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TOWARDS A SYSTEMIC ANALYSIS OF THE IMPACTS OF CLIMATE CHANGE ON AGRICULTURAL PRODUCTION IN NIGERIA

By

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Abstract

The impacts of climate change on the agricultural sector in Nigeria going forward are expected to be severe, but so far there is a dearth of systemic analysis of how these impacts would develop over time, or how they would interact with other drivers impacting Nigerian agriculture. Such a systemic analysis could contribute to adaptation efforts by identifying policy mechanisms that serve as system 'levers' to effect change given the considerable uncertainty associated with both the socio-economic and ecological aspects of climate change. This study begins to provide a systematic analysis of the impact of climate change on agricultural production in Nigeria using a participatory research method. We convened a workshop of key stakeholders with diverse and in-depth knowledge of Nigerian agriculture in Ibadan, Nigeria, in June, 2016. Using a causal loop diagramming (CLD) technique, we grouped these stakeholders by region and led them through an exercise in which they drew diagrams depicting the barriers to, and opportunities for, Nigerian agricultural development. CLD is a method used in system dynamics modeling, and it is effective for identifying causal relationships between variables as well as feedback mechanisms. As expected, there were interesting differences across the 6 geopolitical zones of Nigeria reflecting their agro ecological differences. However, all groups identified at least one reinforcing feedback loop linked to agricultural productivity. This indicates a current 'low productivity trap'—low productivity levels reinforcing a state of low productivity—which could potentially turn into self-reinforcing productivity gains with some systemic interventions. There was also a clear indication of other environmental factors (separate but linked to climate change) affecting Nigerian agriculture. This indicates the need to evaluate the combined impact of multiple environmental drivers, rather than attributing all potential impacts to climate change.

Introduction

The impacts of climate change on the agricultural sector in Nigeria are expected to be severe [1], but so far there has not been a systemic analysis of how these impacts would develop over time, or how they would interact with other drivers affecting Nigerian agriculture. Global climate models indicate that West Africa will become hotter in a warmer world, with increasing temperature and precipitation anomalies observed under 2ºC warming or greater [2]. Precipitation forecasts are more uncertain, with some regional climate models anticipating decreased overall rainfall in West Africa under climate change, and others demonstrating increased annual rainfall [3]. Currently, West Africa is experiencing an increase in annual precipitation from historic lows in the 1970's and 80's, which is more pronounced in the Sahelian zone than the Guinean zone [4].

Global climate models coupled with crop production models forecast a range of lower yields by 2050 as a result of climate change [5], with more severe yield reductions occurring in the period between 2030 and 2050. Water stress as the result of higher temperatures which increase evapotranspiration is the dominant mechanism by which yields would be reduced under climate change. Boubacar investigated the impacts of drought on the agricultural sector in 8 Sahelian countries from 1970 to 2000 using Just-Pope Stochastic Production Function of maize, millet and sorghum. The results showed increase in daily temperature (degree-days) has a negative effect on crop yield [6]. By mid-century, demand for food in sub-Saharan Africa is expected to double, and this growing gap between demand and local supply could lead to substantially higher food prices [5]. In addition to lower yields, climate change could impact the agricultural sector indirectly, through inducing migration or aggravating existing natural resource conflicts [7]. Pest and disease distribution may also shift under an altered climate regime [8].

Complicating this picture is the fact that West Africa has historically experienced severe drought and highly variable precipitation, even before the era of anthropogenic climate change [9]. Because of this variability, farmers and other actors involved with the agricultural sector have developed coping strategies to help them deal with reduced yields associated with drought and other extreme events [10]. These coping strategies are potentially a source of resilience in the Nigerian agricultural sector, but they have not been systematically collected and assessed for their suitability in the face of anthropogenic climate change and other agricultural sector transformations.

Moreover, the region is undergoing a wide range of other dynamic changes, including the world's highest rate of urbanization [11], high levels of population growth, and rapid changes in food demand and consumption patterns [12]. There are also significant changes in the agricultural sectors, and land tenure and land use changes, which could create complex feedbacks with climate dynamics [13]. It is extremely difficult for scientists, farmers and other agricultural sector actors, to disentangle the relative impacts of these different drivers.

Anecdotal evidence and some studies indicate that people throughout West Africa are perceiving changes in temperature and precipitation, but the nature of the changes, and their attribution to climate change, are often ambiguous. For example, Mertz et al. [14] found that, throughout five countries in West Africa (including Nigeria), more than 80% of all households reported that overall rainfall had been decreasing, although this was not the case. What respondents were likely reporting was a decreased rainfall amount during the critical growing month of August. Whether this recent decline was attributable to anthropogenic climate change, or natural variability, is not clear. Another study of tomato farmers in Gombe state, Nigeria, found that the majority of them actually expected climate change to have a positive impact on their production [15].

In a study conducted on the effects of climate change on livestock husbandry and practices in Jigawa State, Nigeria, Bidoli et al. found out climate change affects livestock production significantly. The effects include reduction in feed consumption, growth rate, increased abortion, reduced birth rate, increased incidences of parasites, disease conditions and mortality rates [16]. The authors also reported reduced income, migration with family and livestock, conflict with other farmers and competition for grazing area were the climate change effects on livestock nomads.

Egbule and Agwu [17] investigated the constraints to adaptation and food security in Nigeria, Sierra Leone and Liberia. They found inadequate access to information on adaptation, lack of financial resources, poor extension services and lack of access to weather forecasts were the constraints to climate adaptation in West Africa.

Ademola and Oyesola [18] reported the perceptions and adaptation strategies of selected tree crop farmers to climate variation in Oyo State, Nigeria. They found farmers perceive hot evenings, increased sun intensity and temperature, prolonged dry season, fluctuations in rainfall patterns over five years in terms of volume and erosion were adverse climate change impacts in agricultural systems. The farmers also perceived high incidences of pests and diseases, decaying of fruits before maturity and soil moisture deficit. This was also corroborated by the findings of Fatuase and Ajibefun [19] and Owolade (2013).

Oluwatayo and Ojo [20] investigated awareness and adaptation to climate change among yam-based farmers in rural Oyo State, Nigeria. They reported that farmers perceive declining yam output, changes in rainfall pattern and changes in time and length of each fall in the study area. They reported mixed cropping, irrigation, diversification and change in planting dates were the adaptation strategies adopted by the farmers. Similarly, Adetayo et al., [21]; Falaki [22], and Ikheloa et al. [23] reported mixed cropping and mixed farming, adoption of improved varieties of crops and strain of livestock, use of agrochemicals (fertilizers, pesticides, and herbicides etc.) and mulching are the main adaptation strategies used by farmers in Nigeria.

Clearly, farmers experiencing environmental change have a rich experience with adaptation to climatic variability, which should be harnessed for increased resilience of the agricultural sector; however, their understanding of climate change and the threats it poses may be very different from the ways in which scientists understand or represent climate change impacts. This poses an interesting and complex communication challenge.

The high degree of complexity and uncertainty around the effects of climate change on Nigerian agriculture, and the important information held respectively by scientists and stakeholders for better understanding this issue, calls for an analysis which takes a participatory, systems approach. The goal of this study is to begin a systemic analysis that could contribute to adaptation efforts by identifying policy mechanisms that serve as system 'levers' to effect change given the considerable uncertainty associated with both the socio-economic and ecological aspects of climate change in Nigeria.

Methods

We convened a workshop involving stakeholders with diverse and in-depth knowledge of Nigerian agriculture in Ibadan, Nigeria, in June, 2016, using a participatory system dynamics modeling approach. System dynamics modeling is a modeling technique used since the 1960's to address problems that involve feedback, non-linear dynamics, uncertainty, and time delays, all of which are relevant to the topic of this research [24]. In recent decades, researchers have been using system dynamics in a participatory manner, involving stakeholders and local experts in the model-building process. This technique has several advantages, including the incorporation of local knowledge into the model; achieving 'buy-in' from stakeholders and policy-makers who will be in charge of implementing the model's recommendations; and providing opportunities for social learning among the modelers and stakeholders as they jointly discuss complex problems in a systemic way [25-27]. In spite of all of these advantages of a participatory system dynamics modeling approach, this technique has not been used to a great extent in agricultural or food systems. Our project represents one of the first to do so in addressing the impacts of climate change on the agricultural system.

Using a causal loop diagramming (CLD) technique, we grouped these stakeholders by region and led them through an exercise in which they drew diagrams depicting the barriers to, and opportunities for, Nigerian agricultural development. CLD is a method used in system dynamics modeling, and it is effective for identifying causal relationships between variables as well as feedback mechanisms [28]. Two kinds of feedback are represented in a CLD: reinforcing (or positive) and balancing (or negative). A loop in which the initial action is reinforced is termed 'reinforcing', and tends to lead to runaway growth or decline. A loop in which the initial action is opposed or dampened is called balancing, and tends to exhibit stabilizing or equilibrium-seeking behavior. Many complex systems contain both types of feedback loops, and the behavior of the system depends on which loop dominates. A quantitative simulation is necessary to determine loop dominance; this information is not contained in a CLD.

We deliberately did not frame the activity in terms of climate change, in order to avoid over-attribution to climate change compared with other drivers operating in the agricultural sector. There were a total of 11 groups, representing five regions of the country (Northwest, North Central, Southeast, Southwest, and South South), with no more than six participants per group. Because the majority of participants were from the Southeast and Southwest regions, there were three and four groups diagramming these regions respectively, to avoid groups that were too large to sustain inclusive discussion.

Following the development of the CLDs, the groups presented their diagrams to one another in a general group discussion. This served to clarify the meaning behind ambiguous variables and linkages, answer questions about the causal logic behind the diagrams, and compare and contrast diagrams made by different groups. The modeling team collected all diagrams and notes at the end of the workshop, and used them to generate the combined CLDs described below. For regions which were represented by multiple groups, the diagrams for each group were aggregated by region.

Results and Discussion

Although stakeholders were divided into groups by region in order to draw out regional agricultural dynamics, the diagrams generated were all remarkably similar in terms of the variables identified and the connections between them. All groups identified at least one reinforcing feedback loop linked to agricultural productivity. This indicates a current 'low productivity trap'—low productivity levels reinforcing a state of low productivity—which could potentially turn into self-reinforcing productivity gains with some systemic interventions. However, some groups also identified balancing feedback loops involving agricultural productivity, indicating that productivity gains, if not managed in an ecologically or socially sensitive manner, could create conditions that limit further productivity growth (Figure 1). For example, as investment in agriculture leads to increased land under cultivation and increased application of chemical fertilizers and pesticides, forest area could decrease and pollution of waterways and soil could increase (Figure 1). In addition, increased yields could lead to nutrient mining of the soil if fallowing and organic matter application are not also increased.

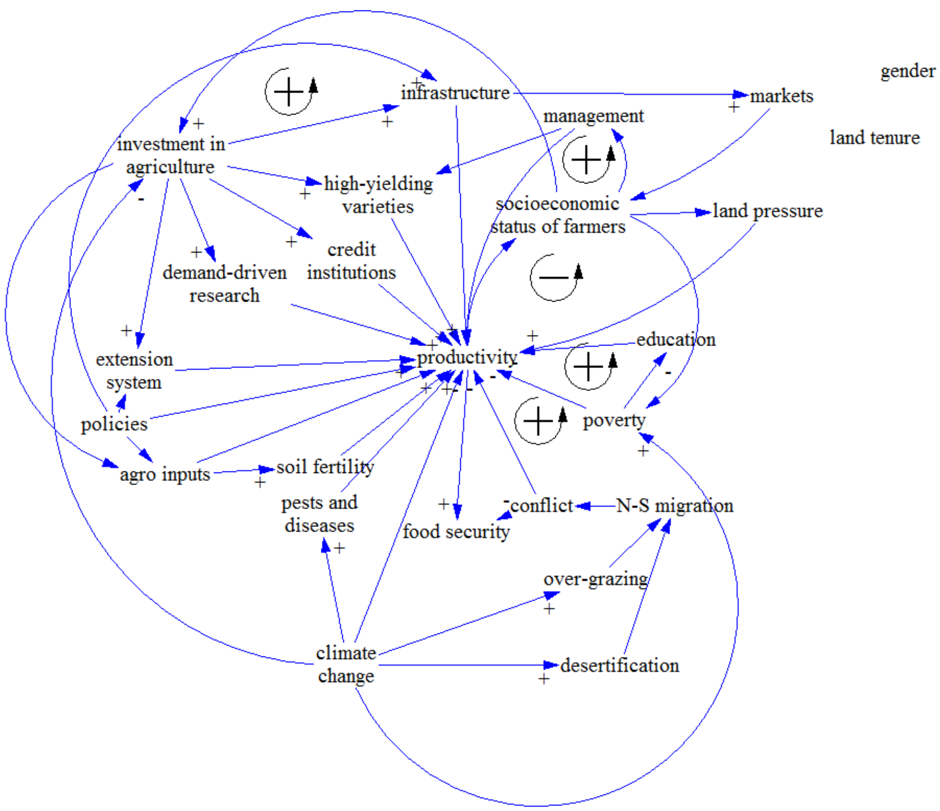

Figure 1. Causal loop diagram generated by stakeholders from Southeastern Nigeria, depicting five feedback loops (four reinforcing and one balancing) involving agricultural productivity.

As the socio-economic status of farmers increases, farm management improves, which further improves productivity (R4). However, as the socio-economic status of farmers improves, farmers use more intensive practices. If not implemented in a sustainable manner, this can lead to reduced productivity (for example, through reduced fallowing periods that are not compensated for with organic matter addition), forming a balancing loop (B1).

Several groups from both northern and southern regions identified north-south migration as an important potential driver of conflict. At the time of the workshop, these types of conflicts were prominent in national news and political discussions, and they may be an under-studied aspect of climate change and environmental change in Nigeria. While several groups—particularly those from the Southeast and Southwest—explicitly mentioned climate change as a driver of low productivity, the South South group highlighted environmental drivers such as soil degradation, deforestation and pollution as being more influential in their current impacts on Nigerian agriculture. This indicates the need to evaluate the combined impact of multiple environmental drivers, rather than attributing all potential impacts to climate change.

Groups that mentioned climate change explicitly in their diagrams included the Southeast and the Southwest. These groups saw climate change as contributing to erratic rainfall patterns, droughts, floods, increased incidence of pests and diseases affecting agriculture, desertification, and migration of pastoralists and others from the north to the south. The North Central group also described increased heat, erratic rainfall, flooding, desertification and drought as impacting the agricultural sector, but did not use the phrase 'climate change' in their causal loop diagram. Expectations of increased heat are consistent with climate model projections throughout West Africa [2]. The projected effects of climate change on precipitation regimes in Nigeria are more uncertain, and are closely tied with land use change, as suggested by the diagram developed by the South-South group [13].

The combined CLD merging all groups' responses contains nine reinforcing feedback loops and four balancing feedback loops. These feedback loops are depicted in Figures 2-5 and described below. Several groups mentioned gender dynamics, youth involvement in agriculture, and land tenure as critically affecting the development of the agricultural sector, but the causal mechanisms behind these influences were not clearly articulated, so they were left off of the combined diagram.

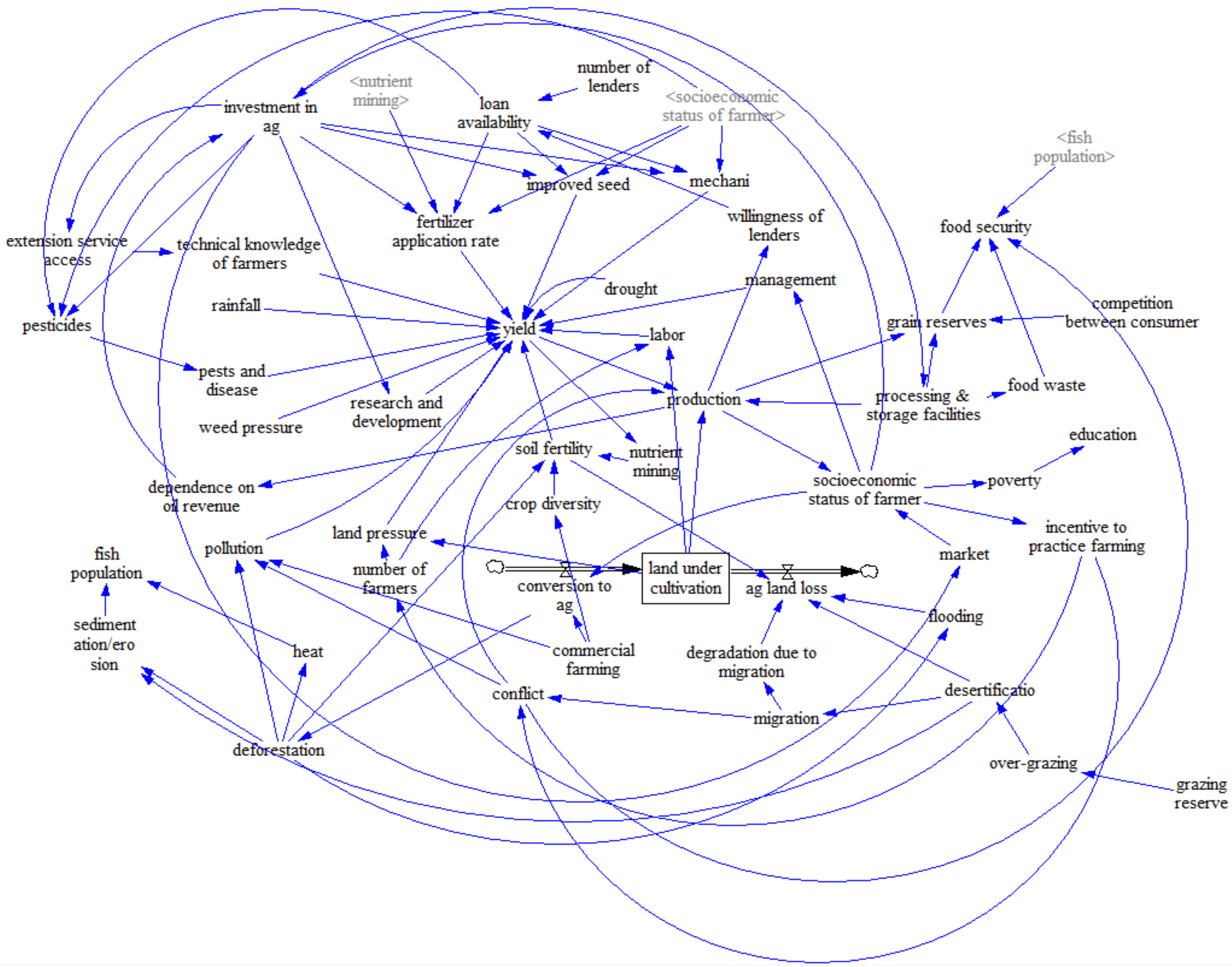

Figure 2. Combined causal loop diagram with variables and connections from all workshop groups combined.

Individual causal loops are highlighted in Figures 3-5.

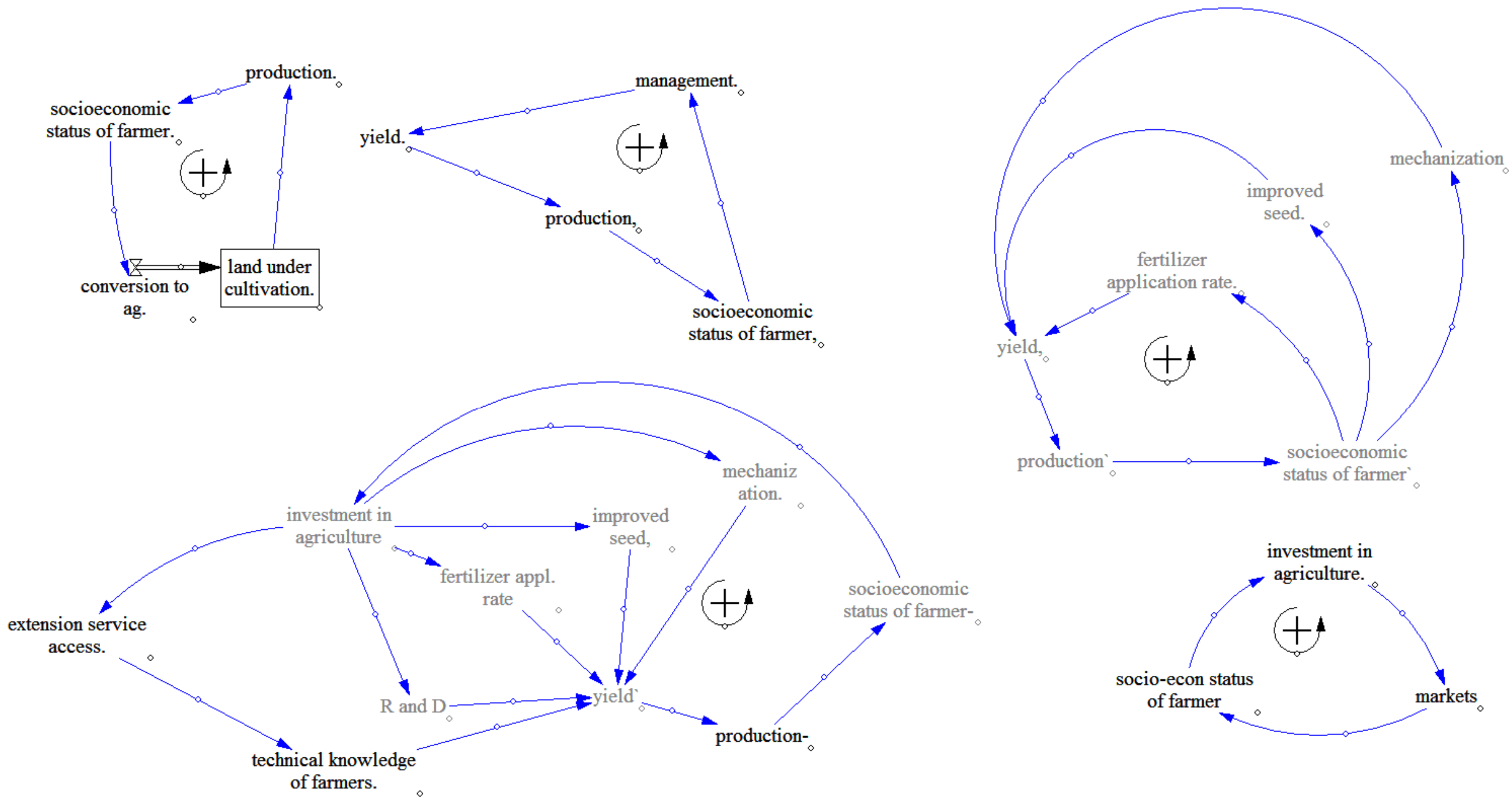

Figure 3. Reinforcing feedback loops R1-R5 described in the text.

Upper row L-R: Land conversion feedback loop, management feedback loop, farmer status feedback loop. Bottom row L-R: investment feedback loop, markets feedback loop.

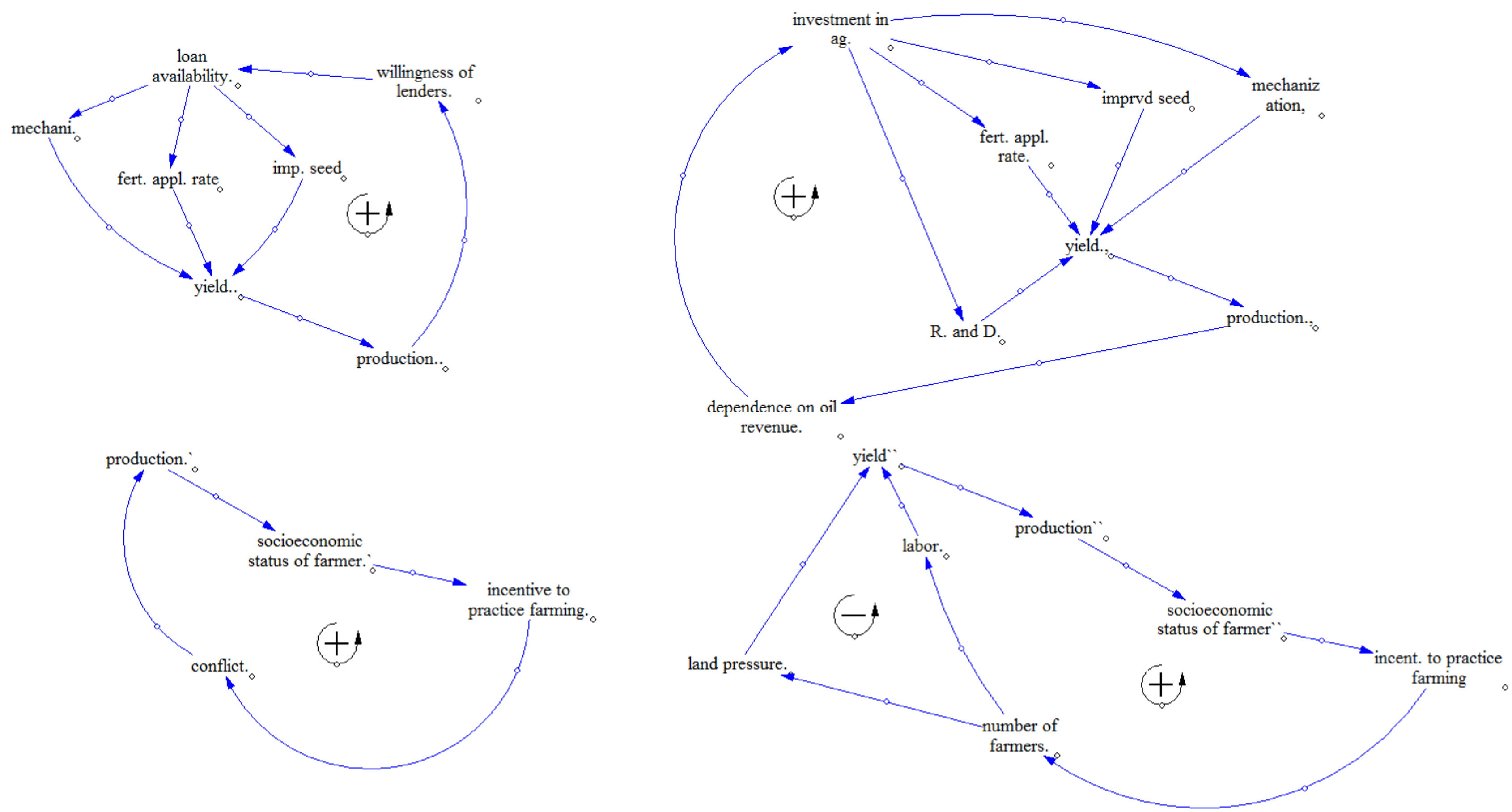

Figure 4. Reinforcing feedback loops R6-R9 and B3 described in the text.

Upper row L-R: Lending feedback loop, oil dependence feedback loop. Bottom row L-R: Conflict feedback loop, land pressure balancing loop, labor feedback loop.

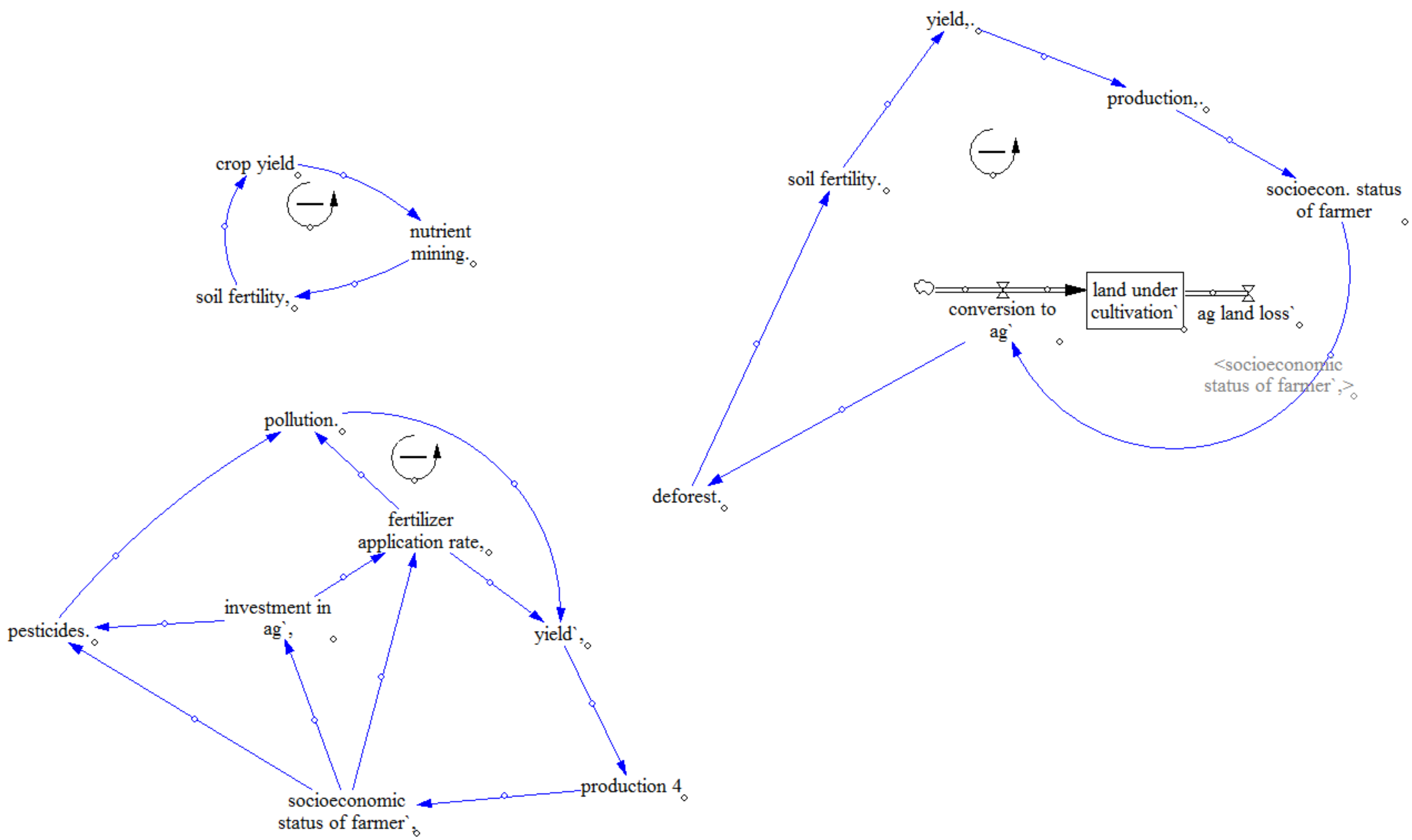

Figure 5. Balancing loops B1, B2 and B4 as described in the text.

Top row, L-R: Nutrient mining loop, deforestation loop. Bottom row: pollution loop.

Reinforcing feedback loops

R1: Land conversion feedback loop. As land under cultivation increases, production increases, improving the socio-economic status of farmers and enabling them to put more land under cultivation.

R2: Management feedback loop. As yields and production increase, the socio-economic status of farmers improves, as does their management of farmland, further increasing yields.

R3: Farmer status feedback loop. As yields and production, increase, the socio-economic status of farmers improves. This allows farmers to implement further yield improvements, such as buying improved seed varieties and inputs, and investing in mechanization. Mechanization may improve yields by allowing farmers to prepare land for cultivation in a timely manner, to make the most of the rainy season onset.

R4: Investment feedback loop. As yields and production increase, the improved socio-economic status of farmers gives them more political and economic power, which spurs the government to invest in agriculture. This enables increased farmer access to inputs and mechanization, as well as research, development and extension services which further increase yields.

R5: Markets feedback loop. Improved socio-economic status of farmers leads to more government investment in agriculture, which leads to more developed and accessible markets. This further increases the socio-economic status of farmers.

R6: Lending feedback loop. As the productivity of the agricultural sector increases, lenders are more willing to provide loans to farmers, which enables them to buy inputs, further increasing yields.

R7: Oil dependence feedback loop. As the productivity of the agricultural sector increases, the emphasis placed by the Nigerian government on the oil sector as a revenue generator declines relative to agriculture. This leads to further government investment in the agricultural sector, which enables increased productivity.

R8: Conflict feedback loop. As farmers' socio-economic status increases, the incentive to practice farming also increases, leading young people away from conflict or illegal activities, such as oil theft. This allows agricultural production to further increase because of the stable socio-political environment.

R9: Labor feedback loop. As farmers' socio-economic status increases, the incentive to practice farming also increases, drawing more people into the agricultural sector. This provides more labor, further increasing yields.

Balancing Feedback Loops

B1: Nutrient mining balancing loop. As yields increase, the soil is mined of nutrients, leading to declining fertility and lowered yields.

B2: Deforestation balancing loop. As yields and production increase, so does the socio-economic status of farmers, which leads to further land conversion for agriculture. This increases deforestation, which has negative impacts on soil fertility because of the loss of erosion control and water retention. Lower soil fertility leads to lower yields.

B3: Land pressure balancing loop. As the socio-economic status of farmers increases and more people are drawn into the agricultural sector, the pressure on land resources increases. This leads to reduced fallowing periods (for example), and declining yields.

B4: Pollution balancing loop(s). As production increases and the socio-economic status of farmers improves, they apply more chemical pesticides and fertilizers. This leads to pollution of waterways, potentially reducing yields.

There are several important points pertaining to these feedback loops identified by workshop participants. First, reinforcing loops may operate in either direction. According to the stakeholders, these loops are currently operating to keep Nigerian agriculture in a 'low productivity' trap. To take R4 as an example, low productivity of the agricultural sector currently discourages the government from investing in it, which exacerbates the state of low productivity. However, if yields were boosted, and the opportunity for profit both at the individual farm scale and at the national scale were increased, creditors and investors would seek to take advantage of that opportunity by putting resources into the agricultural sector, thereby triggering the positive side of the reinforcing loop. The understanding that government investment in an economic sector would make that sector more profitable seemed to be universal among participants, although some analysis of Nigerian government spending calls that assumption into question [29].

Multiple groups mentioned intangible variables such as 'mindset', 'perception', and 'attitude' when describing chronic under-investment in the agricultural sector by the Nigerian government. There appeared to be widespread consensus that politicians at the federal level do not view agriculture as a sector that can contribute to the development of the nation's economy and workforce, so it remains under-prioritized compared to e.g. the petroleum sector. Corruption was also mentioned, as some pointed out that opportunistic politicians will not champion agricultural initiatives unless they see the potential for kickbacks. For these reasons, many workshop participants expressed skepticism that government investment in agriculture would increase, even if Nigerian agriculture becomes more productive. Expectations of increased investment were focused more on the private sector.

The treatment of climate change by the 11 workshop participant groups varied slightly across regions, but was exclusively represented as an external driver rather than as part of a feedback loop. Impacts of climate change discussed in the large group session included varied/unpredictable rainfall patterns; drought; desertification; an increase in pests and diseases; flooding; and increased heat. The concern about flooding was mentioned in the South South group and one of the Southwest groups, while groups from five regions also discussed drought, heat, and unpredictable rainfall as concerns pertaining to climate change. These variables, as seen in the CLD above, may impact multiple outcomes in the model, including yields and socio-political variables such as conflict and migration.

System dynamics posits that models are typically dominated and controlled by feedback loops, so addressing these feedback loops and their behavior tends to exert more leverage in a system than varying the impacts of external drivers [30]. In the context of Nigerian agriculture, that would imply that, while the impacts of climate change could be substantial, addressing the numerous feedback loops which keep the agricultural sector stuck in a low productivity trap could compensate for productivity losses due to climate change. However, there is also a danger that the additional productivity losses caused by climate change could prevent agricultural production from reaching the tipping point at which it triggers the positive reinforcement of productivity gains due to increases in investment, credit, and markets. Put simply, climate change could prevent Nigerian agriculture from realizing its potential in the absence of interventions.

Going forward, we intend to develop a quantitative simulation model using system dynamics methods, based on the causal structure of the CLDs drawn by stakeholders, and focusing on Nigerian staple crops from different regions of the country (maize, rice, sorghum, yam, and cassava). We will also use Bayesian techniques to evaluate conditional probabilities of different intervention and adaptation strategies [31]. Both of these methods (systemic dynamics and Bayesian analysis) are well-suited to problems operating at multiple scales under conditions of high uncertainty, which is why we have selected them for this ongoing project. Our simulation of the impacts of climate change on agriculture in Nigeria will also be bounded by the national-level scenarios developed under IFPRI's IMPACT model [5].

Conclusions

Stakeholders involved in Nigerian agriculture from different regions of the country identified a total of nine reinforcing feedback loops that are currently keeping the agricultural sector in a 'low productivity trap'. They also identified a total of four balancing feedback loops which could limit growing agricultural productivity through pollution, soil degradation, land pressure, and deforestation. According to stakeholders, climate change impacts agricultural productivity via a number of pathways, including variable rainfall, drought and flooding, pest and disease incidence, heat, and desertification. While climate change was held up by some stakeholders as an important factor in limiting future productivity, other stakeholders pointed to the multiple drivers maintaining the low productivity trap, and to other types of environmental degradation, as more important. This study suggests the need for a quantitative modeling exercise to tease out the relative impacts of these different drivers on the trajectory of agricultural productivity in Nigeria. It also indicates that care should be taken on the part of policy-makers and scientists not to over-emphasize the relative importance of climate change in the context of all other drivers currently limiting agricultural productivity.

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