Appendix to paper:
Food security and food aid; persistent insecurity

Bernhard Rootinck

20-3-2023

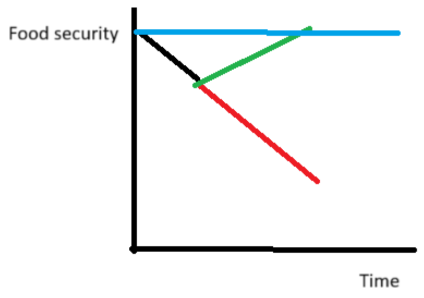
Appendix to the submitted paper
System dynamics society conference 2024

Table of contents

Appendix 1: Reference modes.

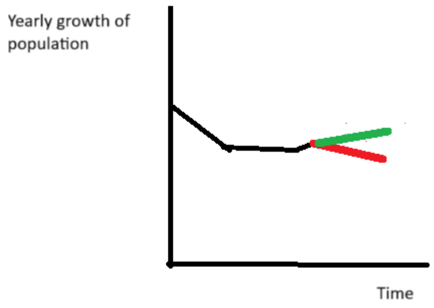
Below are the reference modes for the model. The black line represents historical data. The red line represents the expected behavior if there is no intervention in the system. The green line represents the desired result.

Reference mode 1: Food security



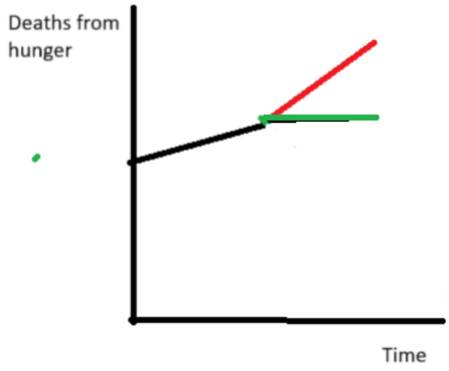
(IPC, 2023). Note blue line represents when food security is optimal, aka when there is no hunger.

Reference mode 2: Yearly growth of Kenyan population



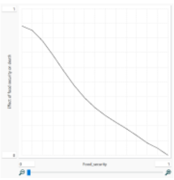
(World o meter, n.d.).

Reference mode 3: Deaths from hunger.



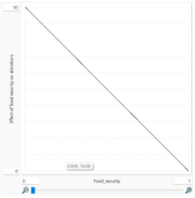
(Save the childeren, n.d.). Note it is not possible to bring down the amount of people who have already died. Therefore the desired behavior is to keep it steady and not allow further increases.

Appendix 2: Model documentation

Element	Equation	Units	Documentation
Course_of_population:			
Anchor_ fraction_of_ population_ dying_from_ hunger	0.4	dmnl/year	This variable sets a base fraction for passing away from hunger. Set at 0.4. Its unit is dmnl/year.
Deaths_from _hunger	Population* Fraction_of_popul ation_dying_from _hunger	person/years	This outflow controls how many of the population pass away from hunger. It takes the population and multiplies this with the effect of the 'effect of food security on death' graphical function. It then divides this with the starvation delay. Its unit is in person/year. This represents how many people pass away from starvation. The less food is available the more people pass away. This is not instant, hence the starvation delay which represents how long people can survive without food.
Effect_of_ food_ security_on_ death	GRAPH(Food_ security) Points(15): (0.000, 0.88), (0.071, 0.85), (0.21, 0.68), (0.42, 0.39), (0.50, 0.32), (0.57, 0.27), (0.64, 0.22)		This variable determines the influence of food security on death. When the food security decreases its output increases. When food security is one then output is near zero. Meaning there is enough food so no one dies of hunger. As food security gets closer to zero the effect increases exponentially. Meaning that with each increases in food insecurity the amount of people dying of hunger increases more relative to when there was more food. This simulates that the relative impact of death on a population with between 2250 calories and 200 calories is less than those with 1500 vs 1000 calories. Its unit is dmnl. This represents the effect of hunger on death. When food security drops this means that the Kenyan people have increasing malnutrition eventually resulting in death.

Fraction_of_population_dying_from_hunger	Effect_of_food_security_on_death* Anchor_fraction_of_population_dying_from_hunger	dmnl/year	This variable controls how long the population is able to survive without food. Its unit is in year. This represents the ability of people to survive without food. This is generally tough to be between one and two months (Barrell, 2023).
Initial_population	55000000	person	The population of Kenya at the start of the simulation. About 55 000 000 in 2022 (Macrotrends, n.d.). Its unit is in person.
Natural_death	Population* Normal_death_fractional_rate	person/years	The rate at which the population dissipates. Represents exogenous factors such as life expectancy, health care quality etc. Calculated by taking the population and multiplying this with the normal death rate. Its unit is in person/year.
Net_birth	Population* Normal_birth_fractional_rate	person/years	This flow calculates the annual amount of persons being born each year. This is then added into the population stock. It does this by taking the population and multiplying this with the net birth. Its unit is in person/year
Normal_birth_fractional_rate	0.014	1/years	The base rate at which the population grows, unaffected of hunger. Its unit is 1/years. Normal birth rate per 27 per 1000 (Statista, 2023 -a). So 0.027% The population distribution is almost 50% male 50% female. Therefore birth rate would be halved into 0.014
Normal_death_fractional_rate	0.008	1/years	The normal rate at which the population dissipates, unaffected by hunger. Its unit is 1/years Death rate is 8 per 1000 (Statista, 2023 -b) so 0.008%.

Population(t)	Population(t - dt) + (Net_birth - Natural_death - Deaths_from_hunger) * dt	person	The amount of population in Kenya. It accumulates via the birth flow and dissipates via the natural death and deaths from hunger outflows.
Food_aid_realization:			
Amount_of_donations(t)	Amount_of_donations(t - dt) + (Incoming_donations - Usage_of_donations) * dt	dollar	The stock contains all incoming donations. It represents the total amount of dollars available for buying food aid to send to Kenya. It accumulates via the incoming donations inflow and dissipates via the usage of donations outflow. Note this is an stock. Therefore when the food situation in Kenya declines these funds can be instantly used to supplement it. But because it takes time for donations to come in when food security decreases. So donations only delay the inevitable food shortage. The used unit is dollars. This stock represents the funds available to governments / aid organizations. They can use these funds to buy food and then send this to Kenya.
Anchor_donations_per_year	125000000	dollars/year	This variable sets the baseline amount for donations. Starting value of 125 000 000 based on US aid (2023 -a) statement.
Availability_gap	Total_food_needed-Consumption_rate	Kilograms/Years	This variable calculates the difference between the amount of food needed and the amount of food available. It does this by dividing the consumption rate with the total food needed. If the amount of food needed is higher than the consumption rate there is a food shortage. If the amount of food needed is equal to the consumption rate there is enough food. The model structure does not allow the consumption rate to be higher than the total food needed. Its unit is in kg/years.
Donations	Anchor_donations_per_year* Effect_of_food_security_on_donations	dollars/year	Calculates the total amount of dollars to be generated each timestep. It multiplies the effect of food security on donations with the anchor donations per year. Its unit is in dollars/year. This represents the amount of dollars that would be donated/collected to provide food aid to Kenya.

Donations_needed_to_supplement_availability_gap	Availability_gap*Kg_per_dollar	dollars/year	This variable converts the needed kg from the availability gap into the needed amount of dollars to fulfill the gap by multiplying it. Its unit is dollar/year.
Effect_of_food_security_on_donations	GRAPH(Food_security) Points: (0.000, 10.00), (1.000, 0.00)		This variable determines what the effect of food security on donations is. When food security is at one the amount of donations being used is zero. Meaning there is no need to buy additional food. Then, the closer food security goes to zero, the more donations will be made. Its unit is in dmnl. When input is 0 there food is secure so no reason to donate. Then once the value rises the more the need for donations is felt so the more gets donated. This represents the willingness of people to donate to charity. This represents that in the beginning people are not so interested but still donate because of morals. Then, when food becomes less secure, people are more motivated to donate. However this has an maximum, people do not donate forever.
Food_bought_from_aid_funds	Usage_of_donations/Kg_per_dollar	kg/Years	This variable calculates how much food there is being send to the food from aid stock. It multiplies the kg per dollar with the usage of dollars. Its unit is in kg/year. This represents the moment of transaction when the donations that the aid organizations use are being exchanged for food.
Food_security	Consumption_rate/Total_food_needed	dmnl	This variable compares the needed kg for healthy population with the available kg. Its output then feeds into the relative food security variable. When consumption and total food needed are the same then food security is one. This means that there is enough food available for the population. When food consumption is lower then total food needed food security goes below zero. This means that there is not enough food to keep the population fully fed resulting in food insecurity.

			Because consumption rate has an first order control via the maximum consumption rate food consumption can never go higher then total food needed. Meaning people never eat more then they need. As such food security can never go above one. Its unit is dmnl. This variable represents how certain the Kenyan population is of getting enough food to survive. The lower it gets the less the people are able to feed themselves sufficiently.
Incoming_ donations	Donations	Dollars/year	This is the inflow into the donations stock. It determines the amount of dollars added per timestep. This is determined by the donations variable. Its unit is dollars per year. This represents the actual moment the donated dollars are added to the funds of the aid organizations.
Initial_ amount_of_ donations	10000000	dollars	This variable determines how much dollars the aid organizations have available at the start of the simulation. Its unit is in dollars.
Kg_per_ dollar	0.85	dollar/kg	This variable determines how much kg food each dollar brings. Its unit is in kg/dollar. This represents the prices food suppliers ask for their product (Tridge, n.d.). Set at 0.85.
Maximum_ donations_ usable	Amount_of_ donations/Time_to _use_donations	dollars/year	This variable serves as an first order control to the amount of donations stock. It serves to safeguard the donation stocks from going negative since it is assumed that aid organizations are not able to go into dept for food aid. Its unit is in dollars / year.
Time_to_use _donations	0.1	years	This variable determines how quickly the aid organizations are able to put the donations into effect aka to buy food aid with them. The unit is in years. This represents the administrative process of aid organizations. When dollars are donated they need to be registered, converted into another currency (Dollars to Kenyan Shilling), send to food suppliers etc. This takes time.

Usage_of_ donations	MIN(Maximum_ donations_usable, Donations_needed _to_supplement_ availability_gap)	dollars/year	This outflow dissipates the amount of donations stock. Due to the max function it either takes the needed donations or the maximum donation usable. It unit is in dollars/year. This represents aid organizations acting on food shortages and actually using donations to provide food aid to Kenya.
Food_production_and_usage:			
"Calories_ per_kg."	IF Policy_2_Increase d_calories_per_kg =1 OR "Combined_policy _1_+_2"=1 THEN 930 ELSE 860	calories/kg	A simple variable determining the calories per kg conversion rate. Based on the fact that 100 grams of corn contains 86 kcal (US department of agriculture, 2019). So 1000 grams has 860 kcal.
Acres_per_ farmer	1.85	acres/person	This variable determines how many acres each farmer can maintain. Its unit is in acres/person. This represents the average farm size in Kenya at 1.85 acres as stated by Birch (2018) at 1.85 acres.
Actual_acres _being_ farmed	MIN(Maximum_ acres_to_be_ farmed, Maximum_acres_ available)	acres	This variables determines the actual amount of acres that are being farmed. Its input is from the amount of acres able to be farmed on and the maximum acres available variables. Then it compares these with a min function. Its unit is in acres.
Consumptin _rate	MIN(Total_food_ needed, maximum_consum ption_rate)	kg/years	This outflow determines how much the food stockpile must dissipate. Due to the max function it either takes the required amount of food or the maximum consumption rate. Its unit is in kg/years. This represents the Kenyan population consuming the food.
Farmers_ fraction	0.25	dmnl	This variable determines how many of the population become farmers and thus contribute to the production of

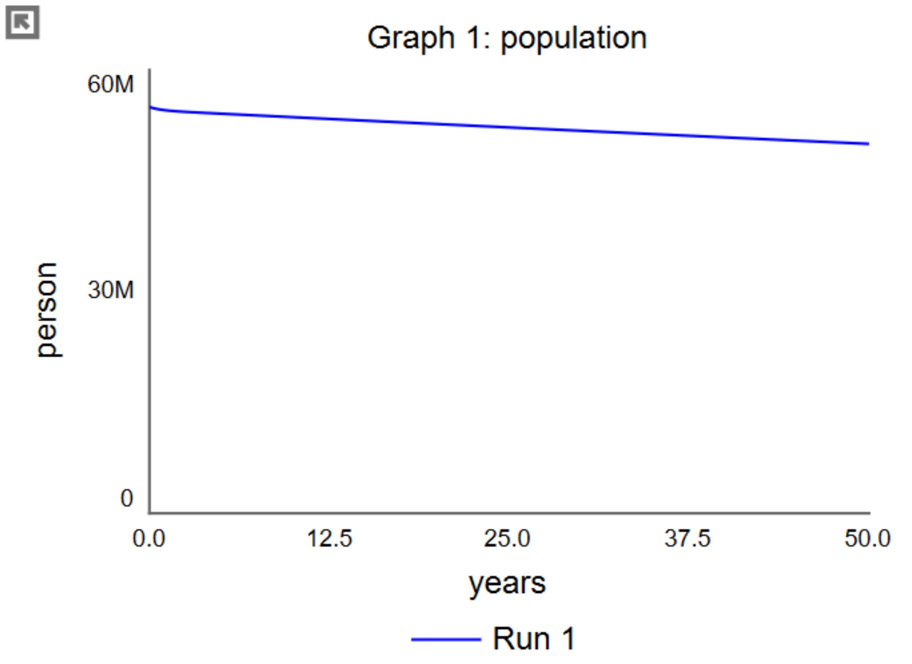
			food. Set at 0.25. Its unit is dmnl. This represents that a part of the Kenyan population become farmers to grow crops (US aid, 2023 -B).
Food_from_ aid	Food_bought_ from_aid_funds	Kilograms/Years	This outflow adds to the food stockpile. The amount is determined by the food bought from aid funds variable. Its unit is in kg/year. This represents the actual delivery of the food bought by aid organizations to Kenya.
Food_ stockpile(t)	Food_stockpile(t - dt) + (Production_rate + Food_from_aid - Consumption_rate) * dt	kg	This stock accumulates and dissipates the total amount of food that Kenya has available to provide the population with food. It accumulates via the production rate and the food from aid inflow sand dissipates with the consumption rate outflow. It is safeguarded against going zero via a min function in the consumption rate outflow. Its unit is in kg. It represents the interaction between domestic production and supply. It allows domestic production to store its harvest for later dates and the population to withdraw when needed. In addition when charities buy food for Kenya this will also be added to this stockpile so it can be distributed to the population.
Initial_food_ stockpile	49000000000	kg	How much food is available at the beginning of the simulation. Its unit is in kg.
Maximum_ acres_ available	27600000	acres	This variable is to keep the maximum amount of acres being farmed in control so it does not go to infinity. Its unit is in acres.
Maximum_ acres_to_be_ farmed	Total_farmers* Acres_per_farmer	acres	This variable calculates how many acres can be maintained based on the amount of farmers. It takes the total amount of farmers and multiplies this with the acres per farmer.

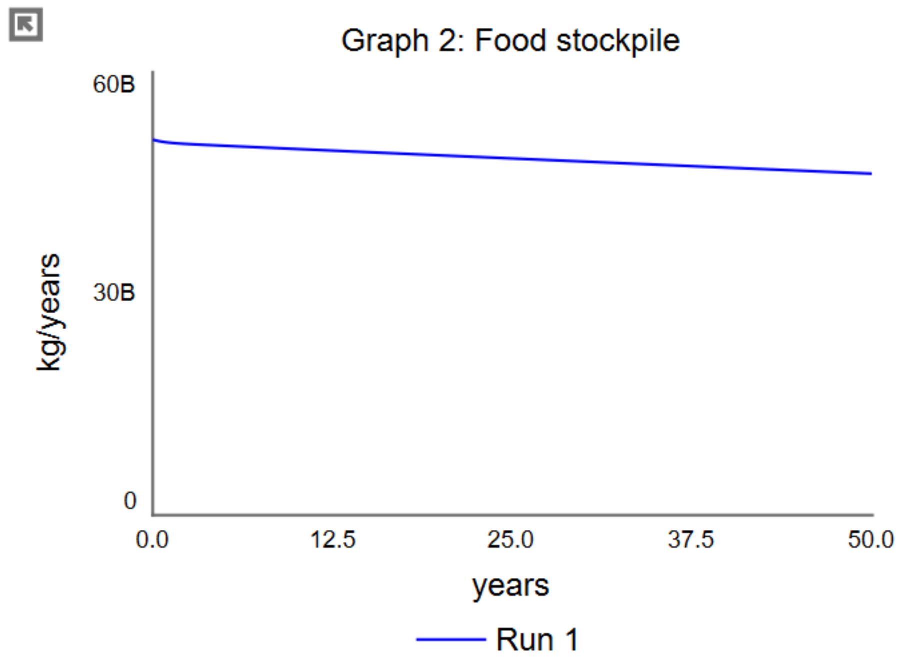
			Its unit is in acres.
maximum_consumption_rate	Food_stockpile/stockpile_coverage_time	Kilograms/Years	This variable determines how much the maximum consumption is. It
Needed_calories_per_year_for_healthy_living	821250	calories/person/year	The amount of calories a person needs to consume on a yearly bases in order to remain healthy. Healthy defined as not passing away prematurely due to not receiving enough calories. Taken from the average of needed calories for men and woman which is 2250 (Brazier, 2023). Since the model is in years yearly calorie intake must be 2250*365=821 250. Its unit is in calories/person/year.
Needed_kg_per_person_per_year_for_healthy_living	Needed_calories_per_year_for_healthy_living/"Calories_per_kg."	kg/person/year	This variable calculates the amount of kg needed per year in order to keep a persons healthy. It multiplies the needed calories per year for healthy living with the calories per kg. Its unit is in kg/person/year
Production_rate	Actual_acres_being_farmed*Yield_per_acres	kg/years	This inflow calculates the amount of food that will be produced and be added to the food stockpile. It takes the actual acres being farmed and multiplies this with the yield per acres. Its unit is in kg/years. This represents the amount of food that the Kenyan farmers are able to produce in order to feed the population .
stockpile_coverage_time	1	year	
Total_farmers	Population*Farmers_fraction	person	This variable calculates the total amount of farmers. It takes the population and multiplies this with the farmers rate variable. Its unit is in person.
Total_food_needed	(Population*Needed_kg_per_person_per_year_for_healthy_living)	kg/Years	This variable calculates how much kilograms of food is needed to keep the population healthy. It multiplies the population with the needed kg per person per year for healthy living. Its unit is in kg/year.

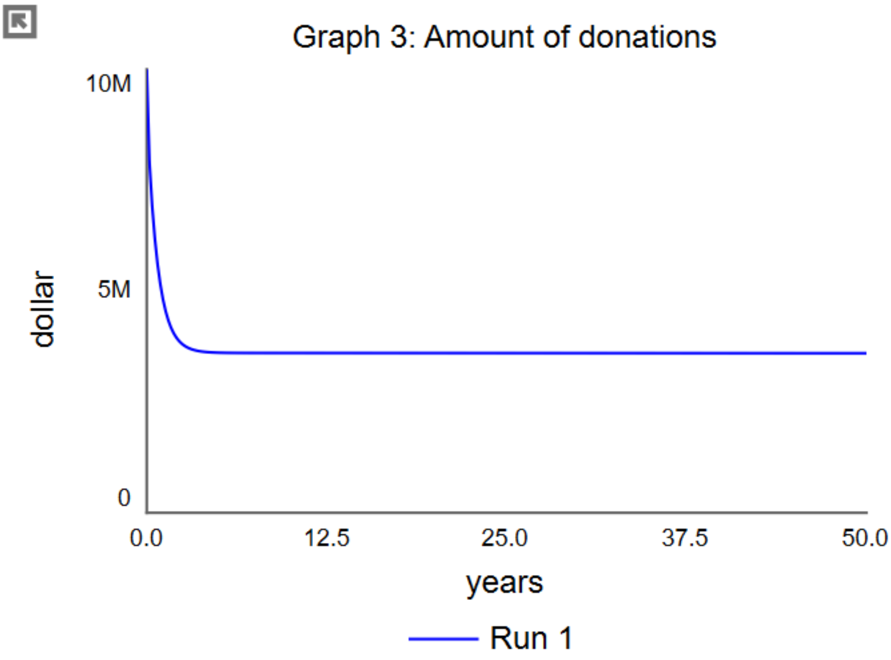
			This represents the total demand from the Kenyan population regarding food.
Yield_per_acres	IF Policy_1_Increased_yield_per_acre=1 OR "Combined_policy_1_+_2"=1 THEN 2500 ELSE 2000	kg/acres/year	According to the Kenyan agriculture and livestock research organization (n.d.) maize yields an average of 2000 kg per acre per year. Maize is the reference crop used in the model for it accounts for 65% of the calories Kenyans consume (Mathenge, 2016). Its unit is in kg/acres/year
Policy_command_center:			
"Combined_policy_1_+_2"	0		Set to one to see results of combined policy one and two, set to zero to turn off.
Policy_1_Increased_yield_per_acre	0		Set to one to see results of policy one, set to zero to turn off.
Policy_2_Increased_calories_per_kg	0		Set to one to see results of policy one, set to zero to turn off.

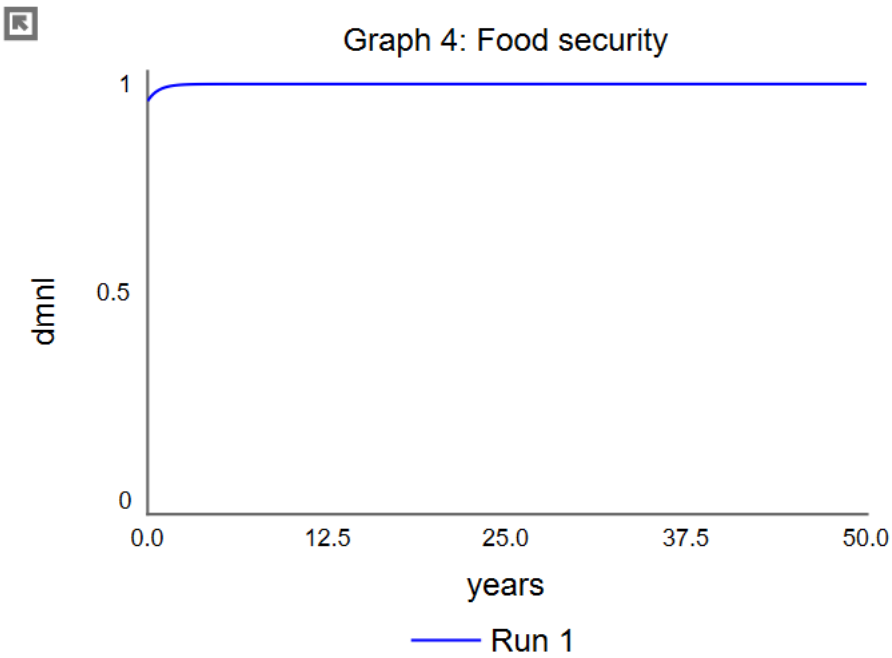
Appendix 3: Baseline scenario

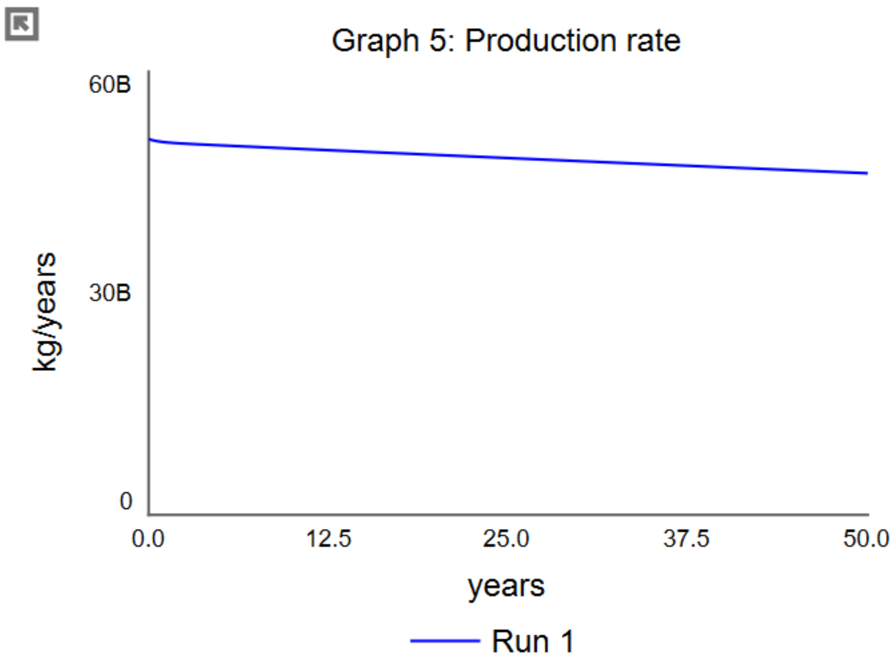
The following graphs display the behavior of the main elements in the model during a base line run with the standard values.

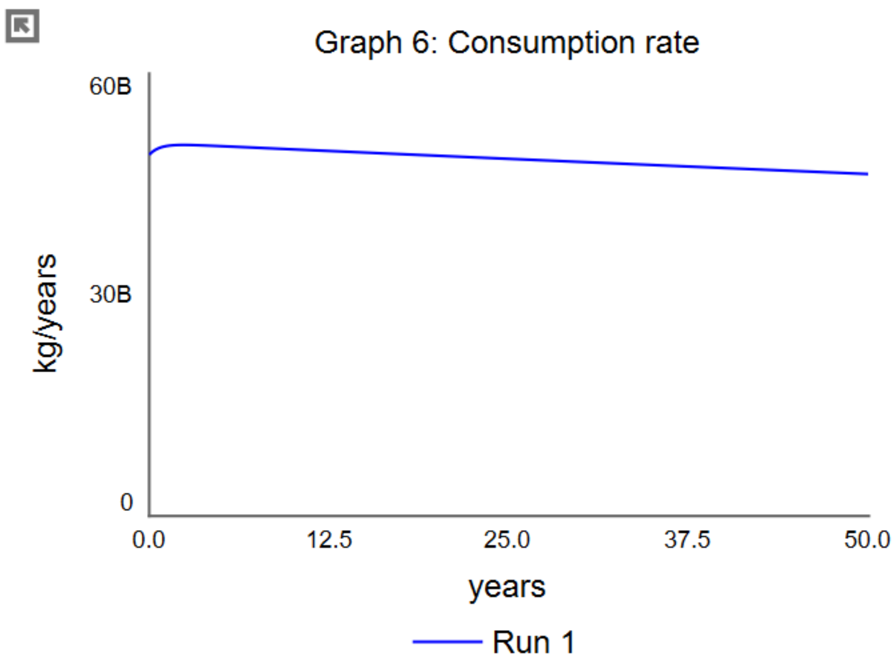


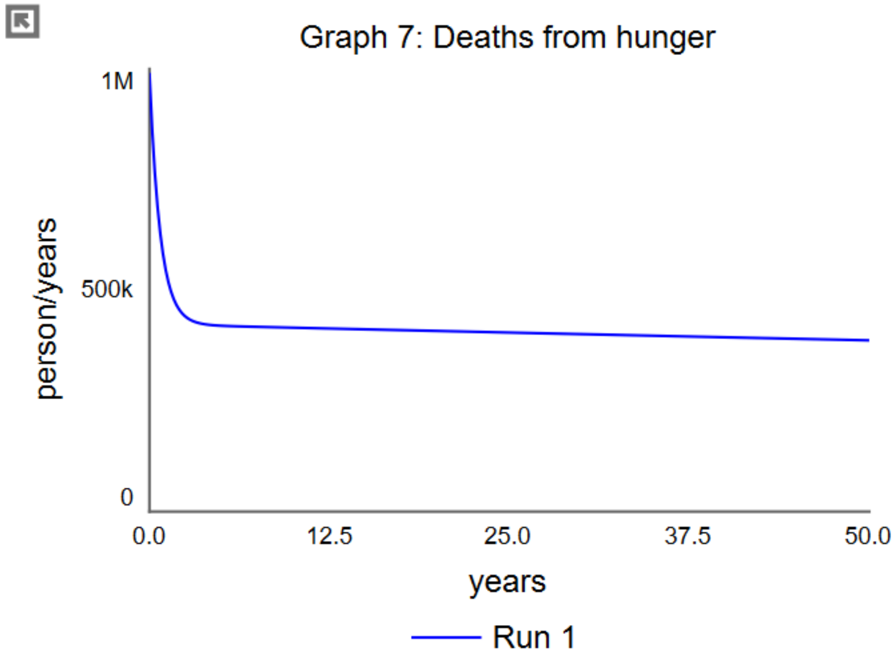


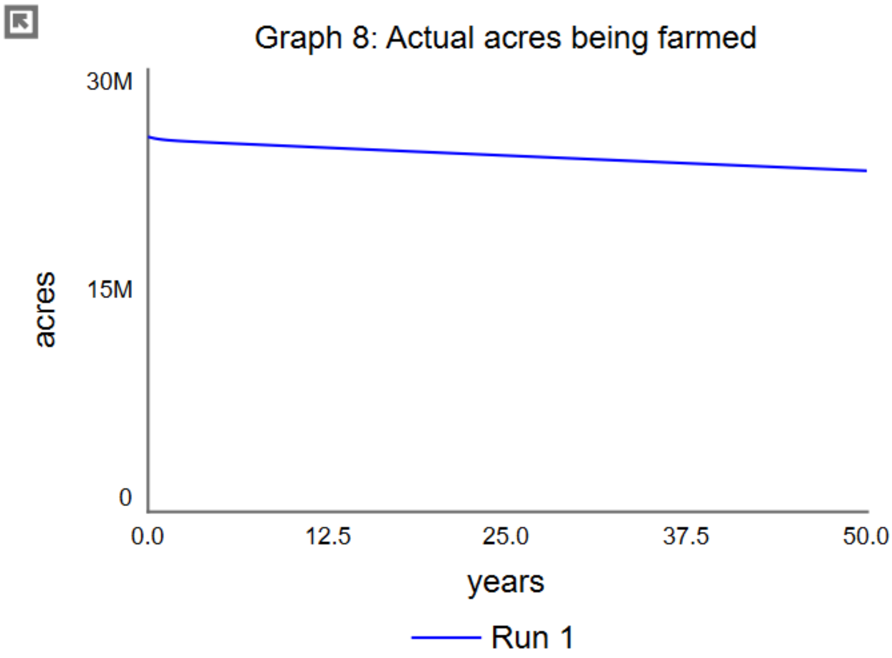

Graph 3: Amount of donations
10M
5M
0
dollar
0.0
12.5
25.0
37.5
50.0
years
Run 1


Graph 4: Food security
1
0.5
0
dmnl
0.0
12.5
25.0
37.5
50.0
years
Run 1


Graph 5: Production rate
60B
30B
0
kg/years
0.0
12.5
25.0
37.5
50.0
years
Run 1


Graph 6: Consumption rate
60B
30B
0
kg/years
0.0
12.5
25.0
37.5
50.0
years
Run 1

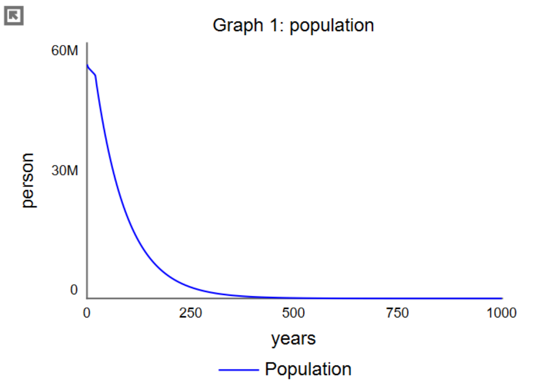

Graph 7: Deaths from hunger
1M
500k
0
person/years
0.0
12.5
25.0
37.5
50.0
years
Run 1

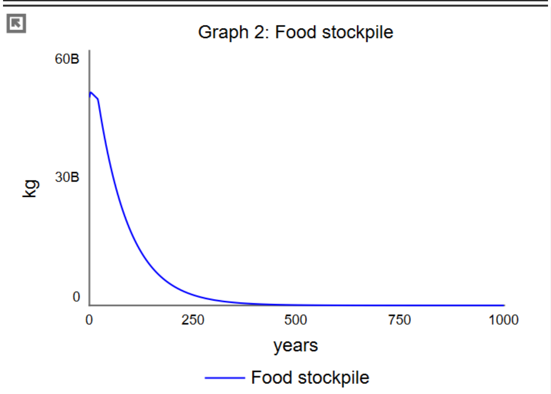

Graph 8: Actual acres being farmed
30M
15M
0
acres
0.0
12.5
25.0
37.5
50.0
years
Run 1

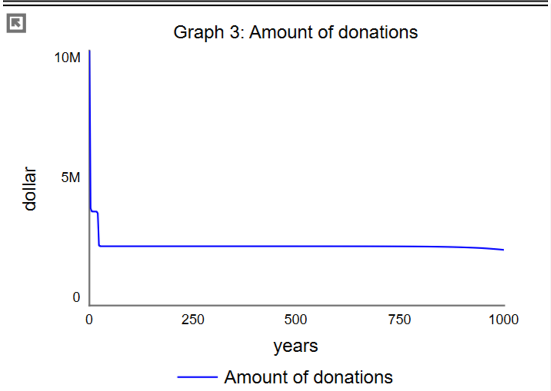
Appendix 4: Indirect extreme condition tests

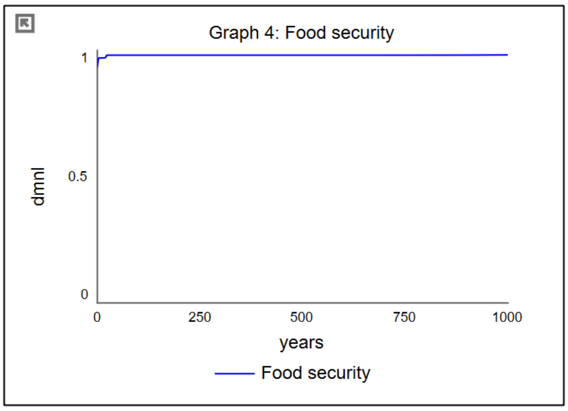
Test 1: Normal birth fraction rate step.

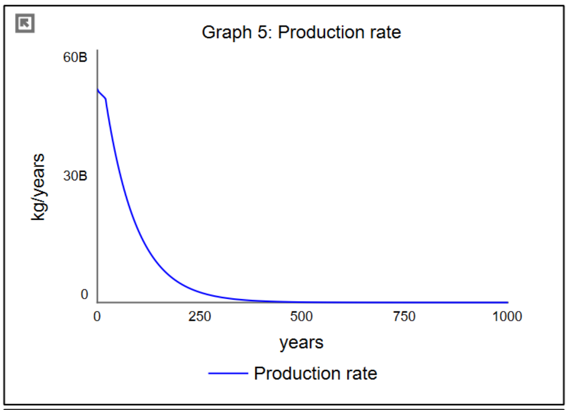
Testing if setting net birth rate to zero will result in goal seeking state. Set equation to 0.014 +STEP(-0.014, 20). Results in all graphs showing behavior as expected. Food security stabilizes whilst all others show decline.

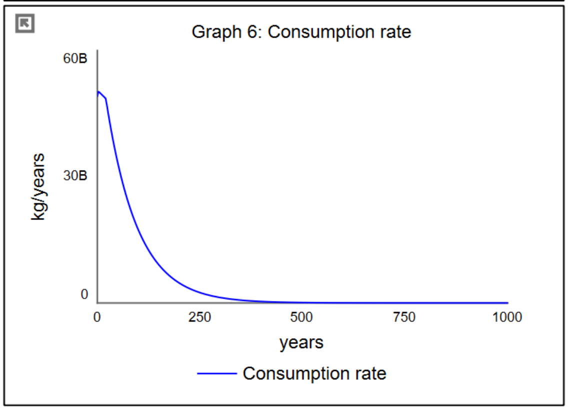


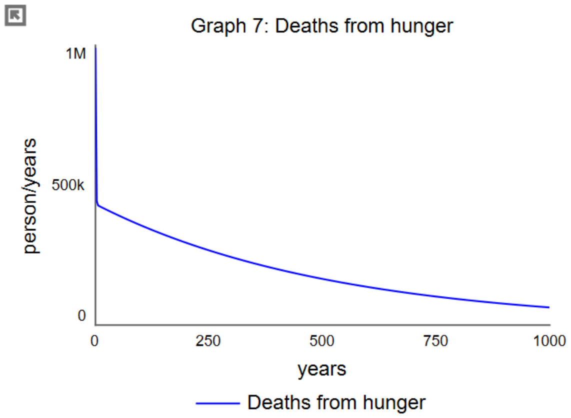


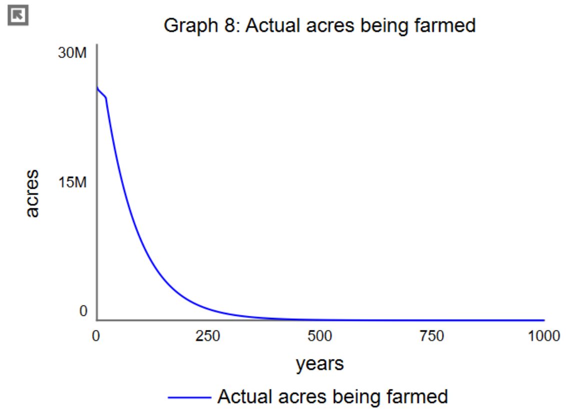






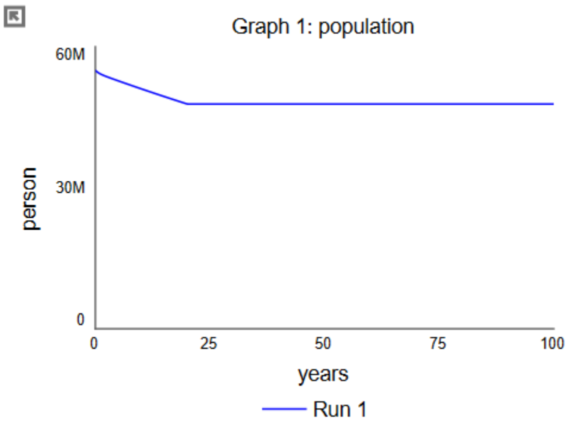


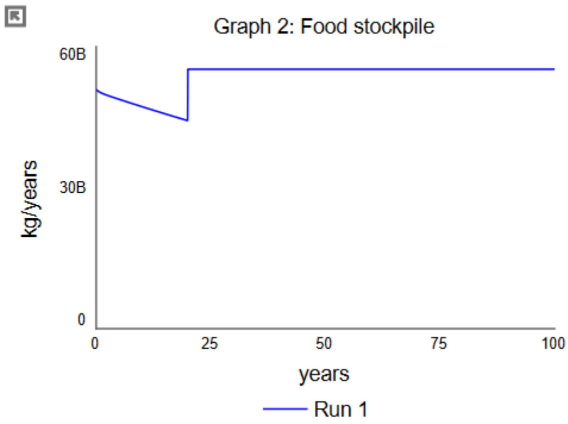


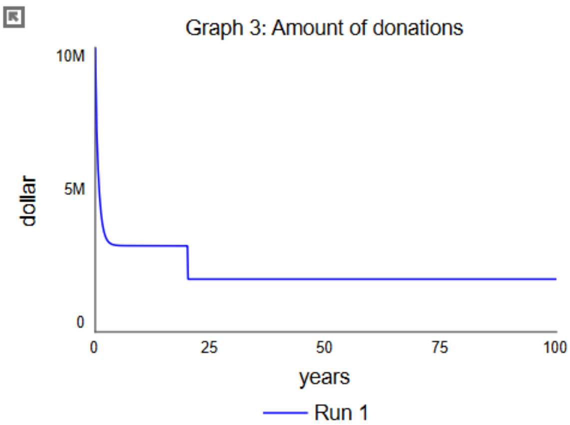


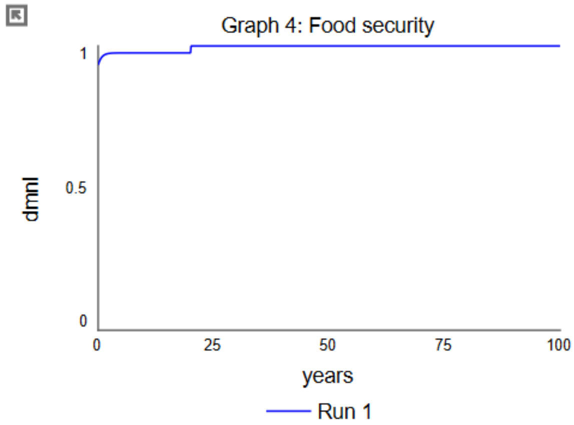
Test 2: Farmers fraction increase

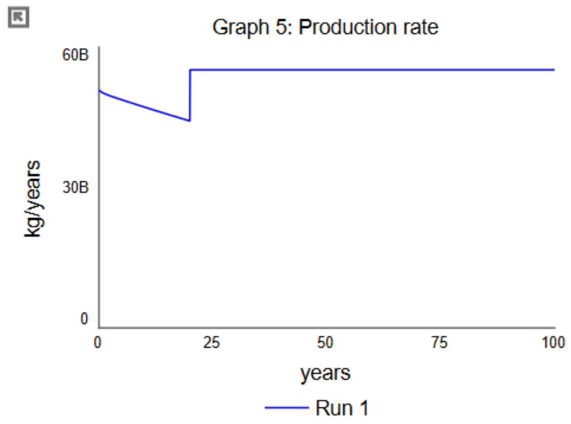
XX original graphs have been changed. Recheck text. Testing if doubling farmers fraction will result in behavior similar to the baseline behavior as seen in appendix XX. Farmers fraction equation set at 0.25 + STEP(+0.25, 20). Behavior is not as expected. The system goes into equilibrium. In the model the maximum amount of acres that can be farmed is locked at 27.6 million. With the farmers increase this limits the total production. What seems to be happening is that, when farmers increase, there comes an situation where each death from hunger is compensated with a birth. This is not wanted behavior but due to time constraints it could not be solved. A possible suggestion would be to build in an age chain so that birth is dependent on the fertile age of the population.

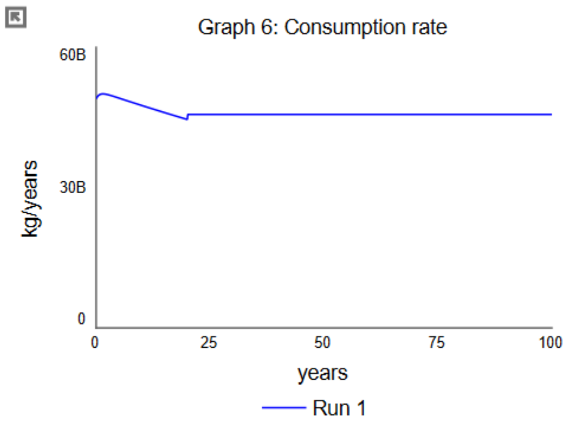


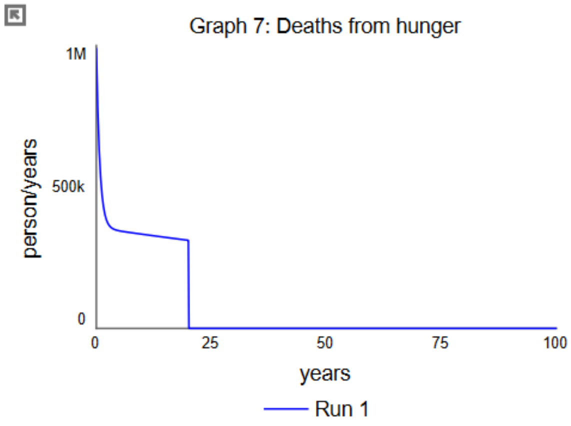


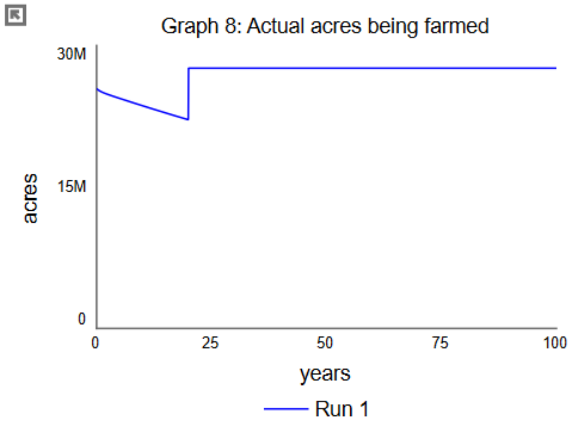








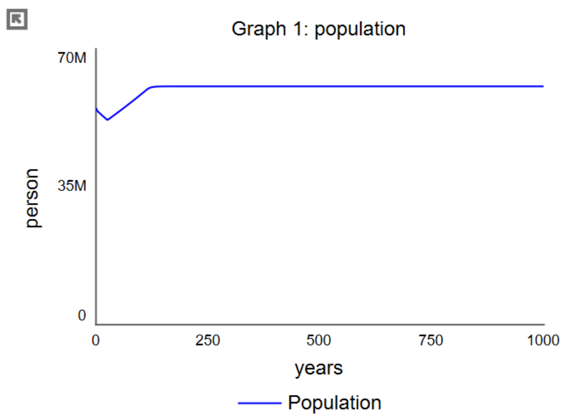


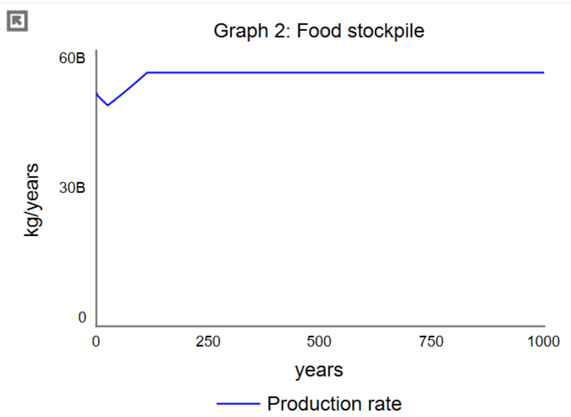


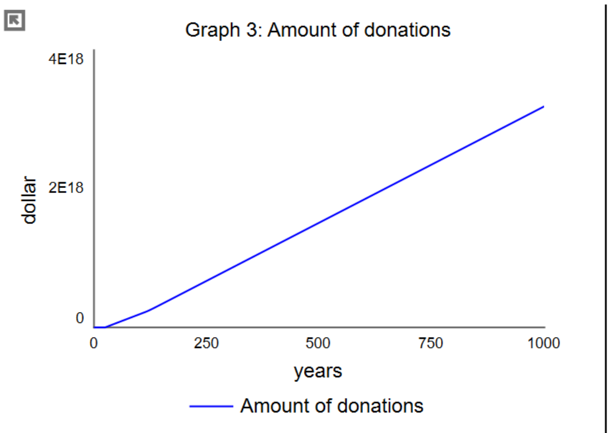
Test 3: Increasing anchor of donations

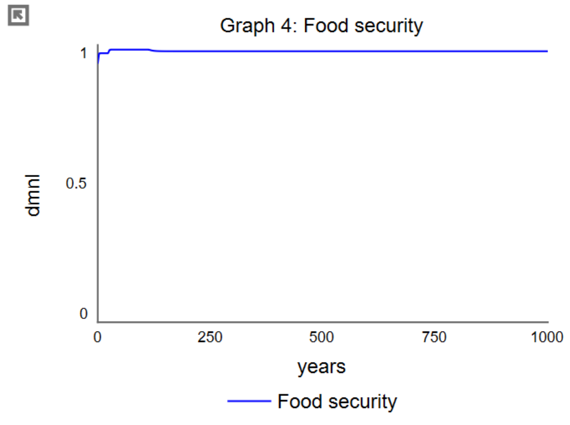
Testing if increasing the anchor of donation makes the system behave as seen in test 2 meaning an equilibrium state limited by the maximum amount of acres. Reasoning is that although there are more funds to buy food aid, the food aid still arrives too late due to the fact that it takes time to arrive (delays from the usage of material and before its gets added into the food stockpile, it takes a timestep during which the population who needed it are already passed away and new aid does not get send until there is a need again).

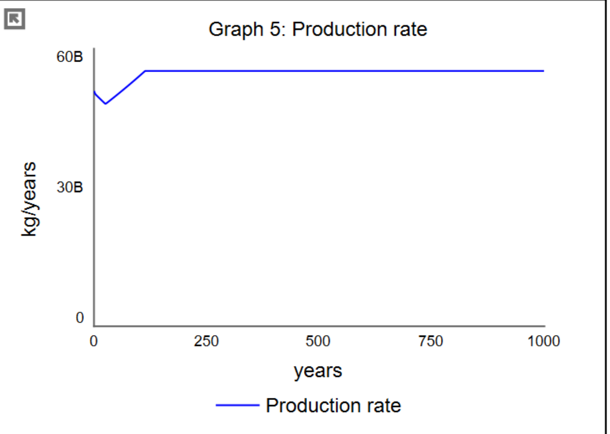
Results are mostly as expected except for deaths from hunger. It seems to drop when the extra donations kick in, acceptable, but then climbs back up in a irregular way.

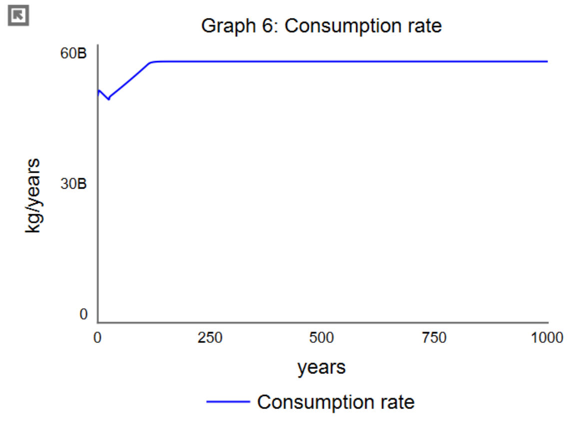


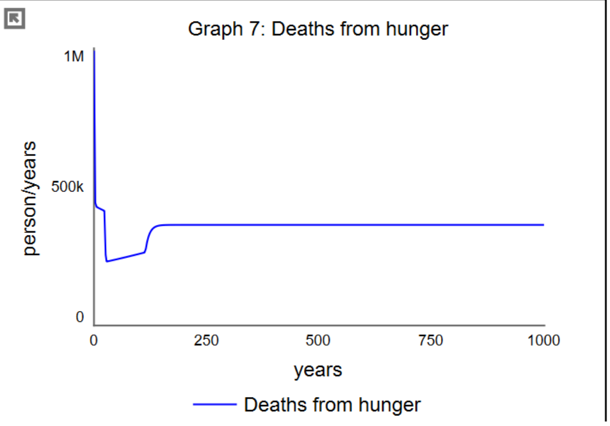


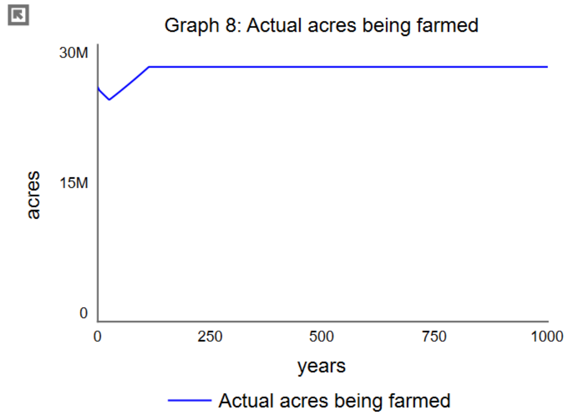

Graph 3: Amount of donations
4E18
2E18
0
dollar
0
250
500
750
1000
years
Amount of donations


Graph 4: Food security
1
0.5
0
dmnl
0
250
500
750
1000
years
Food security


Graph 5: Production rate
60B
30B
0
kg/years
0
250
500
750
1000
years
Production rate

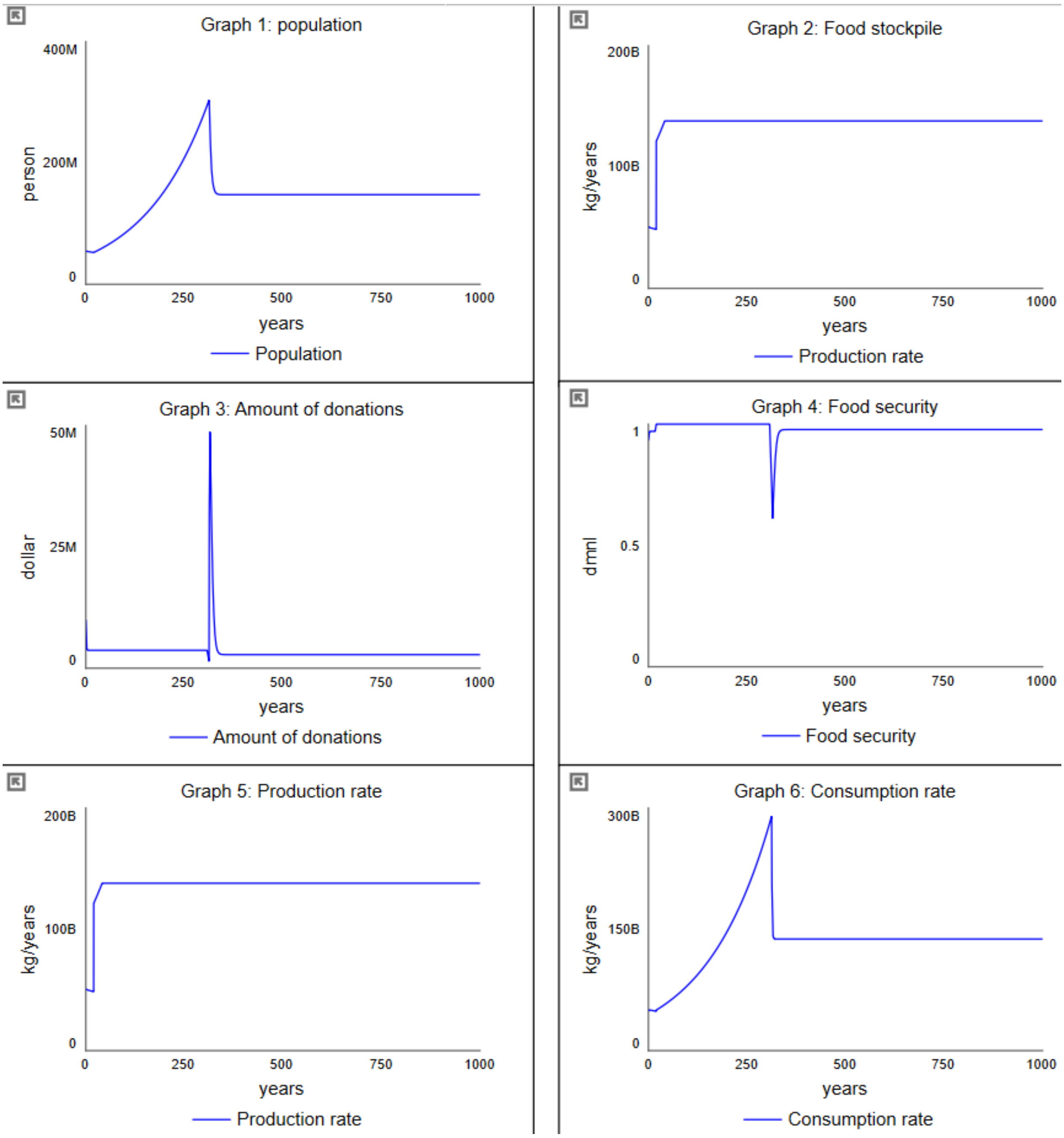

Graph 6: Consumption rate
60B
30B
0
kg/years
0
250
500
750
1000
years
Consumption rate

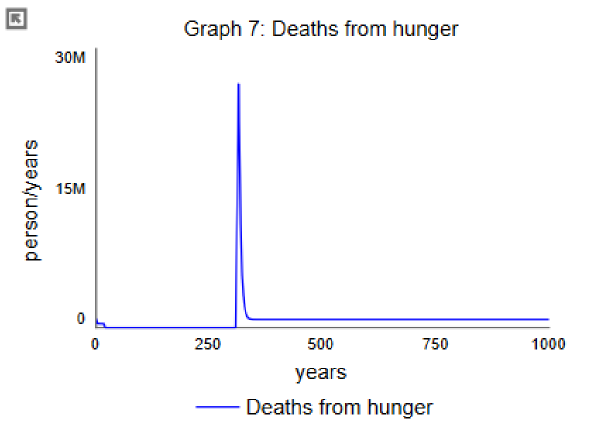

Graph 7: Deaths from hunger
1M
500k
0
person/years
0
250
500
750
1000
years
Deaths from hunger

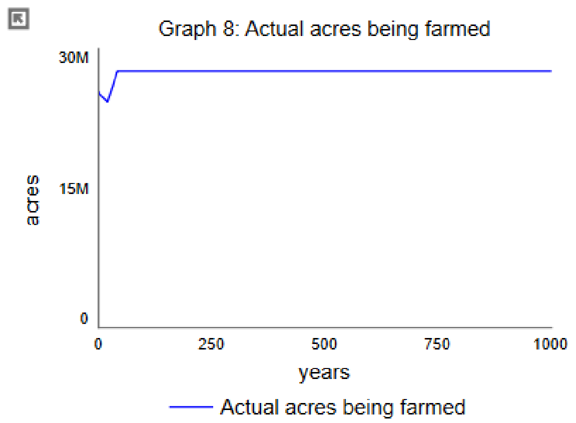

Graph 8: Actual acres being farmed
30M
15M
0
acres
0
250
500
750
1000
years
Actual acres being farmed

Test 4: Increasing yield per acre

Testing if increasing the yield per acre causes behavior equal to the baseline scenario. Equation used is 2000+ STEP(+3000, 20). Results are mostly equal to the results of test 2 and partly of test 3. All factors show abrupt spikes when the step function sets in which is expected. Then the system compensates for the stock but instead of resuming the original behavior as in the baseline tests it goes into an equilibrium.

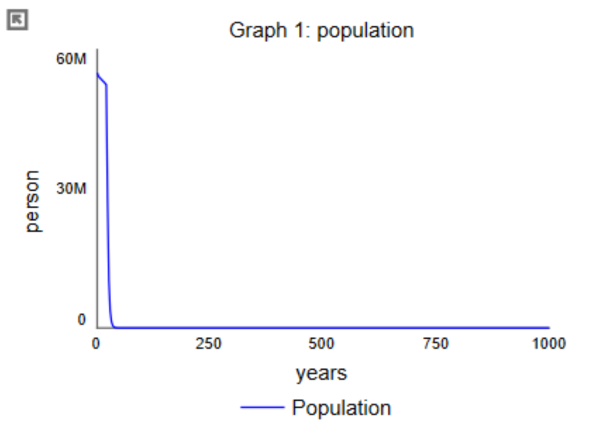


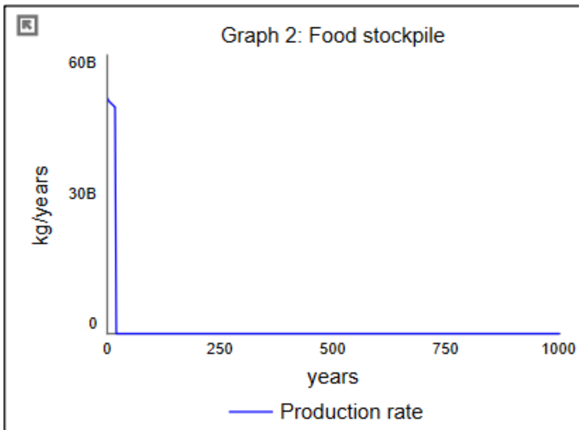


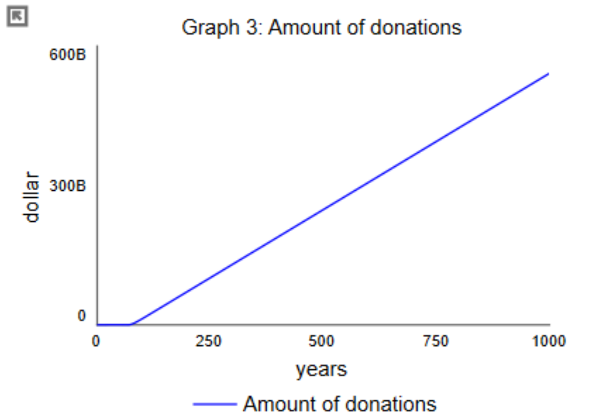


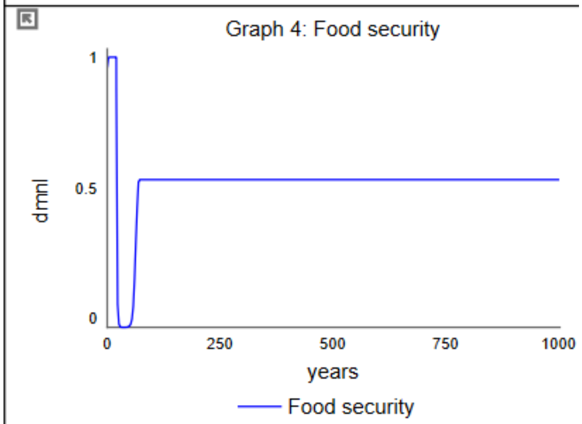
Test 5: Decreasing yield per acre

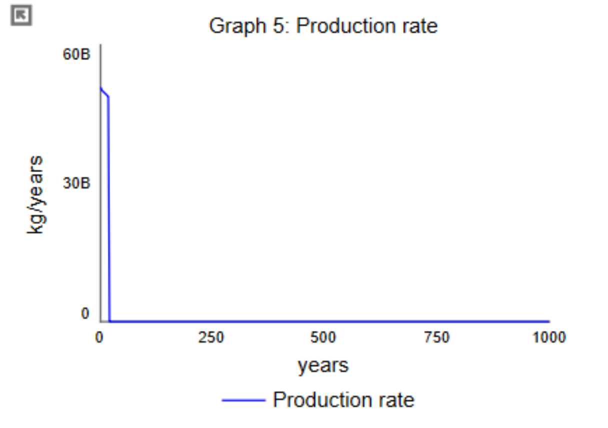
Testing if decreasing the yield per acre results in behavior similar as the baseline scenario but in an more extreme form. Meaning an quicker population decrease, increased hunger deaths etc. Equation used is 2000+ STEP(-2000, 20). Behavior is as expected. Population quickly dies off when the production stops. This results in the expected spike in hunger deaths when food inflow stopped and loss of acres being farmed. Also the donation stock keeps rising. This is because, as mentioned in chapter 2, aid organizations are always behind in delivering food. The model structure does not allow for instant compensation of food shortages. So there is never enough motivation to use the donations. This could be further expanded upon and make more detailed in further research.

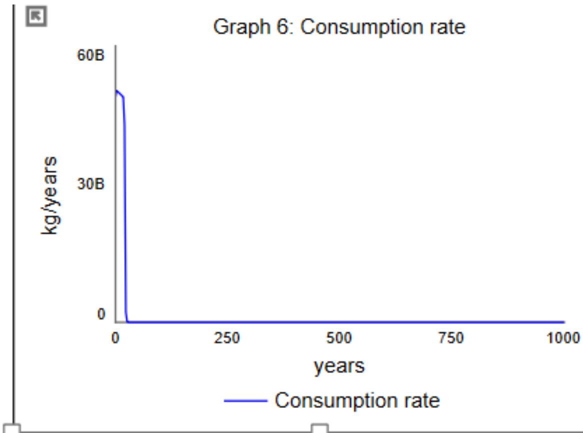


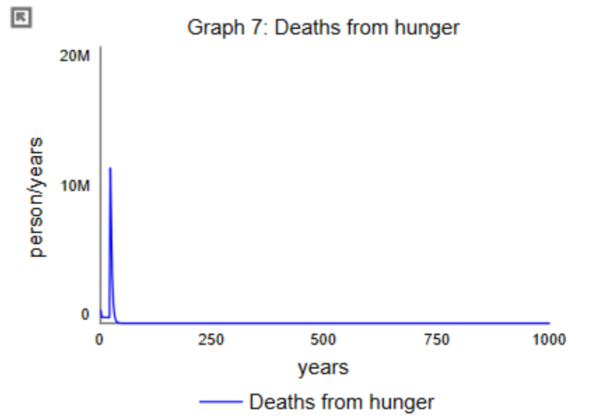


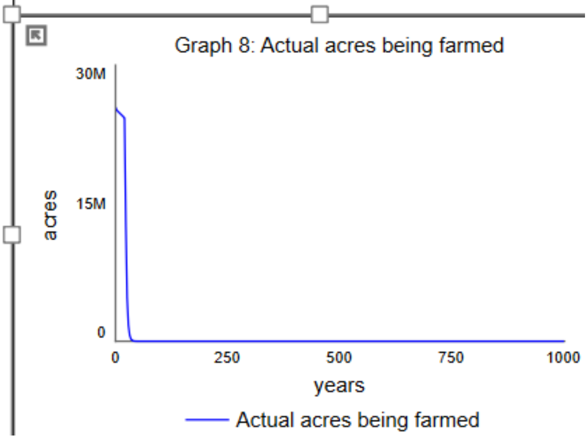





Graph 5: Production rate
60B
30B
0
kg/years
0
250
500
750
1000
years
Production rate


Graph 6: Consumption rate
60B
30B
0
kg/years
0
250
500
750
1000
years
Consumption rate


Graph 7: Deaths from hunger
20M
10M
0
person/years
0
250
500
750
1000
years
Deaths from hunger

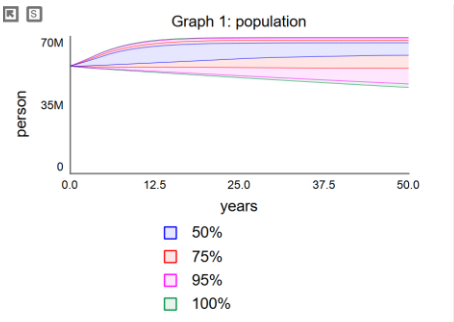

Graph 8: Actual acres being farmed
30M
15M
0
acres
0
250
500
750
1000
years
Actual acres being farmed

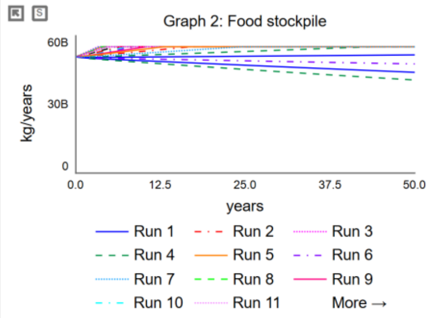
Appendix 5: Behavior sensitivity tests

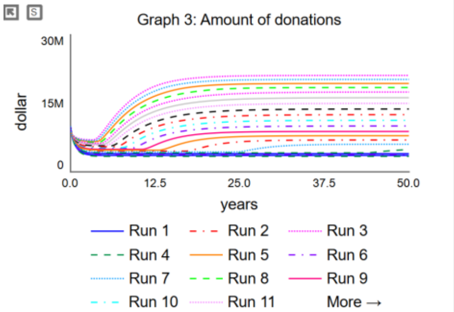
Course of population sector

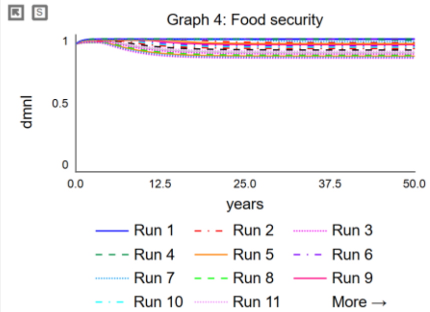
Normal birth fraction:

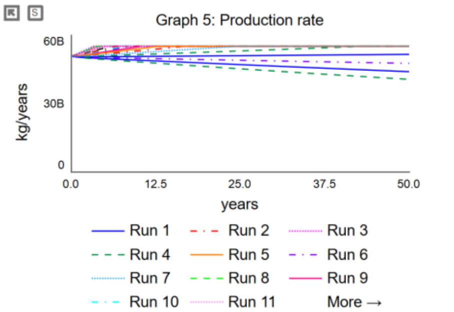
The tests show that the model is behavioral sensitive to changes in the birth fraction. All parameters display increasing and decreasing behavior based on the run. Food security goes towards an equilibrium state were the other graphs continue to display ‘unwanted’ behavior.

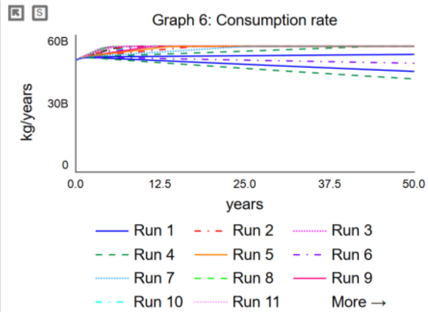


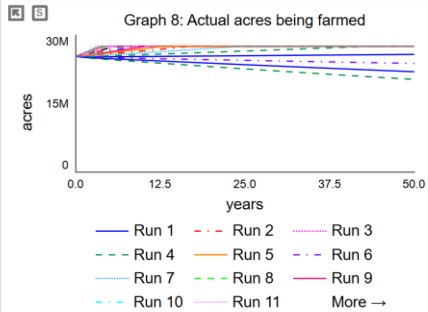






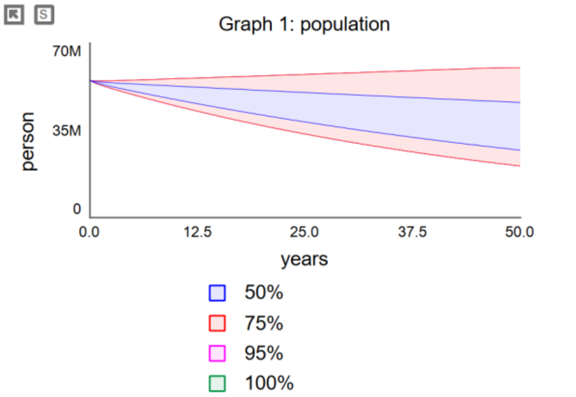


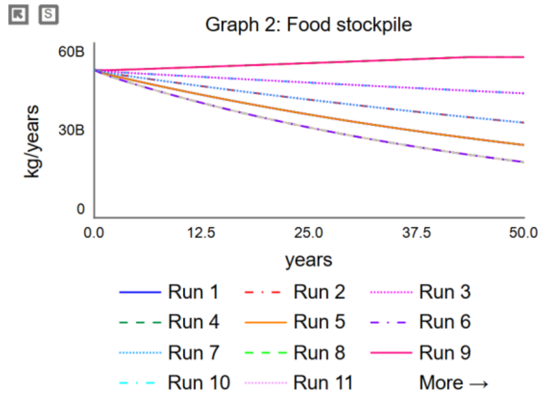


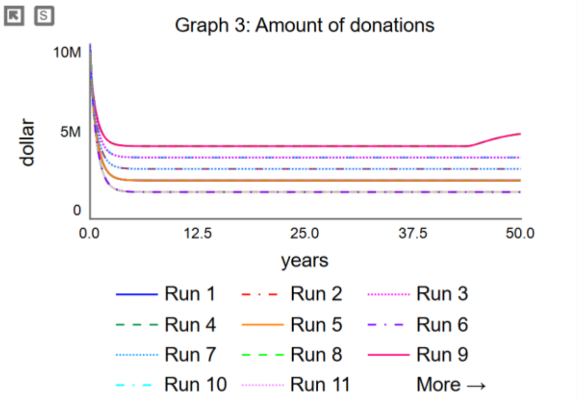


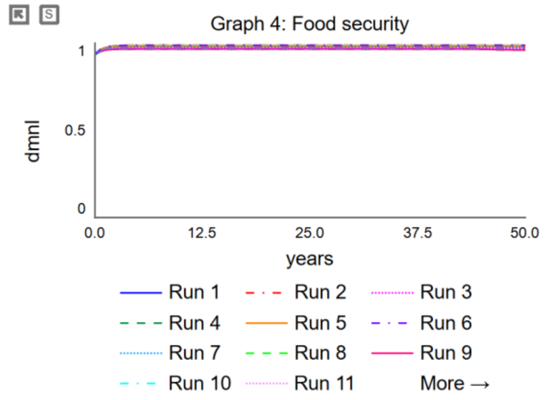
Normal death fraction

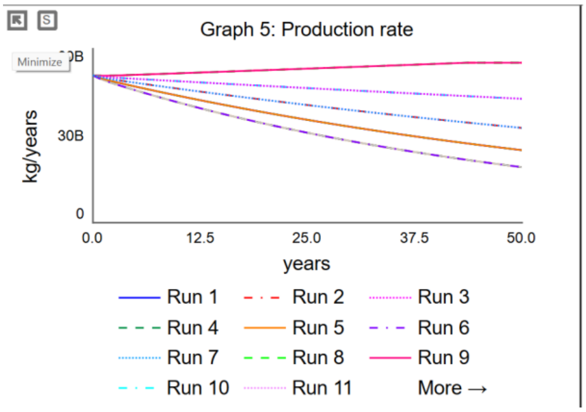
Test show that, as with normal birth fraction, the death fraction gives behavioral changes. One interesting point is that donations, asides from two runs, shows an equilibrium state.

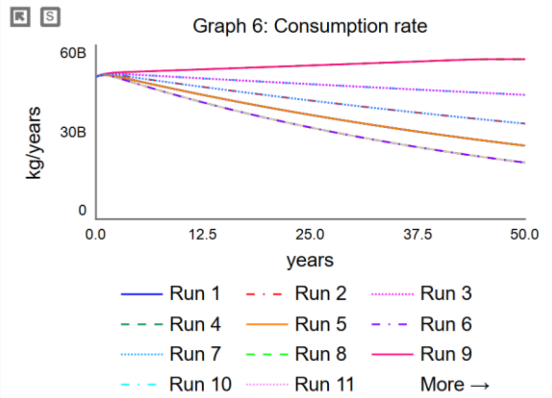


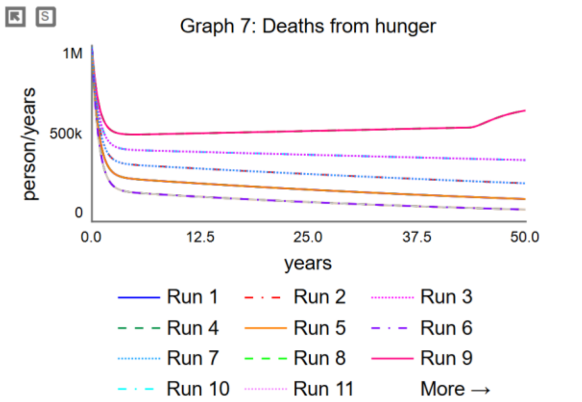


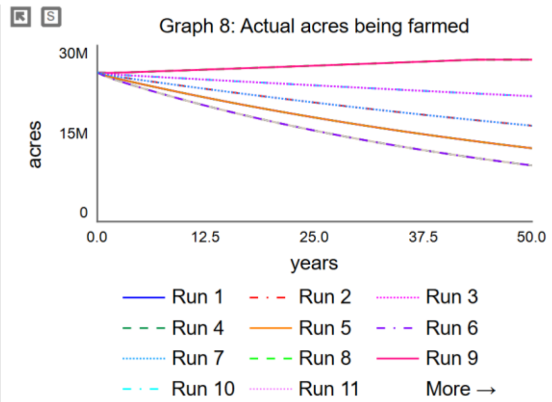








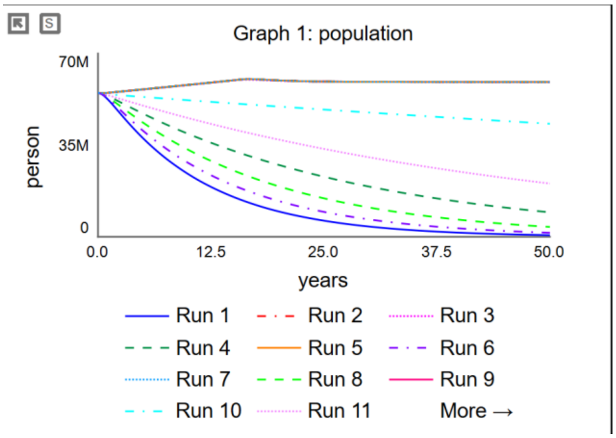


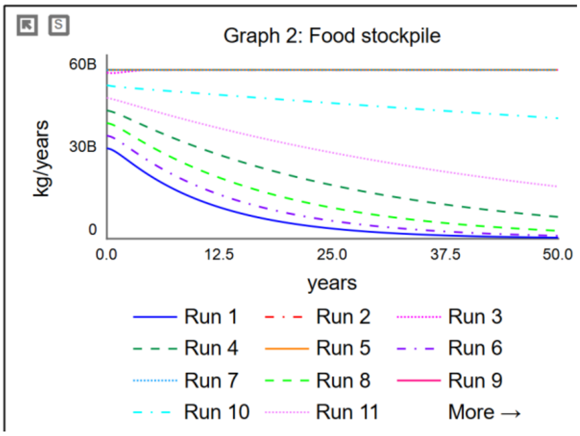


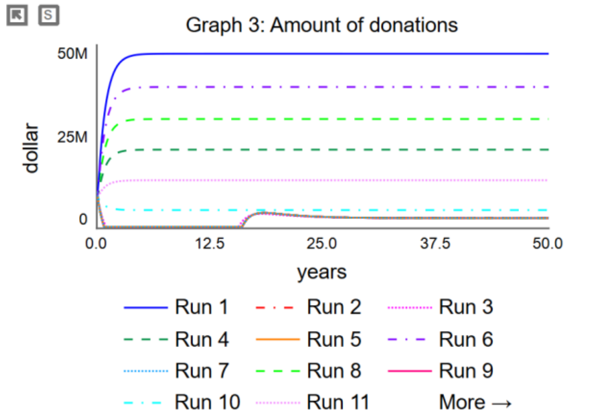
Food production and usage sector

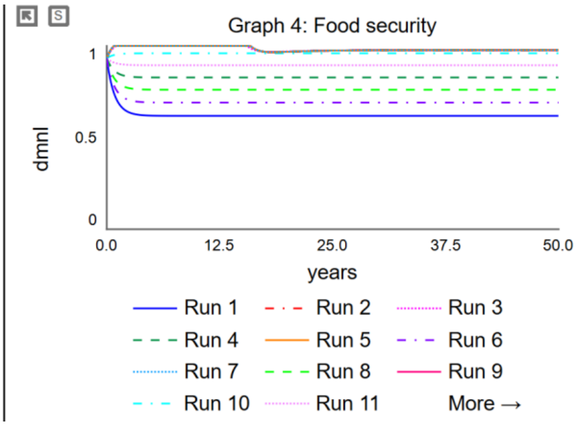
Acres per farmer

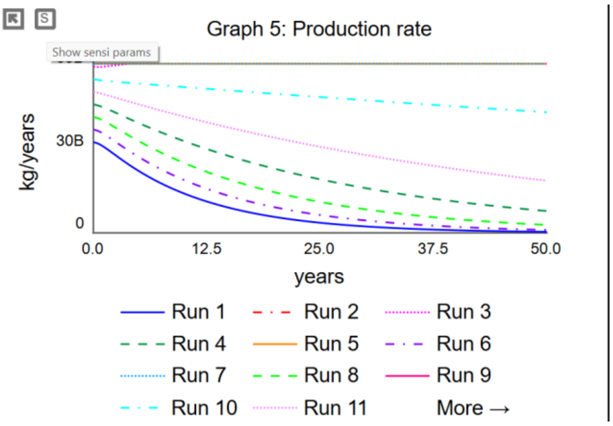
Tested with setting acres per farmer between 1 and 4. Results in behavioral changes. All graphs show either and increase or decrease at the beginning. Whereas graph 3 and 4 eventually result in an equilibrium the other graphs keep displaying continuous decreasing behavior.

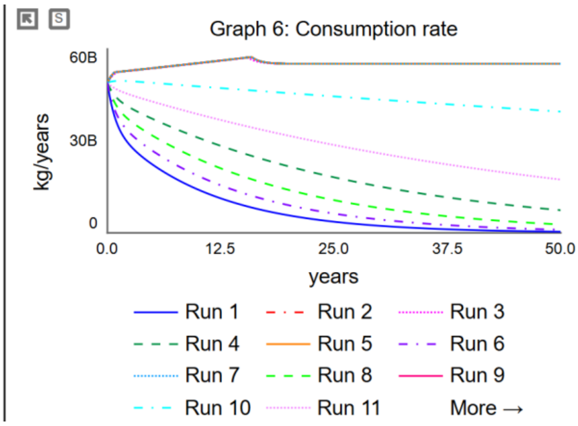


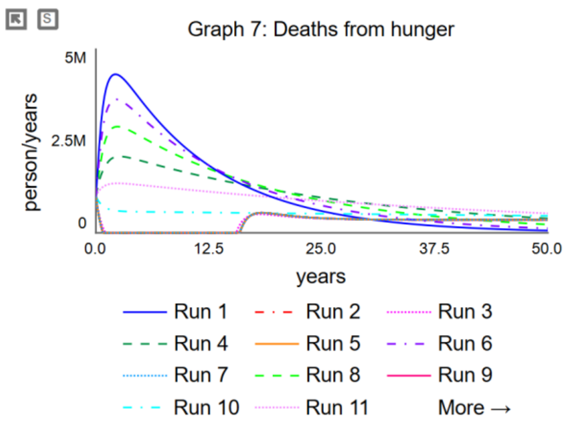


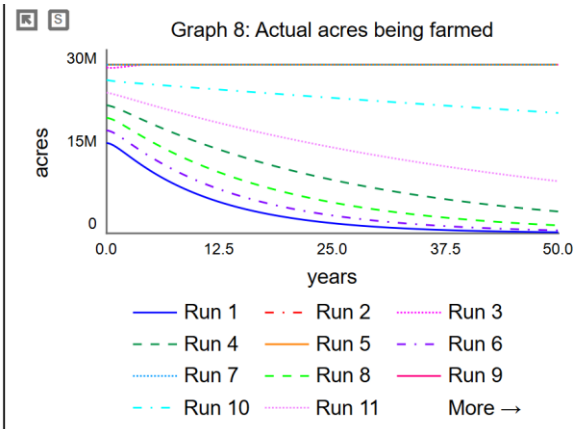






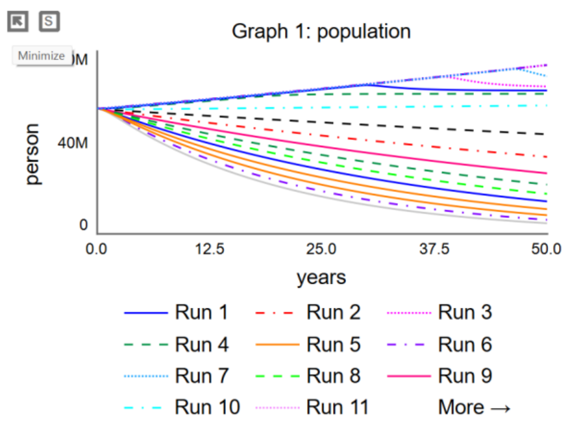


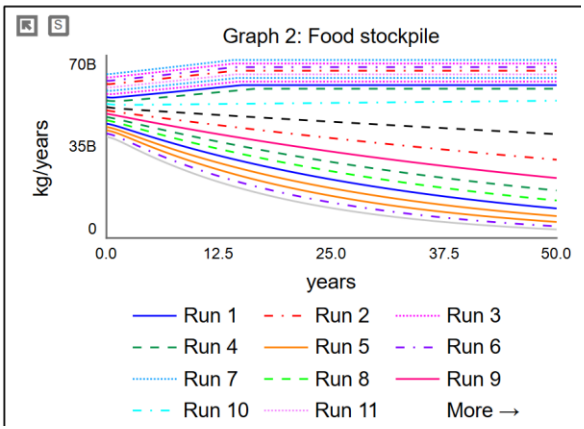


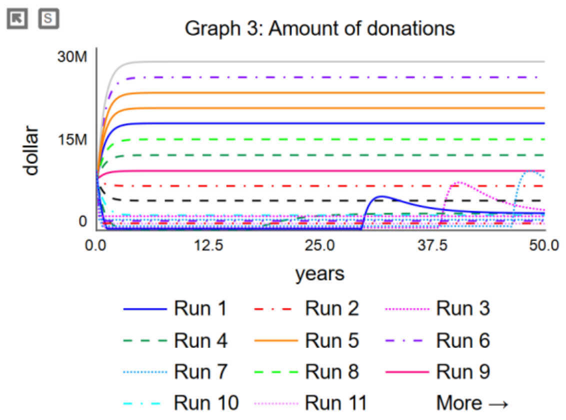


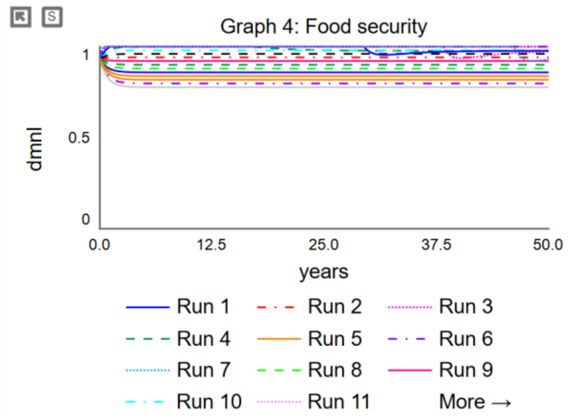
Yield per acre

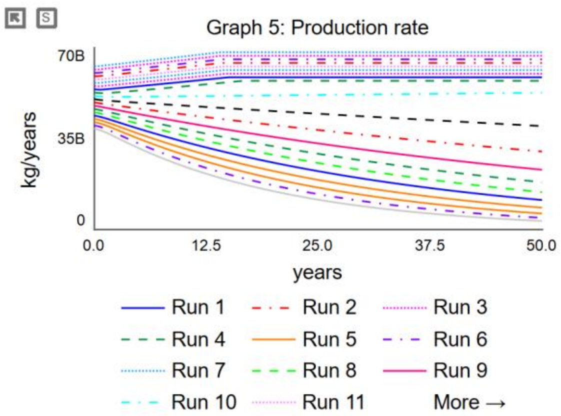
Test yield per acre between 1500 - 2500. Results in behavioral changes. Yield is a sensitive point in the model. Small changes result in large behavioral impacts. Logical since yield is one of the most determining factor in food supply.

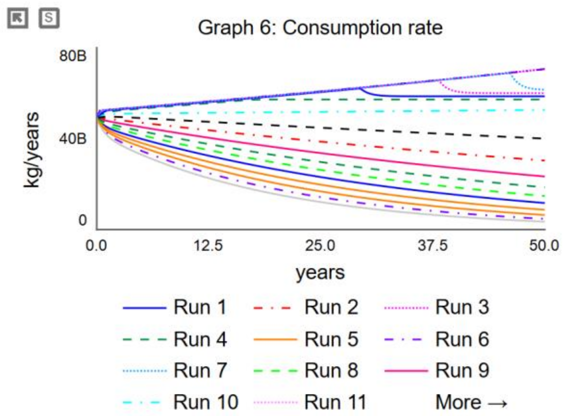


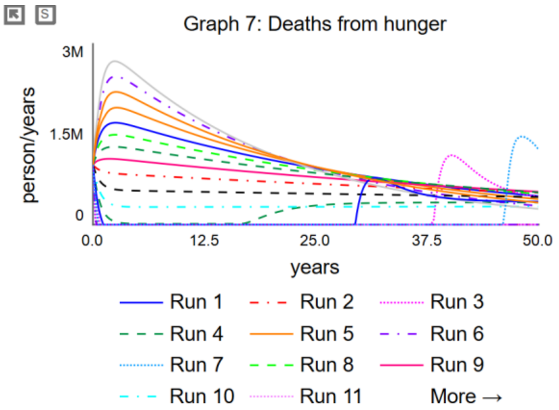


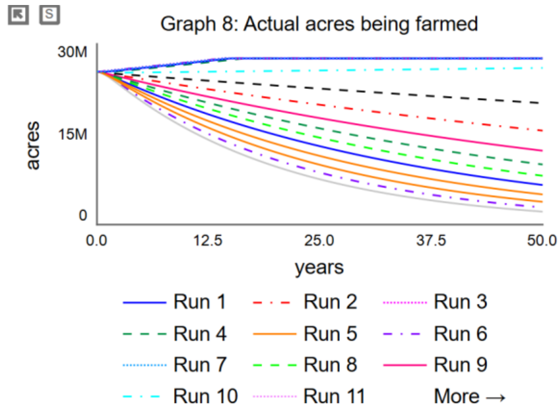






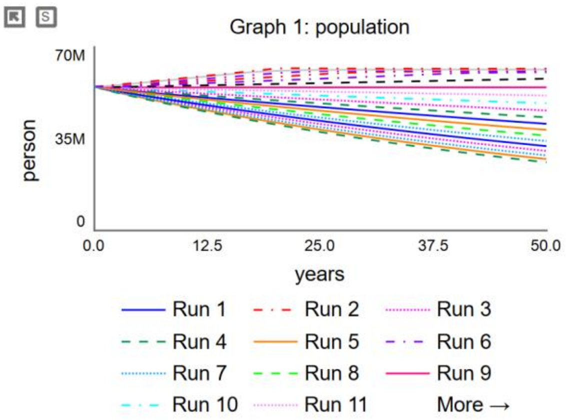


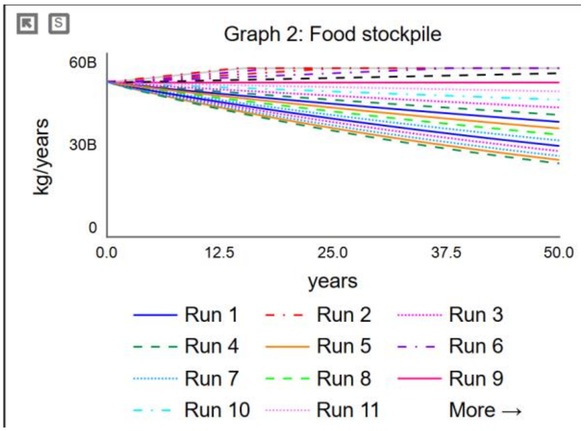


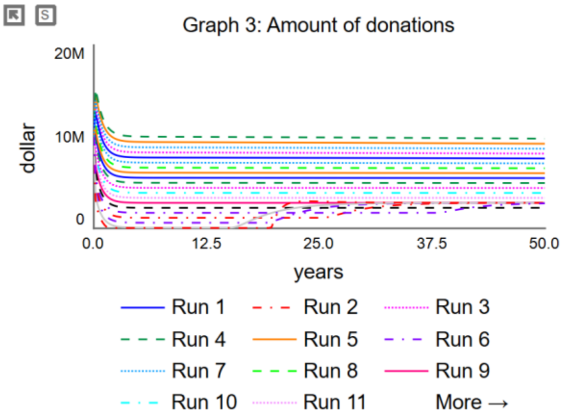


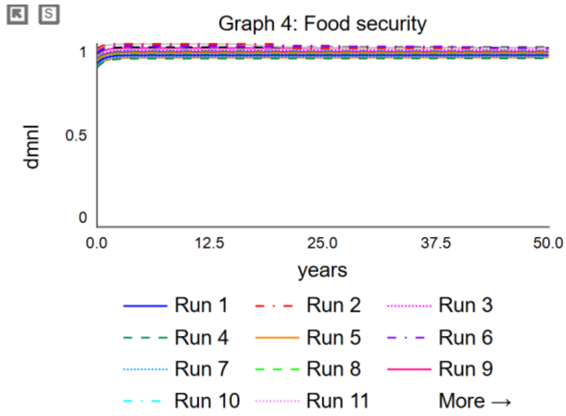
Calories per kg

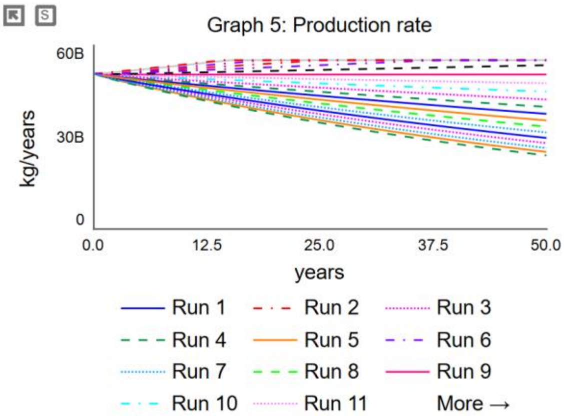
Test calories per kg. Set between 800-900. Results in behavioral changes. This is logical. The model uses large numbers when calculating the amount of kg in the system, into billons. Therefore a small change per kg has a hugely impacts the amount of needed to sustain the population. This allows the behavior to switch.

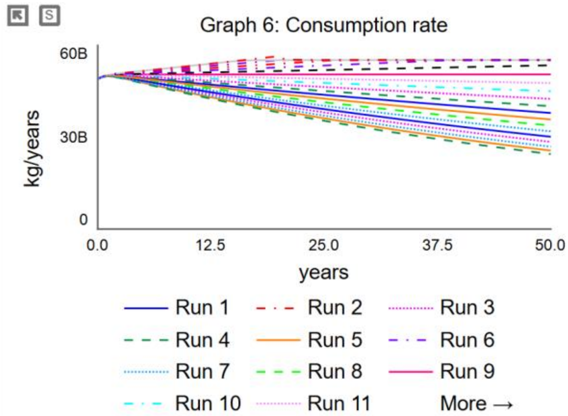


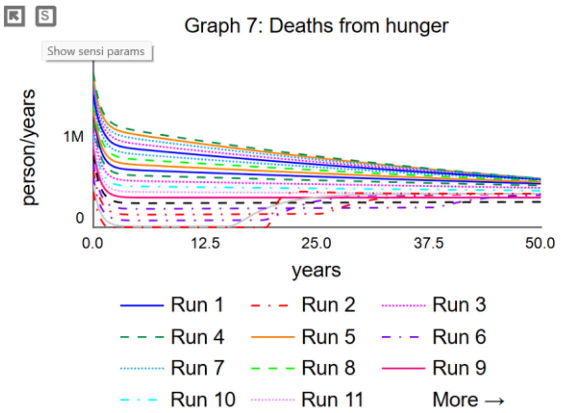


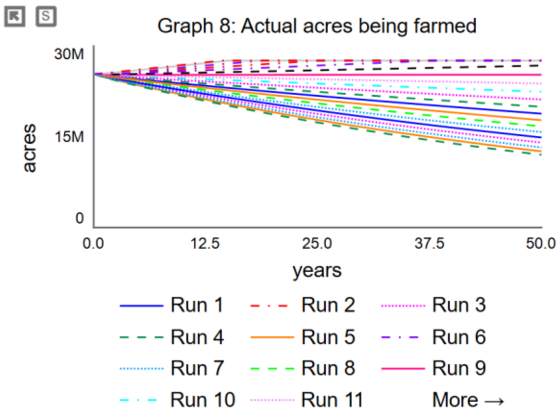

Graph 3: Amount of donations
dollar
20M
10M
0
0.0
12.5
25.0
37.5
50.0
years
Run 1 Run 2 Run 3
Run 4 Run 5 Run 6
Run 7 Run 8 Run 9
Run 10 Run 11 More →


Graph 4: Food security
dmnl
1
0.5
0
0.0
12.5
25.0
37.5
50.0
years
Run 1 Run 2 Run 3
Run 4 Run 5 Run 6
Run 7 Run 8 Run 9
Run 10 Run 11 More →


Graph 5: Production rate
kg/years
60B
30B
0
0.0
12.5
25.0
37.5
50.0
years
Run 1 Run 2 Run 3
Run 4 Run 5 Run 6
Run 7 Run 8 Run 9
Run 10 Run 11 More →


Graph 6: Consumption rate
kg/years
60B
30B
0
0.0
12.5
25.0
37.5
50.0
years
Run 1 Run 2 Run 3
Run 4 Run 5 Run 6
Run 7 Run 8 Run 9
Run 10 Run 11 More →

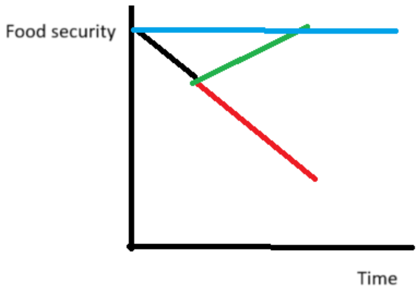

Graph 7: Deaths from hunger
Show sensi params
person/years
1M
0
0.0
12.5
25.0
37.5
50.0
years
Run 1 Run 2 Run 3
Run 4 Run 5 Run 6
Run 7 Run 8 Run 9
Run 10 Run 11 More →


Graph 8: Actual acres being farmed
acres
30M
15M
0
0.0
12.5
25.0
37.5
50.0
years
Run 1 Run 2 Run 3
Run 4 Run 5 Run 6
Run 7 Run 8 Run 9
Run 10 Run 11 More →

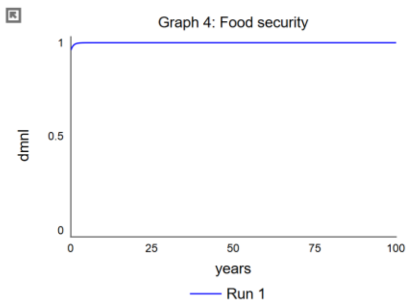
Appendix 6: Behavior reproduction tests

Comparison 1: Amount of people with food insecurity

Reference mode 1: Food security



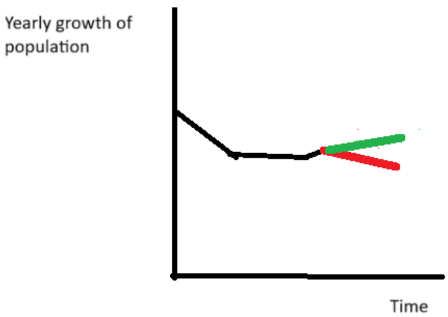
Graph 1 Food security



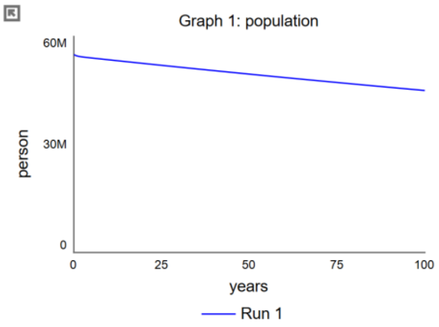
When comparing the reference mode of food security it can be seen that the reference mode is not a full match. One would expect to have food security increase as seen in the red line. However food security comes into a near equilibrium. It is suspected that a bit of structure is missing. The model in its current form assumes if total food need is near consumption rate that there is food security. Each timestep the calculations are instant. Instant adding of crops to the stockpile and instant consumption. In further versions of the model the food stockpile needs to take growth time into account. That harvests are once a year and food distribution takes time whilst consumption and population growth is throughout the year. In that scenario food would come once a year, get drained throughout the year then get restocked the next year.

Comparison 2: Yearly growth of population

Reference mode 2: yearly growth of population



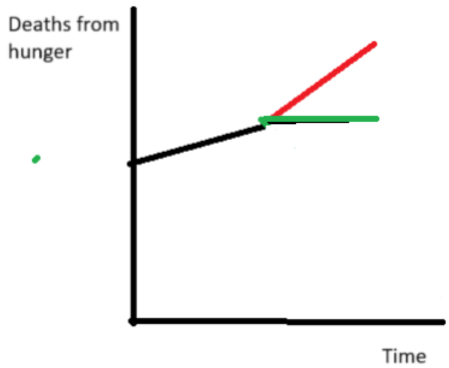
Graph 2: Population



In this comparison it can be seen that the historical data and negative business as usual prospect are reproduced. Although not a point by point comparison it still shows that population is declining.

Comparison 3: Deaths from hunger

Reference mode 3: Deaths from hunger



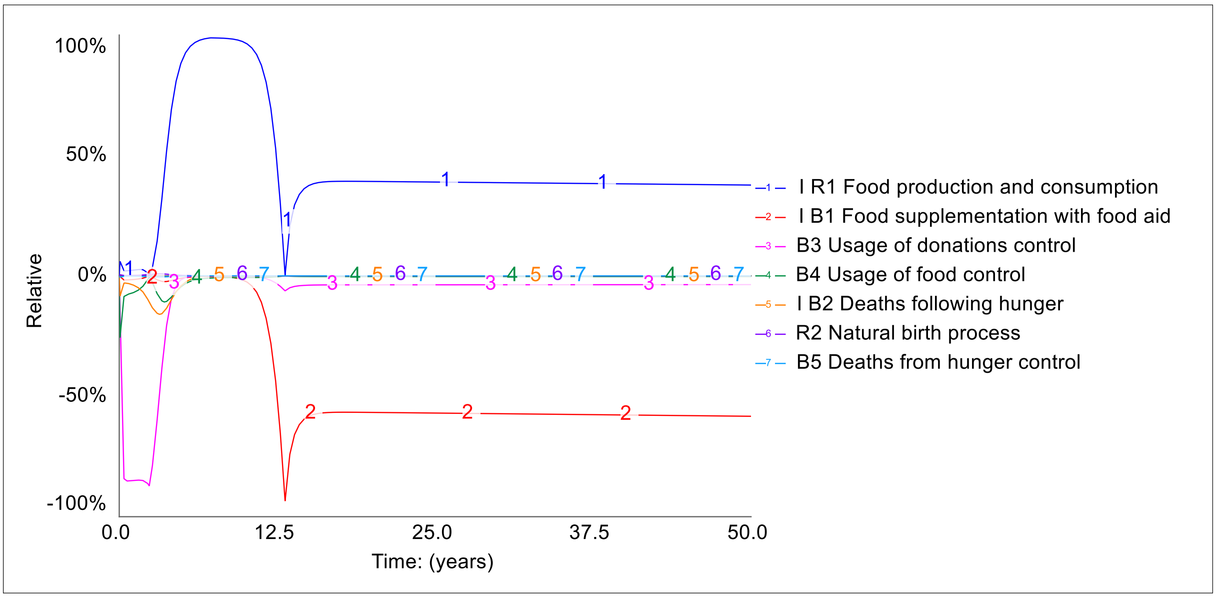
Graph 3: Deaths from hunger

In this case the reference mode does not fully match the results. In the model food production is dependent on the amount of farmers. As said in comparison 1 of the behavior reproduction tests there is no delay between population, the amount of farmers, production and consumption. They get calculated in the same timestep. Therefore they decrease gradually instead of with more extreme behavior. Next to that the food is distributed equal on the population. In reality farmers would keep food for themself first then distribute to the population. This would result in the farmers having enough food and the rest with less. The model does not account for this.

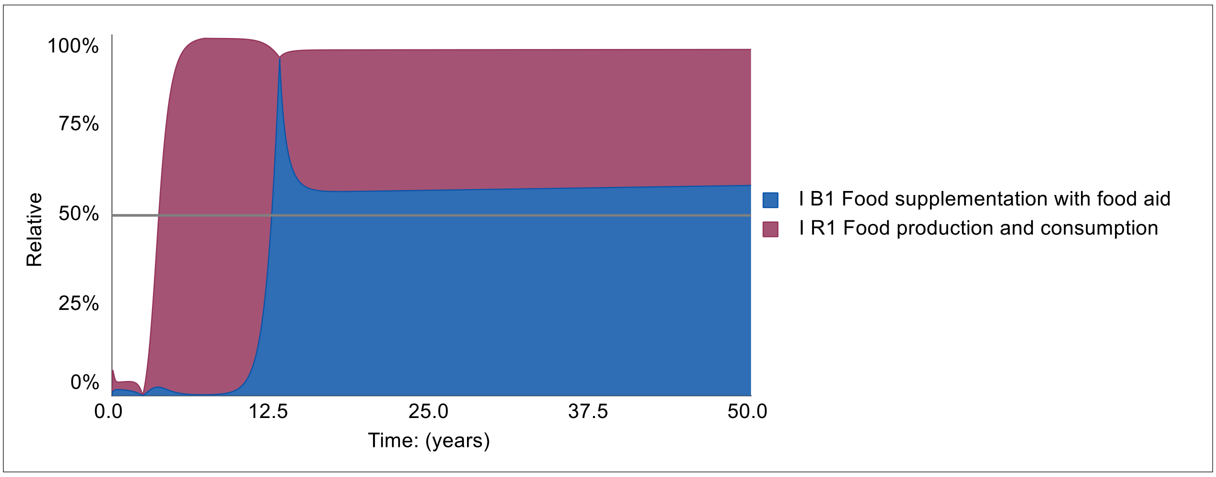
(Save the childeren, n.d.). Note it is not possible to bring down the amount of people who have already died. Therefore the desired behavior is to keep it steady and not allow further increases.

Appendix 7: Loop dominance during base simulation

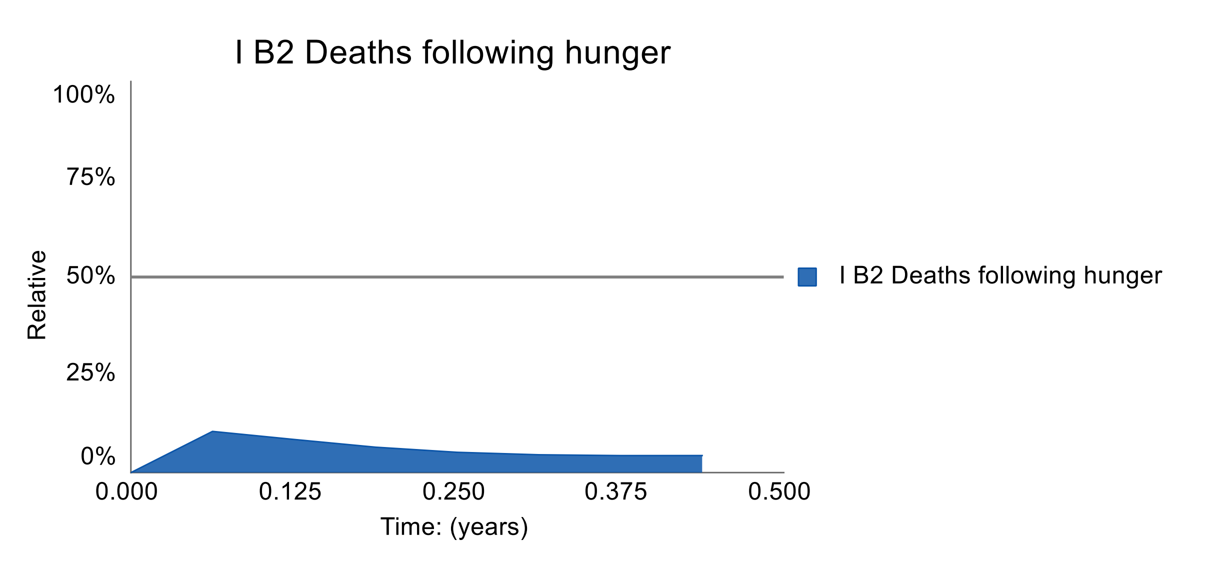
All loops Line graph



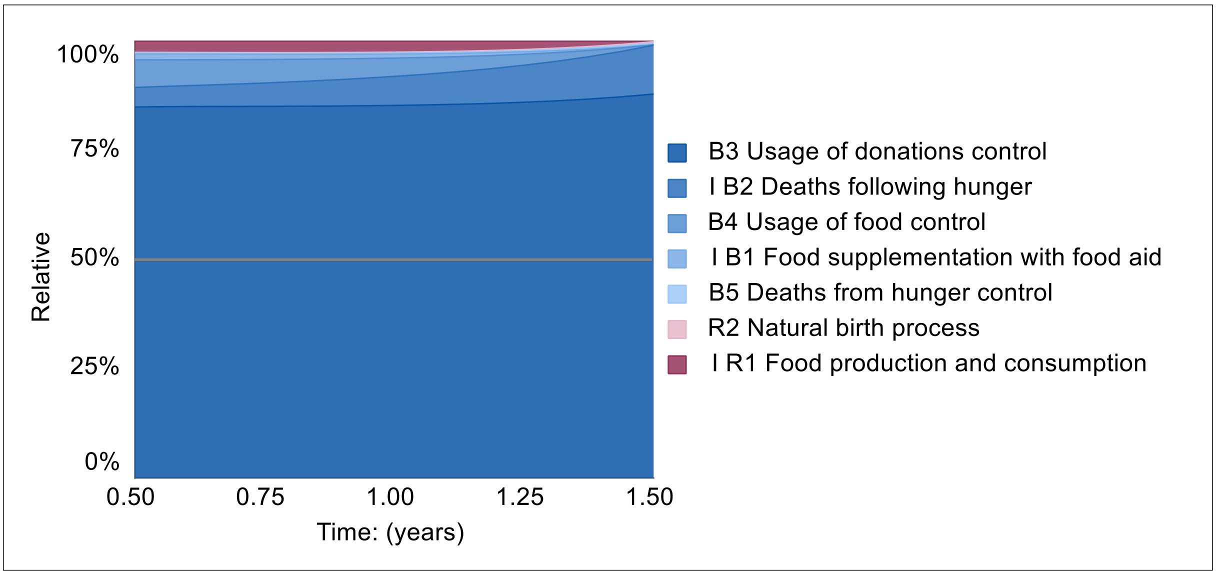
Loops describing 80% of behavior



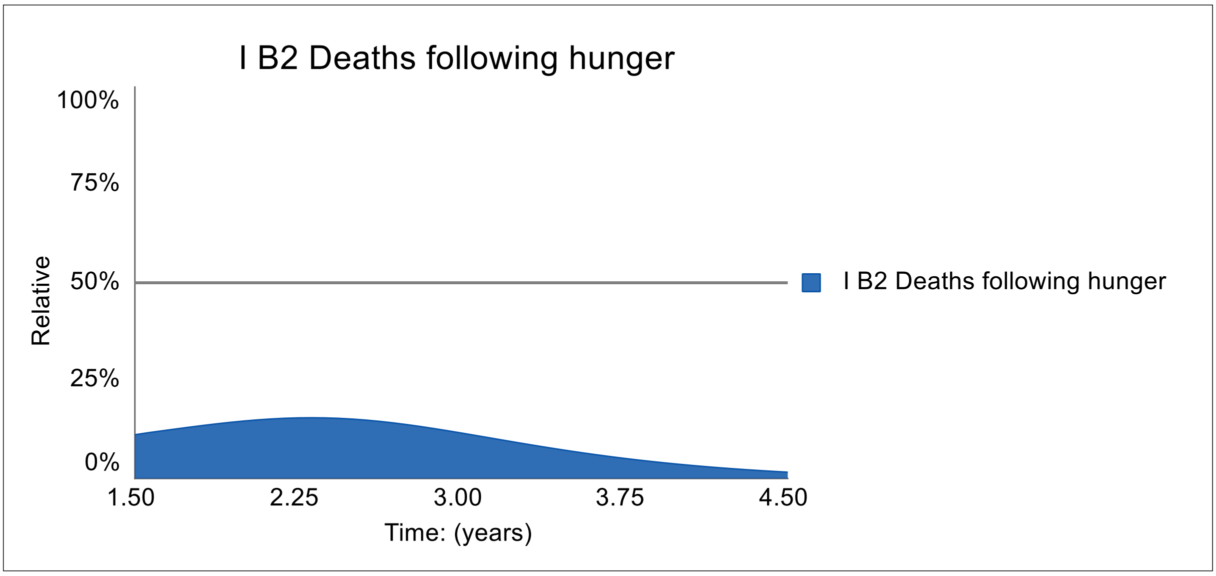
Deaths following hunger year 0 - 0.5.



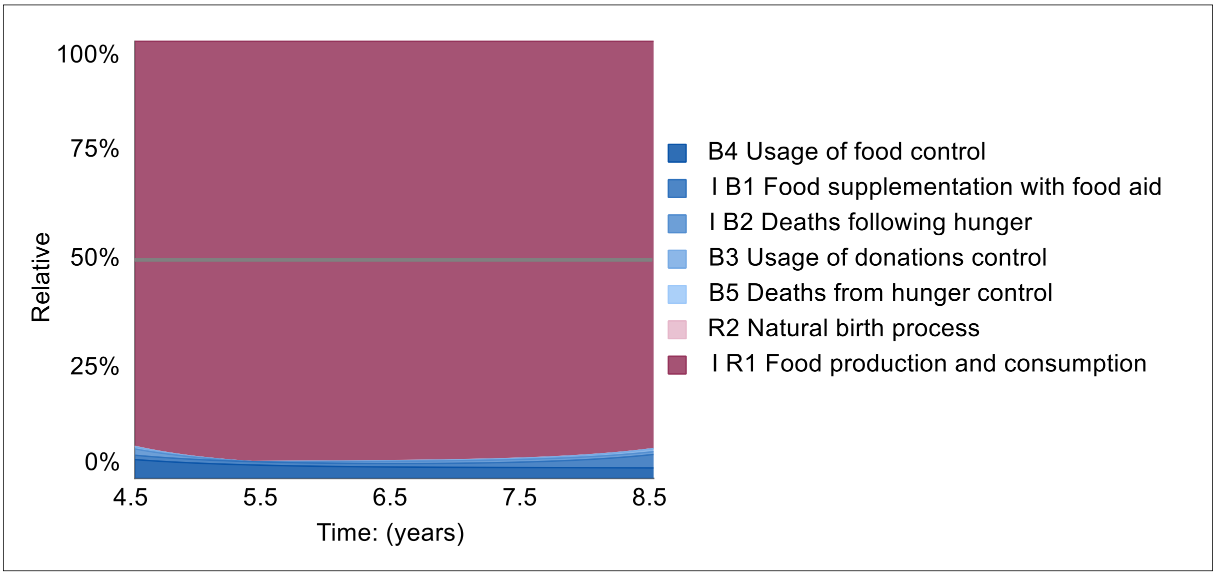
All loops year 0.5-1.5



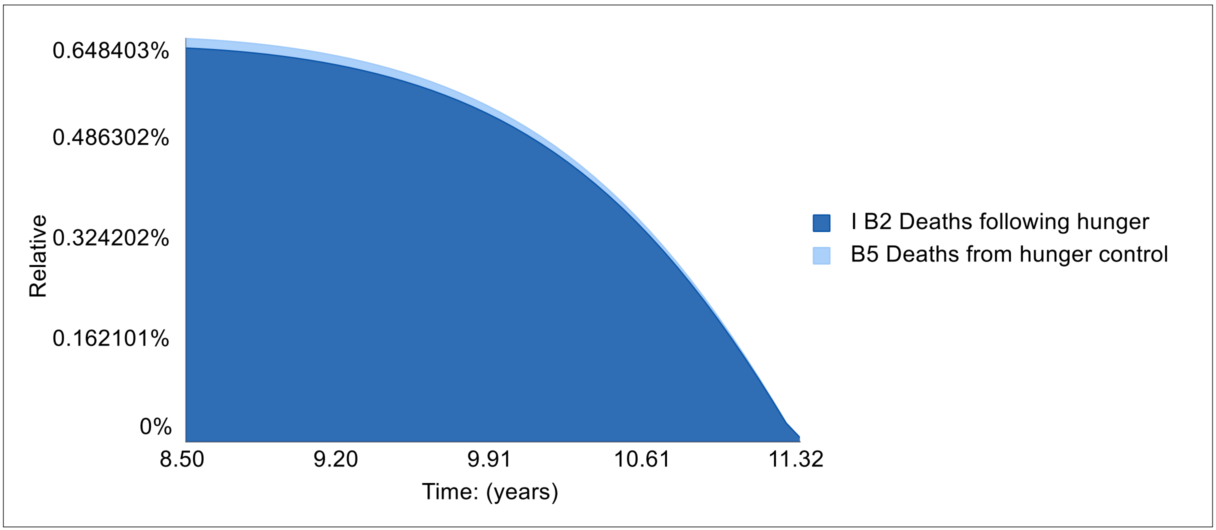
Deaths following hunger year 1.5-4.5



All loops year 4.5 - 8.5

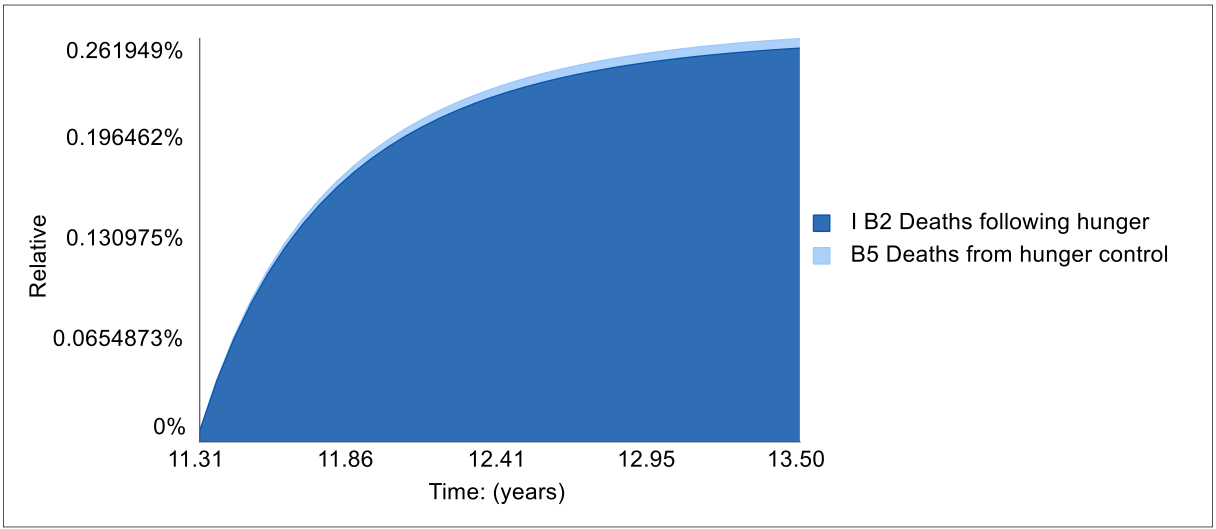


Death following hunger year 8.5-11.3



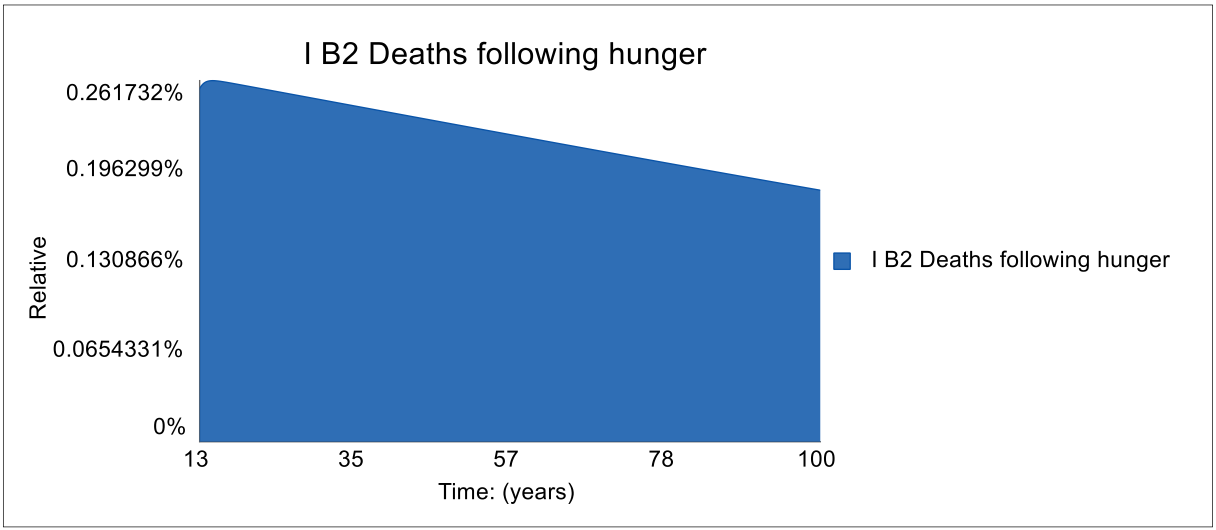
Note this graph is unscaled

Deaths following hunger year 11.3-13.5



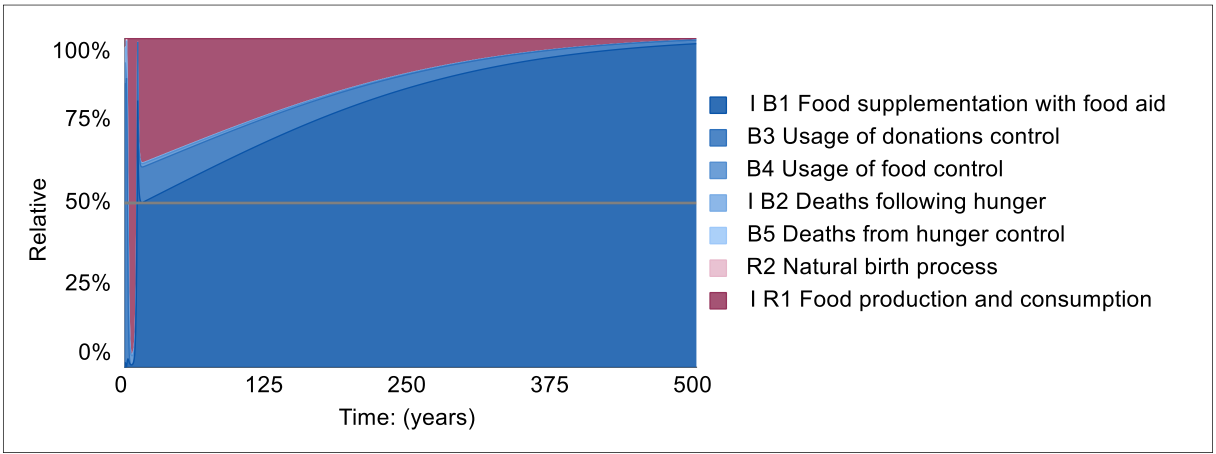
Note this graph is unscaled

Deaths following hunger year 13.5-100

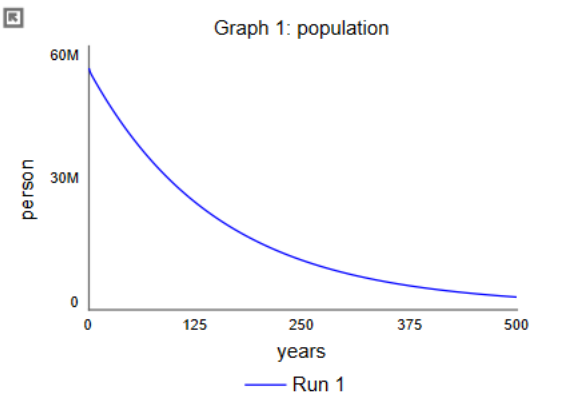


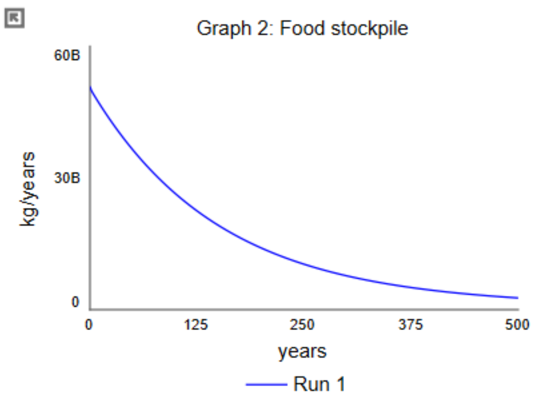
Note this graph is unscaled

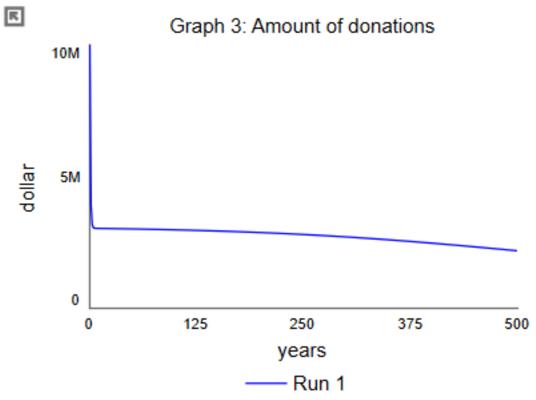
Run of 500 years - Stacked area graph

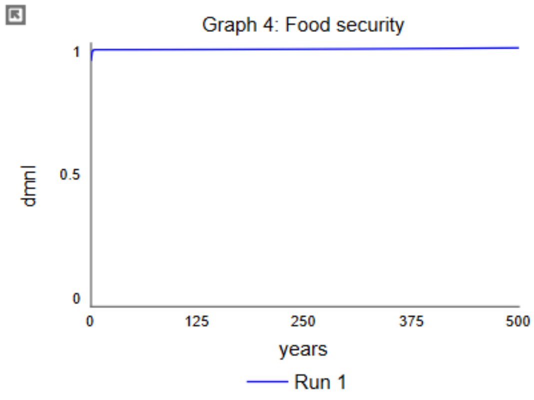


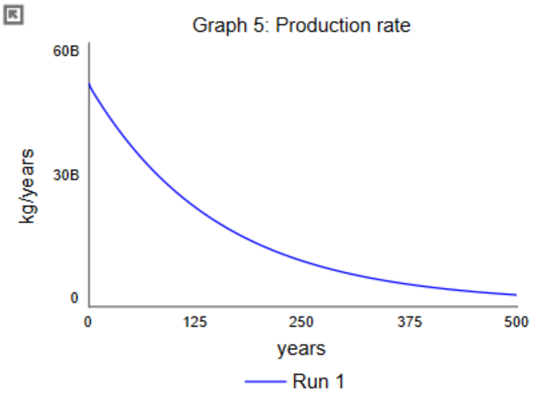
Run of 500 years - Baseline scenario graphs

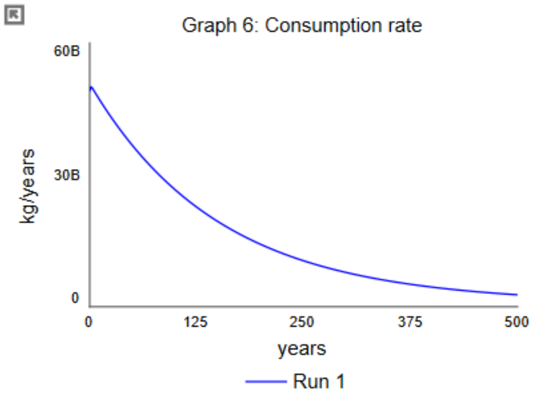


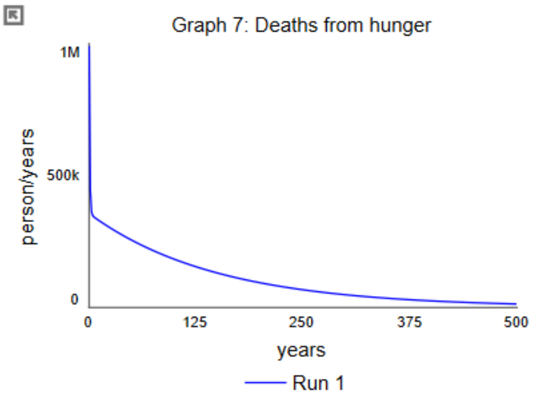


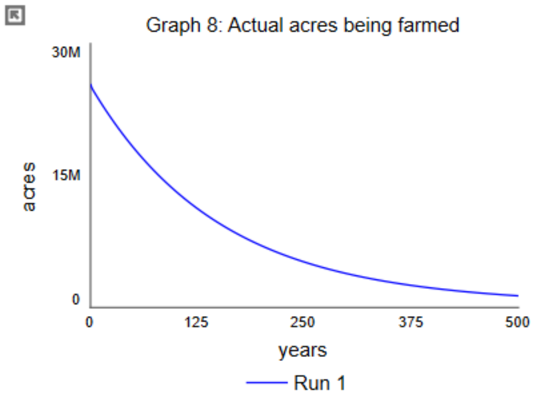

Graph 3: Amount of donations
dollar
10M
5M
0
0
125
250
375
500
years
Run 1


Graph 4: Food security
dmnl
1
0.5
0
0
125
250
375
500
years
Run 1


Graph 5: Production rate
kg/years
60B
30B
0
0
125
250
375
500
years
Run 1


Graph 6: Consumption rate
kg/years
60B
30B
0
0
125
250
375
500
years
Run 1

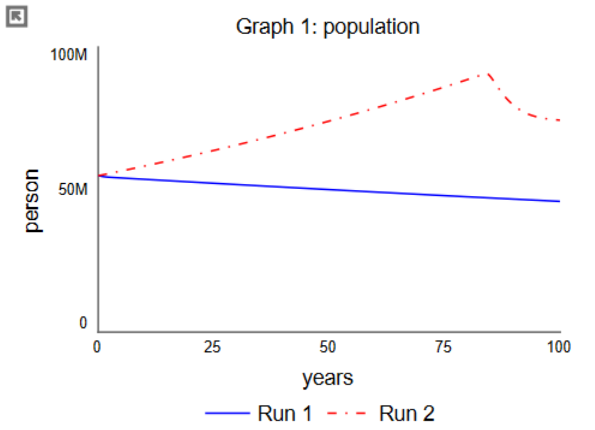

Graph 7: Deaths from hunger
person/years
1M
500k
0
0
125
250
375
500
years
Run 1

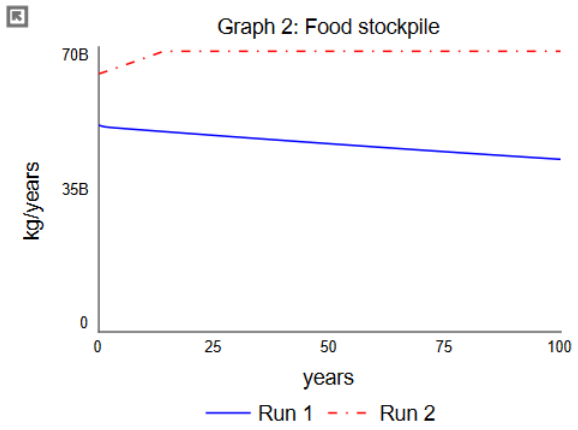

Graph 8: Actual acres being farmed
acres
30M
15M
0
0
125
250
375
500
years
Run 1

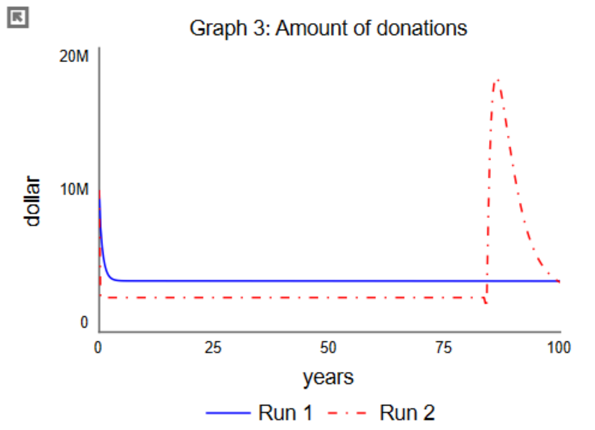
Appendix 8: Potential policy points

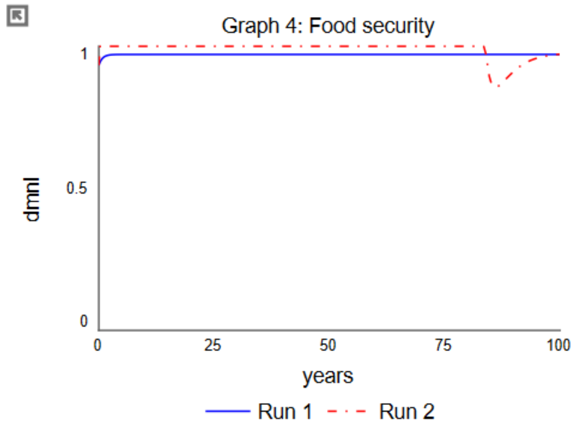
Policy point 1: Increased yield per acre.

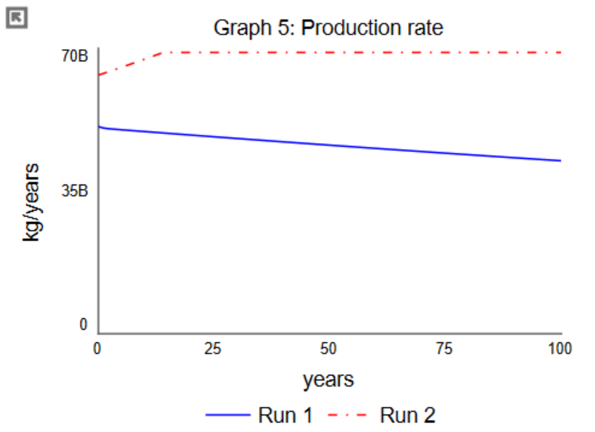
The graphs below show the behavior of the model if yield per acre gets increased from 2000 to 2500 kg per acre. Run one is the base scenario, run two with the increased yield per acre policy.

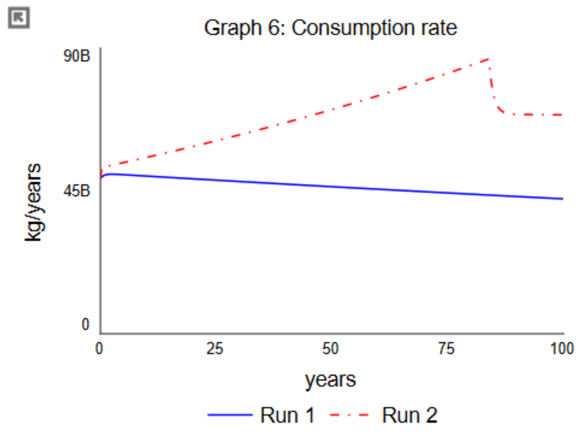


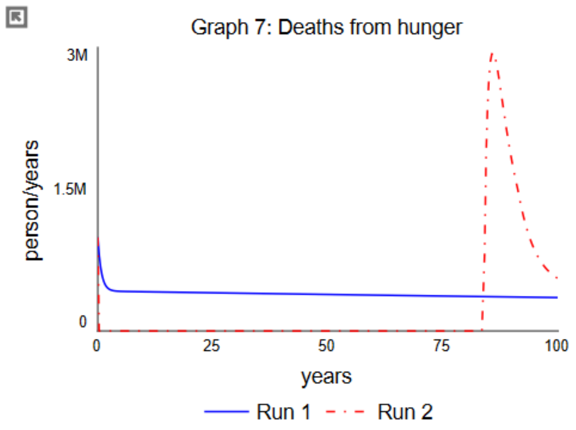


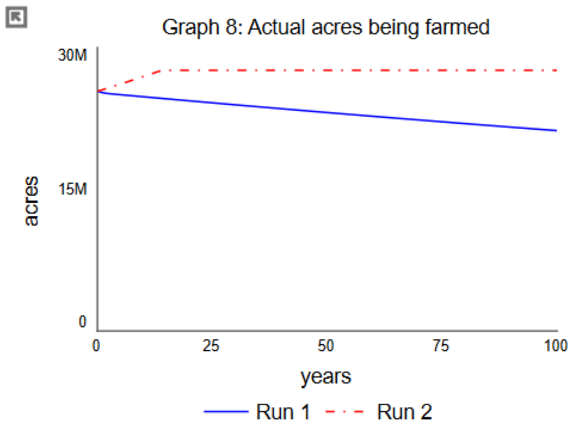


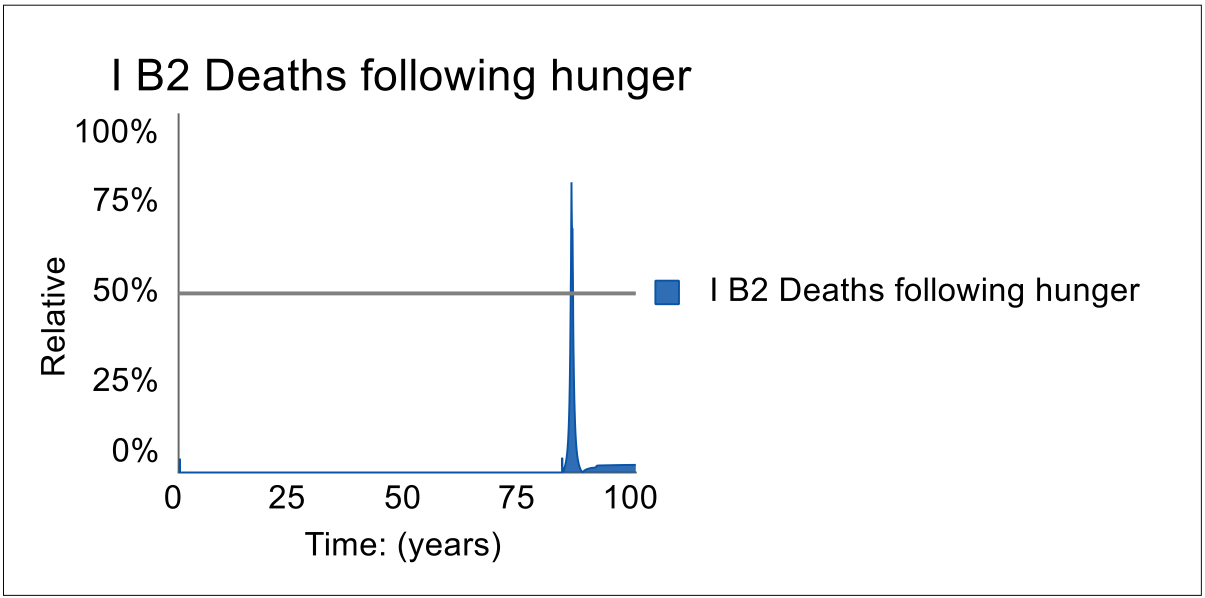






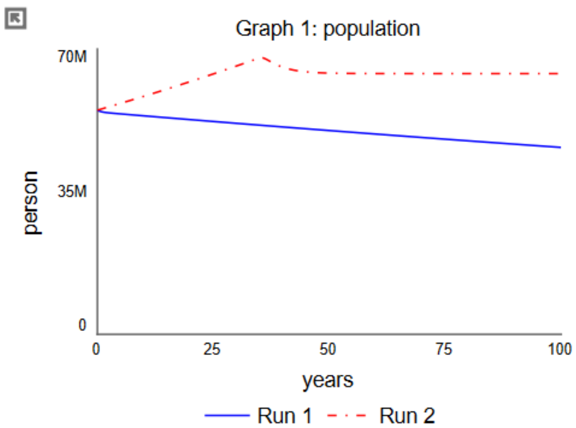


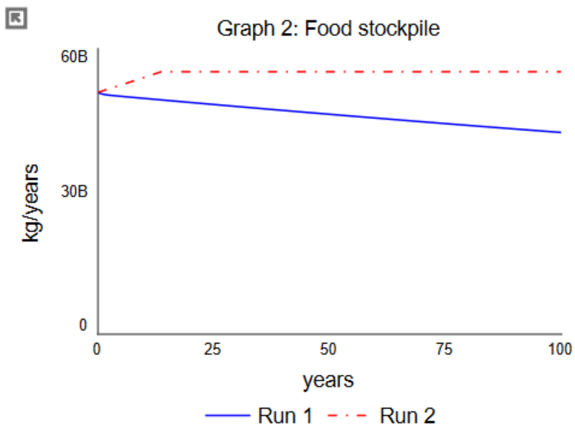




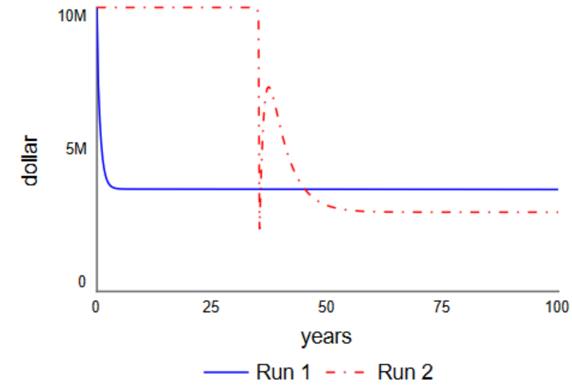
Policy point 2: Calories per kg

The graphs below show the behavior of the model if the amount of calories per kg increases from 860 to 930. Run one is the base scenario, run two with the increased yield per acre policy.

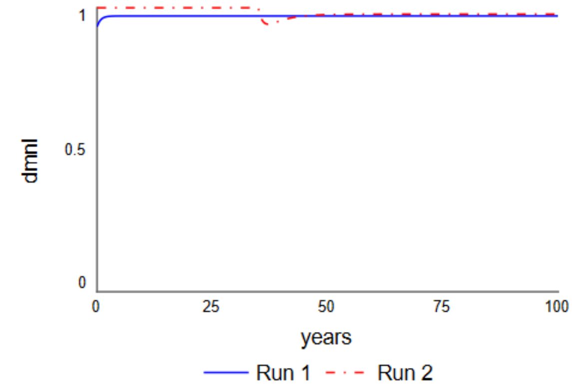




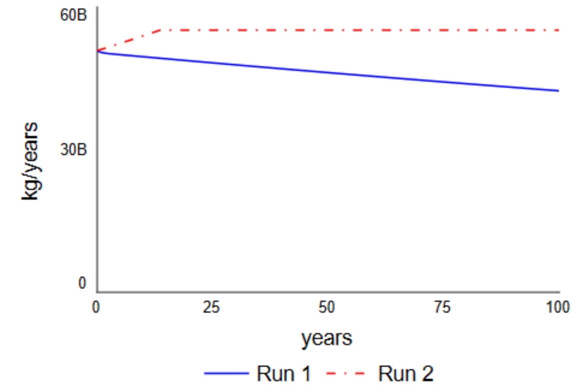
Graph 3: Amount of donations



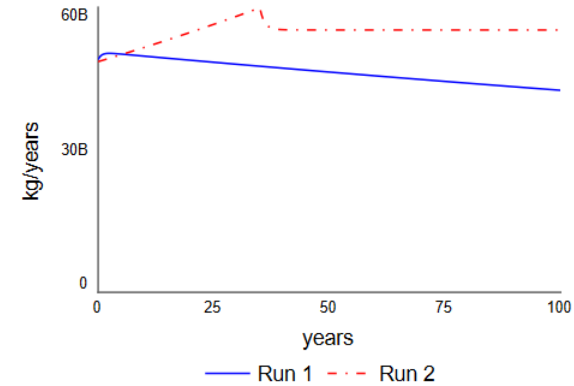
Graph 4: Food security



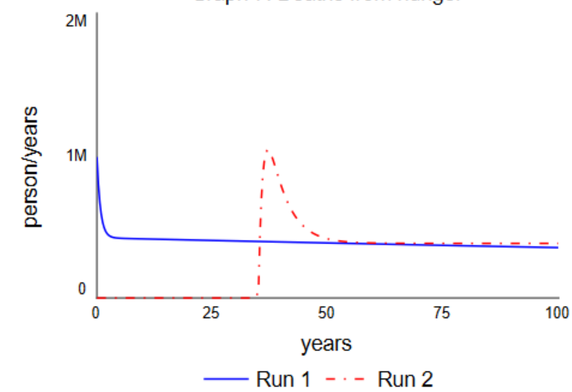
Graph 5: Production rate



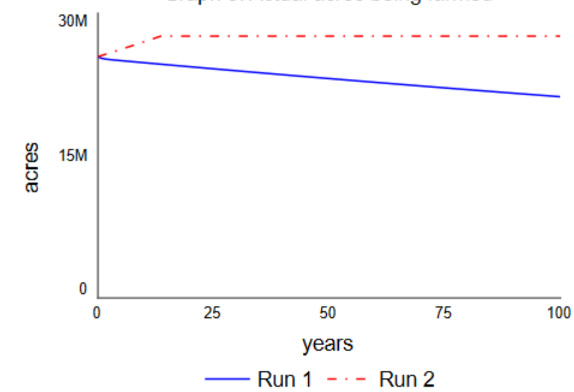
Graph 6: Consumption rate

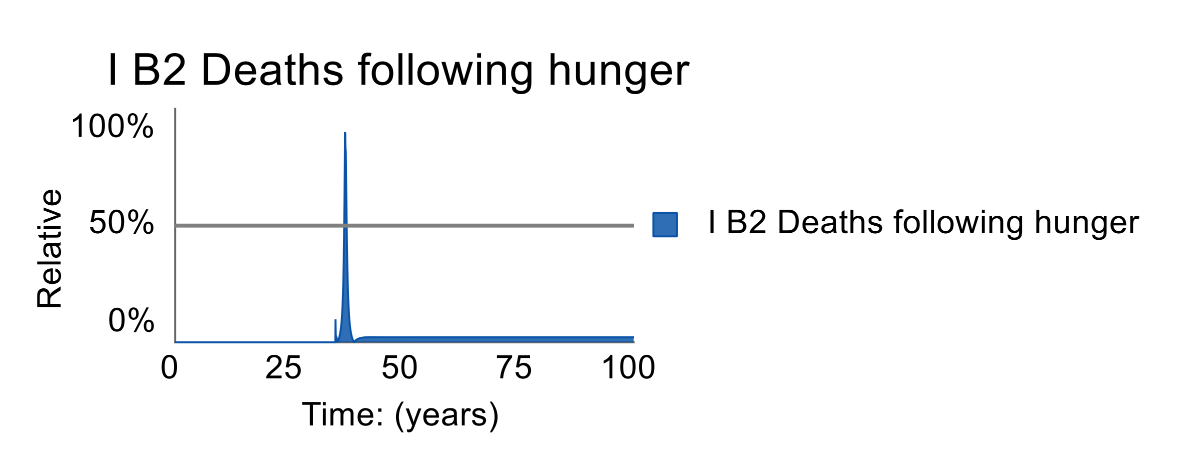


Graph 7: Deaths from hunger

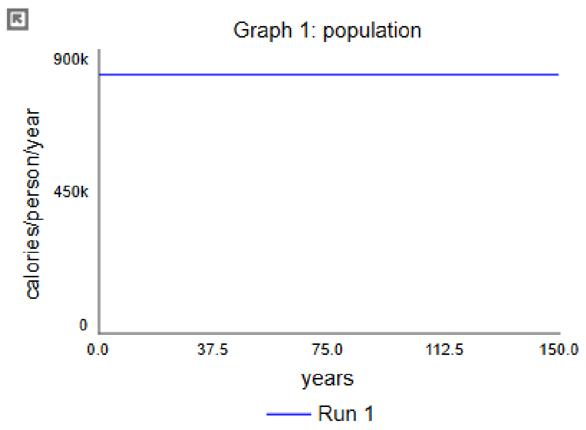


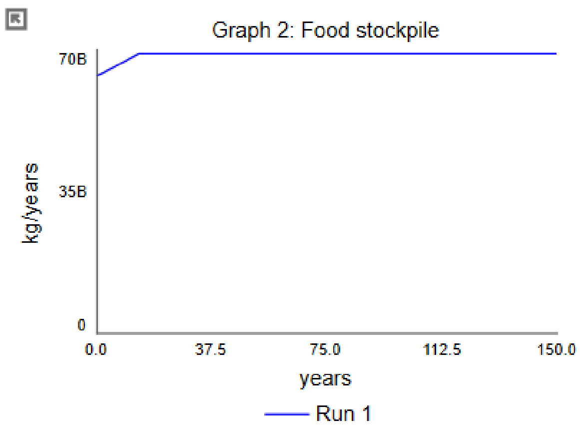
Graph 8: Actual acres being farmed

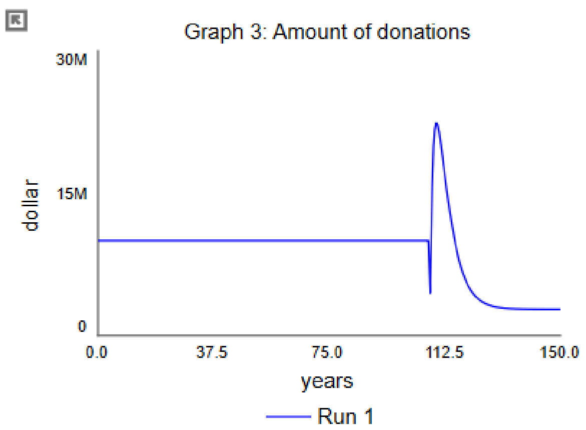


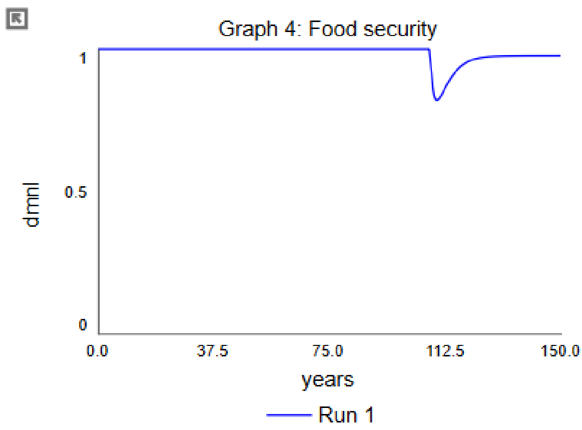


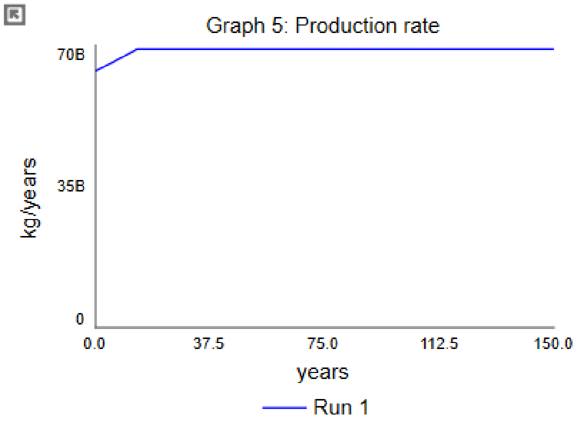
Combined policy 1 and 2

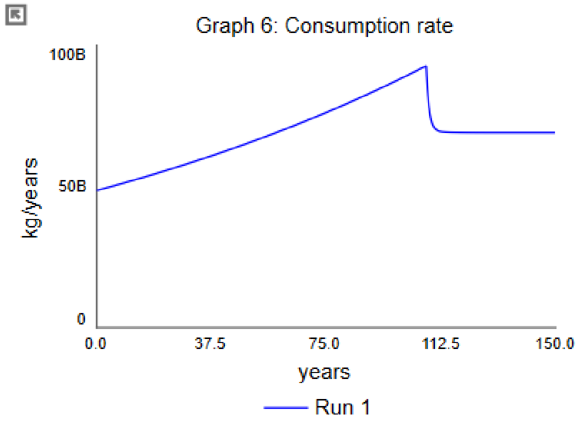


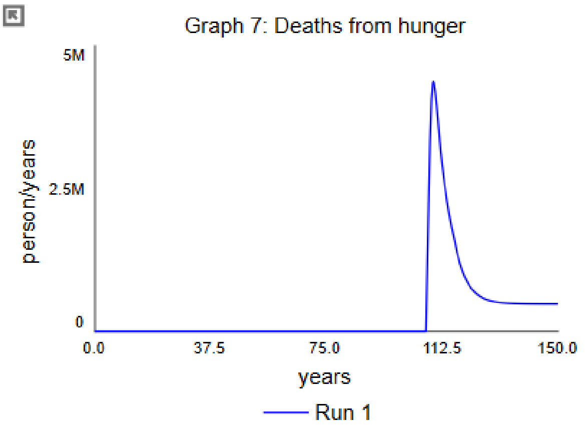


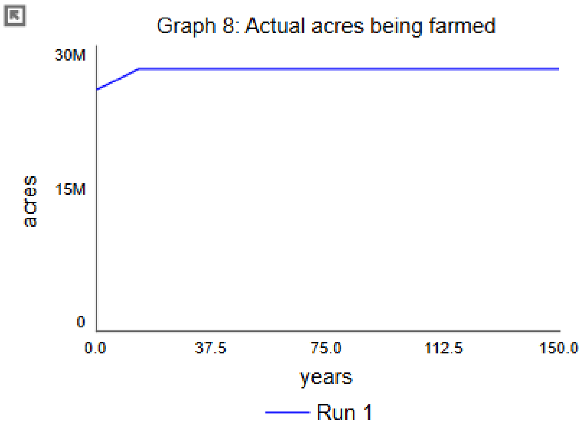


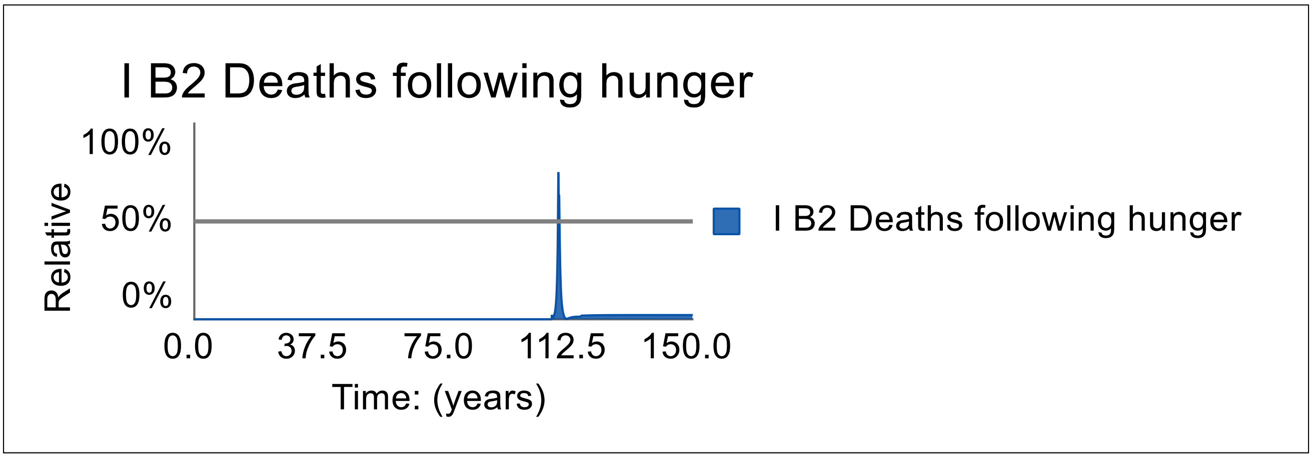



Graph 5: Production rate
70B
35B
0
kg/years
0.0
37.5
75.0
112.5
150.0
years
Run 1


Graph 6: Consumption rate
100B
50B
0
kg/years
0.0
37.5
75.0
112.5
150.0
years
Run 1


Graph 7: Deaths from hunger
5M
2.5M
0
person/years
0.0
37.5
75.0
112.5
150.0
years
Run 1


Graph 8: Actual acres being farmed
30M
15M
0
acres
0.0
37.5
75.0
112.5
150.0
years
Run 1


I B2 Deaths following hunger
100%
50%
0%
Relative
0.0
37.5
75.0
112.5
150.0
Time: (years)
I B2 Deaths following hunger