

a Percentage change relative to baseline

Source: Model simulations

4.2 Dynamic results

4.2.1 Baseline results

Baseline results from the model show that small- and medium-scale dairy farmers in Matiguás experience expected large seasonal swings in milk production. The GMB group stated that about 100,000 kg of milk is produced every day in Matiguás. As this model only focused on small- and medium-scale producers, the group estimated the average weekly amount of milk production to be about 450,000 kg of milk with seasonal swings. The model simulation results reveal levels of milk inventories of 443,000 kg of milk per week on average over ten years. The group also estimated that there is about a 50% difference in milk production between the dry and wet season, but that a larger or smaller difference could also occur depending on the feeding system. Model results under baseline assumptions show milk production ranges from approximately 325,000 kg in the dry season to 580,000 kg of milk per week in the best peak season for milk production (see figure 2 below and figure F.1 in Appendix F).

The baseline scenario includes a fixed use of concentrates to 20% of the cows in the dry season, which is based on estimates from the GMB participants. Without the use of concentrates, the difference in milk production between the wet and dry season would be even larger. Milk production falls slightly during the first three years, which is in accordance with the reference mode with no interventions made by the GMB participants and due to low feed production and limited land availability. The total cattle population shows a slight increase of just under 4,000 animals over 10 years.

During the dry season, milk production is not profitable. The profitable rainy season leads to some investments in improved pasture, resulting after six years into equal areas of improved and traditional pasture (see figure F.2 in Appendix F). In the baseline, farmers earn on average about 2,900 NIO (97 USD) per month, taking into account seasonal variation.

4.2.2 Scenario 1: Increasing the use of concentrates during the dry season

Concentrates are an effective, but costly, way to increase milk productivity and therefore are only used when feed is scarce, farmers have sufficient cash, and the return on investment is positive. In this scenario, concentrates are only fed to dairy cows during dry months when there is not enough feed available. In scenario 1, we assume that 70% of cows receive concentrates compared to the baseline of 20% based on the current situation in Matiguás reported by the GMB group. If farmers are not sufficiently sensitized about the benefits of concentrates, or lack access to them, a smaller percentage of the cows would receive concentrates. Additional cows receiving concentrates and greater concentrate use substantially increase milk production in Matiguás (see milk production under scenario 1 in Figure 2) and the gap between milk production in the dry and wet season is reduced by about 50%. The ability to provide a constant or less fluctuating supply to the dairy industry makes small- and medium-scale farmers potentially more competitive. Policymakers can facilitate increased use of concentrates by sensitizing farmers about their benefits through extension officers and cooperatives, but reducing the price of concentrates would have the greatest effect in increasing their adoption.

When drought occurs, dry season milk production is above its baseline value, with feeding concentrates making up for the feed deficit. Drought also severely reduce milk production during the rainy season (see milk production in scenario 1 with drought in figure 2). It takes about six years for the amount of milk produced after the drought to fully recover. This illustrates the risks farmers face when dealing with erratic weather. Drought results in a relative increase in profitability in the short run, a considerable reduction in relative profitability in the medium run, and in the long run the scenario reverts back to the pre-drought situation since the drought lasts only two years and farmers make decisions according to feed availability and profit (see figure 3). Drought results in farmers selling dairy cows in the short run, which leads to an initial burst of short-term profit but a subsequent, substantial reduction in milk production and income in the medium term. These dynamic effects highlight the power that SD models convey in revealing how value chains adjust to external shocks that qualitative methods do not provide. On the other hand, investment in concentrates does not impact the number of dairy cows (see scenario 1 in figure 4) since concentrate is used over the short term and has little effect on long term behaviors such as investing in dairy cows.

Based on model simulations, the use of concentrates in scenario 1 is less profitable relative to the baseline since this further increases the costs of production during the dry season. In scenario 1, the gains from increased milk production are offset by high concentrate costs at the current price. However, sensitivity analysis reveals that if the price for concentrates falls by 20%, farmers would earn similar profits as in the baseline. Finding ways to access cheaper concentrates could improve smallholder competitiveness in the Matiguás dairy value chain. As mentioned above, bulk buying and local production are ways to accomplish this.

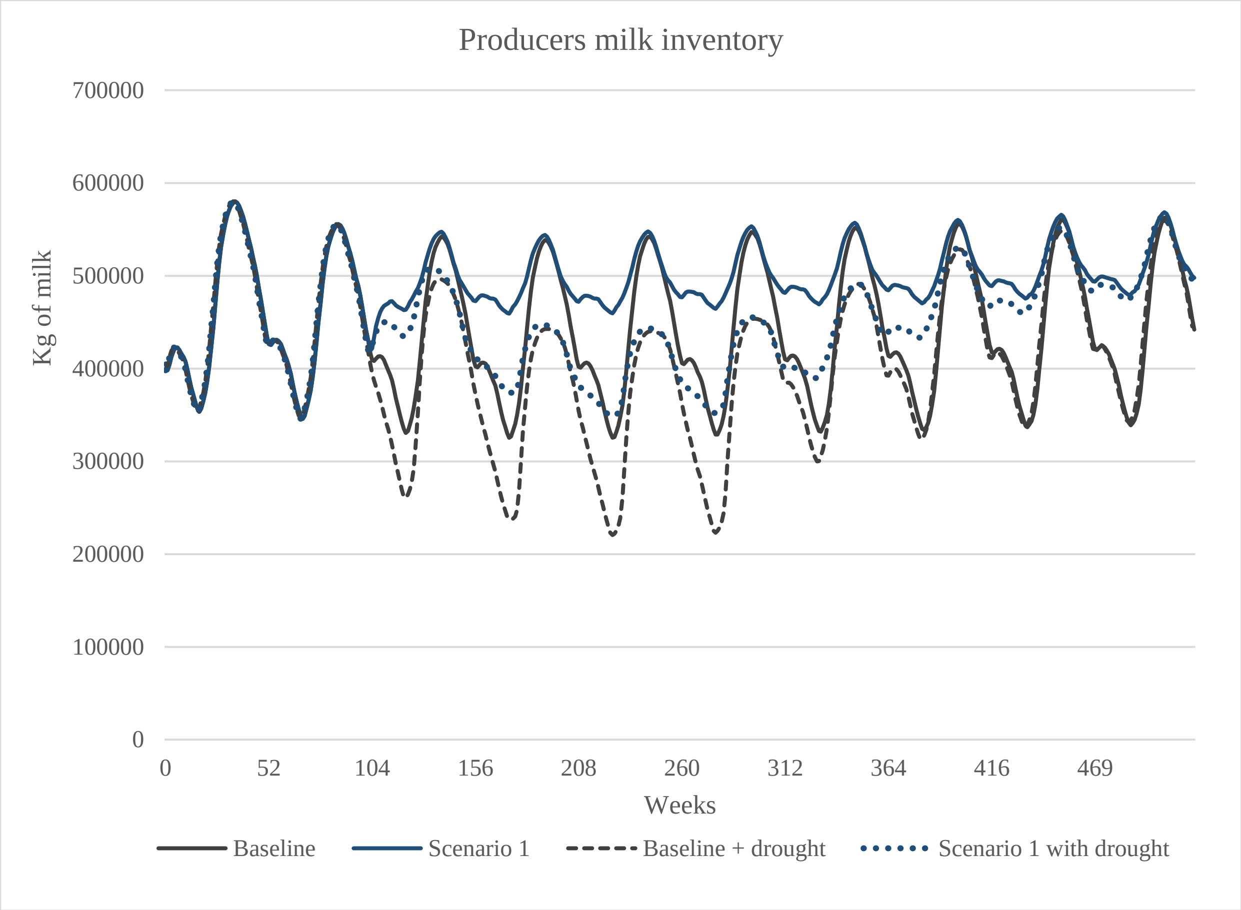

Figure 2: Producer milk inventory in the baseline scenario and scenario 1. Source: Model simulations

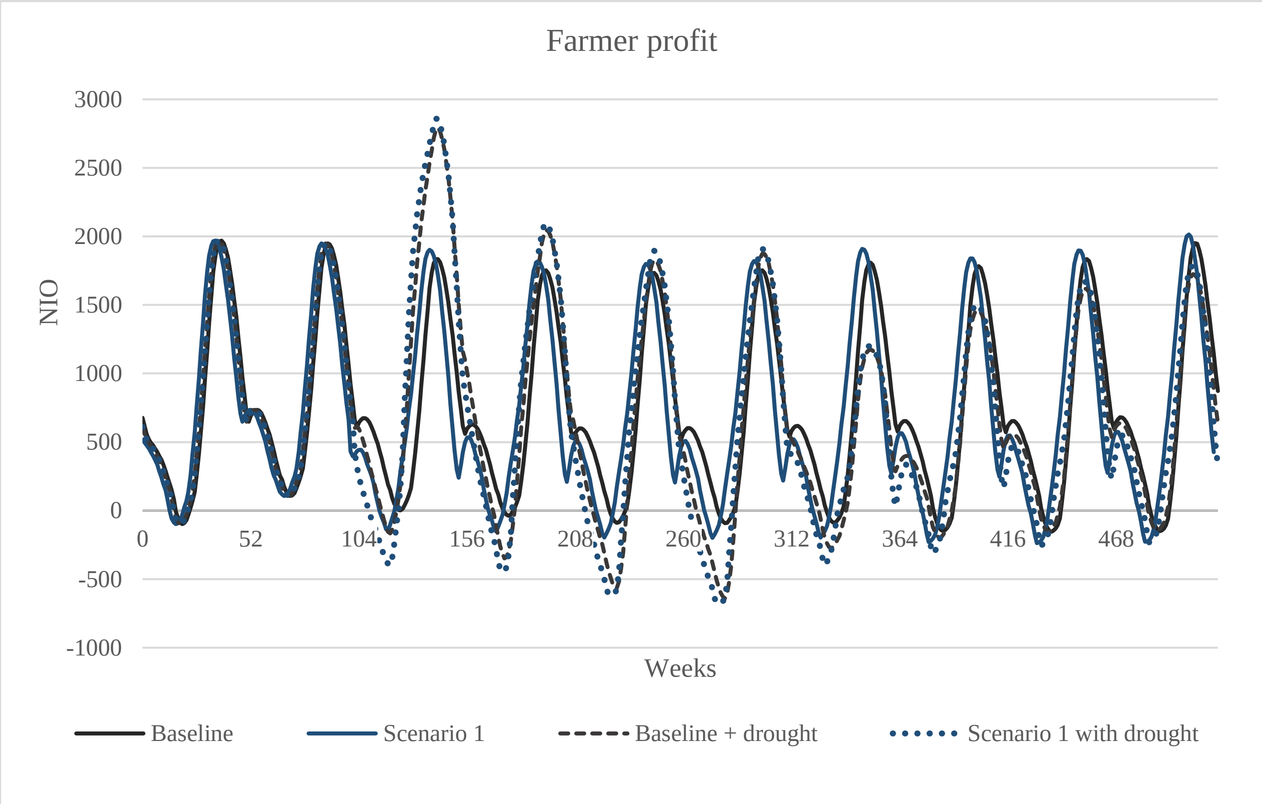

Figure 3: Weekly farmer profit in the baseline and scenario 1. Source: Model simulations

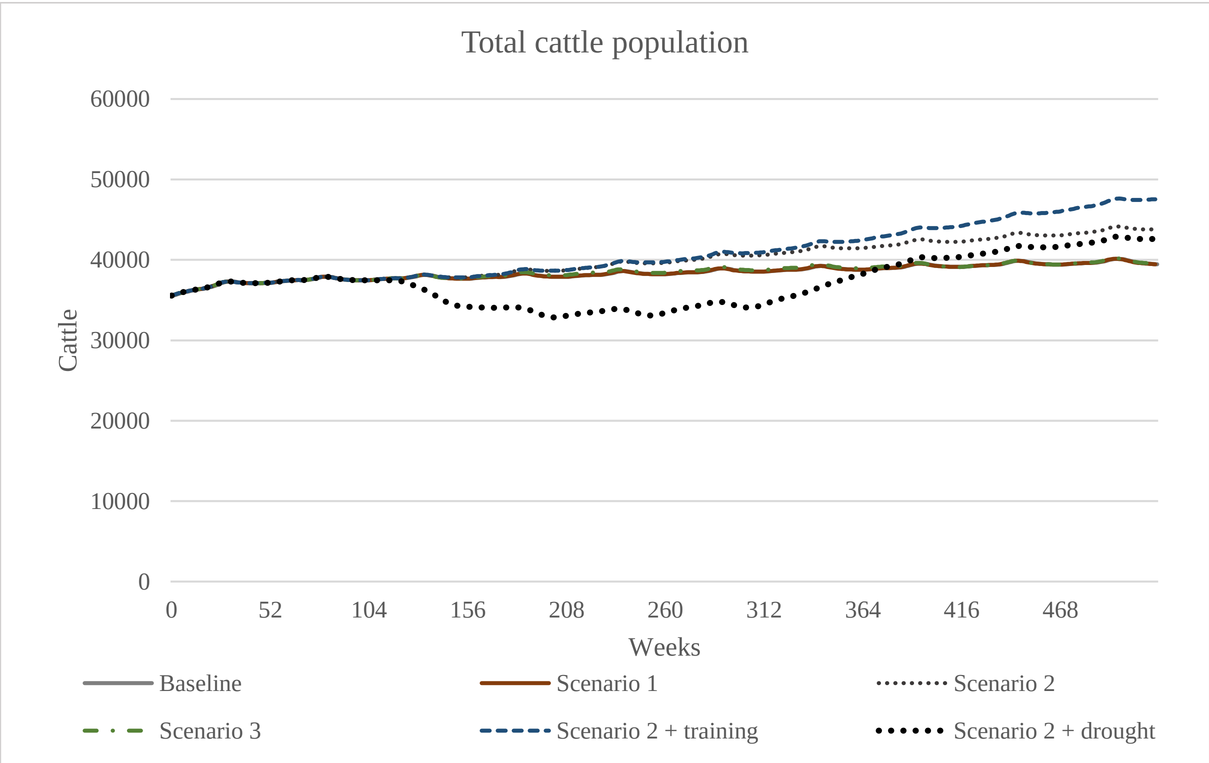

Figure 4: Total cattle population in different scenarios. Source: Model simulations

4.2.3 Scenario 2: Investments in improved pasture

Improved pastures increase feed volumes and quality. Many improved grass species, like Brachiaras, are drought adapted. However, they come with additional costs (seed, labor) and farmers need to assess tradeoffs with the extra income arising from the increase in milk production. In scenario 2, the amount of land allocated to improved pastures steadily increases in accordance with the boost in investment (see figure 5). The sensitivity analysis in appendix D highlights that different assumptions on producer investment behavior in pastures as a function of profitability compared to the baseline imply significant differences in the speed and proportion of land allocated to improved pastures over the ten-year simulation period. Increasing the responsiveness of farmer investment to profitability (through a more conducive environment including improved rural financial markets) could speed up this process considerably with substantial implications for milk production. Improved pastures increase milk production in the peak season by 14%, which result in 540,000 kg/milk produced per week in the short term to 615,000 kg/milk per week in the long term (see figure 6), and by 19% between the dry season in the short and long term.

When pasture investments are combined with farmer training and extension, we observe much higher milk yields over time (particularly in the long run) due to increased pasture productivity, more feed, and higher milk yields per cow (see scenario 2 + training in figure 6). In this sub-scenario, we initiate training at the same time as introducing improved pastures. Policymakers can support the adoption of improved pastures by investing in participatory training, like farmer field schools, establishing model farms, and training technicians and extension agents. In Matiguás, such a strategy has led to the training of 1,000 farmers, of whom 400 have established 5,800 mz of improved pastures and silvopastoral systems. Improving availability and access to medium and long term credit would greatly increase the number of farmers able to invest in improved pastures. Cooperative members have usually only access to short-term credit.

Investing in improved pasture slightly reduces farmer profits in the short run during the peak season due to initial investment costs, and cumulative profit shows similar trends in table 2. Costs of improved pasture are 47% higher than of traditional pasture. In the long run, weekly profits return to scenario 1 values (see figure 7). As in scenario 1, scenario 2 milk production gains and sales are offset by higher investment costs in improved pasture. Improved pasture is only profitable if combined with the proper training of farmers. Milk production under this scenario reaches nearly 700,000 kg/milk per week, while also raising dry season milk production by 120,000 kg/milk per week, a 35% increase relative to the baseline. This leads to an average monthly profit of nearly 3,200 NIO over the simulation period. Investment in improved pasture combined with training is a long-term intervention, reducing relative profitability in the short to medium run, but with a gradual increase in relative weekly profits in the long run (see scenario 2 plus training in figure 7, and cumulative profit numbers in table 2). The decline in weekly profits relative to the baseline in years 7-8 (approximately weeks 330-390) is due to lower sales of dairy cows as improved pasture productivity encourages producers to increase their cattle herd. This in turn results in a gradual increase in milk production and profitability in the subsequent periods.

In the case of drought, milk production decreases substantially during the two drought years and then gradually increases to reach the production levels associated with scenario 2. As before, this decline is partly due to the sale of dairy cows to cope with drought and reduced milk productivity (see scenario 2 plus drought in figure 6). Improved pasture is more drought resistant and produces more feed, resulting in higher production and a faster recovery to pre-drought scenario levels (see figure 6). During drought periods (see scenario 2 plus drought in figure 7), weekly profits increase substantially in the short run because farmers sell dairy cows. These trends in weekly profits show a declining pattern in the medium run and gradually approach pre-drought levels in the long run as the effect of drought dissipates. Investing in improved pasture is thus a good policy to increase farmer resilience to drought. Trained farmers are also better prepared to handle drought, which lowers the impact that drought has on milk production and profitability.

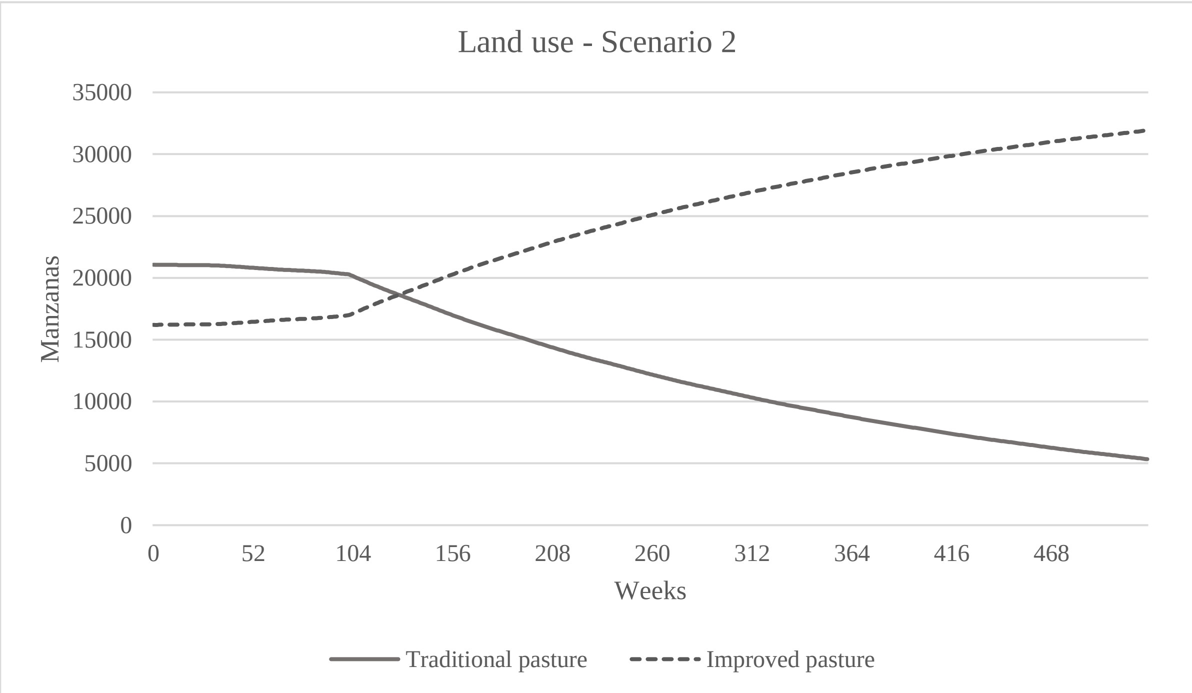

Figure 5: Improved and traditional pasture areas in scenario 2. Source: Model simulations.

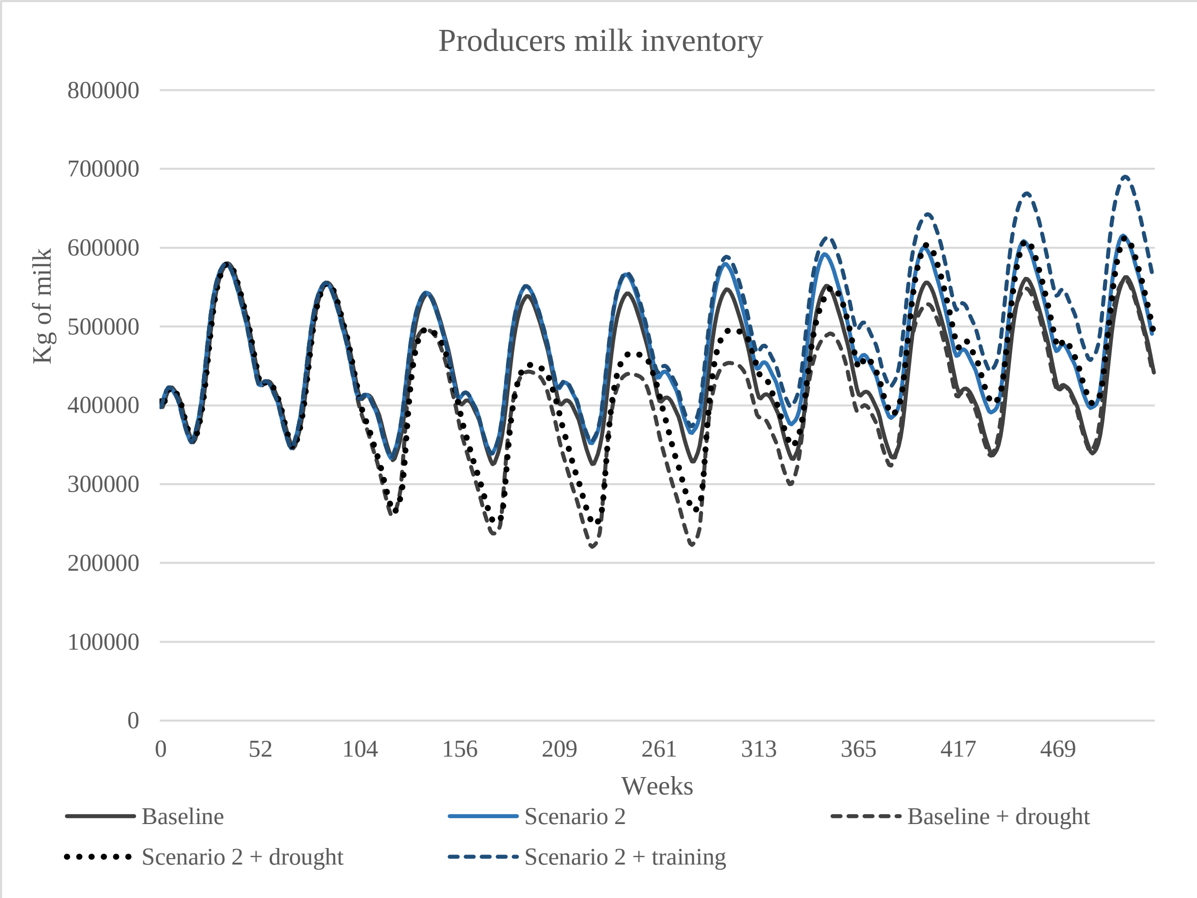

Figure 6: Producer milk inventory in baseline and different versions of scenario 2. Source: Model simulations

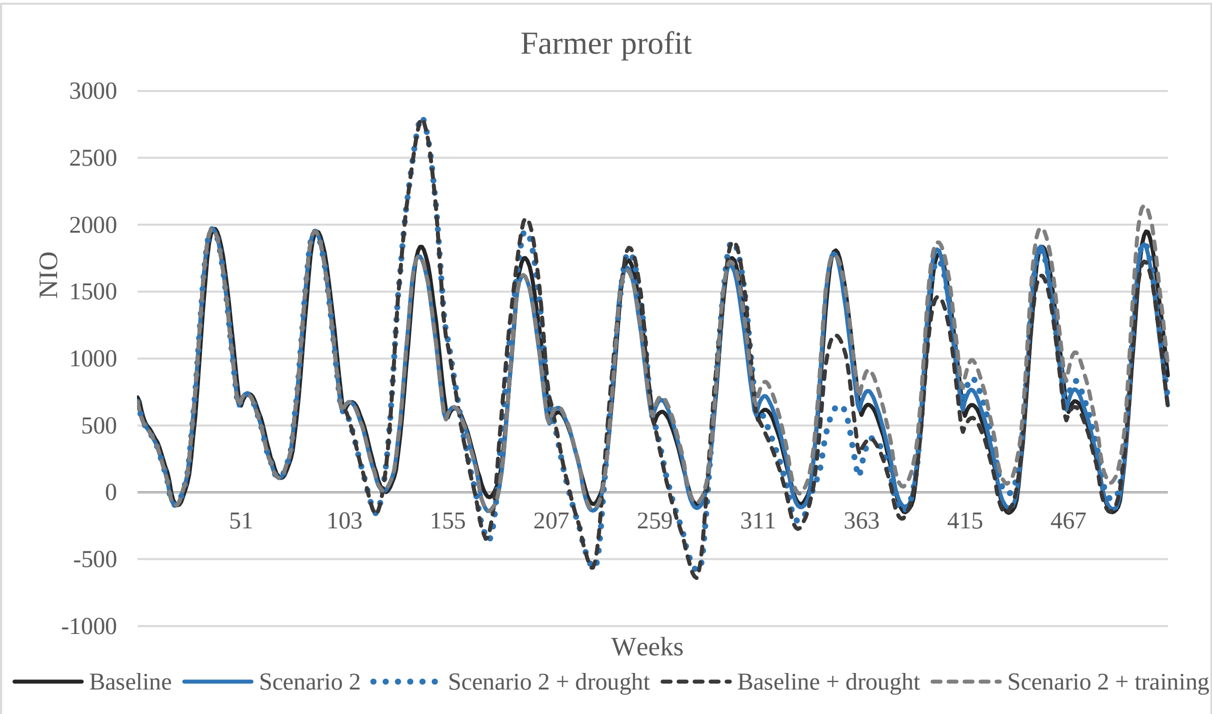

Figure 7: Weekly farmer profit in the baseline and different versions of scenario 2. Source: Model simulations

4.2.4 Scenario 3: Investments in increasing the number of dairy cows

An important goal of increasing the dairy herd is to increase milk production and incomes, for which adequate feed availability is key. As seen from model simulations, investing in dairy cows in Matiguás does not appreciably impact milk production (as seen in figure F.1 in Appendix F) and farmer profits relative to the baseline only vary due to differences in the purchasing and selling of dairy cows (as seen in figure F.3 in Appendix F). Feed availability is the main driving force for sales and purchases of cattle. In Matiguás, year-round feed availability does not allow for an increase of the cattle herd: additional dairy cows bought during the rainy season are sold again during the subsequent dry season (see figure 4 above). However, if the farmers experience an excess in feed availability and higher than expected profitability in the long run, they will invest in dairy cows, as shown in the different versions of scenario 2 in figure 4 above. Strategies aimed at increasing feed availability, such as improved pasture, therefore make more sense than investing in additional dairy cows. Another option would be to invest in improved breeds that produce more milk, but this is beyond the scope of this model, and an area for future research.

4.2.5 Scenario 4: Combination of scenarios 1 and 2

Different policies can target different aspects of one problem. An example of this is promoting improved pasture in combination with the use of concentrates. This scenario reports results of the model based on combining scenario 1 (increasing the use of concentrates) and scenario 2 (investments in improved pasture) and results in a substantial increase in milk production. Most importantly, it also leads to a substantial increase in milk production during the dry season that in the long run exceeds the peak season production in the baseline (see scenario 4 plus training). Training in pasture management further boosts milk production (e.g., see scenario 4 in figure 8). When scenario 4 is combined with drought, milk production drops during the dry season and increases substantially during the rainy season, recovering quickly and reaching a higher level than without drought. The balance between feed demand and feed availability is reached sooner due to the previous drop in number of dairy cows.

In scenario 4, weekly farmer profits fall in the medium run relative to the baseline due to investments made in improved pasture, but their trend in the long run reveals an increase relative to the baseline (see figure 9). Training also reveals an upward trend in weekly profit in the long run.

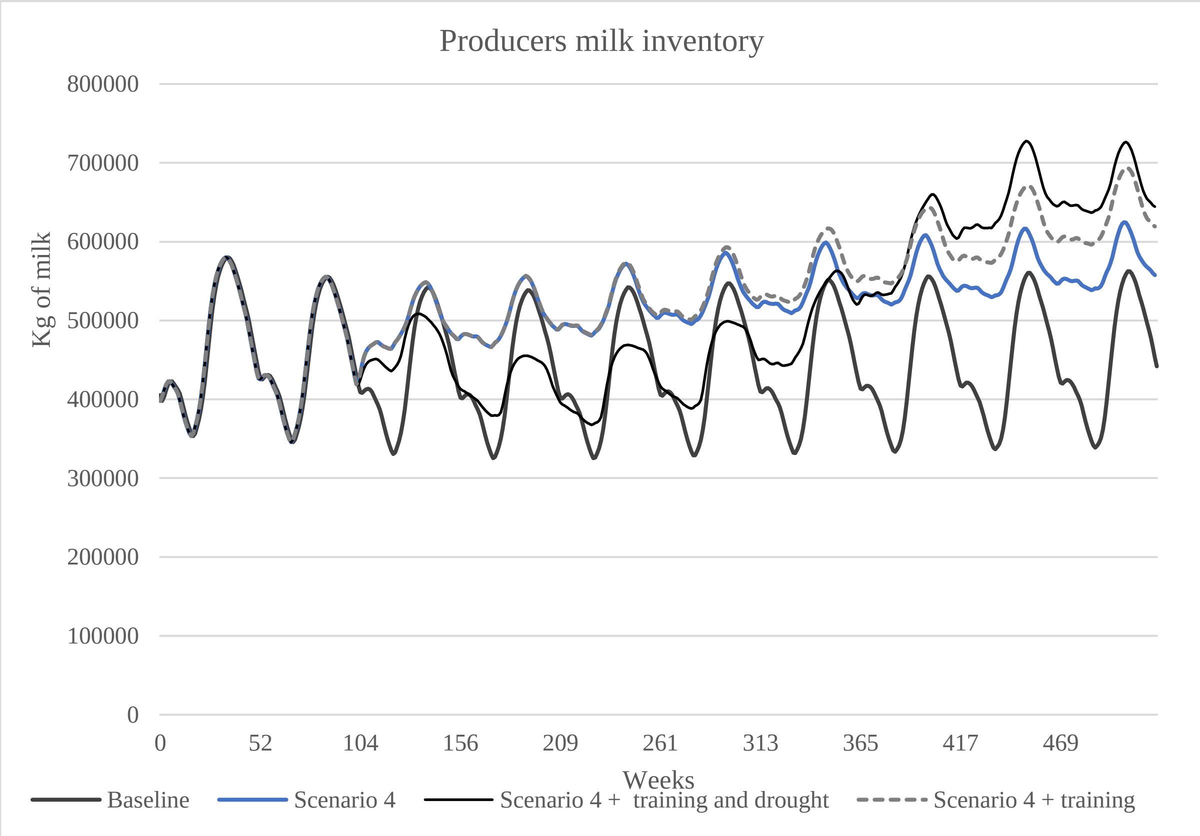

Figure 8: Milk inventory when investing in improved pasture and use of concentrates. Source: Model simulations

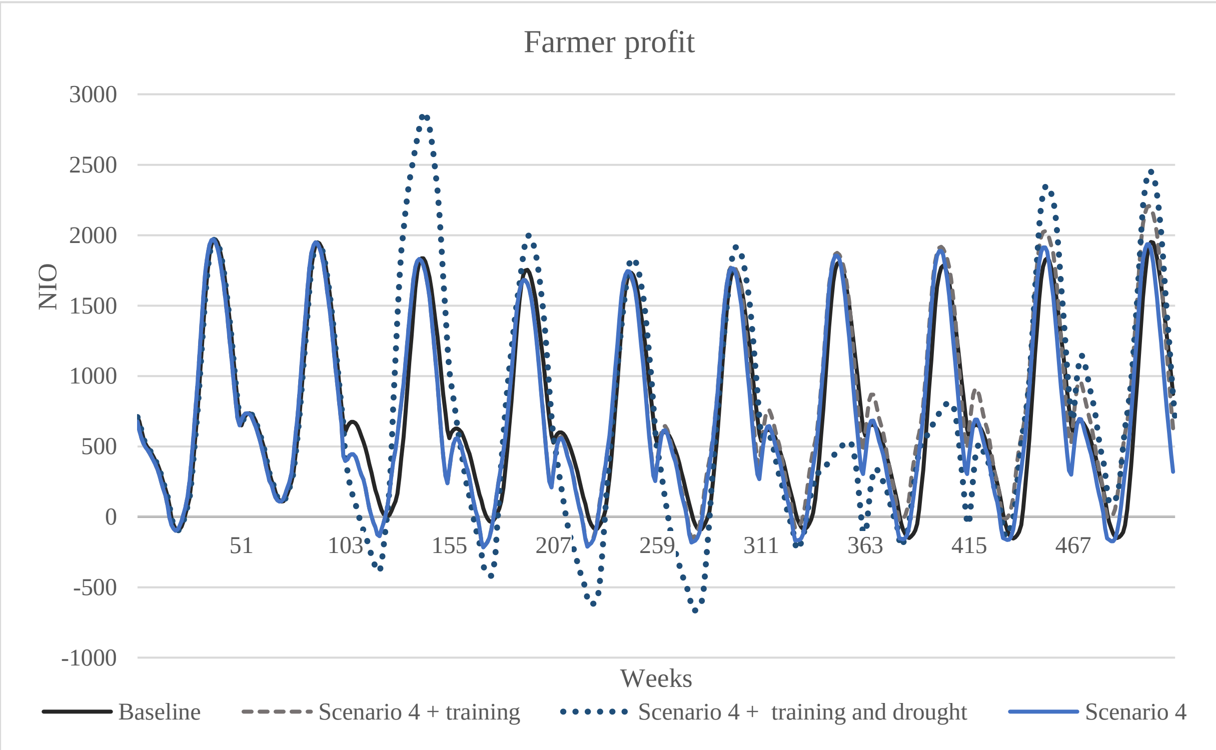

Figure 9: Profit changes for different simulations related to scenario four. Source: Model simulations

5. Discussion

The increasingly competitive landscape of the dairy industry in Nicaragua requires that producers stabilize their milk supplies to the dairy industry and as such strengthen their competitiveness to enter and continue their participation in value chains such as in Matiguás. The analysis from this paper shows that a combination of increasing the use of concentrates during the dry season with longer term investments in improved pasture increases milk production, especially during the dry months, and increases farmer profitability. Reducing the price of concentrates would further have positive effects on farmer profits and might be possible through bulk buying or local production. Cooperatives can contribute to reducing costs of concentrates through bulk buying. National polices could also be put in place to subsidize concentrates when drought occurs as a temporary policy that can be put in place quickly. Alternatives to increasing feed quality (or protein supply) are protein banks with forage legumes and leguminous trees. Apart from producing animal feed, such technologies have also a positive impact on other farming system components. Forage trees, for instance as part of silvopastoral systems, accumulate carbon, and improve soil fertility and water retention. Herbaceous legumes can be intercropped with cereals (maize), producing dry season feed (in combination with maize residues) and improving soil characteristics. Although these interventions require (some) extra labor and seed (which can be produced on-farm), monetary investments are lower than when using concentrates.

Training on pasture management is crucial in order for farmers to benefit from the higher productivity potential and to achieve high returns on investment. Experiences in the Matiguás area with participatory capacity development methodologies (i.e., farmer field schools including model farms, in collaboration with farmer cooperatives) have generated strong impact, but are associated with high costs for policymakers. To be a member of a cooperative comes with access to credit, inputs, equipment, information, and technical advice. Support (of policymakers) to cooperatives to further professionalize their services could increase membership, offering better services, as well as increase their bargaining power with the dairy industry actors to which they supply milk. Improving producer access to longer term and larger amounts of credit, and enhancing rural financial markets in Matiguás would also facilitate investment in improved pastures, since cooperatives today can only offer short-term and small amounts of credit.

In agricultural development, there has been a strong focus on technical interventions that increase productivity. Lately, strengthening market links and inclusiveness (poor farmers, women, and youth) have become more important (Devaux et al. 2016). The Matiguás SD model focuses primarily on technical interventions, but clearly illustrates the links between the different nodes in the value chain, its dynamic nature, how different parts of the system are connected, and that suites of technical and institutional interventions may be required to successfully promote long-lasting inclusive value chain development. For example, investments in better pasture and increased use of concentrates to improve productivity need to be combined with establishing or strengthening market linkages, necessitating strong collaboration between value chain stakeholders. Additionally, the findings from this study repeatedly underline the importance of a long term perspective as it takes time to implement and see the results of interventions. A focus on the short-term may ignore important dynamic effects within the value chain that could influence the sustainability of policies over time.

SD approaches can therefore be an important decision support tool, helping decision makers and stakeholders understand and prioritize investment options. It is, however, important to remember that an SD model does not deliver predictions, but provides a deeper understanding of the behavior of complex and dynamic systems, such as value chains. Participatory processes are an important part of building this understanding, as well as providing a platform for needed collaboration across the chain. Using a participatory process can be time consuming, but provides additional positive outcomes such as team learning, commitment to chosen strategies, and more sustainable value chain interventions, and which will have a positive influence over and beyond the modeling process (Lie et al. 2017).

As noted earlier, an important limitation with our analysis is the lack of information associated with the costs needed to implement the different chosen scenarios. While our analysis highlights value chain impacts associated with intervention options, the costs incurred by government or investors to achieve these and to compute their cost-effectiveness are unknown and could be quite costly. At the same time, our model provides a first step in promoting a process of policy dialogue, highlighting areas where the dairy value chain can be improved and providing a platform that policymakers can use to design appropriate, cost-effective policies that can generate these effects. Another limitation is the focus on small- and medium-sized farmers as an aggregated group at a district level. Individual-level behavior or results are not captured, which if significant heterogeneity exists could bias our results. This would necessitate a more micro-level approach, such as an agent-based model (Berger 2001).

Numerous additional scenarios can be simulated with the current SD model, but due to limited space the focus was on the policies identified by the GMB stakeholders themselves. In addition, different versions of scenarios 1-4 could be simulated by, for example, changing the timing and length of drought, by changing the sensitivity of investment to expected farmer profit, by testing additional price differences for milk and concentrate, and making additional changes to demand. For example, in the GMB stakeholder group, some stakeholders were interested in changing the amount of land used for the different types of feed combined with different herd numbers. Another scenario to test in the future is to consider increasing the proportion of milk going to the formal sector, implying increasing the number of cooperative members. This is important when promoting inclusive value chain development. Other interventions such as introducing improved breeds with higher milk production by increasing the use of artificial insemination or additional coordination interventions would be possible with some additional structure and the collection of new data. Further developing the model to test feeding implications on milk quality and subsequent price changes would also provide valuable insight. Nevertheless, this model provides a good starting point for continued development and assessment of various value chain interventions in Matiguás.

6. Conclusion

The development and adoption of new technologies and improved practices by smallholder farmers can be a good strategy, but also a risky one. It is therefore important to carefully assess the costs and benefits of different value chain policies and interventions, and prioritize them based on their predicted *ex-ante* effects on smallholder farmers. Unlike qualitative VCA, SD modeling enables this type of analysis and communication in a value chain setting, thus providing a deeper understanding of the complex and dynamic nature of agricultural value chains and the interactions between markets, institutional coordination and governance, biophysical phenomena, and income. It also distinguishes between short- and long-term effects. In the Matiguás dairy value chain, model results reveal that investments in improved pastures combined with training in pasture management yield the highest returns in the long run. In the short run, investing in concentrate use raises milk production substantially, but the profitability of this strategy depends on finding ways to reduce the price of concentrates. By providing these types of insights, SD models provide a complementary toolkit to existing value chain methods to improve engagement with inclusive value chain development processes and to target scarce donor resources more effectively.

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8. Appendices

A. Detailed modules descriptions
B. Baseline data
C. Model equations
D. Sensitivity analysis investment percentage in scenarios 1-3
E. Sensitivity analysis of price for concentrate
F. Additional model graphs

Appendix A: Detailed modules descriptions

Herd module

The herd dynamics module, illustrated in Figure A.1, consists of four stocks that represent the different stages of maturing calves to becoming dairy cows or bulls. The model starts out with

10000 *calves*[11], 5000 *heifers*, 20000 *dairy cows*, and 500 *breeding bulls*. The flows between these stocks drive the process from *being born* until becoming *dairy cows* or *breeding bulls*. During each stage of the maturation process some animals die due to disease, or are culled due to undesired characteristics. All male calves are sold after one year except for 2% that are kept for breeding purposes. Dairy cows are also sold on occasions if there is not enough fodder to feed all animals, which is denoted by the variable *effect of feed on net purchasing rate* (the interconnections between the different modules are illustrated by using shadow (copy) variables with the respective color of each of the four modules). The decision to sell or buy dairy cows is also influenced by whether long-term profits are higher than expected over time. Long-run decision making is considered to be over a three year time horizon. Where profits are greater than expected, we assume that farmers will buy dairy cows, while if profits are negative over time relative to expectations we assume farmers will sell dairy cows. The amount of feed available per head of cattle also affects the *birth rate*, *mortality rate*, and *maturing delay*. The flows in this section of the model is measured in cows per week.

[11] Italized words are represented in the model

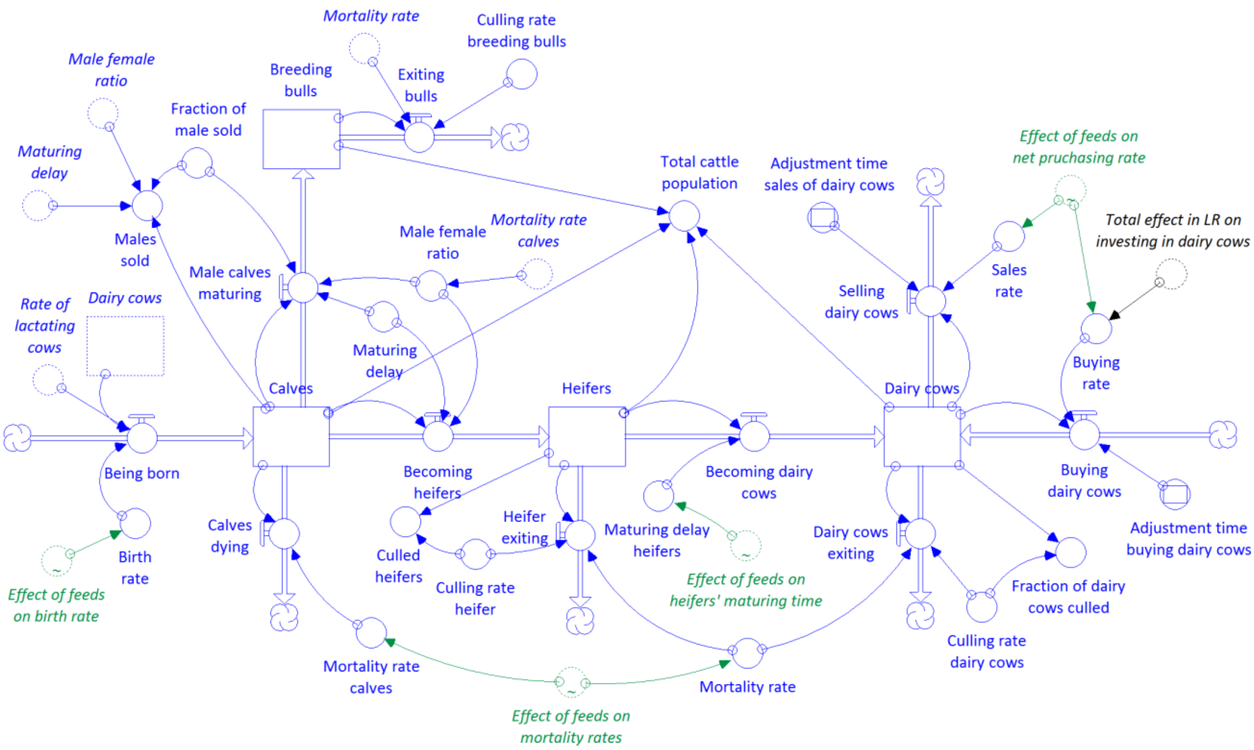


Figure A.1: Structure of the herd module. Source: Developed by the authors

Milk module

The milk module, illustrated in Figure A.2, consists of a sole stock of *producers' milk inventory*. The flow of milk production represents how much milk Matiguás dairy farmers produce per week, on average 450,000 kg. This is measured by multiplying the number of *dairy cows* by the *milk amount per cow* and the *rate of lactating cows*, which is 55% meaning not all cows produce milk at all times due to some being dry for breeding purposes. *Milk amount per cow* is influenced by the *predicted cow productivity,* which is the multiplication of average cow productivity, five liters per dairy cow per day, and the *effect of feed on cow productivity*. The variable *effect of feed on cow productivity* is responsible for seasonalizing milk production since there is lower feed availability in the dry season which consequently reduces the amount of milk produced per dairy cow per week. Further downstream in the value chain, 2.5% of producers' milk inventory is consumed at home. Of the remaining amount, 60% is collected by the cooperative, and the rest supplied to the informal sector. Processors in Managua control the demand for milk through cooperatives. If the demand for milk falls, the collection rate by the cooperative goes down, and more is sold in the informal sector. There is no set limit on the amount that can be supplied, so if milk production increases it is absorbed by the two sectors at a 60-40 rate unless changes are made to demand from processors (slider function).

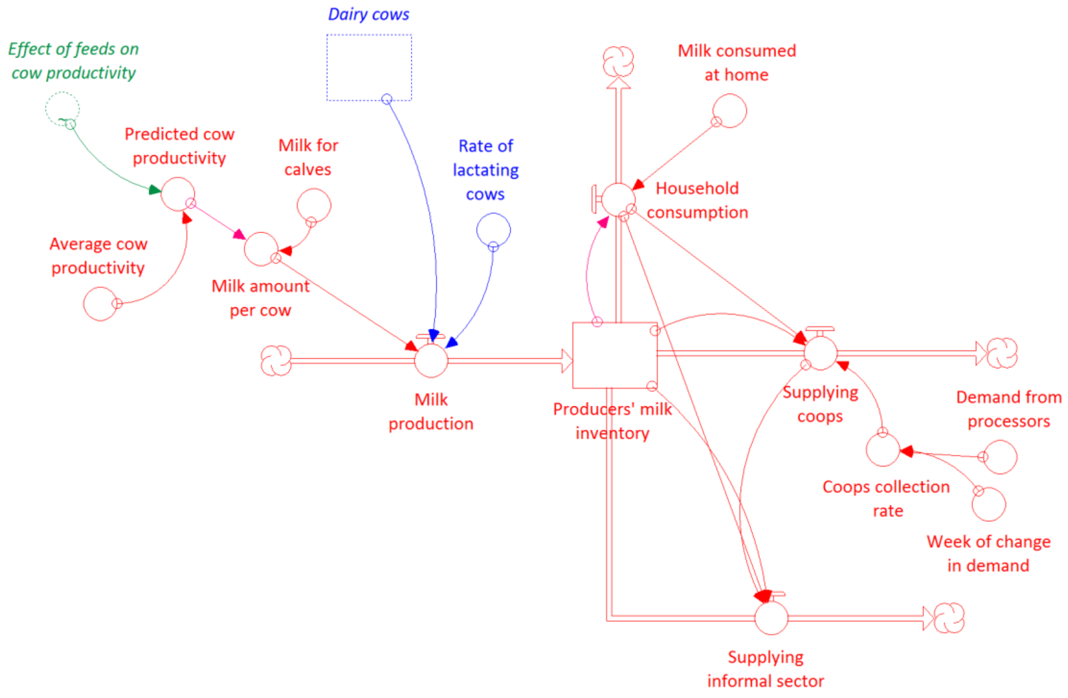


Figure A.2: Structure of the milk processing and sales module. Source: Developed by the authors

Feed module

The feed module, seen in Figure A.3, has the most complex structure in the model, because this is where the interventions and policy changes are implemented. The key building block is the stock *feed availability*. Feed availability is measured as the amount of protein produced in kg per week. Protein is used as the metric of measurement for feed since protein is the most limiting factor for milk production. Many types or large quantities of dry matter of feed could be available, but if the quality is low (in protein terms) it will not lead to high milk production.

This is also the reason for complementing grazing with concentrates, which has a high rate of protein. All feed-related aspects of the feed module are therefore measured in kg of protein, either produced per manzana of land per week, or per kg of concentrate, or per head of cattle.

Three types of feed are produced by Matiguás farmers: *improved pasture, traditional pasture*, and *cut and carry* grasses. About 41% of land is used for improved pasture, with 53% devoted to traditional pasture, and cut and carry grasses 5%. Changing between the two types of pasture is influenced by a higher or lower than expected profit over the medium-term. Medium term is in this case considered to be 26 weeks, half a year. We assume that if farmers experience higher profits than expected over the medium run, they will invest in changing land used from traditional pasture to improved pasture. The total amount of land is constant since there is limited supply of land available, hence the focus on intensification. A change delay of nine months (36 weeks) represents the time it takes to switch from traditional to improved pasture. Each feed type persist of different seasonal productivity. Improved pasture is also of higher quality than traditional pasture. This is included in the model by using graphical functions that indicates the productivity per week during the year. If *drought* occurs the productivity of traditional pasture falls during the dry season (week 1-23) by 50% (scenario parameters are provided in the color purple). The reference group assumes that productivity of improved pasture and cut and carry grasses only reduces by 30%, which is an incentive to invest in these technologies since drought is becoming more common. Productivity of improved pasture also depends on the *increase in knowledge about improved pasture (IP) management* by farmers. This is elaborated in a separate structure, see Figure A.4, illustrating a scenario where farmers increase their knowledge through training. This part of the model is the only section that was not developed during the GMB process.

Concentrates, expressed in kg of protein per week, is a way of complementing grazing (produced feed). In the model, concentrates are bought when there is a *protein gap*. Purchasing concentrate is expensive and therefore depends on farmer profitability in the short run, two weeks, and is only given to lactating cows to boost milk production. The amount of concentrates and amount of produced feed available per head combine to form the most important effect in the model: *effect of feed on cow productivity*. Produced feed per head affects the birth rate, mortality rate, purchasing rate, all found in the herd module. Concentrate is not included in these effects since concentrate is used over the short term and has little effect on long term behaviors.

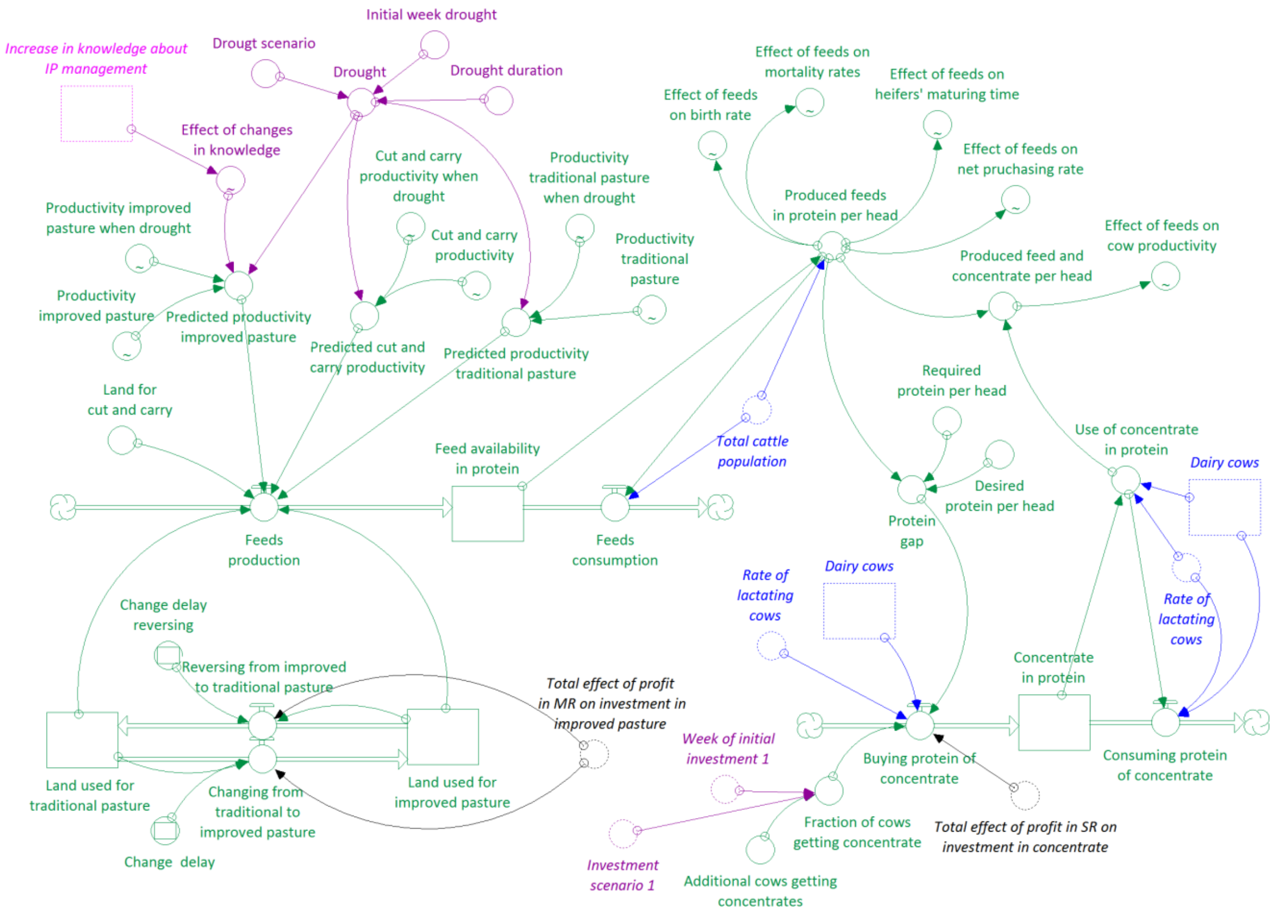


Figure A.3: Structure of feed module. Source: Developed by the authors

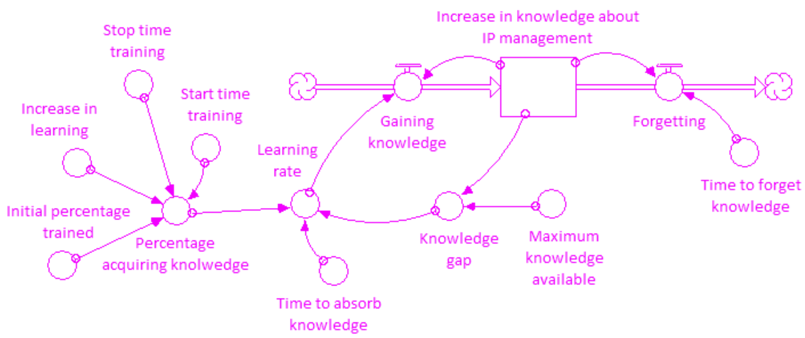


Figure A.4: Structure of learning about improved pasture management. Source: Developed by the authors

Finance module

The finance module consists of one structure that collects the costs and revenues from the three other modules, illustrated in Figure A.5. The second structure, illustrated in Figure A.6, transforms this information into investment decisions, such as investing in improved pasture or buying dairy cows. Milk prices are exogenous in the model because it is unlikely that local dairy producers will heavily influence the milk prices set by the industry actors in the capital. Seasonal price variations are included through the use of graphical functions. The highest price gap is in the informal sector, with a range from 8-13 NIO per kg of milk. In the formal sector, it only ranges between 11-12 NIO per kg of milk. Milk prices can be varied to shock the model. Price differentiation between different quality milk is not included in the model.

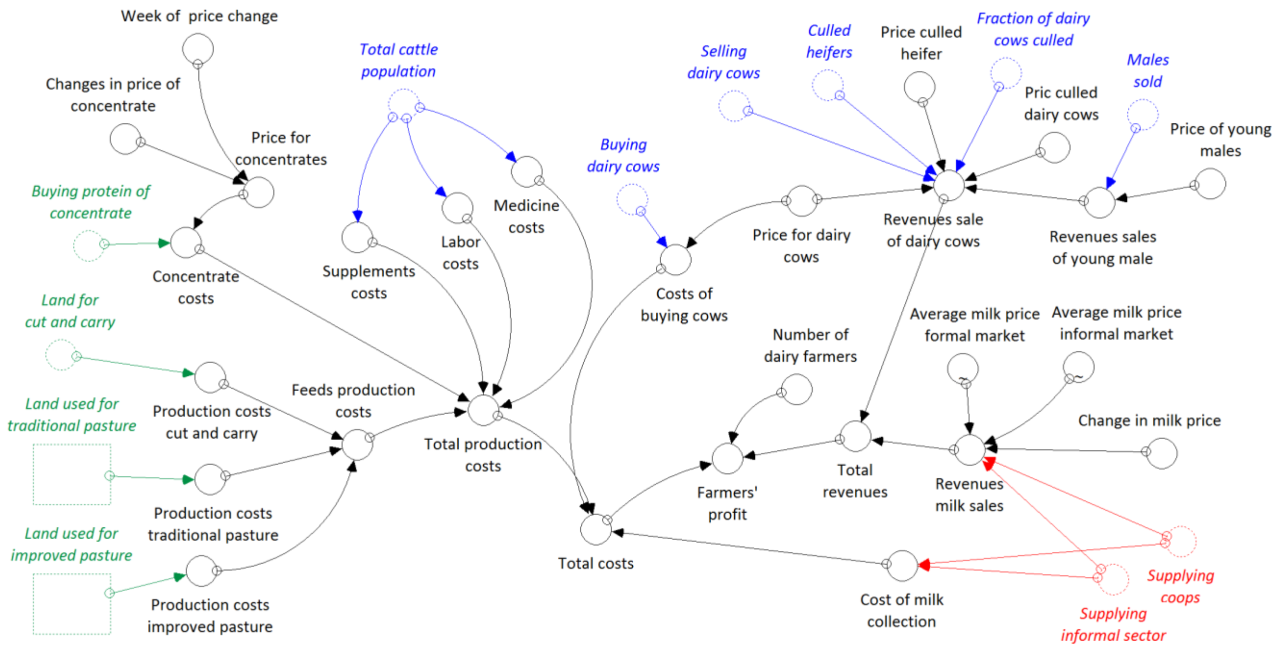


Figure A.5: Costs and revenue structure. Source: Developed by the authors

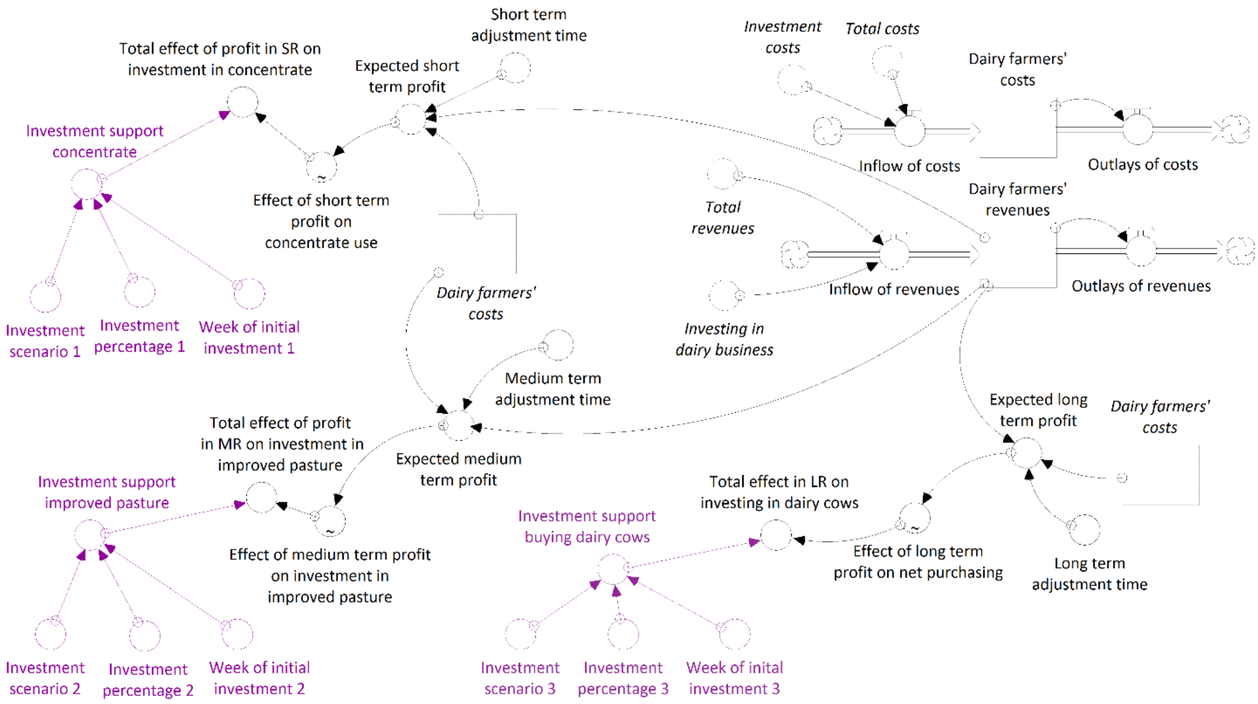


Figure A.6: Investment dynamics structure. Source: Developed by the authors

In the description of the previous modules, assumptions about short-, medium- and long run investments is mentioned. We assume that if Matiguás producers have higher than expected short term (two weeks) profitability they will spend it on concentrates if there is a protein gap (scenario 1). If they have medium run (26 weeks) profitability higher than expected, they will invest in improved pasture (scenario 2). In the long run (156 weeks), farmers with higher than expected profitability will invest in purchasing dairy cows (scenario 3). In other words, different investment decisions are endogenously determined in the model based on expected profits. Additionally, it is possible to run simulations with each of these scenarios where investment decisions are exogenously determined based on potential value chain policies and interventions. The relative size of the investment can be set, as well as the week the investment starts.

Appendix B: Baseline date. Source: Developed by the authors

Herd module	Baseline	Unit	Source
Stocks			
Calves	10000	Cow	Census MAGFOR 2011/GMB
Heifer	5000	Cow	Census MAGFOR 2011/GMB
Dairy cows	20000	Cow	Census MAGFOR 2011/GMB
Breeding bulls	500	Cow	Census MAGFOR 2011/GMB
Variables			
Birth rate	(0.66*Effect_of_feeds_on_birth_rate)/52	Cow/week	GMB
Rate of lactating cows	0.55 (Slider 0-1)	Unitless	Reference group
Mortality rate calves	(0.05*Effect_of_feeds_on__mortality_rates)/52	Cow/week	MAGFOR 2013/GMB
Male to female ratio	0.5*(1-Mortality_rate_calves)	Unitless	GMB
Maturing delay	52	Weeks	GMB
Maturing delay heifer	114*Effect_of_feeds_on_heifers'_maturing_time	Weeks	GMB4
Mortality rate	(0.03*Effect_of_feeds_on__mortality_rates)/52	Unitless	MAGFOR 2013/GMB
Culling rate heifer	0.02/52	Unitless	GMB4
Culling rate dairy cows	0.03/52	Unitless	GMB
Adjustment time sales of dairy cows	16	Weeks	Assumption
Adjustment time buying dairy cows	16	Weeks	Assumption
Fraction of males sold	0.95	Unitless	GMB
Sales delay (male calves)	12	Weeks	GMB
Culling rate breeding bulls	0.1	Unitless	GMB

Milk module	Baseline	Unit	Source
Stocks			
Producers' inventory	350000	kg	GMB
Variables			
Average cow productivity	5 (Slider 0-10)	kg/cow	GMB
Rate of lactating cows	0.55	Unitless	Reference group/GMB
Milk consumed at home	0.025	Unitless	GMB
Milk for calves	2.5	kg	GMB
Coop collection rate	IF Week_of_change_in_demand > 1 THEN 0.6 + STEP((0.60*Demand_from_processors-0.6), Week_of_change_in_demand) ELSE 0.60	Unitless	GMB
Demand from processors	1 (Slider 0-1.7)	Unitless	Scenario function
Week of change in demand	0 (Slider 0-520)	Unitless	Scenario function

Increase in IP knowledge	Baseline	Unit	Source
Stocks			
Increase in knowledge about IP management	0.001	Knowledge	Assumption
Variables			
Stop time training	0 (slider 0-520)	Week	Assumption
Start time training	1 (slider 0-520)	Week	Assumption
Initial percentage trained	0 (slider 0-1)	Week	Assumption
Time to absorb knowledge	29	Weeks	Assumption
Maximum knowledge available	1	Knowledge	
Time to forget knowledge	156	Weeks	Assumption

Feeds module	Baseline	Unit	Source
Stocks			
Feed availability	200000	Protein	Estimate
Land in use for traditional pasture	21060	Manzana	Census MAGFOR 2011
Land in use for improved pasture	16200	Manzana	Census MAGFOR 2011
Concentrate in protein	0	Protein	
Variables			
Land for CC	2025	Manzana	Census MAGFOR 2011
Change delay	36	Weeks	Reference group
Change delay reversing	156	Weeks	Reference group
Required protein per head	8	Protein/cow	Reference group
Desired protein per head	Slider 8-16	Protein/cow	Reference group
Fraction of cows getting concentrate	IF Investment_scenario_1= 1 THEN (0.2 + STEP (Additional_cows_getting_concentrates, Week_of_initial_investment_1)) ELSE 0.2	Cows/week	GMB
Additional cows getting concentrates	0 (slider 0-1)		
Drought scenario	0 (Switch 0=off, 1=on)	Unitless	Scenario function
Productivity reduction improved pasture	0.3	Unitless	Reference group
Productivity reduction traditional pasture	0.5	Unitless	Reference group
Drought duration	0 (slider 0-520)	Week	Scenario function
Initial week drought	0 (slider 0-520)	Week	Scenario function

Costs and revenues	Baseline	Unit	Source
Production costs traditional pasture	1350/52*Land_used_for_traditional_pasture	NIO/manzana	CIAT calculations
Production costs improved pasture	2000/52*Land_used_for__improved_pasture	NIO/manzana	CIAT calculations
Production costs cut and carry	4500/52*Land_for__cut_and_carry	NIO/manzana	CIAT calculations
Medicine costs	(340*Total_cattle_population)/52	NIO/week	GMB
Labor costs	((4000*12)*(Total_cattle_population/15))/52	NIO/week	Reference group
Supplement costs	(Total_cattle_population*762)/52	NIO/week	GMB
Cost of milk collection	Supplying_coops+Supplying_informal_sector*1	NIO/kg	GMB
Price of concentrate	56	NIO/kg	GMB
Changes in price for concentrates	1 (slider 0-2)	Unitless	Scenario function
Week of price change	0 (slider 1-520)	Week	Scenario function
Price of young males	5000	NIO/cow	GMB
Price dairy cows	19000	NIO/cow	GMB
Price culled heifer	12500	NIO/cow	GMB
Price culled dairy cows	15500	NIO/cow	GMB
Number of dairy farmers (households)	1680	Farmer	MAGFOR 2013

Investment dynamics	Baseline	Unit	Source
Stocks			
Dairy farmers' costs	1	NIO	Scenario function
Dairy farmers revenues	1	NIO	Scenario function
Investment	0	NIO	Scenario function
Variables			
Short term adjustment time	2	Week	Reference group
Medium term adjsutment time	26	Week	Reference group
Lon term adjsutment time	156	Week	Reference group

Appendix C: Model equations

Herd module	Equations	Unit
Being born	Dairy_cows*Birth_rate*(1-Rate_of_lactating_cows)	Cows/week
Calves dying	Calves*Mortality_rate_calves	Cows/week
Male calves sold	((Calves*Male_female_ratio)/Maturing_delay)*Fraction_of__male_sold	Cows/week
Becoming heifers	(Calves*Male_female_ratio)/Maturing_delay	Cows/week
Heifer exiting	Heifers*(Mortality_rate+Culling_rate_heifer)	Cows/week
Becoming dairy cows	Heifers/Maturing_delay_heifers	Cows/week
Buying dairy cows	DELAY((Dairy_cows*Buying__rate), Adjustment_time_buying_dairy_cows)	Cows/week
Dairy cows exiting	(Dairy_cows*(Mortality_rate+Culling_rate__dairy_cows))	Cows/week
Selling dairy cows	DELAY((Dairy_cows*Sales_rate), Adjustment_time_sales_of_dairy_cows)	Cows/week
Males sold	((Calves*Male_female_ratio)/Maturing_delay)*Fraction_of__male_sold	Cows/week
Exiting bulls	Breeding_bulls*(Culling_rate_breeding_bulls+Mortality_rate)	Cows/week
Sales rate (dairy cows)	if Effect_of_feeds_on_net_pruchasing_rate<0 then ((1+Effect_of_feeds_on_net_pruchasing_rate)/52) else 0	Cows/week
Buying rate (dairy cows)	if Effect_of_feeds_on_net_pruchasing_rate>0 then ((Effect_of_feeds_on_net_pruchasing_rate+Total_effect_in_LR_on_investing_in_dairy_cows)/ 52) else 0	Cows/week
Total cattle population	Calves+Heifers+Dairy_cows+Breeding_bulls	Cows/week
Males sold	DELAY ((Male_calves_maturing*Fraction_of__male_sold), Sales_delay)	Cows/week
Fraction of dairy cows culled	Dairy_cows*Culling_rate__dairy_cows	Cows/week
Culled heifers	Heifers*Culling_rate_heifer	Cows/week

Milk module	Equations	Unit
Milking amount	if Predicted_cow_productivity<10 then (Predicted_cow_productivity*0.75) else (Predicted_cow_productivity- Milk_for_calves)	Kg/week
Predicted cow productivity	Effect_of_feeds_on_cow_productivity*Average_cow_productivity	Kg/cow
Milk production	SMTH1((Milking_amount*Dairy_cows*Rate_of_lactating_cows*7), Adjustment_time_milk_prod	Kg/week
Supplying coops	(Producers_milk_inventory-Household_consumption)*Coops_collection__rate	Kg/week
Supplying informal sector	Producers_milk_inventory-Household_consumption-Supplying_coops	Kg/week
Household consumption	Milk_consumed_at_home	Kg/week

Increase in IP knowledge	Equations	Unit
Gaining knowledge	Increase_in_knowledge_about_IP_management*Learning_rate	Knowledge/week
Forgetting	Increase_in_knowledge_about_IP_management/Time_to_forget_knowledge	Knowledge/week
Learning rate	Knowledge__gap*Percentage_acquiring_knolwedge/Time_to_absorb_knowledge	Unitless
Percentage aquiring knowledge	MIN(Initial_percentage_trained+RAMP(Increase_in__learning, Start_time_training)-RAMP(Increase_in__learning, Stop_time_training), 1)	Manzana
Knowledge gap	Maximum__knowledge_available-Increase_in_knowledge_about_IP_management	Knowledge

Feed module	Equations	Unit
Feeds production	(Land_for__cut_and_carry*(Predicted_cut_and__carry_productivity))+(Land_used_for_traditional_pasture*(Predicted_productivity_traditional_pasture))+(Land_used_for__improved_pasture*(Predicted_productivity_improved_pasture))	Protein/week
Feeds consumption	Produced_feeds__in_protein_per_head*Total_cattle_population	Protein/week
Changing from traditional to improved pasture	if Total_effect_of_profit_in_MR_on_investment_in__improved_pasture>0 then((Land_used_for_traditional_pasture*Total_effect_of_profit_in_MR_on_investment_in__improved_pasture))/Change__delay else 0	Manzana/week
Reversing from improved pasture to traditional pasture	if Total_effect_of_profit_in_MR_on_investment_in__improved_pasture<0 then ((Land_used_for__improved_pasture*Total_effect_of_profit_in_MR_on_investment_in__improved_pasture)/Change_delay_reversing) else 0	Manzana/week
Buying protein of concentrate	if Protein_gap>0 then Protein_gap*(Dairy_cows*Rate_of__lactating_cows)*(Fraction_of_cows_getting_concentrate+Total_effect_of_profit_in_SR_on_investment_in_concentrate) else 0	Protein/week
Consuming protein of concentrate	Use_of_concentrate_in_protein*(Dairy_cows*Rate_of__lactating_cows)	Protein/week
Predicted cut and carry productivity	IF Drought = 1 THEN Cut_and_carry_productivity_when_drought else Cut_and_carry_productivity	Protein/manzana
Predicted productivity improved pasture	IF Drought = 1 THEN Productivity_improved__pasture_when_drought else (Productivity_improved__pasture*Learning_effect)	Protein/manzana
Predicted productivity traditional pasture	IF Drought = 1 THEN Productivity__traditional_pasture___when_drought ELSE Productivity_traditional_pasture	Protein/manzana
Productivity improved pasture	Productivity_improved__pasture = GRAPH(TIME) (1.00, 8.00), (2.00, 8.00), (3.00, 8.00), (4.00, 7.00), (5.00, 7.00), (6.00, 6.00), (7.00, 6.00), (8.00, 6.00), (9.00, 6.00), (10.0, 6.00), (11.0, 5.00), (12.0, 5.00), (13.0, 5.00), (14.0, 5.00), (15.0, 5.00), (16.0, 5.00), (17.0, 5.00), (18.0, 5.00), (19.0, 7.00), (20.0, 7.00), (21.0, 8.00), (22.0, 8.00), (23.0, 9.00), (24.0, 11.0), (25.0, 12.0), (26.0, 12.0), (27.0, 13.0), (28.0, 14.0), (29.0, 15.0), (30.0, 16.0), (31.0, 15.0), (32.0, 15.0), (33.0, 15.0), (34.0, 14.0), (35.0, 14.0), (36.0, 13.0), (37.0, 13.0), (38.0, 13.0), (39.0, 12.0), (40.0, 12.0), (41.0, 11.0), (42.0, 11.0), (43.0, 11.0), (44.0, 10.0), (45.0, 10.0), (46.0, 9.00), (47.0, 9.00), (48.0, 9.00), (49.0, 8.00), (50.0, 8.00), (51.0, 8.00), (52.0, 8.00), (53.0, 8.00)...	Protein/manzana
Productivity traditionl pasture	Productivity_traditional_pasture = GRAPH(TIME) (0.00, 3.00), (1.00, 3.00), (2.00, 3.00), (3.01, 3.00), (4.01, 3.00), (5.01, 3.00), (6.01, 3.00), (7.01, 2.00), (8.02, 2.00), (9.02, 2.00), (10.0, 2.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 3.00), (19.0, 4.00), (20.0, 5.00), (21.0, 6.00), (22.0, 7.00), (23.0, 7.00), (24.0, 8.00), (25.0, 9.00), (26.1, 10.0), (27.1, 11.0), (28.1, 11.0), (29.1, 12.0), (30.1, 12.0), (31.1, 12.0), (32.1, 11.0), (33.1, 11.0), (34.1, 11.0), (35.1, 9.00), (36.1, 8.00), (37.1, 8.00), (38.1, 8.00), (39.1, 7.00), (40.1, 7.00), (41.1, 7.00), (42.1, 7.00), (43.1, 6.00), (44.1, 6.00), (45.1, 6.00), (46.1, 6.00), (47.1, 4.00), (48.1, 4.00), (49.1, 4.00), (50.1, 4.00), (51.1, 3.00), (52.1, 3.00)...	Protein/manzana
Cut and carry productivity	Cut_and_carry_productivity = GRAPH(TIME) (1.00, 32.0), (2.00, 32.0), (3.00, 32.0), (4.00, 29.0), (5.00, 29.0), (6.00, 29.0), (7.00, 29.0), (8.00, 29.0), (9.00, 29.0), (10.0, 29.0), (11.0, 29.0), (12.0, 25.0), (13.0, 25.0), (14.0, 25.0), (15.0, 25.0), (16.0, 25.0), (17.0, 25.0), (18.0, 25.0), (19.0, 25.0), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 0.00), (35.0, 0.00), (36.0, 0.00), (37.0, 0.00), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 0.00), (47.0, 0.00), (48.0, 0.00), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 32.0)...	Protein/manzana
Productivity traditional pasture when drought	Productivity__traditional_pasture___when_drought = GRAPH(TIME) (0.00, 1.50), (1.00, 1.50), (2.00, 1.50), (3.01, 1.50), (4.01, 1.50), (5.01, 1.50), (6.01, 1.50), (7.01, 1.00), (8.02, 1.00), (9.02, 1.00), (10.0, 1.00), (11.0, 0.5), (12.0, 0.5), (13.0, 0.5), (14.0, 0.5), (15.0, 0.5), (16.0, 0.5), (17.0, 0.5), (18.0, 1.50), (19.0, 2.00), (20.0, 2.50), (21.0, 3.00), (22.0, 3.50), (23.0, 7.00), (24.0, 8.00), (25.0, 9.00), (26.1, 10.0), (27.1, 11.0), (28.1, 11.0), (29.1, 12.0), (30.1, 12.0), (31.1, 12.0), (32.1, 11.0), (33.1, 11.0), (34.1, 11.0), (35.1, 9.00), (36.1, 8.00), (37.1, 8.00), (38.1, 8.00), (39.1, 7.00), (40.1, 7.00), (41.1, 7.00), (42.1, 7.00), (43.1, 6.00), (44.1, 6.00), (45.1, 6.00), (46.1, 6.00), (47.1, 4.00), (48.1, 4.00), (49.1, 4.00), (50.1, 4.00), (51.1, 3.00), (52.1, 1.50)...	Protein/manzana
Productivity improved pasture when drought	Productivity_improved__pasture_when_drought = GRAPH(TIME) (1.00, 5.60), (2.00, 5.60), (3.00, 5.60), (4.00, 4.90), (5.00, 4.90), (6.00, 4.20), (7.00, 4.20), (8.00, 4.20), (9.00, 4.20), (10.0, 4.20), (11.0, 3.50), (12.0, 3.50), (13.0, 3.50), (14.0, 3.50), (15.0, 3.50), (16.0, 3.50), (17.0, 3.50), (18.0, 3.50), (19.0, 4.90), (20.0, 4.90), (21.0, 5.60), (22.0, 5.60), (23.0, 6.30), (24.0, 11.0), (25.0, 12.0), (26.0, 12.0), (27.0, 13.0), (28.0, 14.0), (29.0, 15.0), (30.0, 16.0), (31.0, 15.0), (32.0, 15.0), (33.0, 15.0), (34.0, 14.0), (35.0, 14.0), (36.0, 13.0), (37.0, 13.0), (38.0, 13.0), (39.0, 12.0), (40.0, 12.0), (41.0, 11.0), (42.0, 11.0), (43.0, 11.0), (44.0, 10.0), (45.0, 10.0), (46.0, 9.00), (47.0, 9.00), (48.0, 9.00), (49.0, 8.00), (50.0, 8.00), (51.0, 8.00), (52.0, 8.00), (53.0, 5.60)...	Protein/manzana
Cut and carry productivity when drought	Cut_and_carry_productivity_when_drought = GRAPH(TIME) (1.00, 22.0), (2.00, 22.0), (3.00, 22.0), (4.00, 20.0), (5.00, 20.0), (6.00, 20.0), (7.00, 20.0), (8.00, 20.0), (9.00, 20.0), (10.0, 20.0), (11.0, 20.0), (12.0, 20.0), (13.0, 17.0), (14.0, 17.0), (15.0, 17.0), (16.0, 17.0), (17.0, 17.0), (18.0, 17.0), (19.0, 17.0), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 0.00), (35.0, 0.00), (36.0, 0.00), (37.0, 0.00), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 0.00), (47.0, 0.00), (48.0, 0.00), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 22.0)...	Protein/manzana

Protein gap	if Desired_protein>8 then (Desired_protein-Produced_feeds__in_protein_per_head) else (Required_protein_per_head-Produced_feeds__in_protein_per_head)	Protein
Effect of feeds on net purchasing rate	Effect_of_feeds_on_net_pruchasing_rate = GRAPH(Produced_feeds__in_protein_per_head) (0.00, -1.00), (1.60, -0.6), (3.20, -0.2), (4.80, 0.00), (6.40, 0.00), (8.00, 0.00), (9.60, 0.00), (11.2, 0.00), (12.8, 0.2), (14.4, 0.4), (16.0, 0.8)	Unitless
Effect of feeds on birth rate	Effect_of_feeds_on_birth_rate = GRAPH(Produced_feeds__in_protein_per_head) (0.00, 0.4), (2.00, 0.6), (4.00, 0.8), (6.00, 1.00), (8.00, 1.10), (10.0, 1.20), (12.0, 1.20), (14.0, 1.20), (16.0, 1.20)	Unitless
Effect of feeds on mortality rates	Effect_of_feeds_on__mortality_rates = GRAPH(Produced_feeds__in_protein_per_head) (0.00, 2.00), (2.00, 1.70), (4.00, 1.30), (6.00, 1.00), (8.00, 0.8), (10.0, 0.7), (12.0, 0.7), (14.0, 0.7), (16.0, 0.7)	Unitless
Effect of feeds on heifers' maturing time	Effect_of_feeds_on_heifers'_maturing_time = GRAPH(Produced_feeds__in_protein_per_head) (0.00, 1.35), (2.00, 1.35), (4.00, 1.20), (6.00, 1.00), (8.00, 0.8), (10.0, 0.55), (12.0, 0.55), (14.0, 0.55), (16.0, 0.55)	Unitless
Produced feeds in protein per head	Feed_availability_in_protein/Total_cattle_population	Protein
Effect of feeds on cow productivity	Effect_of_feeds_on_cow_productivity = GRAPH(Produced_feed_and__concentrate_per_head) (0.00, 0.00), (2.00, 0.5), (4.00, 1.00), (6.00, 1.40), (8.00, 1.80), (10.0, 2.00), (12.0, 2.00), (14.0, 2.00), (16.0, 2.00)	Unitless
Use of concentrate in protein	Concentrate_in_protein/(Dairy_cows*Rate_of__lactating_cows)	Protein/Cow
Effect of drought on improved pasture	if Drought_scenario =1 then (step(Productivity_reduction_improved_grasses,1) + step (-Productivity_reduction_improved_grasses, 23)) else 0	Unitless
Effect of drought on traditional pasture	if Drought_scenario =1 then (step(Productivty_reduction_trad_pasture,1) + step (-Productivty_reduction_trad_pasture, 23)) else 0	Unitless
Effect of changes in knowledge	Effect_of_changes_in_knowledge = GRAPH(Increase_in_knowledge_about_IP_management) (0.00, 0.8), (0.1, 0.82), (0.2, 0.84), (0.3, 0.86), (0.4, 0.88), (0.5, 0.9), (0.6, 0.92), (0.7, 0.94), (0.8, 0.96), (0.9, 0.98), (1.00, 1.00)	Unitless

Costs and revenues	**Equations**	**Unit**
Total production costs	Feeds_production_costs+Supplements_costs+Labor__costs+Medicine_costs+Concentrate_costs	Cordoba/week
Feeds production costs	Production_costs_traditional_pasture+Production_costs_improved_pasture+Production_costs_cut_and_carry	Cordoba/week
Concentrate costs	Buying_protein_of__concentrate*Price_of__concentrate	Cordoba/week
Total costs	Total_production_costs+Costs_of__buying_cows+Cost_of_milk_collection	Cordoba/week
Costs of buying cows	Price_for_dairy_cows*Buying__dairy_cows	Cordoba/week
Revenues sale of dairy cows	(Fraction_of_dairy__cows_culled*Pric_culled_dairy_cows)+(Culled_heifers*Price_culled_heifer)+(Selling__dairy_cows*Price_for_dairy_cows)+Revenues_sales_of_young_male	Cordoba/week
Revenues sales of young males	Males_sold*Price_of_young_males	Cordoba/week
Total revenues	Revenues_sale_of_dairy_cows+Revenues_milk_sales	Cordoba/week
Revenues milk sales	(Supplying_informal_sector*(Average_milk_price_informal_market*Change_in_price))+(Supplying_coops*(Average_milk_price_formal_market*Change_in_price))	Cordoba/week
Average milk price formal market	Average_milk_price_formal_market = GRAPH(TIME) (1.00, 12.0), (2.00, 12.0), (3.00, 12.0), (4.00, 12.0), (5.00, 12.0), (6.00, 12.0), (7.00, 12.0), (8.00, 12.0), (9.00, 12.0), (10.0, 12.0), (11.0, 12.0), (12.0, 12.0), (13.0, 12.0), (14.0, 12.0), (15.0, 12.0), (16.0, 12.0), (17.0, 12.0), (18.0, 12.0), (19.0, 12.0), (20.0, 12.0), (21.0, 12.0), (22.0, 12.0), (23.0, 12.0), (24.0, 12.0), (25.0, 11.0), (26.0, 11.0), (27.0, 11.0), (28.0, 11.0), (29.0, 11.0), (30.0, 11.0), (31.0, 11.0), (32.0, 11.0), (33.0, 11.0), (34.0, 11.0), (35.0, 11.0), (36.0, 11.0), (37.0, 11.0), (38.0, 11.0), (39.0, 11.0), (40.0, 11.0), (41.0, 11.0), (42.0, 11.0), (43.0, 11.0), (44.0, 11.0), (45.0, 11.0), (46.0, 11.0), (47.0, 11.0), (48.0, 11.0), (49.0, 11.0), (50.0, 11.0), (51.0, 11.0), (52.0, 11.0), (53.0, 12.0)...	Cordoba/kg
Average milk price informal market	Average_milk_price_informal_market = GRAPH(TIME) (1.00, 13.0), (2.00, 13.0), (3.00, 13.0), (4.00, 13.0), (5.00, 13.0), (6.00, 13.0), (7.00, 13.0), (8.00, 13.0), (9.00, 13.0), (10.0, 13.0), (11.0, 13.0), (12.0, 13.0), (13.0, 13.0), (14.0, 13.0), (15.0, 13.0), (16.0, 13.0), (17.0, 10.0), (18.0, 10.0), (19.0, 10.0), (20.0, 10.0), (21.0, 10.0), (22.0, 10.0), (23.0, 10.0), (24.0, 10.0), (25.0, 10.0), (26.0, 10.0), (27.0, 10.0), (28.0, 10.0), (29.0, 8.00), (30.0, 8.00), (31.0, 8.00), (32.0, 8.00), (33.0, 8.00), (34.0, 8.00), (35.0, 8.00), (36.0, 8.00), (37.0, 8.00), (38.0, 8.00), (39.0, 8.00), (40.0, 8.00), (41.0, 8.00), (42.0, 8.00), (43.0, 8.00), (44.0, 8.00), (45.0, 8.00), (46.0, 8.00), (47.0, 8.00), (48.0, 8.00), (49.0, 8.00), (50.0, 8.00), (51.0, 8.00), (52.0, 8.00), (53.0, 13.0)...	Cordoba/kg
Change in price	1 (slider 0-2)	Unitless
Farmers profit	SMTH1 ((Total_revenues-Total_costs)/Number_of__dairy_farmers, 4)	Cordoba/week

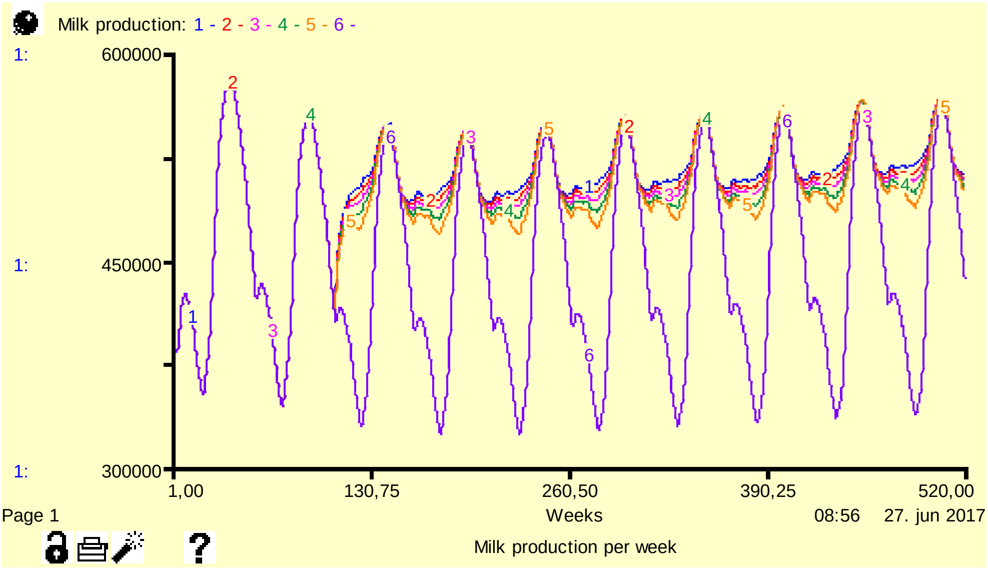
Investment dynamics	Equations	Unit
Inflow of costs	Total_costs+Investment_costs	Cordoba/week
Outlays of costs	pulse(Dairy_farmers'_costs,1,1)	Cordoba/week
Inflow of revenues	Total_revenues+Investing_in_dairy_business	Cordoba/week
Outlays of revenues	pulse(Dairy_farmers'_revenues,1,1)	Cordoba/week
Investment support concentrate	if Investment_scenario_1=1 then step(Investment_percentage_1,Week_of_initial_investment_1) else 0	Unitless
Investment scenario 1	0 (Swith 0=off, 1=on)	Unitless
Investment percentage 1	0 (Slider 0-1)	Unitless
Week of initial investment 1	1 (Slider 1-520)	Week
Total effect of profit in SR on investment in concentrate	Effect_of_short_term_profit_on_concentrate_use+Investment_support_concentrate	Unitless
Effect of short term profit on cencentrate use	Effect_of_short_term_profit_on_concentrate_use = GRAPH(Expected_short_term_profit) (-1.00, -1.00), (-0.9, -0.9), (-0.8, -0.8), (-0.7, -0.7), (-0.6, -0.6), (-0.5, -0.5), (-0.4, -0.4), (-0.3, -0.3), (-0.2, -0.2), (-0.1, -0.1), (0.00, 0.00), (0.1, 0.1), (0.2, 0.2), (0.3, 0.3), (0.4, 0.4), (0.5, 0.5), (0.6, 0.6), (0.7, 0.7), (0.8, 0.8), (0.9, 0.9), (1.00, 1.00)	Unitless
Expected short term profit	if Dairy_farmers'_revenues >0 then SMTH1(((Dairy_farmers'_revenues-Dairy_farmers'_costs)/Dairy_farmers'_revenues), Short_term_adjustment_time) else 0	Cordoba/week
Investment support improved pasture	if Investment_scenario_2=1 then step(Investment_percentage_2,Week_of_initial_investment_2)	Cordoba/week
Investment scenario 2	0 (Swith 0=off, 1=on)	Unitless
Investment percentage 2	0 (Slider 0-1)	Unitless
Week of initial investment 2	1 (Slider 1-520)	Week
Total effect of profit in MR on investment in improved pasture	Effect_of_medium_term_profit__on_investment_in_improved_pasture+Investment_support_impr	Unitless
Effect of medium term profit on investment in improved pasture	Effect_of_medium_term_profit__on_investment_in_improved_pasture = GRAPH(Expected_medium_term_profit) (-1.00, -0.3), (-0.9, -0.26), (-0.8, -0.22), (-0.7, -0.18), (-0.6, -0.14), (-0.5, -0.1), (-0.4, -0.06), (-0.3, -0.04), (-0.2, -0.02), (-0.1, 0.01), (0.00, 0.00), (0.1, 0.01), (0.2, 0.02), (0.3, 0.04), (0.4, 0.06), (0.5, 0.1), (0.6, 0.14), (0.7, 0.18), (0.8, 0.22), (0.9, 0.26), (1.00, 0.3)	Unitless
Expected medium term profit	if Dairy_farmers'_revenues>0 then SMTH1 (((Dairy_farmers'_revenues-Dairy_farmers'_costs)/Dairy_farmers'_revenues), Medium_term_adjustment_time) else 0	Cordoba/week
Investment support buying dairy cows	if Investment_scenario_3=1 then step(Investment_percentage_3,Week_of_inital_investment_3) else 0	
Investment scenario 3	0 (Swith 0=off, 1=on)	Unitless
Investment percentage 3	0 (Slider 0-1)	Unitless
Week of initial investment 3	1 (Slider 1-520)	Week
Total effect in LR on investing in dairy cows	Effect_of_long_term_profit_on_net_purchasing+Investment_support_buying_dairy_cows	Unitless
Effect of long term profit on net purchasing	Effect_of_long_term_profit_on_net_purchasing = GRAPH(Expected_long_term_profit) (-1.00, -0.2), (-0.9, -0.18), (-0.8, -0.16), (-0.7, -0.14), (-0.6, -0.12), (-0.5, -0.1), (-0.4, -0.08), (-0.3, -0.06), (-0.2, -0.04), (-0.1, -0.02), (0.00, 0.00), (0.1, 0.02), (0.2, 0.04), (0.3, 0.06), (0.4, 0.08), (0.5, 0.1), (0.6, 0.12), (0.7, 0.14), (0.8, 0.16), (0.9, 0.18), (1.00, 0.2)	Unitless
Expected long term profit	if Dairy_farmers'_revenues>0 then SMTH1(((Dairy_farmers'_revenues-Dairy_farmers'_costs)/Dairy_farmers'_revenues), Long_term_adjustment_time) else 0	Unitless
	Not included in paper	
Investing in dairy business	if Investment_scenario_4 = 1 THEN (STEP((Investment_amount_per_week*(Number_of__dairy_farmers*Fraction_of_farmers_investing)), Start_week_investment) + step ((-Investment_amount_per_week*(Number_of__dairy_farmers*Fraction_of_farmers_investing)), Start_week_investment+Investment_duration)) else 0	Cordoba/week
Investment costs	(Investment*Interest_rate)/Payback_time	Cordoba/week
Investment scenario 4	0 (Swith 0=off, 1=on)	Unitless
Fraction of farmers investing	0 (Slider 0-1)	Unitless
Start week investing	1 (Slider 1-520)	Unitless
Investment duration	0 (Slider 0-520)	Week
Investment amount per week	0 (Slider 0-2000)	Cordoba
Interest rate	0 (Slider 0-1)	Unitless
Payback time	0 (Slider 0-520)	Week

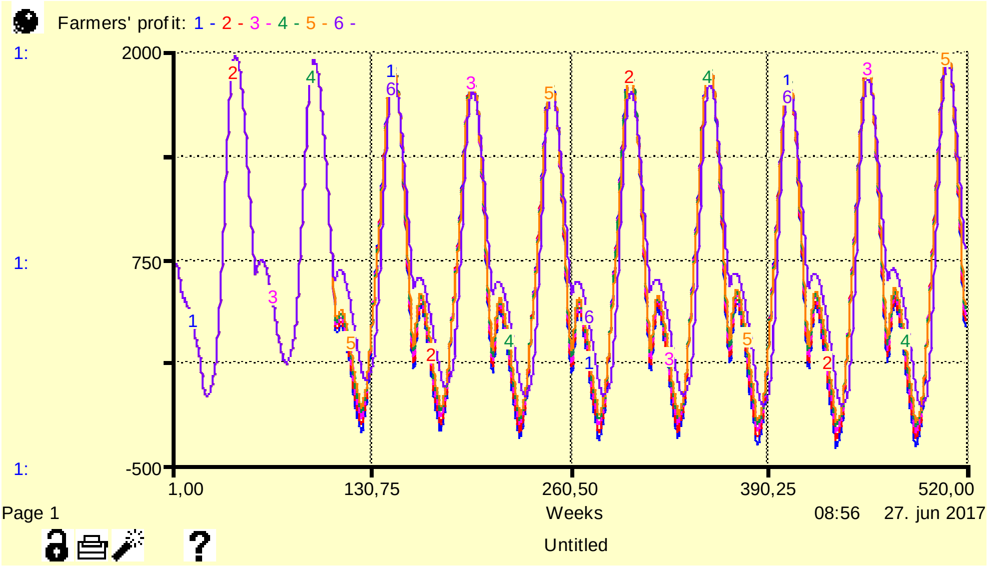
Appendix D: Sensitivity analysis investment percentage in scenarios 1-3

Scenario 1 investment sensitivity

The uncertainty of this parameter necessitated a sensitivity analysis of different options for investment percentages. The sensitivity analysis illustrates that all investment percentages, combined with a 50 percentage point increase in the fraction of dairy cows receiving concentrates, have substantial impact on milk production and farmer profit. We decided to choose a relatively high investment percentage of 20% to analyze farmer responsiveness to large amounts of concentrates and the level of price reduction needed to facilitate profitable concentrate use.

Simulation overview
1 = 0.25
2 = 0.2
3 = 0.15
4 = 0.1
5 = 0.05
6 = Baseline

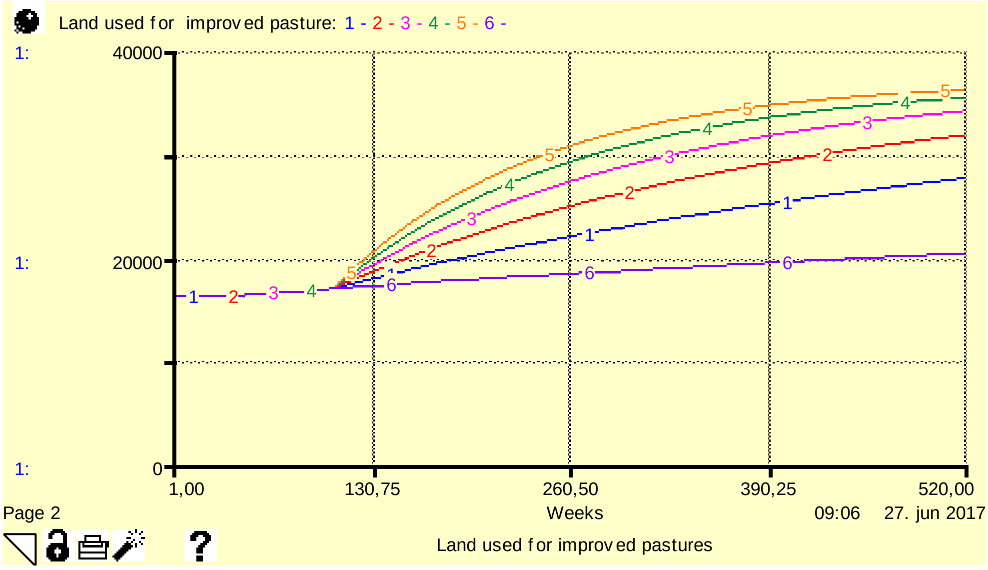


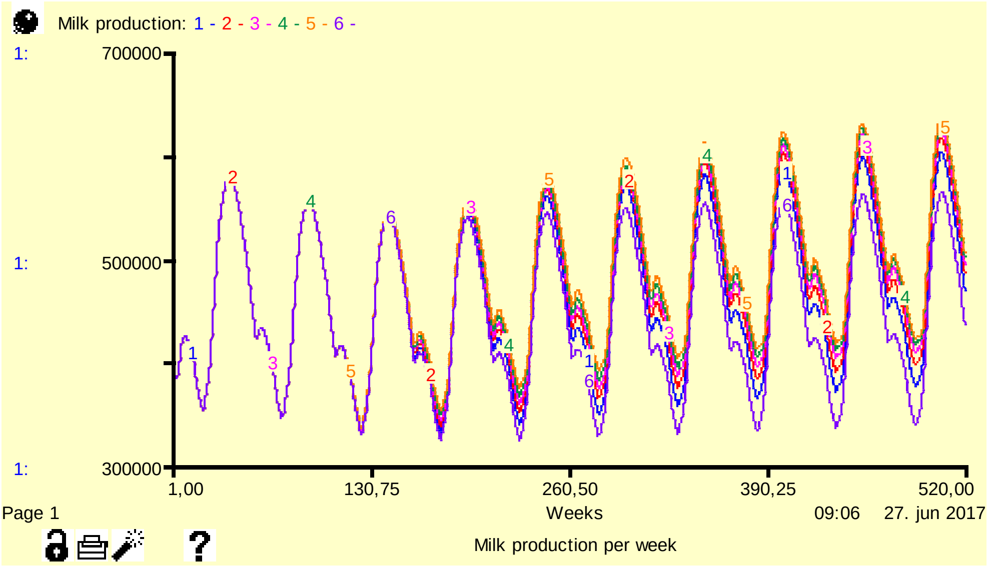


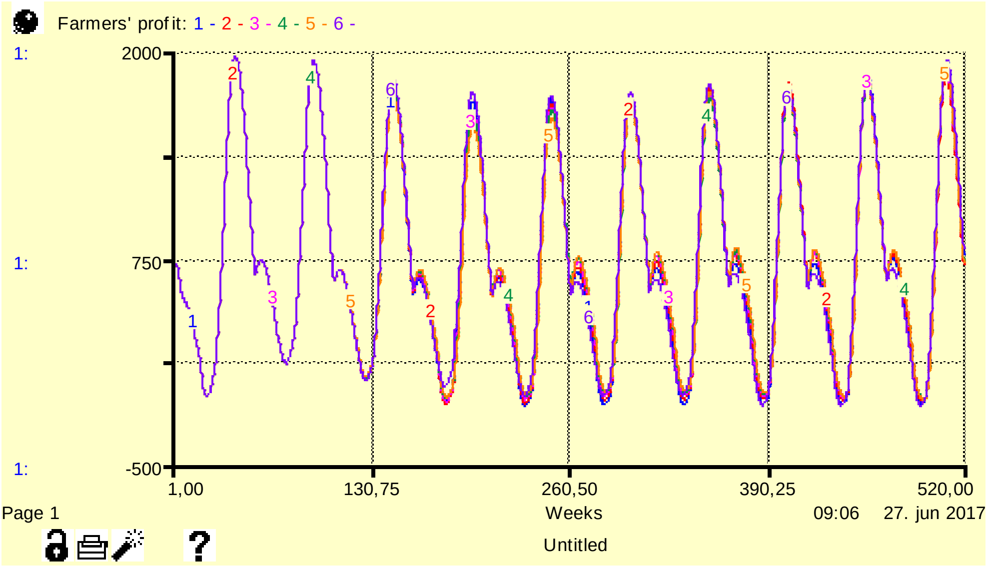
Scenario 2 investment sensitivity

The uncertainty of this parameter also necessitated a sensitivity analysis of different options for investment percentages. The sensitivity analysis reveals that the different percentage options have different effects on increasing the amount of land used for improved pasture. They also affect milk production, farmer profitability, and total cattle population differently. Based on the analysis, we decided to use 10% as the investment percentage since it both yields significant changes and is a realistic percentage in terms of farmer willingness to invest.

Simulation overview
1 = 0.05
2 = 0.1
3 = 0.15
4 = 0.2
5 = 0.25
6 = Baseline


Land used for improved pasture: 1 - 2 - 3 - 4 - 5 - 6 -
1: 40000
1: 20000
1: 0
1,00
130,75
260,50
390,25
520,00
Page 2
Weeks
09:06 27. jun 2017
Land used for improved pastures

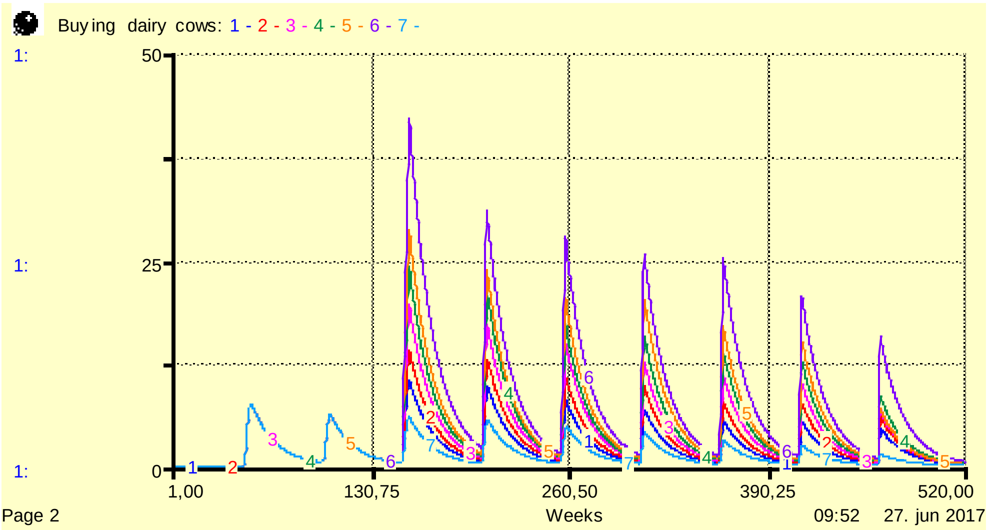

Milk production: 1 - 2 - 3 - 4 - 5 - 6 -
1: 700000
1: 500000
1: 300000
1,00
130,75
260,50
390,25
520,00
Page 1
Weeks
09:06 27. jun 2017
Milk production per week

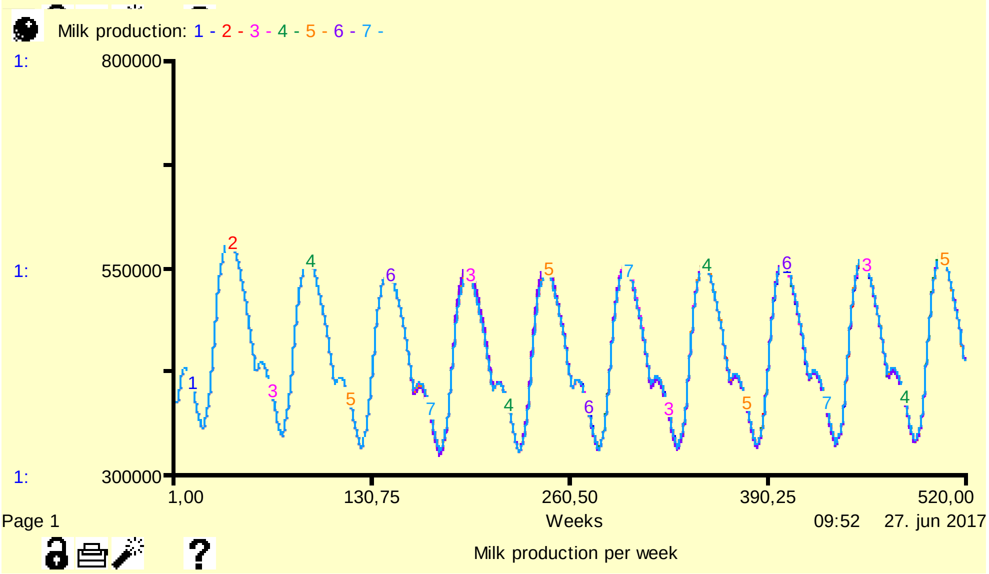

Farmers' profit: 1 - 2 - 3 - 4 - 5 - 6 -
1: 2000
1: 750
1: -500
1,00
130,75
260,50
390,25
520,00
Page 1
Weeks
09:06 27. jun 2017
Untitled

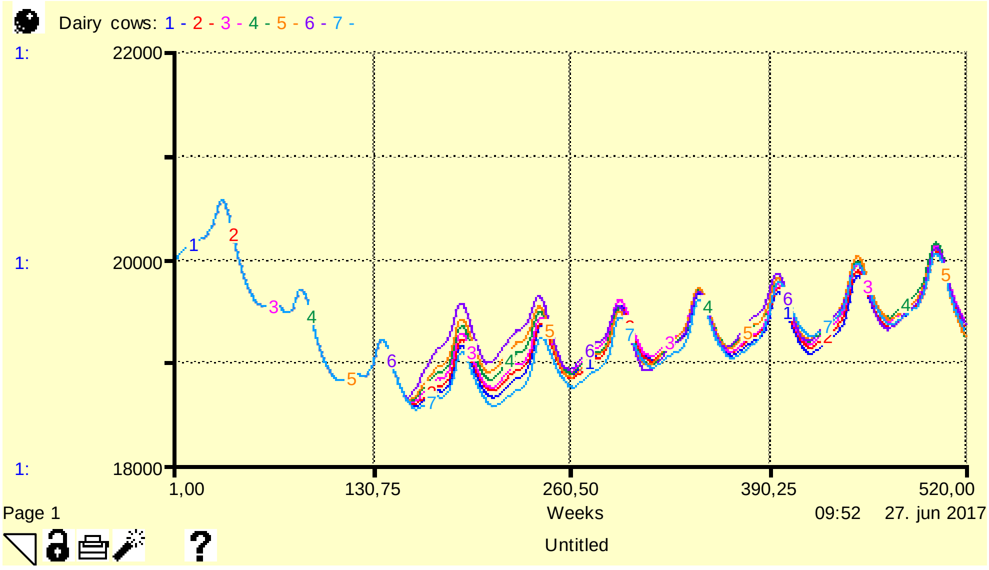
Scenario 3 investment sensitivity

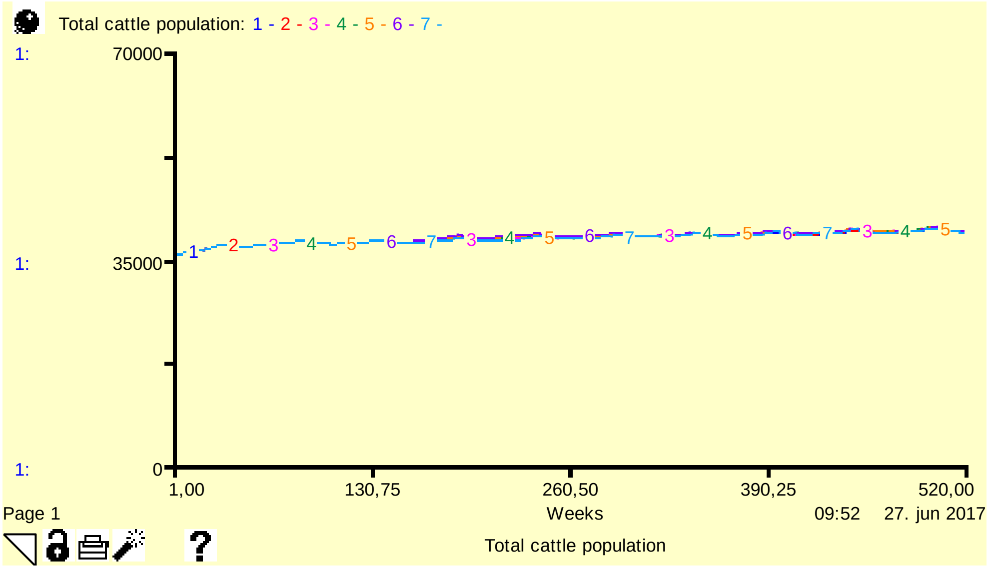
The sensitivity analysis illustrates that none of the investment percentages has any impact on the total cattle population or milk production. They only have a slight impact on farmer profit, which is only due to the purchase and sale of dairy cows within the same year. We therefore chose a relatively modest investment percentage of 10%.

Simulation overview
1 = 0.05
2 = 0.1
3 = 0.15
4 = 0.20
5 = 0.25
6 = 0.4
7 = Baseline





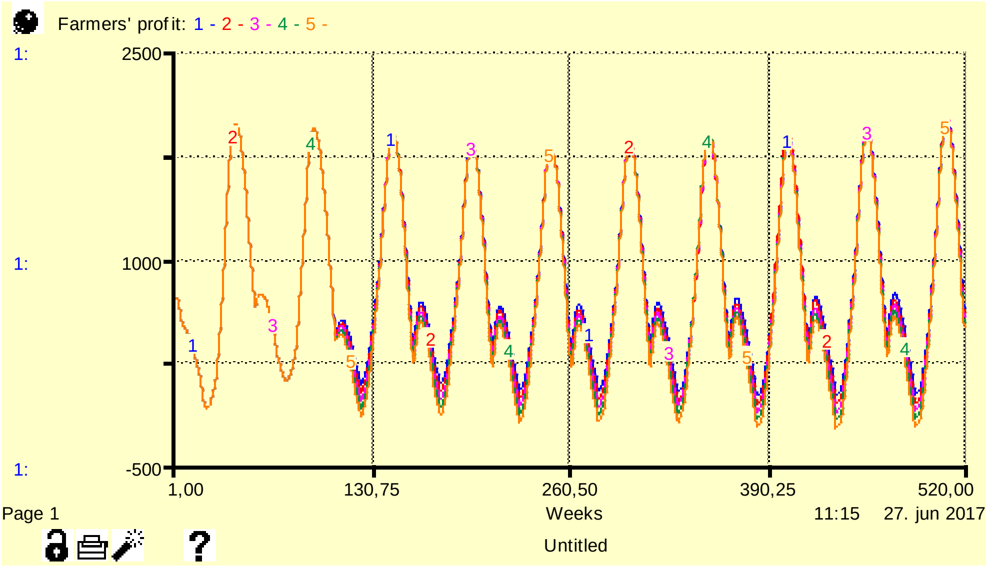




Appendix E: Sensitivity analysis of price for concentrate

The sensitivity analysis illustrates that only a 20% reduction of concentrates prices leads to a profitable milk production during the dry season when concentrates are used.

Percentage decrease in concentrate price:
1 = 20% (45 NIO/kg of protein)
2 = 15% (48 NIO/kg of protein)
3 = 10% (50 NIO/kg of protein)
4 = 5% (53 NIO/kg of protein)
5= 0% (56 NIO/kg of protein)


Farmers' profit: 1 - 2 - 3 - 4 - 5 -
1:
2500
1000
-500
1,00
130,75
260,50
390,25
520,00
Page 1
Weeks
11:15 27. jun 2017
Untitled


Price for concentrates: 1 - 2 - 3 - 4 - 5 -
1:
80
40
0
1,00
130,75
260,50
390,25
520,00
Page 2
Weeks
11:15 27. jun 2017
Price for concentrates

Appendix F: Additional model graphs

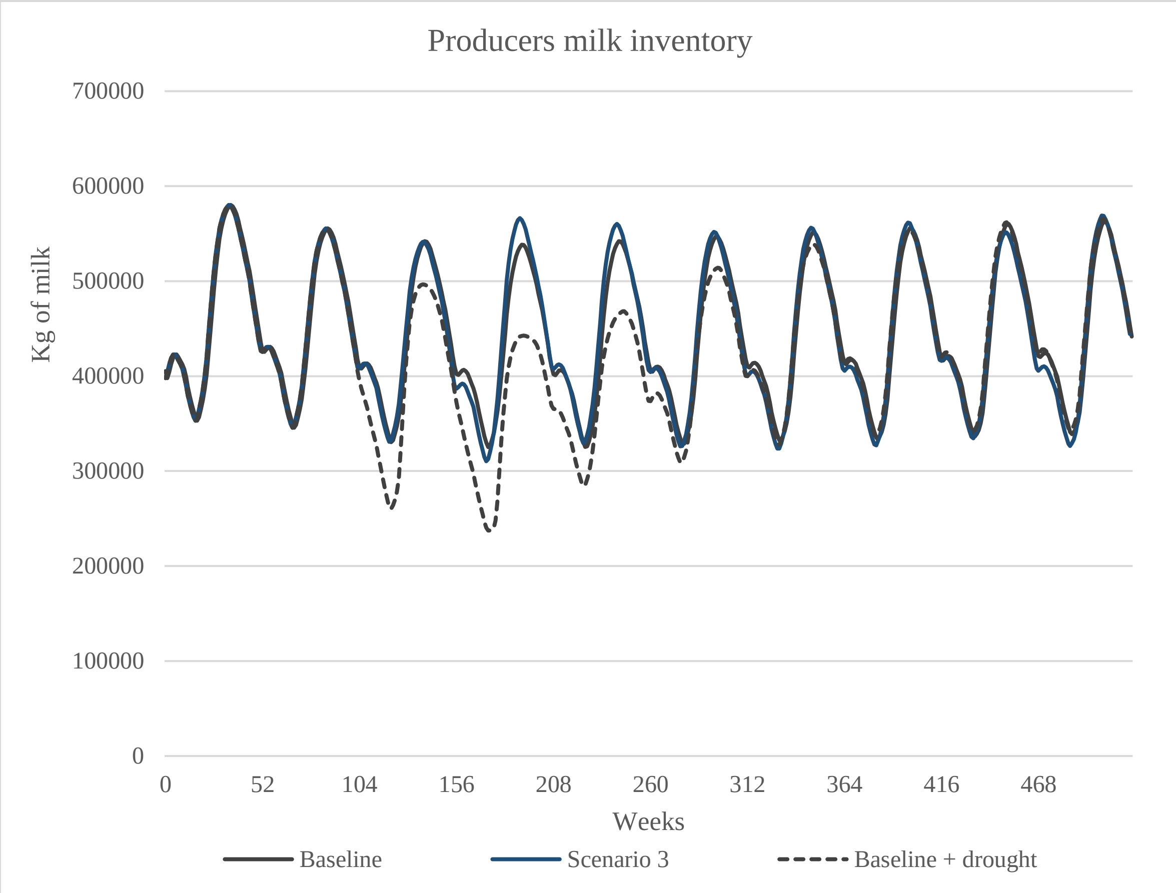


Figure F.1: Producers milk inventory in different scenarios. Source: Model simulations

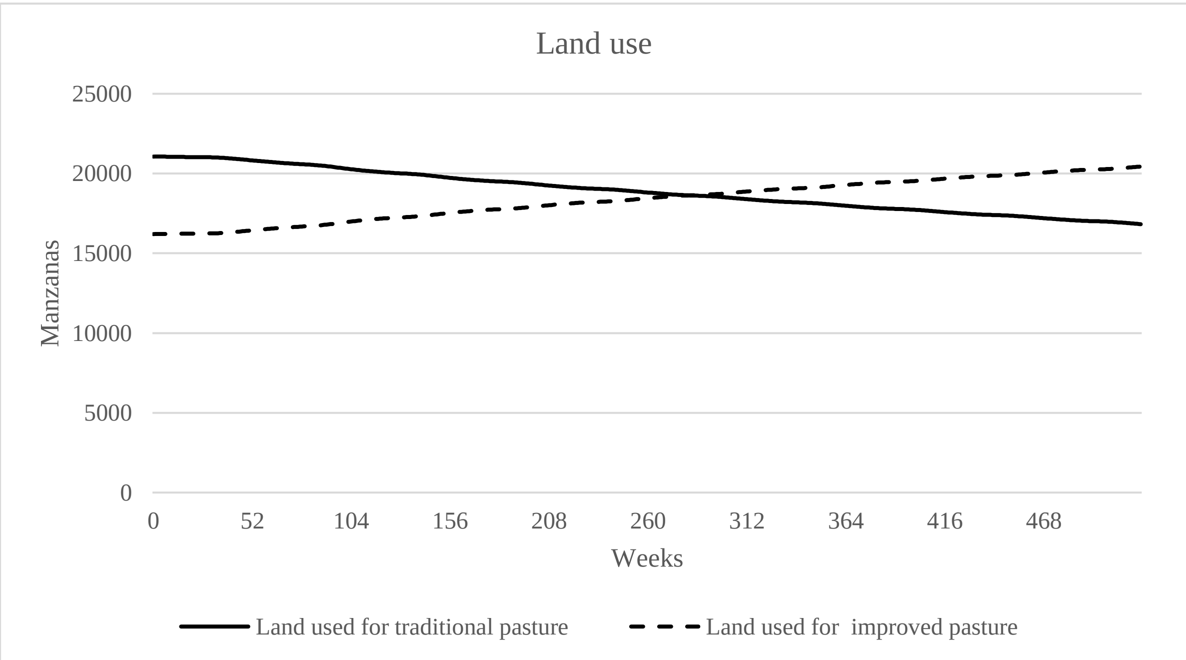


Figure F.2: Land use baseline scenario. Source: Model simulations

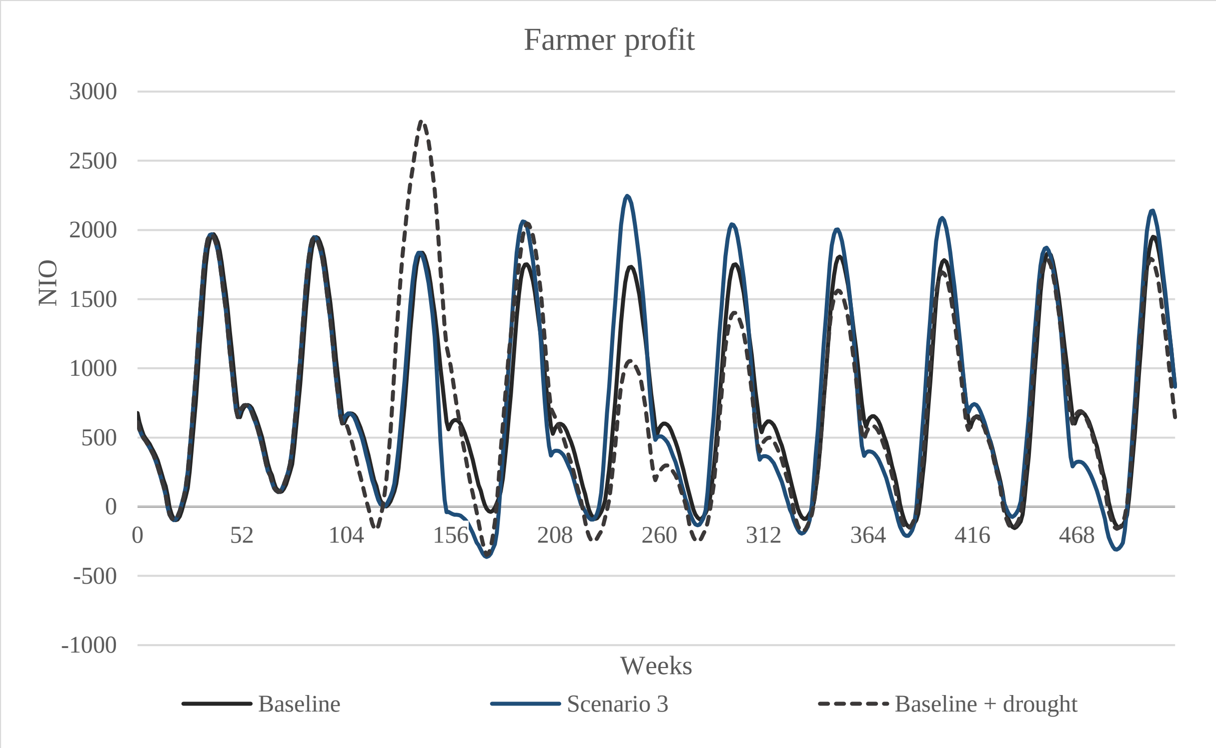


Figure F.3: Farmer profit in different scenarios. Source: Model simulations