MODELING THE IMPACT OF LOSS IN U.S. SOYBEAN PRODUCTION RESULTING FROM SOY RUST DISEASE

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Proceedings of the 23rd International Conference of the System Dynamics Society
Boston, MA, USA, July 17-21, 2005 (Draft dated June 1st, 2005)

Our objective is to examine the consequences of soy rust to the U.S. agriculture in the next 2-5 years. In 2000, the U.S. harvested approximately 2.8 billion bushels of soybeans from almost 73 million acres of cropland, accounting for more than 50 percent of the world's production. The crop generated $12.5 billion dollars, $6.66 billion in exports. Soy rust established itself in the south last November and is expected to disseminate and deposit in the crops during this year's planting season. The extent of outbreaks depends upon climatic conditions. Early detection is crucial since soy rust is deadly to the soy plant within 48 hours. Monitoring systems will warn farmers of the presence of the spores and farmers are instructed on how to identify and treat it. There is uncertainty regarding the sufficient and timely availability of fungicide. In addition to historical data, we incorporate observations of on going planting and harvesting. Parameter ranges in the model are narrowed as more information becomes available and existing uncertainties dissipate. The impact of soy rust is analyzed in aggregate, looking at overall production and market share contrasted against natural noise in the yields.

Key words: Soybean, grain, soy rust, plant disease, corn blight, agriculture

Introduction

This paper reports on-going efforts to model the U.S. agricultural infrastructure, in particular examining the consequences of a soy rust outbreak starting in the 2005 harvest. Soybean is the second largest crop in U.S. agriculture. In 2000, approximately 2.8 billion bushels of soybeans were harvested from almost 73 million acres of cropland, accounting for more than 50 percent of the world's production. The crop generated $12.5 billion dollars in cash receipts from sales; $6.66 billion in the form of exports. [CITE]

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† Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000. The Department of Homeland Security, Science & Technology Directorate, provided funding for this work. This draft describes on-going research involving the authors, Nancy Brodsky, Sharon Deland, and Vanessa Vargas. We thank Andy Ford and four anonymous reviewers for their constructive critiques and helpful comments.

Soy rust established itself in the south past November and over wintered. Now it is expected to disseminate and deposit in the crops during this year's planting season. [CITE] The extent of an outbreak is heavily dependent on climatic conditions, as illustrated in Figure 1. [CITE]

Fig. 1 – USDA map of soy rust susceptibility across the United States (Overlapped with soybean production)

There are two varieties of rust, and one is deadly to the soy plant within 48 hours. [CITE] Early detection is crucial for adequate treatment using fungicides, but it is unclear whether the two forms can be distinguished by farmers. Monitoring systems are being put in place to warn farmers of the presence of the spore in their regions, and farmers are being instructed on how to proceed to identify the disease and treat it effectively. [CITE] But, there is uncertainty regarding the availability of fungicide and equipment to timely respond to outbreaks. [CITE]

The objective of this study is to examine the consequences of soy rust to U.S. agriculture. An important opportunity presents itself, which is to have the modeling effort take place at the same time that soybeans are being planted and harvested in North America, for the first time subject to this disease. In addition to historical data, we can incorporate observations of on going planting and harvesting. Parameter ranges in the model can be narrowed as more information becomes available and existing uncertainties dissipate. Every week there will be new information available, both to parameterize the model, and to contrast real data with model behavior. This means that this modeling work will not be helpful in terms of informing this year's soy production. But, a good model that skillfully represents what's going on in the fields and in the grain market will potentially be useful for medium and long-term analyses of soy rust impact.

Although present and dangerous, soy rust is not expected to be devastating to U.S. soy production. Overall it only marginally affected productivity in South America; moreover, production in these countries has actually continued to increase. [CITE] The U.S. will benefit from existing experience dealing and controlling the disease in other countries. The EPA already granted approval to use fungicides to treat the disease. [CITE] A strong market has flourished to provide farmers with product and equipment to treat it. [CITE] Therefore, it is likely that the disease will be controlled adequately.

However, soy rust is bound to have some impact in U.S. agriculture. It will increase the cost of producing soybeans (due to increased labor, purchase of fungicide and new equipment, and the cost of application) and its risk might induce farmers to substitute other crops for soybeans or even avoid planting. Therefore, it is possible that soy rust will cause a reduction in the U.S. market share in the global market due to comparative disadvantage, since soybean production will become more labor intensive, and labor in this country is more expensive than for main competitors in developing countries, primarily Brazil and Argentina.

The increased use of fungicide is likely to raise concerns related with human health and environmental degradation. Also, some inequities vis-à-vis other bean crops may come into play since special EPA authorization applies only to soybeans, while other types of beans are equally susceptible to the disease.

Yet another significant issue may result from an imbalance between the demand and supply of fungicide in one season, potentially leading to market overreaction in the following season – similarly to this winter's shortage of the flu vaccine due to overproduction and underutilization last winter. [CITE] Therefore, there may be a supply management problem here, resulting in oscillations due to imbalances between the supply and demand of fungicide. This would indicate market failure –a problem that could be aggravated to the extent that the fungicide produced for this year may not be useful anymore next year, as the fungus builds-up resistance to the fungicides used in the treatment of the crops– resulting in economic losses either to fungicide producers or consumers, whoever bears the burden of the unused product. In the case of the flu vaccine it was the manufacturers that were stuck with the bill, and some went bankrupt as a result. [CITE] In the case of fungicide, it is more likely that those toward the end of the distribution chain will bear the burden, since fungicide is currently being sold with a nonrefundable, no-return policy. [CITE]

A definitive solution to the soy rust problem may take five to ten years, and it will involve developing a genetically resistant soybean. [CITE] This hinges on the assumption that the needed strain is available in a gene bank. Otherwise, it has to be genetically modified, raising yet new problems since genetic modification of food is a highly controversial issue. [CITE]

Taken together, these issues suggest there is value in building a system dynamics model to look at the consequences of soy rust, and to examine problems that may unfold within a two to five years time horizon.

Building toward a "generic" crop model

Our soybean model builds upon the corn model reported in Conrad (2004), but it incorporates international competition from southern hemisphere countries already exposed to and experienced in this disease. It treats the disease itself exogenously, and relies upon expert estimation of the overall seasonal crop losses. For now, foreign supply and demand are treated exogenously too, but foreign production is accounted for in the computation of the price received by U.S. soybean farmers. In this estimation we use an econometric model developed by Plato and Chambers (2004). But, the system dynamics model will endogenously balance the supply and demand loops, giving shape to key dynamic indicators such as: relative coverage (ratio of supply to demand), soybean price, seasonal crop planted and on-going demand. The impact of soy rust is analyzed in aggregate, looking at overall production and market share contrasted against natural noise in the yields.

This year's crop production will be monitored carefully to parameterize and calibrate the model. By August most of the existing short-term uncertainties will have been clarified (changes in production due to risk perception, incidence of the disease, timely diagnosis, availability of fungicide and equipment, timely treatment, and overall seasonal crop losses). In addition, we intend to test the model simulating the consequences of the 1970 corn blight –which affected in average 25-30 percent of the national harvest, completely destroying as much as 80-100 percent of the crop in some areas of the country. Thus, behavioral reproduction tests –contrasting model output with real data, both historical and for this harvest– will help us refine, calibrate, and build confidence in the model.

Figure 2 is a systems-level diagram of our generic crop model. The description of the diagram and the order in which we are building the layers of complexity is more or less as follows:

Fig. 2 – Systems diagram of generic crop model

1. The stock-and-flow structure captures the processes of planting, growing, harvesting, storing and selling the grains. Some of the key inputs to this production chain are: farmer's seasonal planting commitment, period of the planting season (start and duration), time for the crop to mature (LOS in fields), duration of the harvest, yield under normal conditions, and demand for grains

2. We are interested in studying and contrasting two exogenous effects upon this production chain, soy rust disease vs. noise in the system (mostly how the weather affects the yields)

    a. A key parameter in the model is the net *fraction of crop loss*. It depends upon a number of things, such as fraction of the crop vulnerable, disease education, crop monitoring, timely diagnosis, treatment training, availability of fungicide and equipment, and timely treatment. The better we measure this risk, the narrower its range of variance. Thus, the validity of our conclusions in the comparison between noise vs. impact of the disease relies heavily on this parameter

    b. Another important exogenous element is the magnitude of the impact of weather on the yields, captured as historical variance in the yield, controlled for advances in productivity

3. The seasonal planting commitment by farmers depends on a number of things: the forecasted price of grains provided by the USDA, the price of grains in the futures market, elasticity of grain supply, government subsidies, risk perception regarding soy rust disease, availability/cost of insurance, return on alternative investments (including other crops), and availability of land to plant. Some of these inputs to farmers' decisions are easier to comprehend and synthesize than others. We'll do our best to capture as many as possible. Note that the subsidized price of grains, if greater than the break-even price, constitutes a floor in terms of production, and land availability constitutes a ceiling. The broader the range between the floor and the ceiling, the more important it is to capture accurately these things that shape farmers' planting decisions

4. To close the production loop, we need to capture the processes through which the future price of grains (and/or the price of grains in the futures market) is forecasted. This involves examining both the USDA and Chicago Board of Trade (CBT) forecasting procedures, and perhaps reconciling them. We assume these forecasts are based upon a number of things, such as: expected demand for grains (domestic and foreign), adequacy of the physical inventory (grain in storage vis-à-vis grains needed to meet demand until the next harvest, or for the following "N" months), adequacy of the upcoming harvest

(what will be the yield coming into the inventory?), and the impact of inventory coverage upon grain prices (coverage elasticity)

5. Crop loss and subsequent reduction in harvested yields is likely to trigger a number of compensating mechanisms:

    a. More production, provided the shortage makes prices rise, and provided there is additional land to plant

    b. More imports to accommodate existing demand

    c. Rationing if the shortage is serious and imports are not available

    d. Adjustments in demand due to rise in the price of grains. This, in turn, depends upon the elasticities of demand (for animal feed and for other usages)

6. We will consider expanding the model boundary to treat endogenously some of the exogenous parameters or time series:

    a. Building the interdependencies between the demand and supply of fungicides (interdependency with chemical industry) and equipment

    b. Building the interdependencies between irrigation (energy and water infrastructures) and crop land availability

    c. Including corn as a separate sector and examining the interactions between these two commodities (both in terms of production and consumption)

    d. Endogenizing foreign production to address global grain interdependencies (both in production and consumption)

    e. Coupling the soybean and corn sectors with the beef and dairy sectors; adding poultry and hogs

This is an ambitious scope of work. For this paper, we would like to be able to conclude item 4 and as many as possible of the compensating mechanisms mentioned in item 5.

Modeling foundation

This modeling work builds upon Meadows' (1970) hogs' model, addressing commodity production cycles. The basic feedback structure for production cycles proposed by Meadows is shown in Figure 3. Inventory coverage is at the center of a pair of negative feedback loops which act to eliminate imbalances between demand and supply; the resulting price acts as its signal in promoting the efficient allocation of resources (production and consumption). However, due to delays in capacity acquisition and bounded decision making by producers, market reactions of demand and supply to price are very slow, resulting in oscillations (Sterman, 2000; Meadows, 1970). Additional instabilities and delays are introduced to the extent that commodities are interdependent or act as substitutes. For example, grains (such as corn and soybeans) are used in animal feed, and the price of feed influences decisions regarding animal heard sizes, which in turn affects the consumption of feed, thus closing the loop through its influence in grain prices. Moreover, different grains (corn vs. soybeans) can be used in the production of animal feed, depending upon their relative prices, thus changing relative demand and serving to balance grain prices.

Fig. 3 – Feedback loop structure of production cycles (copied from Meadows, p. 19)

Conrad (2004) described an initial crop model capturing the production cycle for corn, and how it interacted with beef and dairy production. Figure 4 shows the corn sector. The negative feedback loop for production is identified by the orange arrows. The total corn inventory and the corn sales together determine the corn coverage time, which in turn determines the price of corn. Since corn production is so strongly seasonal (planted in the spring and harvested in the fall), seasonal effects are explicitly captured in the model. Although in reality farmers can respond to price signals during the growing season by varying their applications of fertilizer and pesticide, the foremost way they respond to price is in their decision about how much corn to plant in the spring. In the model this is the only way for corn producers to respond to price. Corn production responds to relative coverage (through price) but is confined within a range characterized by a floor (the subsidized corn price or a break even price) and a ceiling (the maximum acres of land available for production). Harvested corn accumulates in the fall and is depleted over the course of months until the next harvest. Harvested corn is distributed primarily as animal feed (~ 58 percent), [CITE] but it also goes to dry and wet mills and exports. Consumption depends upon demand from the various types of buyers.

Fig. 4 – Corn sector diagram (copied from Conrad, p. 5)

Rasmussen and Becker (2004) did an initial stability and sensitivity analysis of Conrad's three-commodities model. Their assessment focused upon behavioral stability of the agricultural sub-sectors (corn, beef and dairy) given parameter changes, particularly changes in assumptions regarding aggregate agent reactions to prices and sector stresses, captured in the model as *elasticities*[1]. They found model behavior to be highly sensitive to these elasticities. For corn, they demonstrated that dramatic oscillations occur in *acres of corn (planted)*, with small increases in *corn planting elasticity* (the elasticity of supply), as illustrated in Figure 5.

Fig. 5 – *Acres of corn* under different assumptions for *corn planting elasticity*, 0.5, 0.625 and 0.75 (copied from Rasmussen and Becker, p. 6)

Rasmussen and Becker concluded that two key elements dominate the sector dynamics: (1) the manner in which agents react to prices and sector stresses, and (2) where production delays occur and their nature. In order to advance the modeling effort, they recommended (i) adopting model simplifications to clarify model functionalities, (ii) further investigation of the human decisions

[1] Coverage, production and consumption elasticities – i.e., what effects will *coverage* have on price? What effects will price have on *production* and on *consumption*?

models/curves to limit the family of resulting behaviors to the range of realistic dynamics, and (iii) using historical time series to gain better insight into the agricultural sub-sector dynamics. In spite of the concerns raised, they concluded that this version of the model provided "good initial systems approximations and, in particular, a wealth of information about how to model the detailed sub-sector price formation processes." (p. 1)

We believe this modeling extension follows suggestions (ii) and (iii). This work aims towards careful estimation and calibration of model parameters and table functions, within empirically derived ranges whenever available, using both "snapshots" and time series comparisons to refine and build confidence in the model and simulations. A better understanding of the physical and behavioral processes captured in the crop model will allow us to narrow the range of feasible real-world model behaviors. Hopefully this will provide not only better insights into structural-behavioral links, but also more robust forecasts of soy rust impacts on U.S. agriculture and economy. (Appendix 1 illustrates the use of parameterization and calibration spreadsheets to substantiate and document parameter ranges, as well as available data, for the piece of the model dealing with planting and harvesting with disease.)

On-going model refinements

Introspection and feedback from several reviewers led to the following list of model refinements and tests:

- √ Reformulation of the *planting* and *harvesting* processes
- √ Reformulation of the *disease scenario* and *crop losses*
- ➢ Reformulation of *relative coverage*
- Logistic growth issue involving formation of the *unsubsidized corn price* (goal-seeking vs. S-shaped adjustment)
- Revisit resource allocation formulation (*sales*)
- Parameterization and calibration of the *production* and *consumption* loops (including coverage, production and consumption elasticities)
- "Snapshot" behavioral reproduction tests to examine model output against cross-sectional data
- "Longitudinal" behavioral reproduction test, replicating the 1970 Corn Blight, to contrast model behavior with actual time-series data

The first two items in this list were addressed and are reviewed in the next section. We are currently working on the third item, the reformulation of *relative coverage*, also discussed below.

Planting and harvesting with disease

The motivation to reformulate the planting and harvesting with disease processes in the model was due to:

- Desire to parameterize these processes drawing upon *length of planting season*, *length of stay of crop in the fields*, and *length of harvesting season*, in addition to *start of planting*, using auxiliaries to capture *end of planting*, *start of harvesting* and *end of harvesting*, previously treated as parameters
- Elaborate the disease scenario to include *fraction of crop vulnerable*, as well as make the formulation more flexible and robust in terms of variations in the *fraction of crop loss scenario* and the timing of the disease (*onset of disease* and *disease duration*)
- Capture both physical *crop loss* (acres/month) and *yield loss* (tons/month), using a co-flow structure
- Generate an indicator of *fractional yield loss* while the crop is in the field, as an early signal about the yield of the future harvest

The resulting model diagram is depicted in Figure 6.

Fig. 6 – Planting & harvesting with disease model diagram

The results of a five year simulation –assuming a *net fraction of crop loss* of 25 percent during the second season– are captured in Figure 7. Every year the crop is planted and harvested, as illustrated in terms of *crop in fields* (line 1). As a function of the disease in year 2, the *average seasonal yield* (line 2) falls during the time the crop is growing and maturing. When the crop is harvested, an equivalent loss in terms of acreage is captured as *crop loss* (line 3). The *fractional yield loss* (line 4) normalizes the *average seasonal yield* and constitutes the signal that there is going to be a problem with the future harvest. This signal is perceived in the market as soon as word is out about the effects of the disease on the crop, and it precedes the physical accounting of soybeans that happens months later, during the harvest itself.

Fig. 7 – Disease scenario (*net fraction of crop loss* = 0.25 during the second season)

Relative coverage

The motivation to revisit the formulation of relative coverage was due to the issues discussed earlier and highlighted in the systems diagram, involving USDA price of grains forecasts and the CBT futures market. Both these forecasts take the perceived adequacy of inventory (plus harvest) vs. expected demand (i.e. relative coverage) as the signal to adjust future prices. Thus, we replaced the previously used table function capturing *desired coverage* with formulation that computes the *desired stock to use ratio* from *coverage needed until harvest* (a combination of *demand* and *time remaining until the next harvest*) and *desired reserves* (a minimum inventory coverage level just before the new harvest begins to refill the inventory). We also incorporated *time to deplete the remaining inventory* and we wish to determine if there is (or could be) a rationing policy in the case of shortages.

As of yet, the revised model does not include the demand feedback loops. *On going demand* is treated for now as constant. The revised model diagram is depicted in Figure 8.

Fig. 8 – Relative coverage model diagram

Figure 9 portrays the results of the same simulation for *harvesting yield* (line 1), *on going sales* (line 2), *harvested crop* (line 3), *adequacy of physical inventory* (line 4), and *perceived adequacy of future inventory* (line 5). During the simulation, *on going demand* remains constant and equal to 20 million tons per month. The saw-shaped behavior of *harvested crop* (inventory level) matches that of the *desired coverage*, except when there is a shortage in the harvest due to disease (during the second season). This shortage unfolds into the following seasons.[2] Note that the *inadequacy of the physical inventory* is not perceivable until the new harvest comes in. However, the *inadequacy of future inventory*, which takes into account the early signal from the health of the crop in the field, is perceivable as soon as word gets out about the disease.[3] *On-going sales* are constrained by the availability of inventory.

Fig. 9 – Relative coverage (*Perceived adequacy of future inventory*)

For now, we used a weighted formula to establish the *adequacy of future inventory* combining both the *adequacy of physical inventory* and the *fractional yield loss* in the field. The weight changes dynamically depending upon where the soy is found –whether in fields or silos. As we can observe in Figure 10, this formula discounts both the disease in the field (between months 15-19) and the shortage in the silos (between months 27-33 and, later, 39-45 and 51-57). It may not be the ideal solution to represent how real people, in this case brokers in the grain market, combine information regarding what's going on in the fields vs. silos.[3] Thus, some empirical research is required to build confidence in this formula.

Figure 10 helps to highlight some issues that come up due to delays in this system:

Fig. 10 – Types of (in)adequacies
(How to combine *fractional yield loss* with *adequacy of physical inventory*?)

1. The *fractional yield loss* (line 1) resulting from a disease in the field between months 15-19 does not translate into a problem in the inventory (*inadequacy of physical inventory*, line 2) until the crop is harvested. Therefore, if folk in the silos did not have information about what's going on in the fields, they would be clueless that there's going to be a problem keeping their inventories at the levels they would like them to be;

2. Worse, the *inadequacy of supply* (line 5) is not truly observed until more than a year later, between months 29-32, just before the next harvest comes through. This is because *on going demand* can be met all the way up until the inventory falls below *desired reserves*;

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[2] In this version of the model soy production is also constant. Thus, the part of the harvest lost in the second season is never compensated, except for reduced sales just before the 3rd, 4th and 5th harvests, when inventory is below the level of *desired reserves*. Normally producers would plant more following the bad season motivated by rise in prices resulting from shortage in supply.

[3] There is at least one more piece of information that we may need to incorporate to establish grain prices, which is the commitment farmers make prior to actual planting, captured and reported by USDA. [CITE] This information may constitute an earlier signal that needs to be considered in the *perception of the adequacy of future inventory*.

3. In addition, the shortage caused due to the disease in the second year propagates throughout future years unless more grains are planted in the subsequent season, to compensate for this season's loss. Essentially, this becomes an inventory management problem. In fact what corrects for this future problem is exactly the upward fluctuation in price due to the shortage. But, as the argued above, this information (of a physical shortage) is not going to be available until more than a year after the problem occurred. Thus, it is the perception that there will be a shortage (or surplus) that drives prices, and not actual shortages and surpluses.

This "market failure" due to inherent delays in the system is compensated by the existence of a futures market, which acts as a proxy for the market's "invisible hand," attempting to forecast future supply and demand for grains, and provide early signals of future prices. [CITE] Therefore, it is important to capture in the model this decision rule that real decision makers use to govern grain prices. This calls for examining how the USDA produces its forecasts, and checking with futures brokers how the CBT establishes futures grain prices. It might be worth representing this forecasting process in a policy structure diagram (Morecroft 1982), capturing the causal structure and time delays involved in this decision.

We continue to work on the relative coverage issue, and other items of the outline of refinements. We are also planning on a number of model additions.

Model additions to adapt the crop model from corn to soybeans

- Introduce specific soy rust issues to disease scenario: timely diagnosis, availability of fungicide and equipment, and timely treatment. These issues help shape the *fraction of crop loss scenario* which, combined with *fraction of crop vulnerable*, determines overall seasonal crop losses (*net fraction of crop loss*)
- Incorporate Plato and Chambers's econometric estimation of the price received by U.S. soybean farmers (accounting for foreign production) in the formulation of *unsubsidized soybeans price*
- Incorporate changes in production due to risk perception (including availability of alternative crops, break-even prices, etc.) to the *production* loop
- Incorporate commodity substitution in animal feed (and maybe other areas of consumption) to the *consumption* loop
- On-going examination of model output vis-à-vis available data as planting and harvesting unfolds
- Revisit parameterization and calibration of *production* and *consumption* loops (including disease scenario and coverage, production and consumption elasticities), given availability of new data from this year's production

The next section addresses where we are headed in terms of model-based analysis and sought-out insights.

Discussion

The purpose of this model is to capture in aggregate level the impact that soy rust will have in U.S. agriculture and economy. For this iteration of the modeling effort, we can define the problem as an attempt to identify and measure the medium and long-term consequences of soy rust in terms of acreage planted, seasonal production, productivity, break-even prices, crop substitutions, grain substitutions, transient or steady state imbalances between supply and demand, volume of sales and exports, and global market share. But the measuring stick used is not one of acres, tons or dollars. Although the model will necessarily indicate values and units that will imply that we can measure the metric decrease in production and dollar increase in price, etc, we are primarily interested in the magnitude represented in the soy rust problem, as well as possibly revealing counter-intuitive insights:

- Is the potential effect of soy rust upon U.S. agriculture, consumers and economy, in the next five years, greater or smaller than have been the historical natural effects of, for instance, weather?
- Will *the current trend* in U.S. market share in this industry remain the same now that soy rust is present in North America?
- Could a relatively minor incidence of the disease this year create a market failure that could result in being unprepared for a more significant manifestation of the disease in future years?

Our working hypothesis is that the effect of soy rust will be smaller vis-à-vis normal fluctuations observed due to weather and noise in this system. If, in the process of conducting this study, we find evidence to reject this hypothesis, then, soy rust presents a BIG problem to the U.S. agriculture and economy. To this end, we will have also shed some light on the following questions:

- Which of the issues related to soy rust present themselves as significant vulnerability issues to this industry and, subsequently, to the U.S. economy?
- What management issues do we need to consider (leverage or sensitive points in the system)?
- What are the infrastructure intra-dependencies between soybean and other agricultural commodities?
- What are the interdependencies between soybean (and grains in general) and other national infrastructures (e.g. chemical industry)?

If we fail to reject our working hypothesis, then, in the absence of better evidence, we must conclude that while the fungus is present in this country, and constitutes a serious danger to soy production, soy rust is not expected to inflict severe aggregate harm to the nation (provided some safeguards are taken!). However, it will likely cause many changes in the way of doing business. These changes will generate new costs and benefits that will reflect in specific gains and losses to specific sub groups within this industry (agriculture), as well as in other industries (e.g. chemical). In addition, we may be able to characterize these sectorial gains and losses, and suggest means by which they might be minimized or compensated provided due cause.

Limitations and future research

There are many limitations to this preliminary effort. First and foremost the fact that soy rust disease is not modeled endogenously, but considered as a scenario in the simulations. We believe other methods and tools are better equipped to model the spread and development of the disease due to spatial considerations that are not well handled in system dynamics models. A number of other aspects in the production of this crop and interactions with other commodities (including other crops) fall outside of the boundary of this study. We attempted to list endogenous, exogenous and excluded variables in a preliminary model boundary chart, illustrated in Table 1.

Table 1 – Preliminary model boundary chart

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Fig. 1 – USDA map of soy rust susceptibility across the United States
(Overlapped with soybean production)

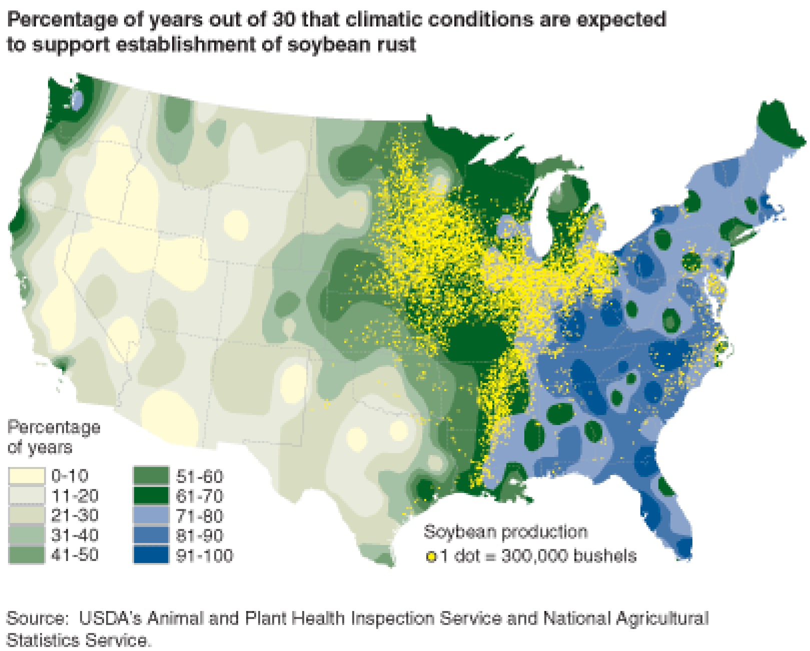

Fig. 2 – Conceptual systems diagram of the generic crop model, displaying interactions between grains (corn vs. soybeans), between U.S. and foreign production, between grains and other agricultural sectors, between agriculture and chemical industry, energy and water infrastructures, and portraying the impact of weather on seasonal yields

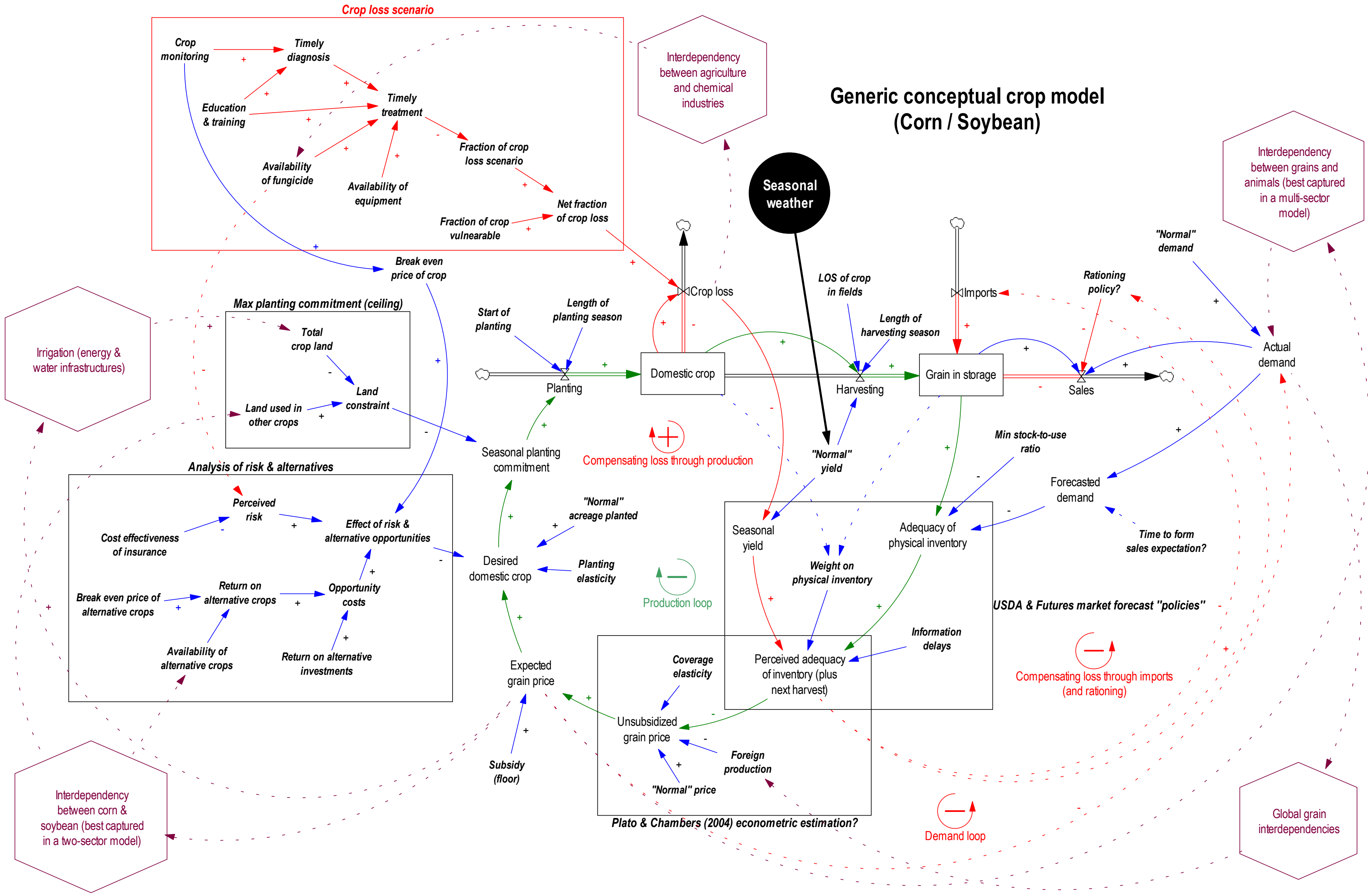

Fig. 3 – Feedback loop structure of production cycles (copied from Meadows, p. 19)

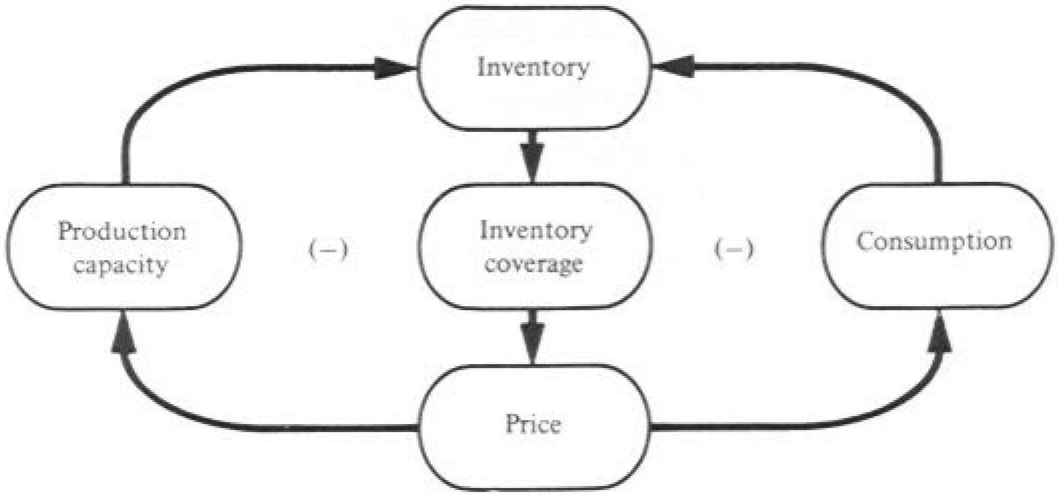

Fig. 4 – Corn sector diagram (copied from Conrad, p. 5)

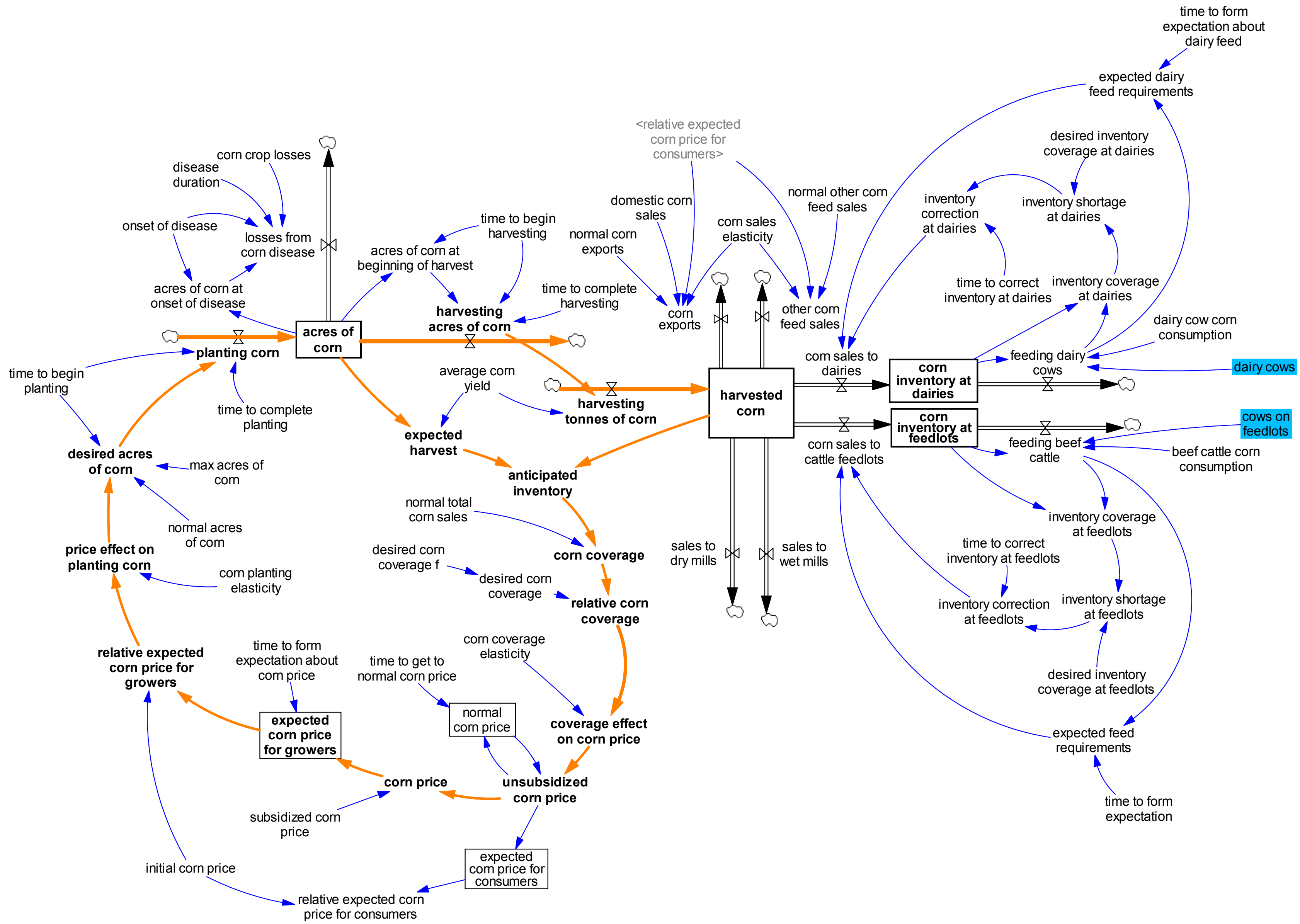

Fig. 5 – *Acres of corn* under different assumptions for *corn planting elasticity*, 0.5, 0.625 and 0.75 (copied from Rasmussen and Becker, p. 6)

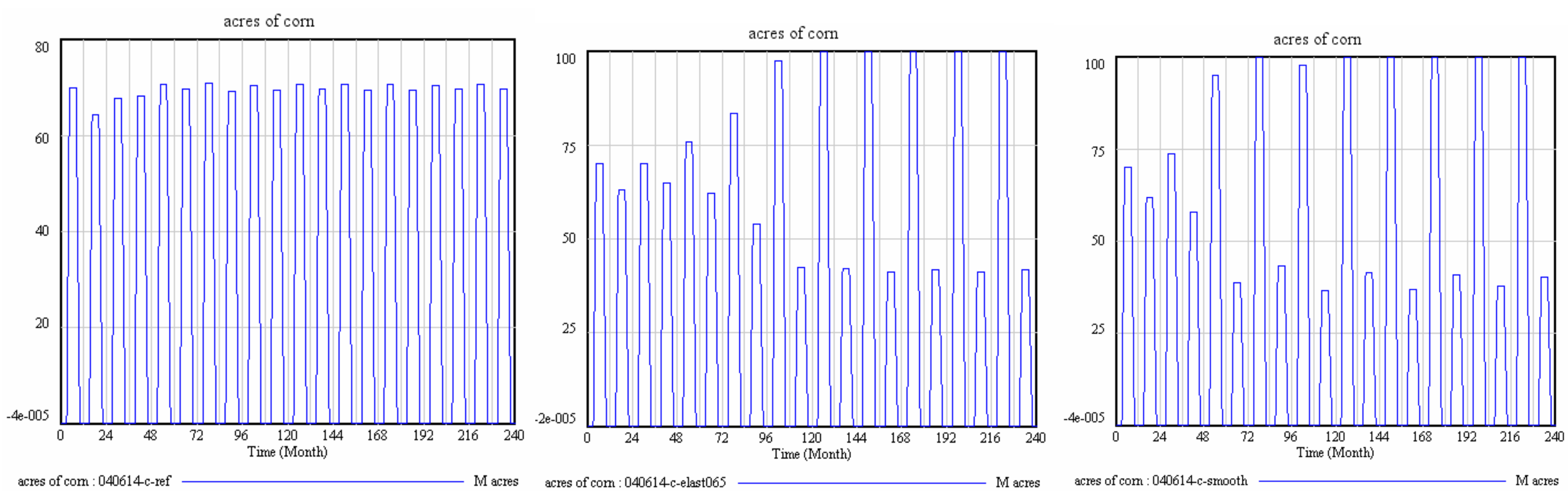

Fig. 6 – Planting & harvesting with disease model diagram

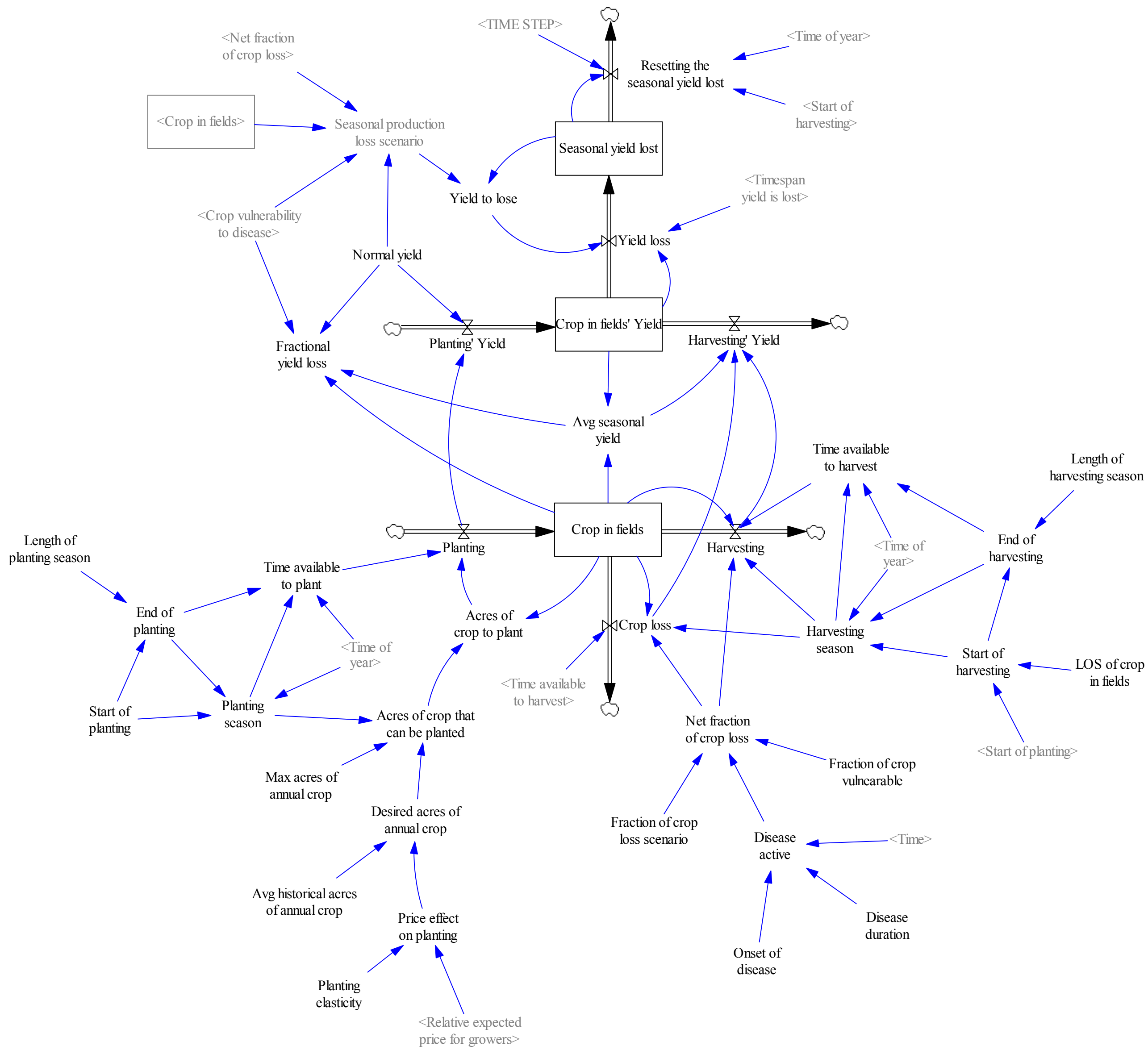

Fig. 7 – Disease scenario (*net fraction of crop loss* = 0.25 during the second season)

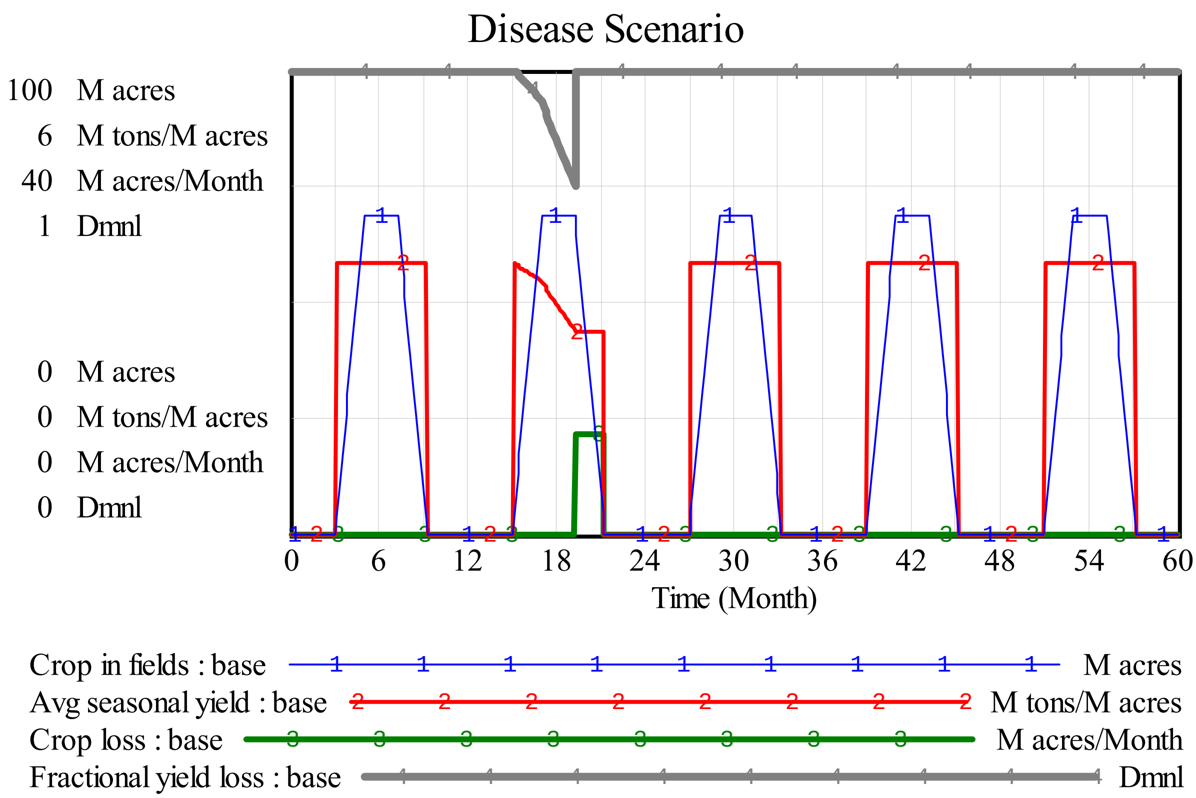

Fig. 8 – Relative coverage model diagram

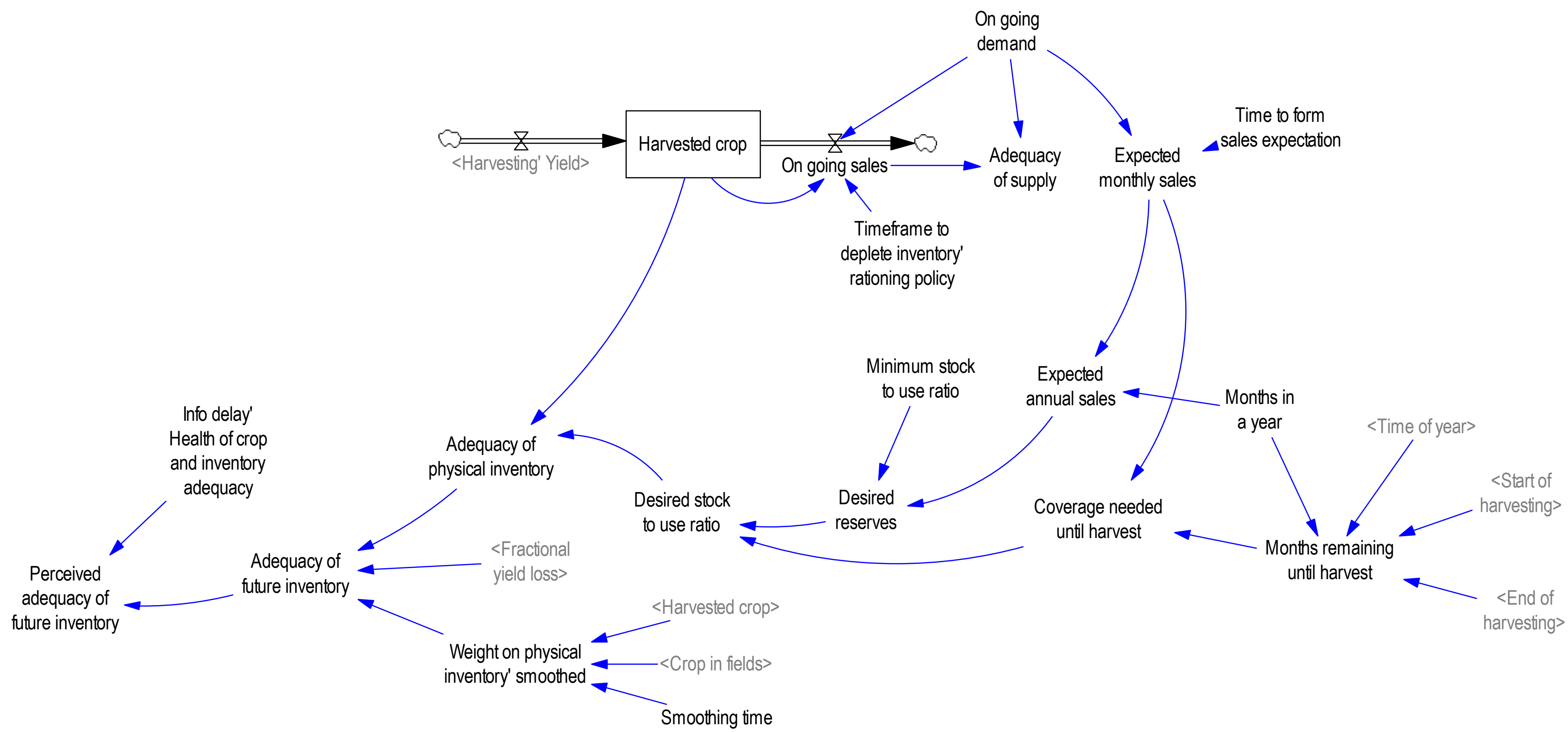

Fig. 9 – Relative coverage (*Perceived adequacy of future inventory*)

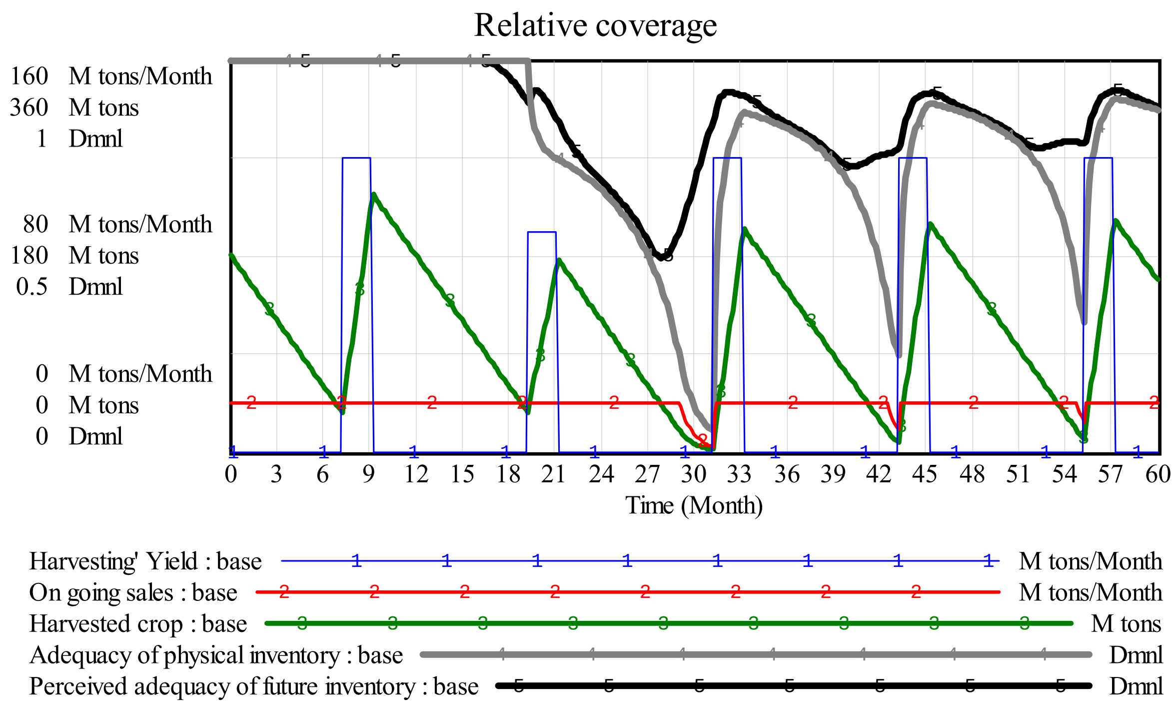

Fig. 10 – Types of (in)adequacies
(How to combine *fractional yield loss* with *adequacy of physical inventory*?)

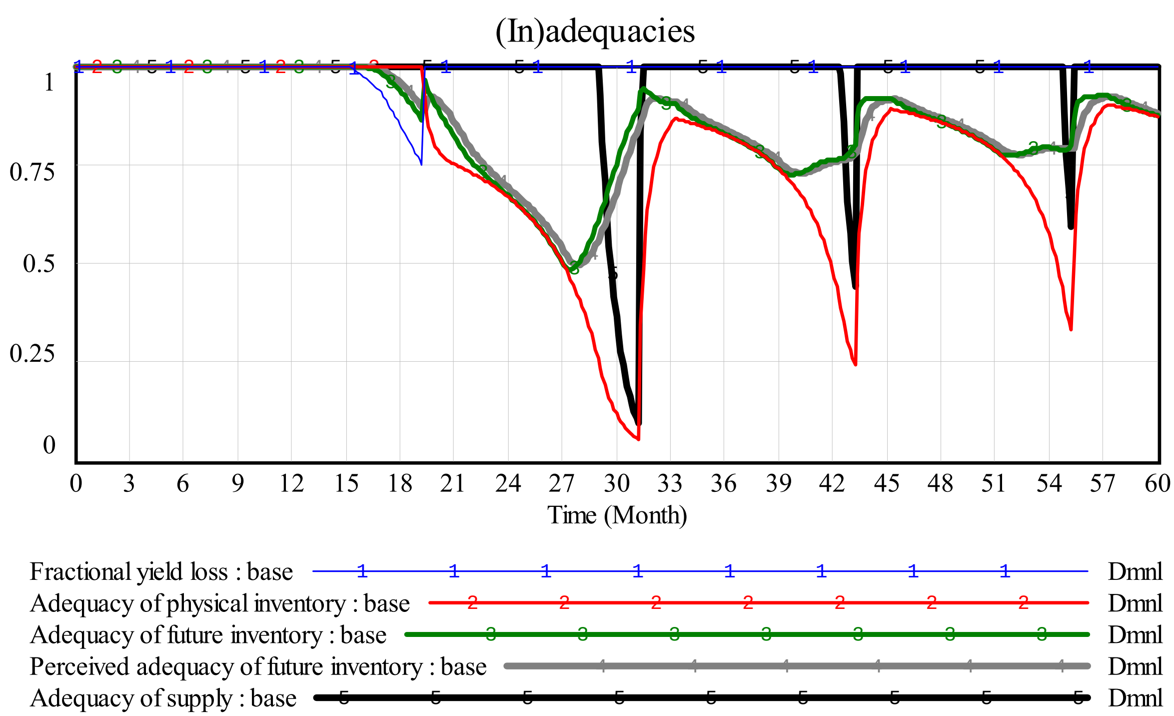

Table 1 – Preliminary model boundary chart

Issue type	Endogenous variables	Exogenous variables	Absent variables
Pathogen and fungicides			
Economic			
Non-economic vulnerabilities			

Appendix 1. Parameterization and calibration spreadsheet to substantiate and document parameter ranges, as well as available data (*planting and harvesting with disease*)

Parameters, auxiliaries, rates & accumulations:	As defined in the model				Range		Actual value		Sources, references & observations:
	Min.:	Value:	Max.:	Units:	Width:	Magnitude:	Source A	Source B	
[Parameters]									
[Auxiliaries, *Rates*]									
[Accumulations]									
Relative expected price for growers		1.00		Dmnl					Ratio of "expected" grain price relative to an "initial" or "normal" price. Research annual time series data on seasonal grain prices (corn & soybean) for the last 10 years. Obtain monthly data for lowest and highest-priced years
Planting elasticity		0.50		Dmnl					For corn, assumed relatively inelastic. Research for both corn & soybean
Price effect on planting		1.00		Dmnl					
Avg historical acres of annual crop		70.0		Million acres					Research annual time series data on seasonal acres of crop planted for the last 10 years (corn & soybean)
Desired acres of annual crop		70.0		Million acres					
Max acres of annual crop		100.0		Million acres					
Acres of crop that can be planted		70.0		Million acres					
Start of planting		3.00		Month					For simplicity sake, assumed planting is uniform during planting season. Research dates when planting begins in the south and ends in the north (corn & soybean)
Length of planting season		2.00		Months					
End of planting		5.00		Month					
Planting		*35.0*		*Million acres per month*					
Crop in fields									
Normal yield		3.50		Million tons per million acres					Research annual time series data on average seasonal yield (productivity) measured in weight (tons, bushels) per unit of land (acres)
Onset of disease				Month					Loss scenario (Paul): Provide estimate and range for fraction of crop vulnerable and fraction of crop loss scenario for each year (2005-2009)
Disease duration				Month					
Fraction of crop vulnerable				Dmnl					
Fraction of crop loss scenario				Dmnl					
Net fraction of crop loss		0%		Dmnl					
LOS of crop in fields		4.25		Months					Research for both corn & soybean
Start of harvesting		7.25		Month					For simplicity sake, assumed harvesting is uniform during planting season. Research dates when harvesting begins in the south and ends in the north (corn & soybean)
Length of harvesting season		2.00		Months					
End of harvesting		9.25		Month					
Crop loss		*0.0*		*Million acres per month*					Loss in productivity due to disease is accounted for as crop loss and subtracts from the harvest.
Harvesting		*35.0*		*Million acres per month*					
Avg seasonal yield		3.5		Million tons per million acres					Fluctuates around normal yield. Min/max for this parameter will be wider than for normal yield due to effect of weather. Research variance in yield for corn & soybean (due to weather?)
Harvested crop									Research annual time series data on the total seasonal yield (production) measured in weight (tons, bushels)
U.S. grains carryover		36		Million tons					Research annual time series data on U.S. sales and amount of grains carried over from one season to another. The stock-to-use ratio is the amount of grains carried over relative to the seasonal sales. What is the desired value for the stock-to-use ratio (corn and soybean)?
U.S. consumption and exports		*20*		*Million tons per month*					
Stock-to-use ratio		15.0%		Dmnl					