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SYSTEM DYNAMIC MODELING FOR FOOD SECURITY IN DEVELOPING COUNTRY

For most developing countries, the increasing need to improve the nutritional demands of their increasing populations highlights the need for sustainable agriculture and agro-based solutions as crucial factors for both environmental and social-economic development.

Nowadays, agricultural sustainability faces multiple challenges ranging from increasing human population growth, deforestation due to an increase in demand for agricultural land and resources, an increasing dependence on fossil energy that comes with both monetary and environmental costs. Therefore, it is important to identify policies that enable doubling of productivity and farmers income of countries by improving the agricultural food production on the available agriculture land without further decline in the forest land with the help of system dynamic modeling.

The modeling for food security was based on four main hypotheses:

1. The increase in population increases household's basic needs thereby creating resource consumption gaps [3].
2. Food consumption per capita subsequently increases with increase in the world's population income, this further creates the pressure on global food availability [4].
3. Fertilizers and farm machinery generally have a critical contribution to the increase in yield and agricultural productivity [5].
4. In many developing countries, population growth and dependence on agriculture will lead to continuing loss of forests [6].

Based on main hypothesis, a causal loop diagram (CLD) has been developed to exhibit the causal relationship between the variables under the study (Fig. 1). The CLDs have been used to describe basic causal mechanisms hypothesized to generate the reference mode of behavior over time [7].

The CLD, illustrated in *Figure 1*, shows the dynamics between agriculture land, deforestation rates, food production, food demand, farmer's income, and yield. It is observed that the population is growing rapidly, putting more pressure on the already fragile food supply system to meet the rapidly growing food demand. This inevitably implies that if the government does not increase the agricultural productivity through structural investment, more forest will be lost due to the need for more arable land. This will deplete natural resources quite fast to increase the total crop and meat production. Increasing food supply is at the very core of plenty of reinforcing feedback loops in the current system. An augmented food supply gives the opportunity to small-scale food producers to sell better – besides their production for subsistence (entering reinforcing loop 1, R1). This enables the farmers to increase their income and increase their output through private procurement of fertilizers, which will have a fruitful effect on the yield thereby increasing the total food production (closing R1). Increased earnings will also have behavioural consequences. Farmers will, for instance, enjoy more attractiveness by others of the profession and are able to employ more people as well through their higher income.

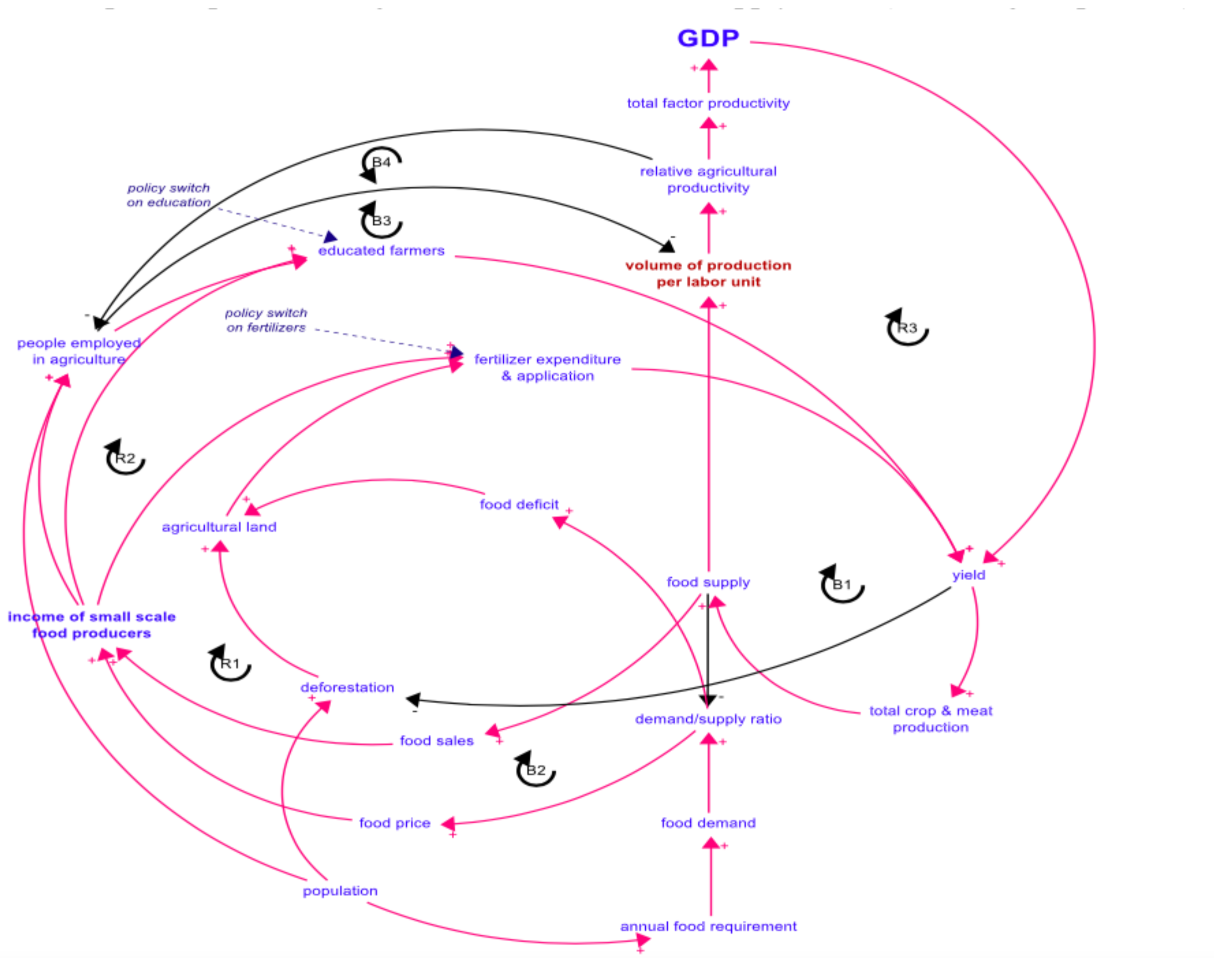


Figure 1. Causal Loop Diagram showing the impact of a growing population on agriculture land, forest land, food production, GDP

Source: created by the authors in Stella Architect Software

Another consequence of a growing population and an increased income is the fact that there will be more farmers employed to increase the yield through education and eventually also food production (reinforcing loop 2, R2). Note that if farmers can enhance their yield, they will need less arable land for the same amount of production. In this way deforestation can be decreased, giving rise to a major balancing loop (B1). Agricultural productivity, which is defined as the volume of production per labour unit (farmer), is a pivotal element considering food security. Moreover, if the current productivity of farmers could be increased, the Government predisposes itself towards prosperity by triggering a very strong reinforcing feedback loop (R3) via an increase in GDP. The positive effect on GDP will increase the food supply even more and drop food prices through a decreased demand/supply ratio (balancing loop 2, B2). Hence, paving the way towards more affordable food for everyone, and, thereby realizing SDG2.

The modelling project started off by identifying the source of the low productivity in agriculture through conceptual modelling using causal loop diagrams. Based on the results of this exercise the desired trajectory for the future of the agriculture sector was proposed where the growth of the agriculture sector should be achieved primarily through improved productivity whilst stabilizing the agriculture land. Based on the results from the conceptualization, the initial model (that was developed throughout the first phase of this project) was edited through the following steps:

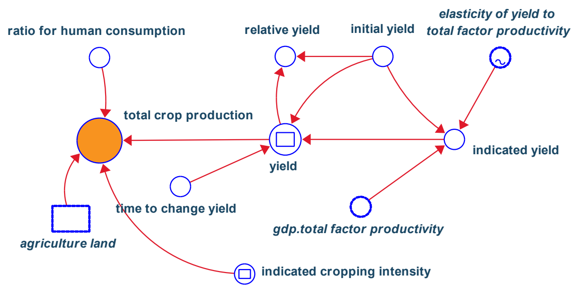
1. The agriculture system was added as an additional model structure consisting of the key processes driving food production, food demand, land use, yield and other parameters.

2. Based on the targeted trajectory for sustainable growth of the sector three possible policy interventions were introduced targeting increased productivity through increasing agriculture yields and reducing land degradation through the introduction of sustainable forestry methods, increasing livestock growth by implementing scientific techniques and increasing yield by training farmers.

3. Interlinkages between the agriculture sector and other sectors were established.

Below is the table that shows model sub-structures with their assumptions (on which sub-structure was based).

Table 1. Model sub-structures with their assumptions

<table>
<tr><th colspan="2">Model Sub-structures</th></tr>
<tr>
<td>Assumption: Annual food requirement (ton/year) is calculated based on daily food intake, 2.5 kcal/person/ day with array of plant and meat daily intake requirement multiply with calorie density of plant and meat products are average values of common food products consumed in developing countries.</td>
<td>

Assumption: Total crop production (ton/year) depends on yield, cropping intensity, and agriculture land. Yield changes with change in TFP. The ratio of total crop production for human consumption is 75% while the rest is used as livestock feeding.</td>
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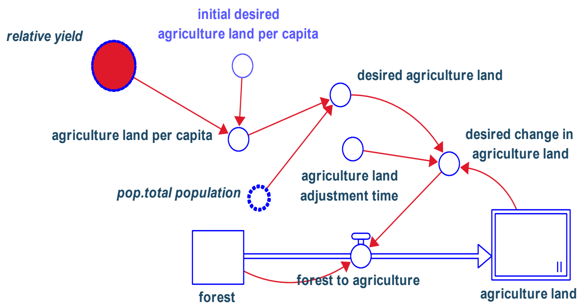
<td>

Assumption: The relative yield change will affect the forest to agriculture land conversion.</td>
<td>Assumption: Livestock is arrayed since the yield is relatively distinct between types of livestock.</td>
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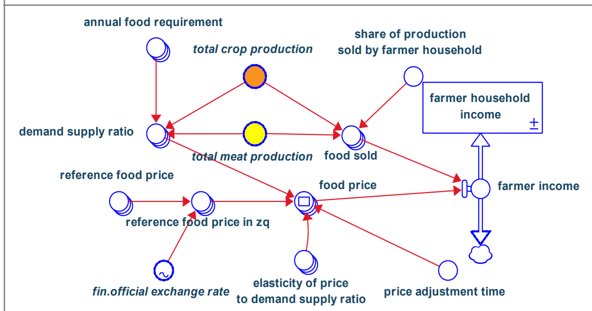
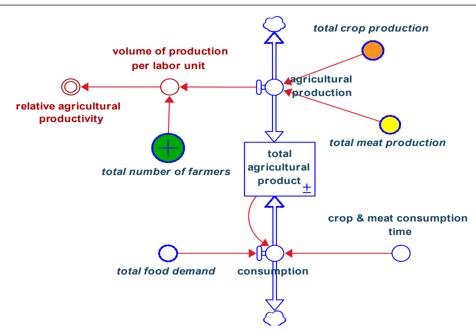
<td>

Assumption: The farmer household income relies on the food sold. The food price is affected by the demand supply ratio with the elasticity of price to supply demand ratio.</td>
<td>

Assumption: The agriculture production by number of farmers determines the volume production per labor unit. The relative change of productivity affects the TFP with the elasticity of TFP to agricultural productivity.</td>
</tr>
<tr>
<td>Assumption: All farmers spend the same amount of time training and acquire the same amount of knowledge during this period. There is no assumption that some farmers need more time to train. If the policy of education is on, It has influence on the effectiveness of educating system. The effectiveness of educating system influence time to train, making It less, and total productivity of farmers, making It increase. As a result, the more total productivity of farmers, the more effect of education system on yield.</td>
<td>Assumption: The policy for subsidizing fertilizer creates two effects: the effect of fertilizer application on yield and the effect of fertilizer application on cropping intensity. Through increase in yield and indicated cropping intensity these effects increase the total crop production. The policy of subsidizing fertilizer is through distributing free fertilizer to farmers instead of adjusting the market price of fertilizer in the country.</td>
</tr>
</table>

Assumption: If forestry conservation policy is on, then It has an effect on forestry regeneration time. The more available budget for policy, the less forestry regeneration time. As a result the inflow degraded land to forest will increase.	**Assumption:** The training of farmers in adopting scientific husbandary practices.

Source: created by the authors in Stella Architect Software

As result of the research, usage of system dynamic approach for food security showed it is ability to find solutions for the problems found. Three policy alternatives that were identified and proposed namely are: reducing post-harvest losses using hermetic storage technology, education to farmers about fertilizer use, and soil improvement methods to achieve a certain level of soil quality to produce rice, maize, and other crops and providing the fertilizer subsidies to increase production yields. The simulation results show the dynamics of agriculture land, forest land, yields and income with population change. The findings suggest that out of the three policy options, reducing post-harvest losses has got the biggest impact. Additionally, increasing farmer education on the fertilizers use and adoption of sustainable farming techniques is also desirable to reduce the productivity gaps.

References

1. Wheat, D. (2007). The Feedback Method. A System Dynamics Approach to Teaching Macroeconomics - Access mode: http://hdl.handle.net/1956/2239.
2. Shone, Ronald (2003). An Introduction to Economic Dynamics, Cambridge, NewYork, 224 p.
3. Guma, Rwashana, & Oyo (2018). Food Security Indicators for Subsistence Farmers Sustainability: A System Dynamics Approach.
4. World Bank (2008). World Development Report: Agriculture for Development, Washington, D.C., World Bank, 386 p.
5. Christos, Naoum, Dimitrios, & Eleftherios (2014). A system dynamics approach towards food security in agrifood supply networks: a critical taxonomy of modern challenges in a sustainability context. 9th Mibes International Conference, pp. 122-138
6. Bruinsma, Office of Assistant Director-General (Economic and Social Department) (2003). World agriculture: Towards 2015/2030, FAO world report, 444 p.
7. Sterman, J. D. (2000). Business Dynamics: System Thinking and Modeling for a Complex World. New York, Irwin. McGraw- Hill. 982 p.