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Exploring Symbiotic Cooperation of Smallholders for Sustainability and Food Security: A Spatio-Temporal Modelling Approach

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Introduction

According to The World Bank (2008), eighty two percent of the hungry people live in transforming countries in rural areas. International Food Policy Research Institute (IFPRI) claims that smallholder farmers in developing countries play a key role in meeting the future food demands, at the same time they remain the most insecure actors in food production.

One of the most notable features of an agricultural system is its reliance on natural resources (e.g. soil, sun, water, nutrients) and living organisms (e.g. crops and livestock, pollinators, soil organisms etc.). This makes agricultural systems and, consequently, food provision especially vulnerable in the face of global change and decline of resources such as phosphorus, freshwater, energy and other inputs (Akhtar, Wibe, Simonovic, & MacGee, 2013). According to Wani et al. (2013, from UNESCO (2013) – p.221), water scarcity and land degradation are the main constraints to realizing higher productivity and improving rural livelihoods in semi-arid regions.

One of the possible strategies to cope with resource scarcity and external shocks in agricultural systems is to create networks or clusters of smallholders allowing for more efficient and effective use of resources, sharing responsibilities, providing central coordination and better access to infrastructure, sharing knowledge and experience and benefitting from economy of scales. According to the International Fund for Agricultural Development (IFAD, 2013), partnership in agriculture can also take forms of co-financed investment projects, outgrower schemes, and other. Smallholders should join forces in cooperatives and associations, further extending partnerships with other private sector entities. Nowadays there is practical evidence of usefulness of such approach (e.g. CATALIST project - IFDC, 2012; Agreco - Pinheiro et al., 2002), however there is still a lack of a methodology and tools for systematic assessment and testing of different solutions in different conditions.

We are moving towards a conceptual framework and a quantitative simulation tool to study the dynamics of an agricultural symbiotic cluster/network in different conditions, to test the sensitivity of the system to the changes in objective functions and input variables, as well as to evaluate the impacts of the implementation of new policies and incentives. As a first step in that direction, we present a simple game Agent-based model to illustrate and test how exchange of labor force and land may affect individual and total productivity under different conditions. Two versions of the model represent two different partnership mechanisms – a more cooperative type, where farms give their surplus land to other farms from their social network in order to avoid land abandonment, and a business model, where farmers get employed at other farms.

Materials and Methods

The model links social and natural systems to highlight the complexity of the issues studied and illustrate interdependencies of the various components contributing to performance of a given system. The presented model assumes some simple rules, which will further require revision and calibration based on real-world data. In a simplified way it highlights importance of some of the factors influencing cooperation:

- Resources: random distribution and allocation among farms;
- Social ties: farms only have information about the other farms they have social relations with; thus, farms can establish partnerships only with the other farms within their social network;
- Behavior: a part of the farms are cooperators, meanwhile the rest of them have no willingness to establish partnerships. Even though the roles are pre-defined, farms can change their behavior due to the influence of the neighboring farms.
- Geography: at the moment geography-related factors are expressed only through the distance between farms and neighborhood concept influencing behavior (see the previous point).
- Environmental or climatic conditions: a share of harvest loss due to the adverse external shocks (pest outbreak, draught, etc.), can be controlled by a user

The model has been developed in the NetLogo environment[1]. The only resources taken into account at the moment are labor force and the amount of land a farm owns.

Some farms may have excess of agricultural land that they are not able to cultivate at the moment. Abandonment of the agricultural fields may lead to negative consequences for farming and food security, such as future costs to re-cultivate the land, higher risk of soil erosion especially if located in the drylands, risk of fires etc. As farms tending to cooperate come up with the solution to avoid abandonment of the excessive land, they offer spare fields to the farmers from their social networks with surplus labor force. The collaboration can be established under the condition that farmers cultivate the land in accordance with organic or conservation agriculture principles and implement soil erosion preventive measures. New land users retain most of the harvest with a small share paid to the landowners. If farmers from various different farms work on the land, the total harvest is shared proportionally to the time spent in the field.

Excess labor force not involved in agricultural activities out-migrates if jobs in the other economic sectors are available. Thus, perhaps farms' initiative to provide excess land to the unemployed farmers may reduce out-migration rates and improve local social situation. Collaboration is re-established every year. Updates of the social networks (some random social links can be destroyed and new ones can be created) can be switched on or off. When it is on, the social network is updated every year. In the current simplified model, change of population at each farm is not taken into consideration. The number of farm holdings can be changed as a parameter before the start of a simulation. The set of farms may be updated every year with the parameters characterizing the "death-" and "birth rates". Farms can also be destroyed if a negative performance threshold, set as a parameter, is exceeded (share of cultivated land or profit). Model interface allows to track changes of the crucial outputs such as profit depending on the land owned, farm population, labor force availability and environmental conditions; share of abandoned land depending on labor force availability and willingness of farms to cooperate, etc.

[1] NetLogo homepage: https://ccl.northwestern.edu/netlogo/

Results and Discussion

As the model has mainly an illustrative character, it only presents a hypothetical situation and does not rely on the real-world data. It, however, to some extent helps address the complexity of the studied system and lets understand possible underlying processes and links between the components comprising the system. Such simple game models can be used to communicate research ideas and coordinate them with the stakeholders in search of emergent properties and trends. The current model also allows experimenting with some parameters to explore some counterintuitive behavioral patterns, and to study scenarios under different conditions. Model interface with diagrams is presented in Figure 1. For illustrative purposes cooperation starts in the year 20, and the difference in aggregated profit before and after cooperation establishment can be easily observed.

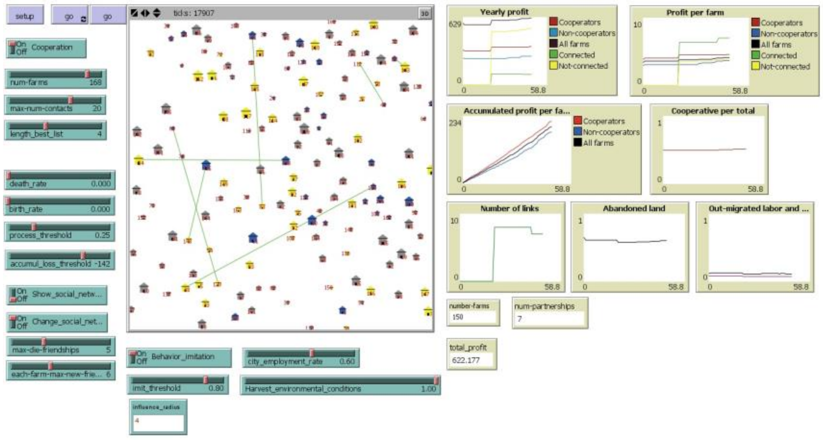

Fig. 1. NetLogo model interface

The benefits of collaboration for two groups of farmers – land providers and land users, can differ significantly based on the conditions under which collaboration is established. Another version of the model considered business relationships between the farms, where farmers are employed at the other farms and receive a specific reward for their work. In this case farms-employers are more vulnerable to conditions determining total harvest – in the cases of emergency (like pests outbreak), where high harvest losses may occur, they are still obliged to give an agreed amount of produce to the employed farmers.

The situation is different if the land is provided under the condition that land users can keep the major share of the crop, then responsibility for obtaining as much of produce as possible lies solely on the land users. In this case land owners may request land users to provide a small share of the total harvest as a reward. Also land owners benefit from the fact that their excessive lands remain cultivated. If managed according to the land use agreement (e.g. implementation of organic farming principles and erosion preventive measures), fields' quality may be improved.

Further on, the model will require more inputs, such as existing theoretical knowledge on cooperation and real-world data to improve the design of the model, parameterize and validate it, as well as to present a model in a spatially explicit framework.

In fact, even with its illustrative character, our toy model helps identify or prioritize research questions for further work. For example:

1. What conditions should be met to push farmers into cooperative behaviour, and what factors determine performance of cooperative groups or networks?
2. Can cooperation improve local social and environmental situation? If yes, to what extent?
3. How may emerging spatial patterns (e.g. land use or environmental impact patterns) affect regional sustainability and biophysical situation?

On further stages of model development it will be interesting to integrate and analyze geography-related aspects using real-world geographic data. For example, spatial distribution of resources and farms, topography and other aspects that may affect establishment of cooperation. Also distribution and fragmentation of cultivated and abandoned fields and their effects on the surroundings and regional sustainability can be a matter of interest. Reflecting applied agricultural practices and their effects on the environment in the model can be crucial to evaluate effects on sustainability of the current farming system.

Conclusions and Outlook

This paper briefly describes a research idea where cooperative networks of agricultural smallholders are studied as a potential means for sustainability enhancement of the local farming systems. As agricultural land use systems usually do not consider sophisticated interactions between farm households, we are moving towards a quantitative simulation tool to study different cooperation scenarios between farms and effects of those interactions on local sustainability. As a first step in this direction, we have developed a simple illustrative agent-based model to simulate two scenarios of cooperation between smallholder farms in order to exchange labor force and land. Such illustrative models help understanding the complexity of the studied system and possible design of a more sophisticated model in the future, as well as communicate research ideas with the stakeholders. It provided an initial insight into possible consequences of partnership in different conditions. Depending on the organizational structure, underlying rules and mechanisms of interactions, cooperation can have different effects on different groups of involved actors, especially under the effects of external shocks. For example, a presented business model fails under the conditions, when farms unpredictably experience high harvest losses, whereas more cooperative type of model shows better performance. The presented model provided some understanding of the interactions between system's elements and triggered new ideas for further developments. It also lead to better understanding of data requirements. The model to some extent allowed to explore capabilities and suitability of NetLogo environment to model direct interactions among agents for exchange of resources. Further, we will see whether NetLogo and its extension package can still be sufficient for our purposes in the development and analysis of more complex systems, such as embedding cooperative groups or networks in the spatially explicit ecological framework.

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