Title

Short-term versus long-term decision trade-offs: Evidence from a model-based observational experiment with African small-scale farmers

Short title

Short-term versus long-term decision trade-offs

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Abstract

Smallholder farmers in sub-Saharan Africa recurrently face situations of complex and dynamic decision trade-offs. Short-term oriented activities such as fertilizer application help to cover immediate food needs, however compromise on future food production. Long-term oriented production activities such as building up soil fertility are important systemic leverage points, however, they compromise on today's harvests. This article uses a semi-computerized observational experiment in Zambia to investigate farm management decision-making with conflicting production objectives in a dynamic context. The results reveal that, overall, Zambian smallholder farmers have a strong and significant preference for short-term oriented production activities, which leads to a suboptimal performance in production in the long term. A mind shift towards more long-term oriented production activities is required to sustainably increase food production. Our findings point at two things in this regard: First, we identify decision rules that successful performers have applied and that should be the basis for capacity building strategies. Second, we indicate that our approach itself contributed to recognition of the importance of a longer-term perspective.

Keywords

Africa; dynamic decision making; observational experiment; food security; system dynamics

1 Introduction

Food insecurity and hunger are on the rise again in sub-Saharan Africa (SSA), mostly because of conflict and climate change (FAO, 2017). The challenge to feed a growing and more demanding population is exacerbated, among others, by low levels of nutrients and organic matter in the soil and unsustainable water withdrawals (Foley *et al.*, 2011). This highlights the urgent need for approaches that enhance food production in a sustainable way. Soil fertility and soil organic matter (SOM) play a central role in this context as they affect agricultural productivity in general and resource efficiency in particular (Kumwenda *et al.*, 1997). Soils rich in SOM also have the potential to buffer external shocks such as droughts or unavailability of synthetic fertilizer (Gerber, 2016; Stave and Kopainsky, 2015). Currently, however, SOM levels are low in SSA, and replenishing SOM levels is a long-term process that conflicts with farmers' short survival-oriented time horizons (Donovan and Casey, 1998). As a consequence, public agricultural policy in many SSA countries focuses to a large extent on efforts to increase synthetic fertilizer use through fertilizer subsidy programs (Banful, 2011; Jayne and Rashid, 2013). The application of synthetic fertilizer is effective in enhancing food production in the short-term. However, synthetic fertilizer application fails to effectively increase SOM stock levels in the long-run (Gerber, 2016; Morris *et al.*, 2007). Farm practices such as conservation agriculture, among other things, improve soil fertility and accumulate SOM. International donors have therefore been promoting conservation agriculture in SSA for extended periods of time. However, conservation agriculture has so far not been able to play a dominant role to the extent that it could become a real alternative to fertilizer subsidy programs (Giller *et al.*, 2009). This indicates a need to better understand how farmers make and adjust decisions, in this context, budget allocation decisions, over time.

Farmers' decisions on whether to allocate their available budget to a short-term solution (purchasing synthetic fertilizer) that compromises sustainable long-term production or to tolerate lower harvests today but increase food production in the future (investing in the replenishment of SOM) is representative for a wider family of decision trade-offs. These decision trade-offs are characterized by capability traps (Repenning & Sterman, 2001; Repenning & Sterman, 2002) or the archetype "shifting the burden" (Senge, 1990) and they are at the heart, among others, of sustainability transitions (in the agricultural context, e.g. Banson et al., 2016; Brzezina et al., 2017). In the "shifting the burden" terminology, the problem symptom of low yields can be relieved by the symptomatic solution, purchasing synthetic fertilizer. Continuous use of synthetic fertilizer, however, has two side effects: first, it diverts attention away from the fundamental source of the problem, i.e., low soil fertility. Second, it makes the application of the fundamental solution, the replenishment of soil organic matter, more and more difficult, thus reinforcing the perceived need for more synthetic fertilizer.

The complexity of the decision trade-off in the context of farm budget allocation is increased by the fact that farmers make individual budget decisions that generate outcomes on several levels. Yield is specific to the individual farm. The aggregated production of individual farms, on the other hand, affects the market price and the market price, in turn, determines the farm's budget for the next growing season and thus for subsequent decisions on the individual farm level.

The objective of this paper is to provide empirical evidence on dynamic decision making on the farm level and to understand what facilitates farmers to prioritize the fundamental solution to their sustainability challenge. We focus on maize dominated farming systems in Zambia. Zambia shares population growth and food insecurity challenges as well as food production system characteristics with many SSA countries. Zambia's food production system consists predominantly of smallholder farmers who consume large shares of their harvests and only sell parts to generate cash (Tembo & Sitko, 2013). Maize is the staple food for a considerable number of people and it has accounted for more than half of the population's total caloric intake since the mid 1980s (FAO,). The literature about farm decision-making in Zambia is limited to topics such as adoption of technology (Grabowski *et al.*, 2016; Langyintuo and Mungoma, 2008; Umar, 2014), identification of the household decision maker (Kalinda *et al.*, 2000), production decisions in response to public market interventions (Mason and Jayne, 2013; Mason *et al.*, 2015; Xu *et al.*, 2009), normative decision modeling (Holden, 1993; Katongo, 1986), and static farm expenditure decisions (CSO, 2015). The dynamic nature of farm budget allocation to competing production activities, however, is largely overlooked in Zambia as well as in SSA at large.

This article contributes to filling this gap by applying a dynamic, semi-computerized observational experiment to the case of maize-producing smallholder farms in Zambia. In the experiment, subjects iteratively decide on how to allocate a yield- and price-dependent budget between fertilizer purchases (representing a strategy to enhance maize production in the short run) and addition of organic matter to the soil (representing a strategy to enhance maize production in the long run, e.g., by retaining crop residues on the field or application of manure). Subjects' individual decisions contribute to overall market outcomes such as total production and price. This has an impact of farm budget and thus on next year's expenditures. While an experimental design that combines individual and aggregated outcomes complicates data analysis, it is important for two main reasons. First, it ensures external validity of the experiment in that it reflects the fragmented nature of agricultural product markets in SSA (The World Bank, 2013). Second, it adds transparency to the experiment in that subjects are fully aware of the fact that there are other players in their market (rather than abstractly formalized market participants in a simulation model). Despite suspicions of a strong preference for short-term rather than long-terms solutions (cf. the high discount rates mentioned in Donovan and Casey, 1998 or the effect of wealth on decisions under risk in prospect theory, Kahneman & Tversky, 1979) our approach is exploratory. This is grounded in the observation that so far, the high discount rates are based on assumptions rather than empirical evidence. Additionally, the complexity introduced by an interaction of individual and aggregated outcomes differentiates our case from other "shifting the burden" settings and makes hypothesis formulation and testing more difficult.

Our study contributes to existing literature and to the policy debate in several ways. First, we corroborate previous assumptions that farmers prioritize short-term strategies over long-term strategies. Second, we find that the more successful farmers decide dynamically based on farm and market information, while less successful farmers decide based on non-dynamic, a priori heuristics. Third, we test the different decision heuristics in a dynamic simulation model and find that the performance of some heuristics depends to a large extent on the endogenous interaction with the heuristics of other players in the same market. Fourth, we find that the semi-computerized observational experiment contributed to the formation of more dynamic decision heuristics and a deeper understanding of the dynamic complexity underlying farm decision making. Our findings are relevant to decision makers and practitioners as a base for sustainable policy formulation.

The remainder of this article is structured as follows. In the next section the experimental design and analytical methods are described. Then, we present the results of the experiment, detect decision patterns and their underlying heuristics, and analyze the heuristics' dynamic implications in terms of performance. Finally, we discuss our findings and draw conclusions based on the results and analyses.

2 Experimental design and analytical methods

2.1 Experimental design and setup

We use a semi-computerized experiment of a five-player market justified in detail in Gerber (2017). The five players (subjects) in this market cannot communicate with each another to avoid collusive behavior. The experiment is based on a bio-economic system dynamics model that investigates the dynamic interaction between fertilizer application, soil organic matter, maize production and maize availability in Zambia. This model integrates production theory, soil dynamics, plant nutrition, and commodity markets (Gerber, 2016). The model, originally developed for national-level policy analysis, was adjusted for the purpose of our experiment. The main adjustments include: constant population, constant arable land area, and differentiation of the production sector in the form of five farms (each managed by one subject). The model contains subject-specific sectors such as the farm sector as well as more general sectors such as the aggregated product market where subjects interact.

The key element of the experiment is dynamic farm endowment. Dynamic farm endowment refers to the mechanism with which the current budget of subject i is determined. This depends on the market price at time t-1, subject i's production, a non-linear share of the subject's production that is sold and a constant share of the total farm income that is allocated to either fertilizer expenditures or investments in soil improvement. Each round, subjects decide on how to allocate their budget and once they make this decision, the simulation model advances by four years before new decisions can be formulated. The full model is specified in Vensim® and available as supplementary material. Figure 1 provides an overview of the model's core feedback mechanisms.

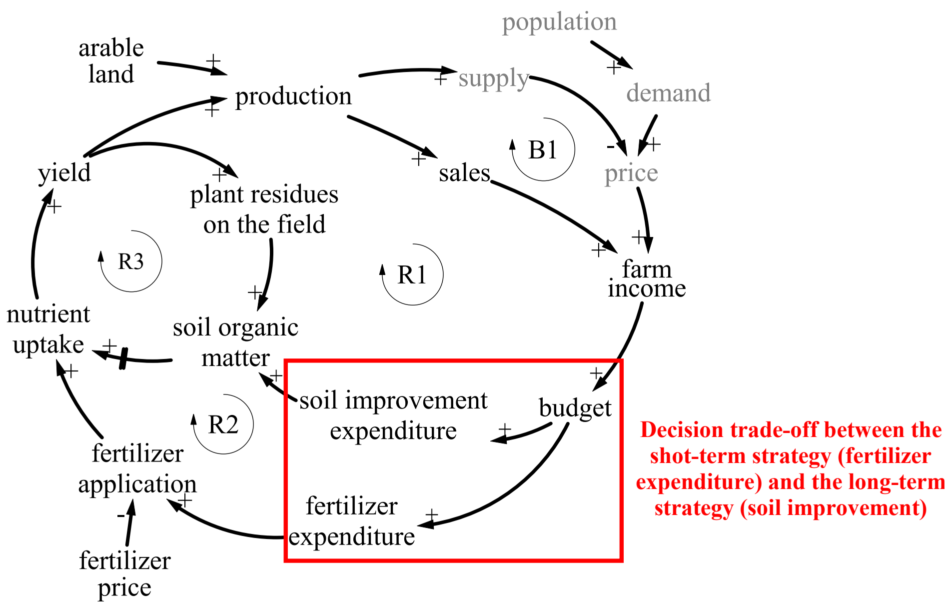


Figure 1: Causal loop diagram of the system dynamics model (Gerber, 2017: 114).

Notes: Variables in black are calculated for each subject individually, grey variables are aggregates. Arrows indicate causal relationships directed towards the arrowhead. A plus (+) at the arrowhead denotes a positive relationship (where the effect changes uniformly directed to the cause) and a minus (-) denotes a negative causality (where the effect changes reversely directed to the cause). Feedback loops consist of circular chains of causal relationships and are either reinforcing processes (which self-reinforce the current behavior) or balancing processes (which adjust the behavior towards a goal). R1: reinforcing soil improvement feedback loop; R2: reinforcing fertilizer feedback loop; R3: reinforcing soil organic matter feedback loop; B1: balancing supply feedback loop.

Higher yields increase production, sales and farm income and thus a farm's budget for the next growing season (R1- and R2-feedback loops, Figure 1). Higher yields, however, also increase aggregated market supply and thus lead to a lower price. This in turn lowers farm income and results in a lower budget for the next growing season (B1-feedbak loop). Through competition among subjects, the B1 loop thus partly offsets benefits from R1 and R2 loops. In addition to these market-centered mechanisms, the R3 loop describes key biological mechanisms. The addition of plant residues to the SOM stock increase yield and thus food availability and budgets with a delay. At the same time, SOM increases farms' resilience to variations of external forces such as public policies (e.g. fertilizer subsidies).

The experiment lasts nine rounds of four years each, in total 35 years. The four-year interval between decision points allows for soil dynamics to unfold before subjects need to make new decisions. As a result of the need to cover household needs, Zambian smallholder farmers maximize production rather than profits (Umar, 2014). Thus, we used total accumulated maize production of each subject as a performance criterion

Figure 3 shows trajectories of this performance indicator for three illustrative cases: the benchmark or optimal allocation of fertilizer, a situation where the entire budget is allocated to fertilizer, and a situation where the entire budget is allocated to soil improvement. In the first rounds, performance is higher if a short-term strategy is adopted. After this initial period, however, long-term strategies outperform short-term strategies and do so even more the more time progresses.

We calculated a near-optimal allocation pattern of the percentage share of expenditure to fertilizer using a Powell hill-climbing algorithm. The resulting benchmark trajectory leads to the highest accumulated production under the premise that all five subjects apply the same strategy. According to Figure 2a, the highest accumulated production can be achieved if a subject starts by prioritizing soil improvement to build up SOM stocks (R1 and R3 loops, Figure 1). Subsequently, a somewhat higher share of the budget can be spent on fertilizer to capitalize on the short-term benefits of this solution. The last two rounds in the benchmark strategy show clear end-of game behavior where the entire budget is allocated to fertilizer purchases in order to boost short-term production (R2 loop). As subjects did not show any such end-of game behavior, we modified the benchmark strategy for the two last rounds to a strategy that uses a going concern perspective (Figure 2b).

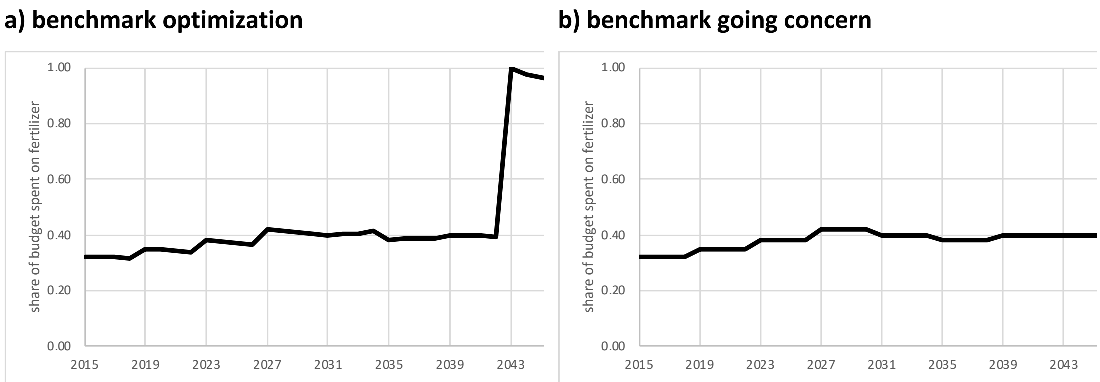


Figure 2: Benchmark share of budget spent on fertilizer

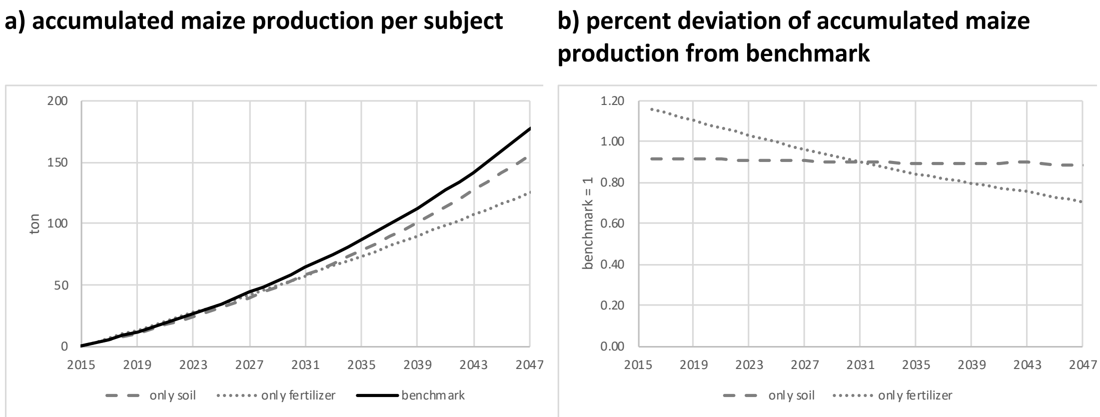


Figure 3: Performance (accumulated maize production) trajectories for short- and long-term strategies as well as for benchmark strategy (Figure 3a). Percentage deviation of performance from benchmark performance (Figure 3b)

2.2 Experimental procedure

We recruited and trained local field officers[1] who introduced and facilitated the experiments. The field officers helped subjects to understand the provided information and enter their decisions. However, they strictly avoided to advise on decisions or reveal structural properties of the simulation model beyond the information provided in the instructions. Experimental instructions were given verbally in local language following a standardized protocol (Appendix A). Instructions included information about the experimental farm (e.g. farm size and costs associated with the two decisions) and that all five players were endowed with farms identical in size and initial bio-economic characteristics. Instructions also explained the objective of the experiment, namely for participants to maximize their accumulated maize production over the entire period of the experiment.

Due to varying degrees of literacy and the rural context in which we were operating (low familiarity with computers necessity to perform the experiment outdoors), we applied a semi-computerized approach to data entry and outcome feedback. The experiment leader entered information about current market price and own current yield, production and budget on a physical record sheet for each subject (Appendix B). Field officers also communicated this information verbally before subjects decided on how to allocate their budget to the two expenditure categories. Field officers then transmitted the record sheets to the experiment leader who entered all five players' decisions in the simulation model and calculated the new market price, yield, production and budget as a basis for the next decision.

Experiments lasted between one and one and a half hours. Experiments were followed by a facilitated debriefing session in which farmers were asked to reflect on their decision strategy and to provide additional, qualitative information about their decisions.

Performance in the experiment was rewarded by five standardized, physical rewards that farmers need in everyday life[2]. The best performer could choose a reward first, then the second, until only one reward remained for the last participant. The legal and cultural context (e.g. strict rules related to gambling) made physical rewards rather than monetary rewards necessary. Monetary rewards would most likely also have distracted subjects from the farm mind-set, which we wanted to analyze. A final argument in favor of physical rewards is that choosing a reward based on the performance position within the group acknowledges the subjective normative judgment of different items (Kelly et al., 2015).

2.3 Subjects

The experiments were conducted in August 2016 in villages around Mumbwa, in Zambia's Central province. The main language in the villages is Tonga. Subjects were

[1] The field officers were local people that were trained in three steps: 1. The field officers took part in the experiment as subjects. 2. The field officers made supervised trial introductions and data collection among themselves. 3. The field officers were supervised and received feedback in the real experimental setting.

[2] 2kg sugar, 1kg sugar, 750ml cooking oil, big laundry soap and small laundry soap

recruited from smallholder farm communities. Thus, all subjects were real decision-makers on farms; however, they had no previous experience in related experiments.

A total of 15 experiments were conducted. With five players per experiment the overall subject pool comprised 75 farmers. None of the subjects participated in more than one experiment. Through the oral and written communication in the course of the experiment, we could assure that the subjects understood their experimental farm and the information they received. The subjects were engaged in the experiment and took the decisions carefully. Many of them made calculations on mobile phones, with pen and paper, or even in sandy soil. From the subjects' reaction during the presentation of the reward items and the award ceremony, it was clear that the physical items motivated the subjects to perform well. The order in which the reward items were chosen varied. This indicates differences in subjective normative judgments of the items and indicates some justification for the choice of physical rewards.

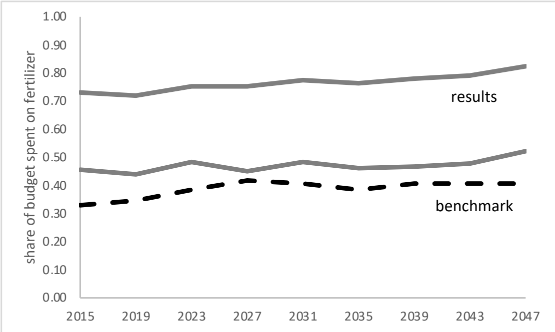
3 Results

Subjects made decisions on fertilizer and soil improvement expenditure in absolute terms, as they would on their real farms. However, given that a subject's individual budget also depends on other subjects' decisions in the same market, absolute decisions and decision outcomes cannot be compared to each other. For this reason, we analyzed expenditure relative to the available budget. We report on and analyze results in terms of the share of the total available budget a subject spent on fertilizer at each decision point. The share of the budget spent on soil improvement is the remaining share of the budget.

3.1 Performance

Figure 4 shows the 95 percent confidence interval for the share of the budget spent on fertilizer over all markets and all subjects (area spanned by the grey solid lines and labeled "results"). The dotted line represents the benchmark. On average, subjects start by spending between around 50 and 70% of their budget on fertilizer, rather than the 30% indicated by the benchmark. Their relative fertilizer expenditures increase over the duration of the experiment. The share of the budget spent on fertilizer is significantly different from the benchmark share and it is significantly higher than the benchmark in all years (one sample t-test, $p < 0.01$). Subjects therefore show a significant bias towards fertilizer, the short-term solution to increasing agricultural production.

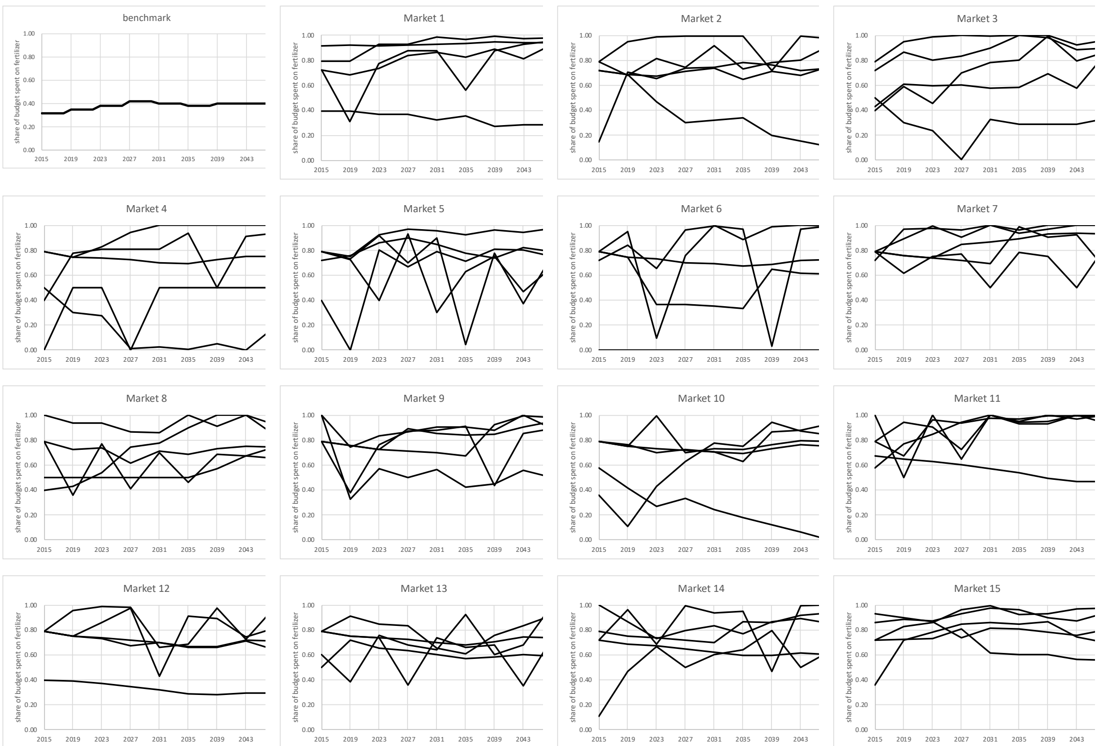
Figure 4: Benchmark (black dashed line) and 95 percent confidence intervals (grey solid lines) for share of budget spent on fertilizer.



3.2 Decisions and decision strategies

Figure 5 displays individual decision trajectories of all subjects, that is, the time-dependent trajectory of the share of the budget spent on fertilizer. The decision trajectories are grouped into the 15 markets of the experiment. The figure illustrates that decision trajectories vary between subjects as well as between markets.

Figure 5: Benchmark and decision trajectories of the subjects in the 15 markets.



The emphasis on fertilizer (rather than on soil improvement) expenditure, in combination with the varying decision and performance patterns revealed by Figure 4 and Figure 5, led us to further investigate the mechanisms linking decisions and performance. For this purpose, Figure 6 plots the decision trajectories of the top 20% (left hand side of the figure, n=15) and the bottom 20% subjects (right hand side of the figure, n=15). The top 20% subjects refer to those participants who were ranked first in their respective experiment. The bottom 20% subjects, on the other hand, are those participants who ranked last (5) in their experiment.

a) Rank 1 subjects **b) Rank 5 subjects**

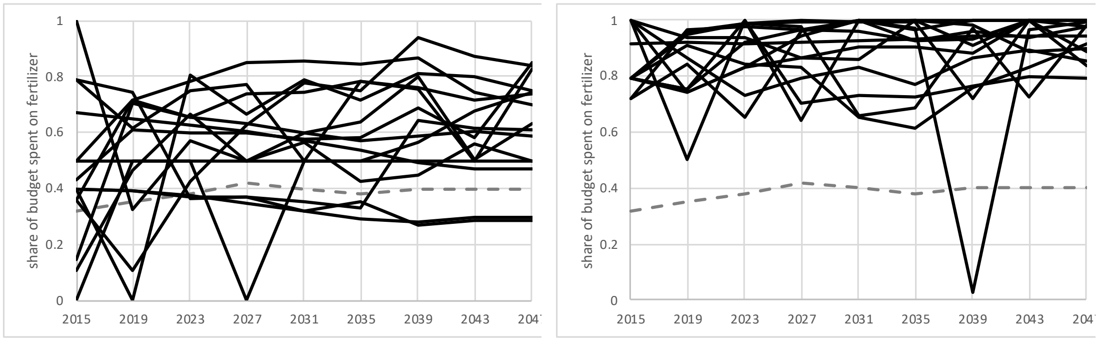


Figure 6: Decision trajectories of the top 20% performers (Figure 7a) and the bottom 20% performers (Figure 7b), benchmark strategy grey dashed line.

The decision trajectories of the bottom 20% performers differed significantly from the benchmark throughout the time horizon of the experiment (one sample t-test, p < 0.01). This was only partly the case for the decision trajectories of the top 20% performers. The decisions of those subjects were not significantly different from the benchmark in the initial periods (one sample t-test, p < 0.01).

From Figure 6, a few patterns in terms of decision rules can be discerned. Subjects belonging to the bottom 20% performers had a very strong preference for fertilizer (80% and more of the total expenditure). In addition, they seem to have decided on fertilizer expenditure without giving much attention to the development of farm (i.e., yield, production) and market (i.e., price) information, that is, they seem to have followed a non-dynamic, a priori defined fertilizer strategy. This is reflected in the low variance in decisions among the bottom 20% performers in Figure 7. One subject, during the debriefing session, explained this strategy with the following statement: "Fertilizer works, we spent large shares of the budget to fertilizer purchases and didn't care about the other option".

The successful subjects belonging to the top 20% performers started with relatively low fertilizer expenditures. In cases where they started with high fertilizer expenditures, they lowered them considerably in the second decision period (year 2019). Thus, they initially focused on the long-term strategy of soil improvement. Then, they repeatedly adjusted their decisions based on dynamic farm and market information cues, which can be inferred from the high variance in decisions among the top 20% performers in Figure 7.

As a consequence of the differences in decision strategies between the top and bottom performers, the variance within the different groups develops differently over the time horizon of the experiment. Figure 7 plots the standard deviation of rank 1 subjects (solid black line) as well as the standard deviation of rank 5 subjects (dotted grey line). Especially in the early years of the experiment, the variance in decisions among rank 1 subjects is considerably higher than that of rank 5 subjects. In these initial years, some of the rank 1 subjects started out with prioritizing soil improvement right away while others only decided to do so at the second decision point. Variance for this group also remains somewhat higher throughout the remainder of the experiment, which is likely because rank 1 subjects continuously adjusted their fertilizer expenditure decisions based on new farm and market information.

The trajectory of variance for the more moderate performers shows an interesting increase in the second half of the experiment. Overall, subjects in these groups applied more static decision rules than top performing subjects (Table 1). However, after a while, about half of the more moderate performers try out reductions in fertilizer expenditure and corresponding increases in soil improvement expenditure. This is reflected in the increase in variance as of the year 2035. During the final two decision points, subjects align again towards high fertilizer expenditure.

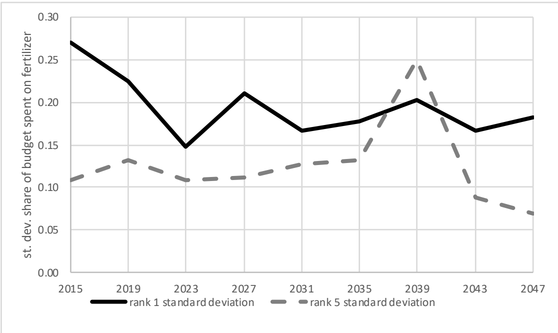


Figure 7: Variance in decisions of the top performers (rank 1) and the bottom performers (rank 5).

3.3 Robustness of strategies

One of the core features of our experiment is that the budget a subject can allocate to either fertilizer or soil improvement not only depends on the subject's own decisions in the previous period and their outcomes but also on the interaction of an individual decision with the decisions of others. In order to test the robustness of successful decision strategies, we therefore performed simulations where we combined successful decision strategies with unsuccessful decision strategies. Figure 8 shows the results of various such combinations. It differentiates between subjects in a market who follow the average strategy of the top 20% performers and subjects who focus entirely on fertilizer. The left-hand side of the figure shows performance outcome for the one subject in the market that always follows the top 20% strategy while the right-hand side of the figure shows performance outcomes for the one subject that always follows the short-term strategy. The figure demonstrates that overall, the differences in performance for a selected farm are fairly low. The successful decision strategies therefore seem to be quite robust to the experiment's endogenous interaction.

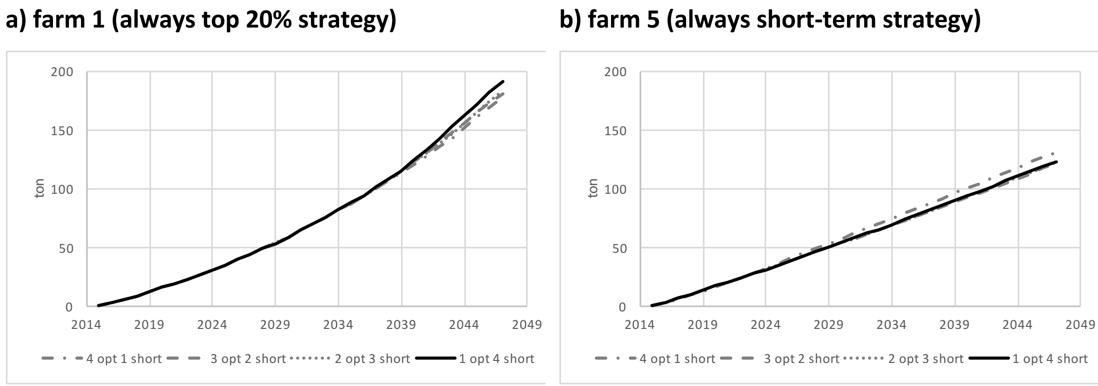


Figure 8: Performance (accumulated maize production) of an individual farm under varying combinations of other farms' strategies. Left hand side: farm that always chooses the top 20% strategy; right hand side: farm that always chooses a purely short-term strategy

Notes:

4 opt 1 short: 4 subjects adopt optimal (benchmark) strategy, 1 subject follows a short-term strategy

3 opt 2 short: 3 subjects adopt optimal (benchmark) strategy, 2 subjects follow a short-term strategy

2 opt 3 short: 2 subjects adopt optimal (benchmark) strategy, 3 subjects follow a short-term strategy

1 opt 4 short: 1 subject adopts optimal (benchmark) strategy, 4 subjects follow a short-term strategy

4 Discussion

Producing enough food for a growing and more demanding population remains a challenge in Zambia and in SSA at large. Smallholder farming systems in particular suffer from natural resource-based poverty traps (Stephens et al., 2012) so that sustainable intensification of agricultural production remains impossible as long as the natural resource base is being depleted. Replenishment of natural resources in general and soil organic matter, which is at the heart of soil fertility, in specific involves a fundamental shift in farmers' behavior away from the continuous and ever-increasing application of synthetic fertilizer, a symptomatic solution to stubbornly low yields.

Feedback on alternative production activities is slow in farming systems and it is very ambiguous, among others as a result of compounding factors such as climatic (e.g., variability in precipitation and temperature), biological (e.g. pests, weeds and diseases) and socio-economic developments (e.g., price volatility, illness of on-farm labor). Because of the delays between activity and outcomes, the signals/feedback from soil improvement activities are much weaker than the feedback from the application of synthetic fertilizer. Competing advice from experts (e.g. government-employed extension services promoting fertilizer application vs. donor-employed extension services promoting conservation agriculture) complicates matters. In the absence of effective support and a fundamental understanding of the dynamic complexity underlying production activities and their outcomes, farmers are prone to draw the wrong conclusions from the information they receive, both on-farm and from experts.

In line with expectations from various streams of literature, our data from a semi-computerized observational experiment with smallholder farmers in Zambia shows that overall, participants in our experiment had a strong and significant preference for decisions that are effective in the short-run but decrease food system outcomes and their resilience in the long-run.

The distinct preference for short-term strategies could be an explaining hypothesis why long-term oriented policies such as the dissemination of conservation agriculture face difficulties in terms of scaling up (Giller *et al.*, 2009). While short-term oriented policies such as fertilizer subsidy programs (FSP) are compatible with farmers' mind set, long-term oriented policies are not. Thus, to achieve the scaling up of long-term oriented strategies, a mind shift in farmers' decision-making is required, for example through agricultural extension. The empirical underpinning of the strong tendency of farmers to favor short-term solutions is also important because the majority of government policies support short-term solutions. A mind shift towards more long-term oriented strategies is thus equally important for policy makers, donors and implementing institutions.

While the finding on a distinct preference for the symptomatic solution (application of synthetic fertilizer) is not surprising per se, the experimental results give rise to a number of possible complementary interpretations and insights. These combine high discount rates on the side of smallholder farmers stuck in natural resource-based poverty traps with a higher weight on risk aversion than potential gains, too slow outcome feedback and lack of trust in the effectiveness of the fundamental solution to the symptom of low yields.

4.1 How to move to the fundamental solution

The fundamental solution to the shifting the burden archetype is represented by the optimal solution or benchmark decision strategy in the experiment. When exploring the link between decisions and performance, we found both, dynamic and non-dynamic decision trajectories that resulted in different performance outcomes. Deciding dynamically alone, that is, basing decisions on the outcome feedback provided by the simulation model, does not guarantee success. Instead we found two pre-conditions or drivers of success for dynamic decision trajectory that results in above-average performance in terms of production and thus facilitates implementation of the fundamental solution. First, the most successful subjects initially focused on replenishing SOM stocks before reaping the short-term benefits of applying inorganic fertilizer. This criterion is necessary to trigger the food production system's long-term leverage point. In a second step, successful subjects dynamically adjusted their decisions based on farm and market information. This criterion is necessary but not sufficient. Subjects who do adjust their decisions dynamically do not perform better than other subjects unless, and only unless they prioritize soil organic matter replenishment at the outset. Dynamic adjustment is thus only beneficial if the first condition is met.

Implementation of these two success factors in practice requires complementary interventions. A precondition for both factors is building awareness and understanding of the dynamic complexity underlying the budget allocation decision trade-off. We discuss this in more detail in the subsequent sub-section.

As replenishment of SOM takes considerable time to substantially increase production and thus creates a severe conflict with the need for reaching short-term benefits, interventions aiming at increasing SOM will have to be combined, at least in the initial years, with the application of synthetic fertilizer to reduce the trade-off between short- and long-term objectives. On-farm research trials in smallholder production systems in Uganda have shown that such a strategy produces both agronomic and economic benefits (Kearney et al., 2012). The need for policy to make long-term investments more affordable and profitable is also in line with related studies in system dynamics that investigate the trade-offs between short-term and long-term investments. Rahmandad (2015), for example, shows that competitive markets promote firms with a focus on short-term performance and make investments in long-term capabilities extremely unprofitable.

Implementation of the second success factor to decision making, the dynamic adjustment of decisions based on outcome feedback, can be facilitated by record keeping. The most appropriate agent for this is most likely agricultural extension. Debriefing comments by experiment participants indicated that participants had learned about the importance of record keeping (cf. subsequent sub-section). This perception by participants is substantiated by empirical evidence on the effectiveness of record keeping. In another study in Zambia, we found that smallholder farmers improved their livelihood situation (as measured, for example, by food availability in the traditional hunger season) when they monitored important stock variables such as livestock numbers, land under cultivation, food harvested, available food on storage, or available household cash on a monthly basis (Kopainsky et al., 2017). Similar results were found for example in India (Eyhorn, 2007).

4.2 Semi-computerized experiment as nudging tool

Similar to other natural resource management issues (e.g., Moxnes, 2004), farmers seem to have difficulties in formulating appropriate mental models of the soil organic matter stock management problem. Replenishment of the SOM stock requires several years of adding more SOM to the soil than retrieving SOM from the soil through harvesting.

During the debriefing session after the experiment, subjects provided some qualitative background information about their decision rules and strategies. They also reported on insights they had gained from the experiment. Despite the unambiguous statement in the introduction to the experiment that we were gathering information for research purposes, the subjects expressed that they themselves learned a lot from the experiment. Common learning outcomes stated by the subjects included the following: the importance of planning; the importance of dynamic book keeping; differentiating between short-term and long-term production activities and knowing their impacts; and differentiating between the concepts of yield and production.

The anecdotal evidence on learning is also substantiated by our data. Among the less-well performing subjects, many of them started exploring the soil improvement strategy in the second half of the experiment (hence the increases in variation in the second half of the experiment in Figure 7). This shift in strategy was too late for soil improvements to have a significant impact on subjects' performance. Nevertheless, it can be seen as an indication of subjects starting to understand the need for long-term strategies.

Our semi-computerized observational experiment therefore seems to also have functioned as a digital nudging instrument (Weinmann et al., 2016) and guided subjects' decisions towards a more desirable behavior. Even in the absence of any instructional overlay, the model-based experiment led to some new insights. In order to exploit the potential as a nudging instrument more, the experiment would have to be used in settings that allow repeated and probably also more collaborative interactions with the underlying simulation model. Farmers need to trust that a less common strategy such as the long-term soil improvement strategy can lead to reliable outcomes. Engaging with the simulation model just once is not sufficient in that regard, especially when the simulation model provides outcome feedback alone, which has been shown to be too slow to fundamentally affect performance (e.g., Moxnes, 2004; Sterman, 1994).

Simulation-based learning tools have the additional benefit that they provide a way to circumvent the complexities and disagreements introduced by discounting. Moxnes (2014) shows that people are able to choose among policies (in our case, production activities) by inspecting graphs over time of policy consequences.

5 Conclusions and further research

Findings from experimental studies are non-conclusive in the sense that they originate from a laboratory environment and not from a real-world context. External validity of experiment-based findings is thus a common concern and ultimately needs empirical confirmation. There is evidence from prior research, however, that the correspondence between lab- and field-based effects of conceptually similar dependent and independent variables is considerable (e.g. Anderson *et al.*, 1999) and we believe that our experimental design, which was as close to the subjects' situation on their farms as possible, contributed to the potential of external validity in regard to our findings. In particular the use of a complex model that included time delays and dynamic endogeneity, and that was calibrated using Zambian data, allowed to mimic a farmer's real-world decision tradeoff.

While this article reveals insights about dynamic decision making of SSA smallholder farmers in the context of short- and long-term oriented production activities with conflicting objectives, there are several ways to expand and complement our research. We found that some of the subjects decided on a priori heuristics that we could not explain with our study design. However, to further develop agricultural extension towards long-term oriented production activities, knowledge about the foundation of a priori heuristics might be useful. Our study design could be enriched by individual, semi-structured interviews with all subjects after the completion of the experiment. These interviews would allow to gather qualitative information about these a priori heuristics and help building adaptive capacity rather than promote the broadest possible diffusion of technical training.

Most importantly, the simulation model currently used as the basis for the observational experiment should be further developed into an interactive learning tool or learning activity that is accessible to extension officers and farmers alike. This would help turning the anecdotal evidence of learning from the simulation to more measurable and particularly more scalable learning impacts that are a crucial precondition for moving towards the fundamental solution to low yields in sub-Saharan Africa.

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References

Anderson CA, Lindsay JJ, Bushman BJ. 1999. Research in the Psychological Laboratory: Truth or triviality? *Current Directions in Psychological Science* **8**(1): 3-9.

Banful AB. 2011. Old problems in the new solutions? Politically motivated allocation of program benefits and the "new" fertilizer subsidies. *World Development* **39**(7): 1166-1176.

Banson, K. E., Nguyen, N. C., & Bosch, O. J. H. (2016). Using system archetypes to identify drivers and barriers for sustainable agriculture in Africa: A case study in Ghana. *Systems Research and Behavioral Science, 33*(1), 79-99. doi: 10.1002/sres.2300

Brzezina, N., Biely, K., Helfgott, A., Kopainsky, B., Vervoort, J., & Mathijs, E. (2017). Development of organic farming at the crossroads: Looking for the way forward through system archetype lenses. *Sustainability, 9*(5), 821. doi: doi:10.3390/su9050821

CSO. 2015. *Rural Agricultural Livelihoods Survey*. Central Statistical Office, Republic of Zambia: Lusaka, Zambia.

Donovan G, Casey F. 1998. *Soil Fertility Management in Sub−Saharan Africa*. World Bank: Washington D.C., US.

Eyhorn, F. (2007). *Organic Farming for Sustainable Livelihoods in Developing Countries? The Case of Cotton in India*. Zurich, Switzerland: vdf Hochschulverlag AG an der ETH Zürich.

FAO. Food Balance Sheets Retrieved 21.07.2018, 2018, from http://www.fao.org/faostat/en/#data/FBS

FAO. (2017). Africa Regional Overview of Food Security and Nutrition. Rome: Food and Agriculture Organization of the United Nations (FAO).

Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, Mueller ND, O'Connell C, Ray DK, West PC, Balzer C, Bennett EM, Carpenter SR, Hill J, Monfreda C, Polasky S, Rockström J, Sheehan J, Siebert S, Tilman D, Zaks DPM. 2011. Solutions for a cultivated planet. *Nature 478*: 337-342.

Gerber, A. (2016). Short-term success versus long-term failure: A simulation-based approach for understanding the potential of Zambia's fertilizer subsidy program in enhancing maize availability. *Sustainability, 8*(10), 1036.

Gerber, A. (2017). *The Dynamics of Food Availability in sub-Saharan Africa.* PhD, University of Bergen, Bergen, Norway.

Giller KE, Witter E, Corbeels M, Tittonell P. 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research* **114**(1): 23-34.

Grabowski PP, Kerr JM, Haggblade S, Kabwe S. 2016. Determinants of adoption and disadoption of minimum tillage by cotton farmers in eastern Zambia. *Agriculture, Ecosystems & Environment* **231**: 54-67.

Holden ST. 1993. Peasant household modelling: Farming systems evolution and sustainabilty in northern Zambia. *Agricultural Economics* **9**: 241-267.

Jayne TS, Rashid S. 2013. Input subsidy programs in sub-Saharan Africa: a synthesis of recent evidence. *Agricultural Economics 44*(6): 547-562.

Kahneman, D., & Tversky, A. (1979). Prospect Theory: An analysis of decision under risk. *Econometrica, 47*(2), 263-291.

Kalinda T, Filson G, Shute J. 2000. Resources, household decision making and organisation of labour in food production among small-scale farmers in southern Zambia. *Development Southern Africa 17*(2): 165-174.

Katongo K. 1986. *Decision making behavior of small scale farming households: the case of Zambia*. Iowa State University: Retrospective Theses and Dissertations. Paper 16541.

Kearney, S., Fonte, S., Salomon, A., Six, J., & Scow, K. (2012). Forty percent revenue increase by combining organic and mineral nutrient amendments in Ugandan smallholder market vegetable production. *Agronomy for Sustainable Development, 32*(4), 831-839. doi: 10.1007/s13593-012-0097-6

Kopainsky, B., Hager, G., Herrera, H., & Nyanga, P. (2017). Transforming food systems at local levels: using participatory system dynamics in an interactive manner to refine small-scale farmers' mental models. *Ecological Modeling, 362*, 101-110. doi: 10.1016/j.ecolmodel.2017.08.010

Kumwenda JDT, Waddington SR, Snapp SS, Jones RB, Blackie MJ. 1997. Soil Fertility Management in Southern Africa. In: *Africa's Emerging Maize Revolutaion*. Byerlee D, Eicher CE (eds). Lynne Rienner Publishers, Inc.: Colorado; 157-172.

Langyintuo AS, Mungoma C. 2008. The effect of household wealth on the adoption of improved maize varieties in Zambia. *Food Policy 33*(6): 550-559.

Mason NM, Jayne TS. 2013. Fertiliser Subsidies and Smallholder Commercial Fertiliser Purchases: Crowding Out, Leakage and Policy Implications for Zambia. *Journal of Agricultural Economics 64*(3): 558-582.

Mason NM, Jayne TS, Myers RJ. 2015. Smallholder Supply Response to Marketing Board Activities in a Dual Channel Marketing System: The Case of Zambia. *Journal of Agricultural Economics 66*(1): 36-65.

Morris M, Kelly VA, Kopicki RJ, Byerlee D. 2007. *Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines*. World Bank: Washington D.C.

Moxnes, E. (2004). Misperceptions of basic dynamics: the case of renewable resource management. *System Dynamics Review, 20*(2), 139-162.

Moxnes, E. (2014). Discounting, climate and sustainability. *Ecological Economics, 102*(0), 158-166. doi: http://dx.doi.org/10.1016/j.ecolecon.2014.04.003

Rahmandad, H. (2015). Connecting strategy and system dynamics: an example and lessons learned. *System Dynamics Review, 31*(3), 149-172. doi: 10.1002/sdr.1541

Repenning, N. P., & Sterman, J. D. (2001). Nobody ever gets credit for fixing problems that never happened: Creating and sustaining process improvement. *California Management Review, 43*(4), 64-88.

Repenning, N. P., & Sterman, J. D. (2002). Capability traps and self-confirming attribution errors in the dynamics of process improvement. *Administrative Science Quarterly, 47*(2), 265-295. doi: 10.2307/3094806

Senge, P. M. (1990). *The fifth discipline: The art and practice of the learning organization*. New York: Doubleday.

Stephens, E. C., Nicholson, C. F., Brown, D. R., Parsons, D., Barrett, C. B., Lehmann, J., . . . Riha, S. J. (2012). Modeling the impact of natural resource-based poverty traps on food security in Kenya: The Crops, Livestock and Soils in Smallholder Economic Systems (CLASSES) model. *Food Security, 4*(3), 423-439. doi: 10.1007/s12571-012-0176-1

Sterman, J. D. (1994). Learning in and about complex systems. *System Dynamics Review, 10*(2-3), 291-330.

Tembo, S., & Sitko, N. (2013). Technical Compendium: Descriptive Agricultural Statistics and Analysis for Zambia. Lusaka, Zambia: Indaba Agricultural Policy Research Institute.

The World Bank. (2013). Unlocking Africa’s Agricultural Potential. An Action Agenda for Transformation *Sustainable Development Series*. Washington D.C.: The World Bank.

Weinmann, M., Schneider, C., & Brocke, J. v. (2016). Digital nudging. [journal article]. *Business & Information Systems Engineering, 58*(6), 433-436. doi: 10.1007/s12599-016-0453-1

Stave KA, Kopainsky B. 2015. A system dynamics approach for examining mechanisms and pathways of food supply vulnerability. *Journal of Environmental Studies and Sciences 5*(3): 321-336.

Umar BB. 2012. From Maize Mono-cropping to Conservation Agriculture: A Multi-perspective Analysis of Smallholder Conservation Agriculture in Southern, Central and Eastern Zambia. Ås, Norway: Norwegian University of Life Sciences.

Umar BB. 2014. A critical review and re-assessment of theories of smallholder decision-making: a case of conservation agriculture households, Zambia. *Renewable Agriculture and Food Systems 29*(3): 277-290.

Weinmann, M., Schneider, C., & Brocke, J. v. (2016). Digital nudging. [journal article]. *Business & Information Systems Engineering, 58*(6), 433-436. doi: 10.1007/s12599-016-0453-1

The World Bank. (2013). Unlocking Africa's Agricultural Potential. An Action Agenda for Transformation *Sustainable Development Series*. Washington D.C.: The World Bank.

Xu Z, Burke WJ, Jayne TS, Govereh J. 2009. Do input subsidy programs "crowd in" or "crowd out" commercial market development? Modeling fertilizer demand in a two-channel marketing system. *Agricultural Economics 40*(1): 79-94.

Appendix

Appendix A: Data Collection Protocol

1. Gather the participants (5 couples, that in real life each actually run a farm together).

2. Introduction and Instructions:

Hello and welcome everybody.

Introduction of all that are present

A. Purpose

Thank you for being here. Today we gather information for learning how you make different decisions. Andreas is doing a schoolwork study for his PhD in collaboration with Dr. Nyanga at UNZA[3]. He is interested in learning how you make decisions as couples. The information will be used for academic purposes and may be published in academic journals. Is that clear and ok for you?

B. Roles

We would like to gather the information through playing a game together. The roles are: I am the moderator, who will interact with you. Andreas is the computer man, who will be putting the information in the computer and giving the results. Cain and Eukeria will help me moderating the process, transmitting information between you and the computer man. You, the couples, are the players who make decisions.

C. Game

Every couple will manage a farm. You all have a common main goal for your farm. In this game the main goal is to maximize your accumulated maize production over the whole game. To reach the goal of maximize your production, you must decide how much money (Kwachas) you want to spend on two options. The first option is buying own fertilizer (not through government or NGO subsidies). And the second option is spending financial means to improve your soil through crop residue retention and manure application. In this game we just have these two options and we are not considering other options such as lime application, crop rotation, Musangu tree plantation, etc.

Here is some information to understand your farm: Each couple cultivates 8 limas (equivalent to 2 hectares) of maize on its farm, so your decisions are limited to this area. The maize yield level is currently around 7 bags of 50kg per lima; the current/starting production therefore is around 60 bags of 50kg per farming season. The current/starting producer price of maize at your market is around 75 Kwacha per 50kg bag.

In the beginning your budget for the two options is 1392 Kwacha. In the first option, which is buying fertilizer, a 50 kg bag of fertilizer cost 550 Kwacha. In the second

[3] University of Zambia

option, which is crop residue retention and manure application, a lima costs you 117 Kwacha, adding external organic matter becomes more expensive.

For you to make decisions, the moderator will come to you and give you information about your budget, yield, current production and market price. You will then decide how much of the budget you want to spend on fertilizer and how much you want to spend to improve your soils. The moderator will take note of your decision and bring it to Andreas. He will put your decision into the computer and calculate the new budget, yield, production and price. The moderator will bring this new information back to you so that you can again decide how much money you will spend for fertilizers and soil improvement. We will have 9 rounds in this game. Thus, these dynamics will continue until we complete 9 periods (you make 9 decisions). The game will be completed in 1-2 hours approximately.

At the end of the game, the computer calculates your total production for the entire game and you will be rewarded with a present depending on your results. We brought a couple of items of which the best performing couple can choose one item first, the second best performing couple second, etc.

Show the goods (2kg sugar, 1kg sugar, 750ml oil, big laundry soap, small laundry soap)

If you have difficulties to make your decision, think of how you decide on your own, real farm and always keep in mind that your goal is to maximize your production!

We will have the possibility to clarify procedural questions during the game, but not ask for help in decision making. So far, is the game clear to you? Are you willing to participate? If you do not want to participate or feel uncomfortable, you can withdraw.

Remarks to the instructor:
It is ok to clarify procedural questions: e.g. what happens after we make a decision? Do we have to spend the entire budget to these two policies? Etc.
It is also ok to clarify the meaning of words (e.g. yield)
Do not give clues that may directly influence the decision making process. E.g. do not answer questions regarding what should be done such as “should I allocate more on fertilizers?” or “How can I make the highest production in the game?”

3. Split the participants up.

In this game it is the idea that you keep your decisions and results as a secret within your farm and do not share them with the other couples. So please, keep communication between the farms at a low level. However, once the game is finished and we have all the results from everyone, you are very free to share experiences and strategies with each other!

Give your best and good luck!!

4. Start the actual rounds.

After first round: explain that yield, production, price and budget changes. Costs stay the same.

5. Save the rounds.

Take a copy (soft or hard) from the interaction sheets and save it.

Give a hard copy to the farmers as a feedback.

6. Conclude with an aftermath session.

At this point the game is over and you are free to leave if you wish. However, if you appreciate, we will have a feedback session explaining some ideas of the game.

Appendix B: Record Sheet

Farm Number:________   Data Collection Set-Nr:___

Name of Participant:

____

Input prices:

- 50 kg Fertilizer costs 550 ZMW
- 1 lima improved soil costs 117 ZMW, for further improvement the price increases

Round 0	Yield 7 bags/lima	Production 60 bags	Price 75 ZMW/bag	Budget 1392 ZMW	Soil	**Fertilizer**
1	Price	Yield	Production	Budget	**Soil**	Fertilizer
2	Production	Price	Yield	Budget	Soil	**Fertilizer**
3	Yield	Production	Price	Budget	**Soil**	Fertilizer
4	Price	Yield	Production	Budget	Soil	**Fertilizer**
5	Production	Price	Yield	Budget	**Soil**	Fertilizer
6	Yield	Production	Price	Budget	Soil	**Fertilizer**
7	Price	Yield	Production	Budget	**Soil**	Fertilizer
8	Production	Price	Yield	Budget	Soil	**Fertilizer**
9	Yield	Production	Price	Budget	**Total Production**	

Date: ______________   Place: ______________

Note: The order of soil and fertilizer expenditure alternates from round to round to avoid any order driven bias.