Assisting smallholder farmers in mixed crop-livestock systems to understand the potential effects of technologies and climate change through participatory modeling

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Abstract
Smallholder farming systems in the semi-arid areas of Zimbabwe are characterized by low production. This low production is not solely due to lack of technologies but also due to a lack of integrating a diversity of viewpoints belonging to local, expert and specialized stakeholders during technology development. Participatory approaches combined with computer-based modeling are increasingly being recognized as valuable approaches to jointly develop sustainable agricultural pathways. The paper discusses the application of this integrated and iterative process in developing and evaluating the impact of interventions aimed at improving food and feed production. The paper concludes that the process allows farmers to determine the impact of their decisions, evaluate new options and define realistic production and management options tailored to their particular circumstances. While in-turn scientists and other stakeholders learn more about the farmers' decision-making process, input and managerial potentials as well as knowledge gaps.

Key words: participatory, modeling, crop-livestock systems, APSIM

Introduction
Smallholder crop-livestock production systems in Zimbabwe are complex systems with various interacting subsystems (biophysical, socio-economic, institutional) that change in response to various interrelated drivers such as increased demographic pressure and climate change, as well as market opportunities and policy interventions. Smallholder farmers and the research community are challenged to respond to the changes in these systems. In addition to the issue of complexity and change, current productive resources in these systems are both limited and being used inefficiently, as evidenced by low production. A shift towards resilient and more productive systems is the key to secure future food security.

The low productivity of these systems is not solely due to lack of technologies, but also due to a lack of integrating a diversity of viewpoints belonging to local, expert and specialized stakeholders (Jones et al., 2008). The conditions under which technologies are developed and used to benefit the farmers matters a great deal. Methods used in technology development mostly lack collective knowledge and visions on how to manage natural resources to effectively benefit the communities. For a number of years now, developed interventions aimed at improving these farming systems have had no impact mainly due to low/non adoption. Low adoption can be attributed to lack of stakeholder participation in developing the technologies, and lack of consideration of market accessibility and incentives (Dorward et al., 2003). Consequently, for research and development to have an impact on systems efficiency, there is need for joint understanding of the potential intervention points based on an understanding of the system's individual components and their interactions in space and time (Ostrom et al., 2009).

Participatory methods have been known to improve adoption because of stakeholder inclusion in technology development, implementation and marketing of the products (Jones et al., 2008). In dealing with changing complex systems natural resource management initiatives are increasingly

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turning towards participatory modeling procedures to effectively integrate local, expert and specialized stakeholder sources of knowledge. Participatory modeling combines a participatory research approach and a computer-based modeling that engages farmers, experts and specialized stakeholders in developing management practices responding to constraints in the system (Cabrera et al., 2008, Jones et al., 2008). Importantly it allows generating better understanding of farmers' preferences, their preparedness to adopt certain technologies and the risk they associate with those. It also provides a valuable framework for systems analysis as it allows us to analyze individual components of complex systems to understand simplistic relationships between inputs and outputs. Participatory modeling can also assist in conducting an ex-ante impact and interaction of increased management input and increased diversity (agro-ecological as well as economic opportunities) and also to determine efficient risk reduction strategies in the context of climate change.

Participatory modeling has been used to achieve relevant and significant interventions in commercial farm management systems in Australia (Cabrera et al., 2007). This approach however has been struggling for relevance in smallholder farmer decision-making processes in Sub-saharan Africa (Carberry et al., 2003). To date participatory modeling has not yet received any significant attention in complex farming systems of Zimbabwe. Constraints to application of this tool are mainly lack of data (soil, climate, crop) and also expertise in the modeling field. This paper attempts to share experiences where participatory biophysical modeling was used to develop and test management practices aimed at improving feed and food in crop-livestock mixed systems in the semi-arid areas of Zimbabwe.

Modus de Operandi

Participatory Modeling combines a participatory research approach and a computer-based modeling that engages farmers, experts and specialized stakeholders in developing management practices responding to constraints as identified through Participatory Rural Appraisals (PRA) (Figure 1). The practice of modeling is also useful in assessing risk and uncertainty associated with the developed management practices and can also assist in exploring a range of constraints and solutions at varying scales. The integrative and iterative participatory approach brings together stakeholders who define the farming systems, constraints and responsible actors. Solutions are highlighted and are dealt with accordingly. For example, biophysical constraints and solutions are worked into biophysical models, whereas those that are related to the socio-economic side will be input into relevant models or directed to developmental organizations or the government. An example of constraints and possible solutions that can be assessed using a biophysical modeling approach are shown in Table 1. Long-term productivity of the selected options and impact of climate change are demonstrated to assist farmers and other stakeholders, especially policy makers, in decision making and agricultural pathway development. Options are then tested under field conditions and results are shared using the same platforms and improvements are made as new situations arise.

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In practice, the participatory modeling approach is composed of three-day workshops with farmers, experts and other stakeholders. Farming systems and management practices are defined with the aid of resource flow maps, which include farmers' previous season production information. These together with expert knowledge are used as input data for bio-physical models, the Agricultural Production Systems Simulator Model (APSIM). which has been tested and calibrated for smallholder farming systems in Zimbabwe (Shamudzarira 2002, Robertson et al., 2005, Ncube et al., 2008, Masikati 2011). Confidence in the modeling process is built by first simulating previous crop production based on farmers' experiences. Results are shared with farmers and stakeholders so they gain confidence in the model's predictive capacity on performance of selected management practices. After the predictive capacity of the model is tested it can be used to answer "what if" questions and also to assess impact of climate change on base systems and alternative systems.

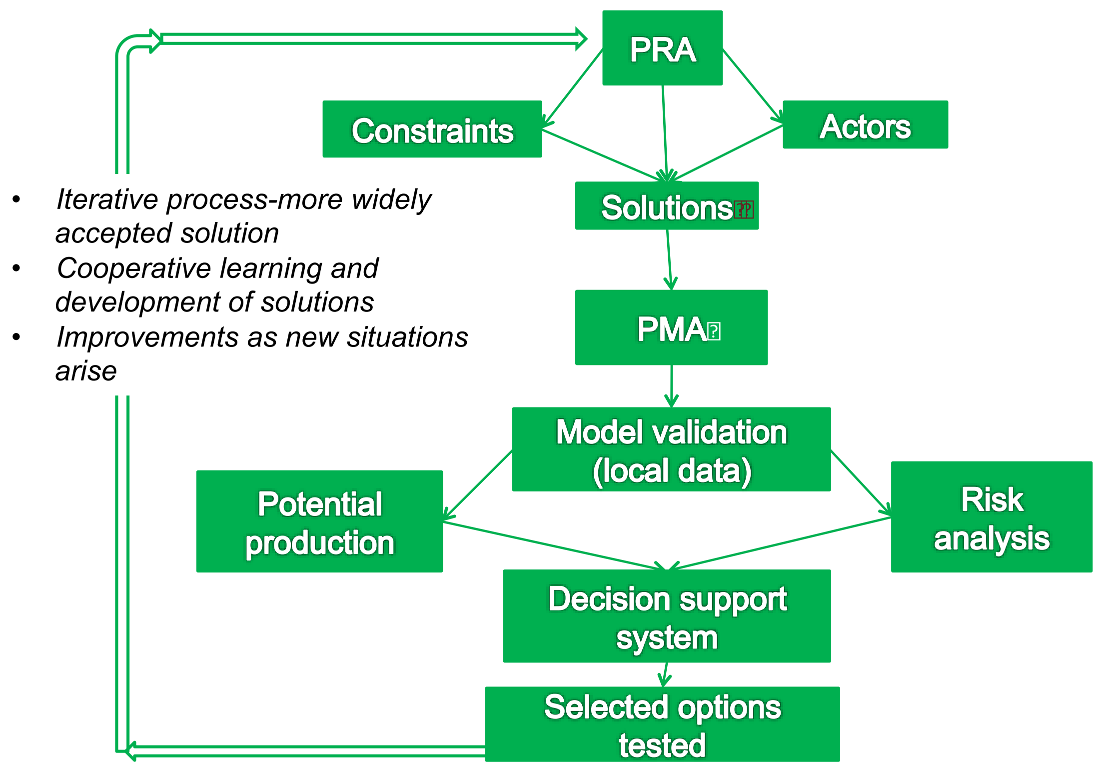

Figure 1. Interactive and iterative process in developing agricultural pathways aimed at improving production in smallholder farmers of Zimbabwe (PRA – Participatory Rural Appraisal; PMA – Participatory Modeling Approach)

Constraints addressed using simulation modeling

Feed shortages during the dry season and poor soil fertility are some of the major constraints to livestock and crop production in smallholder farming systems. Farmers in the study area can only attain on average 40% per year or less of own produced food while the rest is bought mainly using income from livestock (ICRISAT surveys 2012). On the other hand, livestock/cattle production is very low (milk yields <1.5 l $cow^{-1}day^{-1}$, off-take rates 0.8-3% $year^{-1}$ and mortality rates >17%). We therefore used the participatory modeling approach to examine possible interventions that can be used to improve the whole farming system. Together with the farmers and other stakeholders we settled on: alleviating feed shortages and improving soil fertility through inclusion of forage crops into the system. We selected inclusion of legume fodder crops mainly because they have potential to improve soil fertility and feed quantity and quality. In the study area, less than 3% of farmers grow forage crops; hence, this makes it a good intervention to evaluate potential production in the short and long term and also to assess the impact of climate change. The APSIM model was used to assess the potential of crop residues to improve soil fertility and also to alleviate feed shortages during the dry season. Table 2 shows the assumptions made in scenario development.

Table 1. Selected biophysical related challenges, possible solutions and responsible actors within crop-livestock systems in the semi-arid areas of Zimbabwe, identified during the PRA meetings.

Challenges	**Solution**	**Responsibility**
Poor soil management/fertility	Use of soil fertility amendments (organic and inorganic) Crop rotation water management technologies	Farmer and Extension
High input costs	Use of retained seeds, soft loans, subsidized inputs, organic fertilizers	Farmer, Grain Marketing Board, Government, Non-Governmental Organizations
Dry season feed shortages, poor grazing veld (deterioration uncontrolled grazing), expensive commercial stock feed	Growing fodder crops Creation of fodder banks Rotational grazing system	Farmers, Agriculture Extension Services, Livestock Production Department, Department of Research &Specialists Services, Non-Governmental Organizations

Model inputs

Simulations were run for 30 years from 1980 to 2010 using daily weather data (precipitation, minimum and maximum temperatures, and solar radiation) recorded by the national weather bureau of Matopos Research Station. Sandy soils (Appendix 1), which are predominant in the smallholder farming systems of Zimbabwe, were used for the simulations. A short-duration maize variety SC401 and mucuna were planted at 3.5 and 10 plants m^{-2}, respectively, and the sowing window was from November to December each year. Downscaled Global Circulation Model (GCM) data from 2040-2070 were used for future scenarios (Climate Systems Analysis Group-University of Capetown). The treatments evaluated were the Control (FP- no fertility amendments), Micro-dose (MD- 50kg Ammonium Nitrate fertilizer) and Maize-Mucuna Rotation (MMR- maize grown in rotation with mucuna). All treatments were weeded twice at 25 and 50 days after sowing. Crop residues were removed to simulate cut and carry systems; however, under the MMR treatment 30% of mucuna residues were left as surface organic matter each year. An average farmer with household size of 9 people and land and cattle holdings of 3 ha and 15 heads, respectively, was used. Area devoted to maize was 3 ha under the FP and MD treatments while under the MMR treatment 1,5 ha was devoted to maize and the other 1,5 ha to mucuna in a rotation system. Although farmers would have other animals such as goats and donkeys we only used cattle as they are bulk grazers and to keep the model simple at this stage. To compensate for this, the number of cattle was inflated to cater for the other animals.

Table 2. Cattle dry matter requirements

Average cattle holding*	15 heads
Average live weight*	300 kg
Approximate daily dry matter intake**	2.5% of live weight X 60%***
Critical feed shortage period*	August to November (~120 days)

*ICRISAT survey, (2008); **FAO, (2002), *** Animals only get about 40% of required DM from pastures during the dry season (Ngongoni et al., 2007; Mapiye et al., 2009)

Results and discussion from APSIM model

The results from the model shows that the MMR treatment can be used as an alternative technology that can improve total on-farm productivity in mixed crop-livestock systems, and hence make a significant contribution to poverty reduction. For example, the average number of people per household in the study area was 9, and each person requires about 120 kg of grain per year[2]. Total grain required per household would be about 1100 kg yr^{-1}; average maize grain production under the MMR treatment was 2200 kg ha^{-1}. On average, a household can thus have about 1000 kg yr^{-1} of surplus grain. This surplus can be sold or stored in silos for later use, especially when a drought year is forecasted. Cash obtained from grain sales can be used to buy vaccines to improve livestock health and hence improve productivity. In this scenario, maize will serve as both food and cash income, and hence demonstrates potential to reduce poverty and hunger in smallholder farming systems. On the other hand, the biomass obtained from the MMR treatment can also satisfy DM requirements of an average head size of 15 animals for 120 days during the dry season. This would ensure that animal conditions are maintained and farmers would have access to draft animals to plough their fields and also to have animals that can fetch better prices at the market.

From the simulations done using future climate (2040-20170) grain and stover sufficiency under the MMR treatment are expected to be reduced by about 20 and 10% respectively while grain sufficiency will be reduced by about 15% under the MD treatment. However, there will be expected yield increases on both grain and stover under the FP treatment, but although these increase, they will not be able to produce enough grain and stover to attain the required food and feed sufficiency. Increments in production under the FP treatment will mainly be caused by a doubling of carbon leading to higher storage of nitrogen in soils as nitrates, thus providing higher fertilizing elements for plants, providing better yields (http://en.wikipedia.org/wiki/Climate_change). Decreases under the MMR treatment will be caused by water stress under high fertility system. It is forecasted that in the future “the average need for nitrogen could decrease and give the opportunity of changing often costly fertilization strategies” (http://en.wikipedia.org/wiki/Climate_change).

[2] Maize intake g/person/day = 330.9 (FAO, 1992)

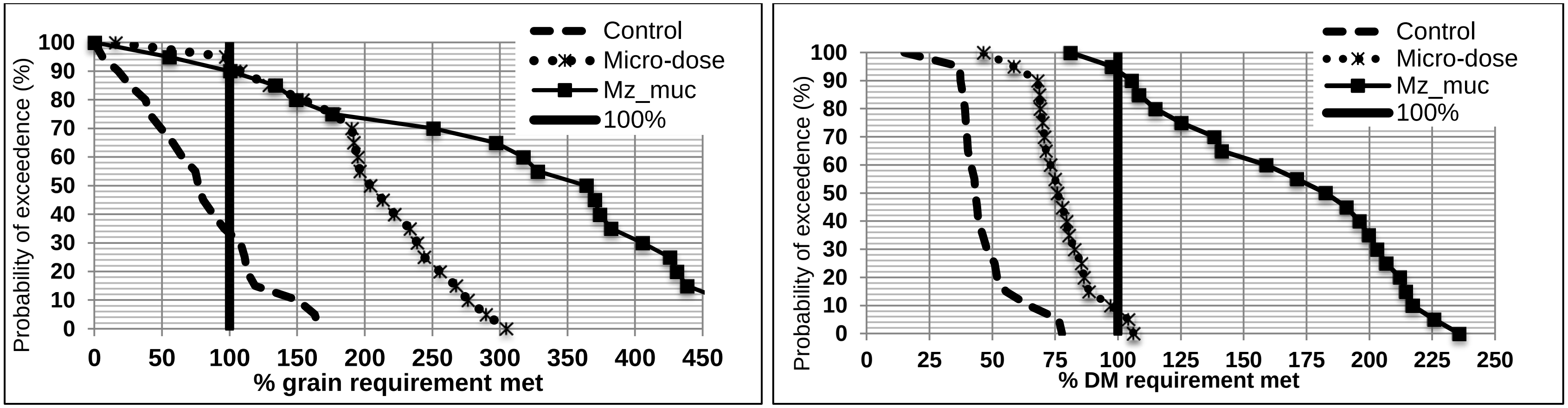

Figure 2a. Probability of exceeding required grain and dry matter for a household of 9 people with 15 heads of cattle doing crop production on 3 ha of land, simulated over 30 years using historical climate data (1980-2010)

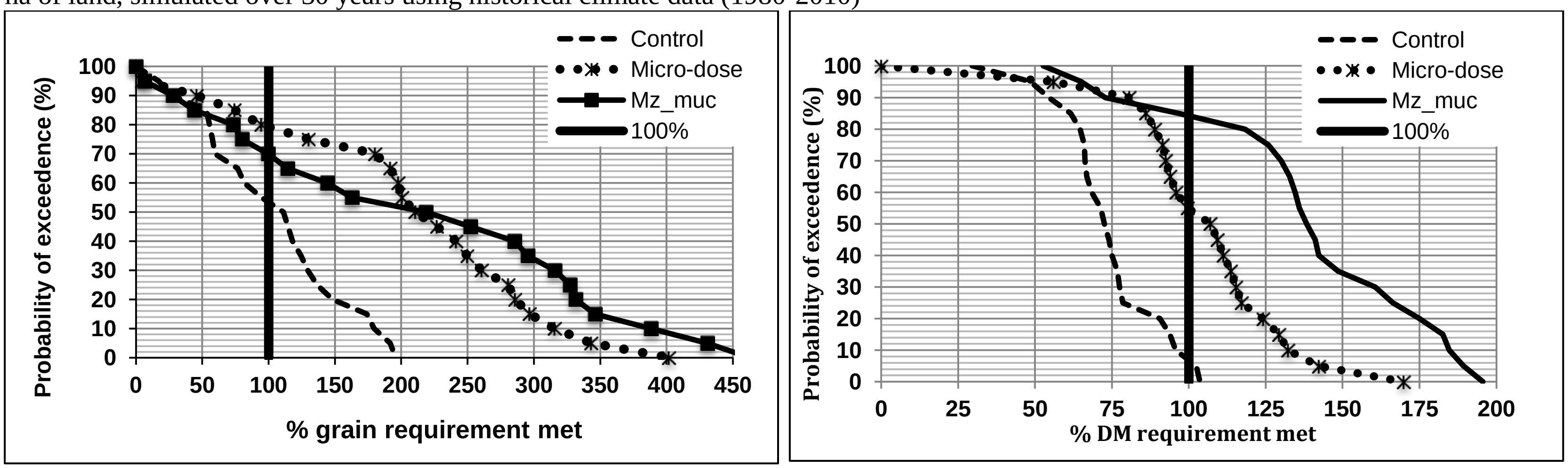

Figure 2b. Probability of exceeding required grain and dry matter for a household of 9 people with 15 heads of cattle doing crop production on 3 ha of land, simulated for 30 years using future climate data (2040-2070)

Conclusions

The complex nature of crop-livestock systems means that there are many entry points for interventions and a wide range of technologies and strategies on offer. This, coupled with the diverse nature of farmers' abilities, knowledge and willingness to invest, makes management recommendations complicated and technology adoption rates low. Computer-based participatory modeling offers scientists, farmers and specialized stakeholders a tool to develop and evaluate the impact of interventions at varying scales in time and space. The process allows farmers to determine the impact of their decisions, evaluate new options and define realistic production and management options tailored to their particular circumstances. In turn, scientists learn more about the farmers' decision-making process, input and managerial potentials as well as knowledge gaps.

Currently three projects funded by CPWF, ACIAR and DFID are using testing these options in four districts in the semi-arid areas of Zimbabwe. They aim to scale up the options mentioned here and others using the Innovation Platforms and Participatory modeling approach. Although these tools are powerful in developing pathways that can be used for sustainable agricultural production, there are still challenges that can impede the use of the tools. These are mainly lack of data (soil, climate and crop) and also computer modeling expertise.

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Appendix 1

Initial soil organic carbon (OC), nitrate-nitrogen (NO_3-N) and soil physical properties used in the simualtions

Parameter	Soil Layer (cm) 0-15	15-30	30-45	45-60	60-75	75-100
OC (%)	0.52	0.43	0.35	0.30	0.21	0.21
NO_3-N (ppm)	3.08	2.16	2.30	2.21	2.55	1.07
Airdry (mm/mm)	0.03	0.07	0.09	0.09	0.09	0.09
LL 15 (mm/mm)	0.06	0.10	0.13	0.13	0.18	0.22
DUL (mm/mm)	0.16	0.18	0.19	0.20	0.22	0.24
SAT (mm/mm)	0.41	0.41	0.41	0.37	0.36	0.34
Bulk density (g cm^{-3})	1.43	1.42	1.42	1.55	1.55	1.61
cn2-bare	85					
u	6					
cona	3.5					