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Might Continued Emphasis on Maize at the Expense of More Drought Tolerant Crops Endanger Food Security in the Horn of Africa?

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Abstract: Maize is widely grown in Africa including in drier areas where alternate crops will often perform better. Although maize will fail in drought years, it produces substantially higher yields than alternates, such as sorghum and millet, in wet years. Although people tend to select which crops to grow based on recent experience with crop harvests and prices, there is a widespread preference for maize even in areas where planting it is risky. This can lead to crop failures when rainfall varies from year to year. Introduction of higher yielding maize varieties might, under some conditions, cause increases in food shortages by further incentivizing the planting of maize in inappropriate situations. A preliminary model helps to investigate this and related issues.

Introduction

Food shortages and famine are frequent occurrences in the Horn of Africa and in other drier parts of northeastern Africa. Climate models indicate that some of this area may be wetter in the future, some may be drier, and the likelihood of inter-annual variability will probably increase. Crop harvests will fluctuate more and prediction of harvest success for any given crop will become more difficult.

Identifying the best avenues for agricultural research will also become more difficult. At present such research tends to focus on major crops to improve overall yield, disease resistance, grain storage properties, drought resistance and other attributes. Research tends to address problems related to those crops most widely grown in the area, and on crops that produce the highest yields and/or the best cash return. However, some of these same crops, maize in particular, tend also to be those which perform poorly in drought years compared to other crop options (such as millet or sorghum). If research is focused primarily on the highest yielding crops, larger scale issues of regional food availability in dry years may not be fully addressed. That is: as farmers plant larger areas of improved versions of these high yielding crops, the risk of food shortages during drought periods of may actually increase because larger areas will be at risk. Issues related to crop research for difficult development situations have been reviewed by Bellon (2006).

Organizations funding research to improve specific crops have an interest in examining the larger agricultural and food systems so that research can emphasize crops, crop mixtures, and farming systems that will best prepare communities, and the region, to withstand adverse climate events. This paper examines the idea that problems of food security could be made worse by focusing crop improvement efforts primarily on the relatively drought intolerant, but very popular crop, maize.

Background

A moderately warmer climate, especially combined with drought will significantly lower maize productivity over much of Africa (Lobell et al. 2011). In the drier parts of east Africa and the Horn of Africa climate change is expected to adversely affect crop production (Lotsch 2007). Some believe that these areas will experience more rainfall variability in the future and there has been some indications that this area will become drier. However, recent reports (De Wit and Stankiewicz 2006; IPCC 2007; Beyene et al. 2010) indicate that this area of Africa may actually receive more rainfall, on the average, than in the past. These predictions of higher average rainfall may strengthen the tendency to favor maize over drought tolerant crops. Nevertheless, increasing rainfall variability will make the possibility of drought caused crop failures more likely. Any investigation of cropping systems in this area needs to the structured in a way that will allow us to examine multiple scenarios with an eye toward developing scenarios that are robust regardless of future climate conditions, especially conditions that are more variable.

Ultimately those interested in food security would like to know how different mixtures of crops will perform under particular climatic regimes. More importantly we would like to know which crop mixtures are most likely to continue to produce food even in years when unfavorable climatic events occur. Such analyses typically require detailed crop models which may examine the sequence of crops planted on each particular plot of land. That approach is sometimes necessary because crops affect soil properties differently. For example legumes will add nitrogen to the soil, and residues from some crops can be used to increase soil organic matter. This is important because such organic matter can help soils retain moisture thus benefiting crops planted in following years.

On the other hand, in systems dominated by maize which characterize large areas of Africa, we can initially take a more straightforward approach by comparing the expansion of maize to a situation where maize and sorghum, a more drought tolerant crop, are both planted. Some believe that the ongoing expansion of maize into areas where it was not formerly dominant will create food security problems, especially if climate becomes more unpredictable (Bazile and Soumare 2003). Note also that there are significant efforts to improve drought resistance of maize (for example, see Banziger et al. 2006).

In simple terms we are interested in areas of intermediate rainfall where both maize and sorghum can be grown, where in dry years sorghum will outperform maize and in wet years maize will greatly outperform sorghum (Figure 1).

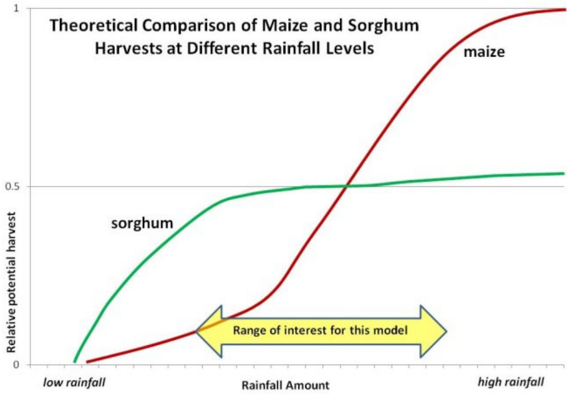

Figure 1. A simplified comparison of the relative harvest of sorghum and maize at different relative rainfall levels. Maize will perform better than sorghum only if rainfall is sufficiently high. At lower rainfall levels sorghum is the more productive crop.

In the real world, the decision as to which crop is grown is made by farmers. So, while crop productivity under different rainfall conditions is one factor of interest, investigators must also consider other factors which influence farmers' decisions. These include the expectation of income from each crop, relatively short-term expectation and prediction of rainfall, and the likelihood that alternate foods can be purchased if crops fail. Because the whole region is becoming more urbanized policymakers are also concerned with the availability of foodstuffs in markets and the effect that food imports and exports might have on food availability, prices and the resulting decisions of farmers.[1]

The purpose of this paper is to examine *some of these issues* at a generic, broad scale level in order to provide an overall indication as to possible dangers of attempting to improve food security by focusing on a single key crop – maize. This basic approach can also help define what more detailed studies might be useful for further investigation.

As a starting point we consider the most obvious factors affecting the planting of two standard crops as potentially seen by farmers in the area (Figure 2). The basic feedback relationship between amount of each crop grown, the resulting price and the effect on profitability is shown. The perceived comparative advantage of growing one or the other crop is based both on potential income and, more directly, on the harvest obtained per hectare. This is because both income as well as use of the crop directly for food are important. Obviously other factors besides rainfall affect harvest per area, and these factors (e.g. relative planting costs, cultural importance of each crop) might be specifically included in a larger model.

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[1] For example maize imported for distribution during food shortages can lower market prices disincentivizing planting of maize the following season if farmers believe such imports will occur again. On the other hand regional purchase of grains by donor agencies can raise prices of those grains incentivizing their planting but raising local prices.

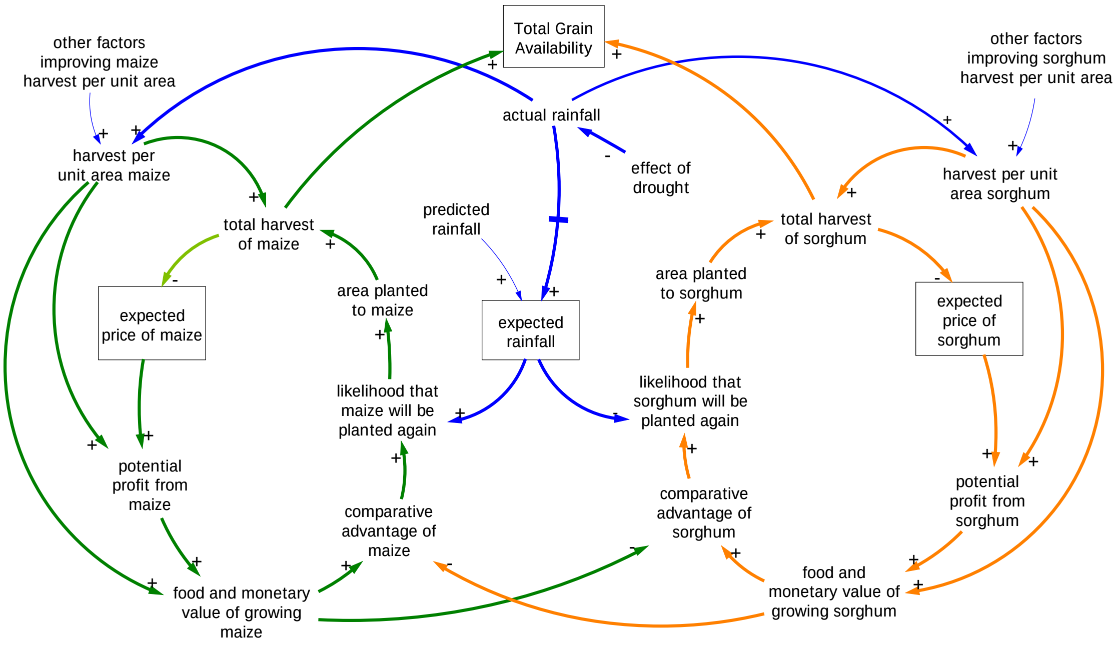

Figure 2. A system involving two standard crops (represented here by maize and sorghum) as affected by the most important immediate factors. In this view there is a balancing feedback loop whereby increased plantings of a crop tend to depress prices for that crop, other things being equal. If this loop dominates the system there would be a tendency for the area planted to this crop to stabilize as other options become more relatively advantageous. Outside that loop the main influences are the importance of other options; in this case the comparative advantage of growing the other major crop found in the area. In the example discussed in this paper sorghum is assumed to be the better crop at lower rainfall levels. External factors, such as research efforts, tend to increase maize harvest per unit area.

A number of other issues not illustrated in this figure might be included depending on the nature of our specific problem or inquiry. If we were interested mostly in the marketing of major crops than we would be more inclined to include issues related to variability of price over the year (e.g. right after harvest and six months later – included in this model as *current price of crop* x) and we would probably want to include issues related to storage of grain (e.g. grain quality, availability of storage facilities, storage costs, transport availability etc.). So, as with any causal loop diagram, or model, we create a model boundary related to our particular problem of interest.

In the case we're dealing with here, our initial question is relatively general:

> How might specific crop research efforts affect the larger issue of food availability if the climate becomes dryer and/or more variable?

A more specific question is:

> Where should available crop research funding be spent to best prepare for expected future food production needs in north eastern Africa?

Because of the fairly general nature of these questions we may need to address subsets related to more specific problems or face the prospect of creating a large and unwieldy model. The following more specific questions provide good starting points:

> How would focusing most research on improving the yield of the single most productive crop effect regional food security as climate variability increases?
>
> How would the diversion of funds to more research on drought resistant crops affect the overall food availability during drought and non-drought years?

More specifically, herein these questions are examined with two specific crops as examples: sorghum, a relatively drought resistant crop which has relatively low yields, and maize a more productive, and more popular, crop that is less drought resistant. Both crops are widely grown in the area of interest, but at present most research funding is directed at improving yields of maize.

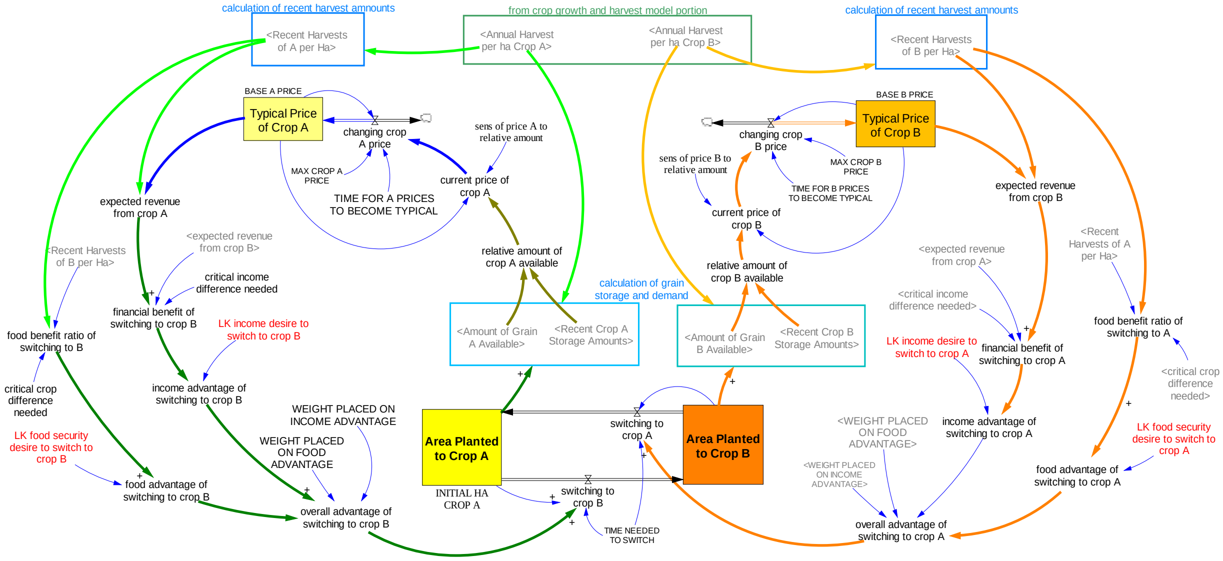

Figure 3. The segment of the model which determines the area planted to each crop based on expected income and food production advantages of each. Labeled outline boxes indicate links to other parts of the model.

Model Development

Decisions affecting which crops farmers plant are based, in the model, on both the food production and income potential of the crop. Food potential of the crop is based on the recent ability of the crop to perform under prevailing climatic conditions in terms of crop yield (kg ha^{-1}). This is implemented as a delay of yield per ha over recent years. Income potential of each crop is based on the expected income per ha based on recent per ha harvests and current expected price. Expected price for each crop is adjusted by both recent harvest amounts, i.e. availability, and by demand. In this model demand is assumed to be relatively constant and roughly equal to total crop production, but is modified by the current price of both crops. Baseline demand for each crop is determined by the long term weighted average of total production of each crop, and can be adjusted so that, over the long term supply does not quite meet demand: a situation of scarcity, typical for this region.

The comparative advantage of planting either crop, based on both income potential and food production potential then determines changes in the proportion of each crop planted, taking into account a minimum difference below which no change would occur. The portion of the model describing these relationships is presented, in simplified form, in Figure 3.

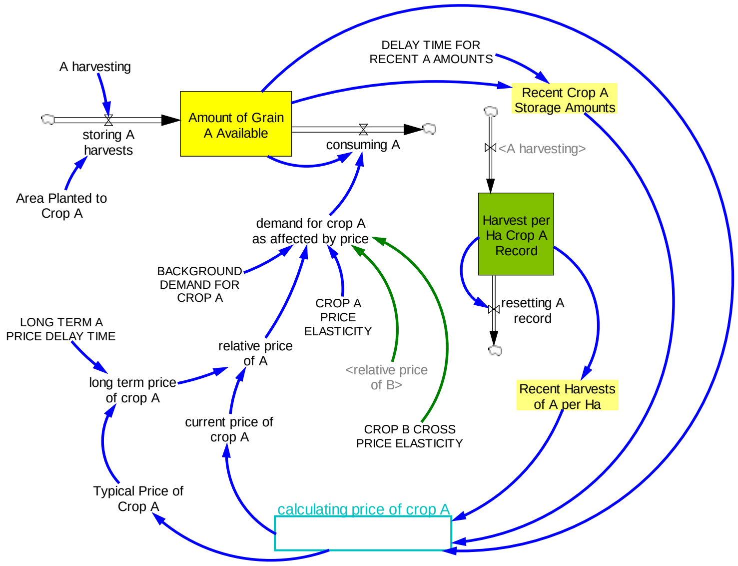

Figure 4. A portion of the model in which the amount of grain available is used to determine price and consequently an adjustment to demand for grain consumption. Illustrated here is the determination for just one of two crop types.

The relative abundance of either crop type determines the price of that crop and consequently the immediate demand for that crop. The combination of the amount of crop in storage, the demand for the crop, and the recent harvests both in terms of harvest per hectare, and in terms of total harvest, influence both demand and price. This is illustrated in Figure 4, for a single crop.

Total harvest of each crop is determined by total hectares planted to each crop as well as by productivity per hectare. Hectares planted is determined as described in Figure 3, but productivity per hectare is much less tightly bound to the remaining parts of the model. In this model factors affecting the productivity of each crop are restricted to soil moisture content which is ultimately driven exogenously by rainfall amount. Each crop has a defined productivity relationship determined by relative soil moisture, and it is assumed herein that other factors affecting crop production are, on the average, minimal (Figure 5).

The exogenous rainfall portion of the model has two random components. One component determines the probability that rainfall occurs at a particular point in time, and the other component can be used to randomly affect the amount of rainfall at any given time. While the second random component is optional, the model must use some value for the first component to determine when rainfall occurs. Detail in the rainfall portion is needed because accounting for the probability of rainfall at a given point in time has a direct influence on the pattern of soil moisture availability, and therefore on the relative productivity of the two crops. That is, soil moisture can be highly variable when rainfall events are infrequent, as in drought prone areas (Figure 6).

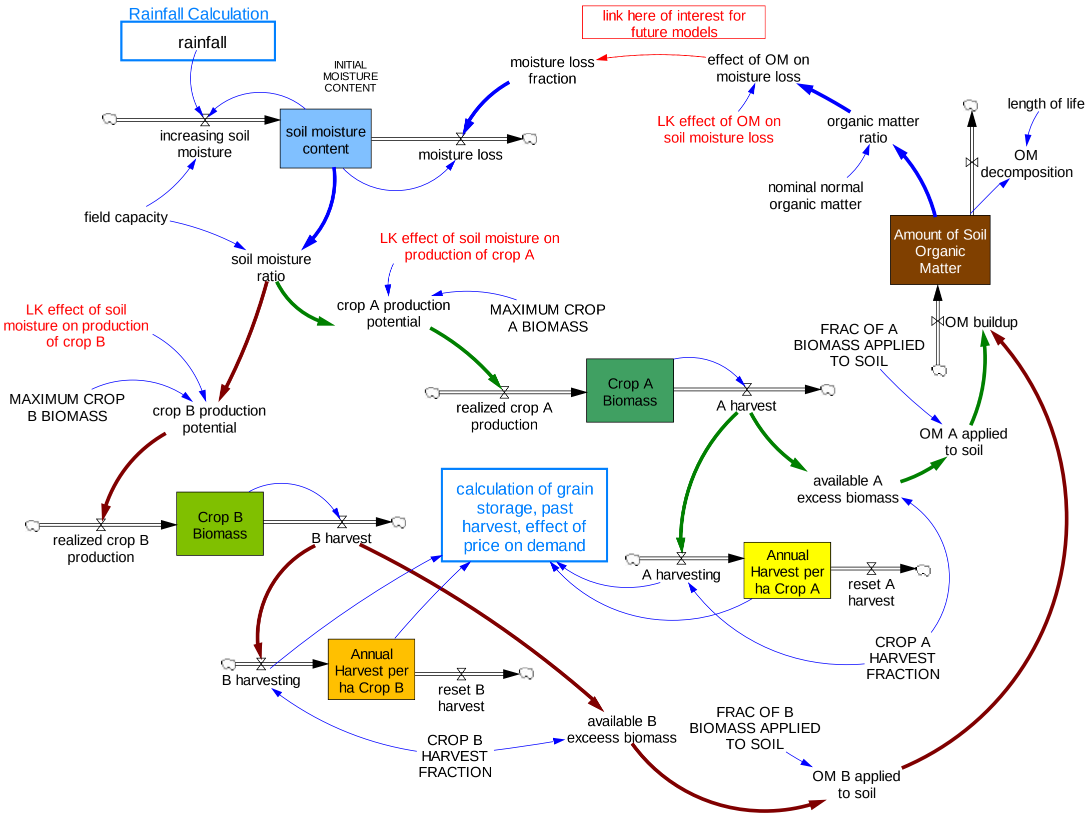

Figure 5. Crop production portion of the model. In this simplified model productivity of the two crop types is determined solely by the soil moisture ratio and by a function determining this productivity for each crop. Harvests of each crop are used further on in the model to determine prices, demand, and area of each crop planted. (In a future version amount of soil organic matter, which differs for the two crops will influence the water holding capacity of the soil and therefore the productivity of the crops planted.)

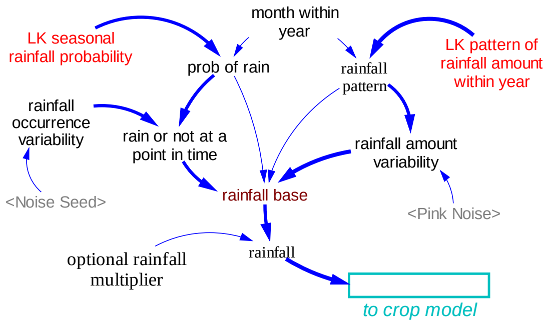

Figure 6. Rainfall is calculated using typical seasonal patterns of rainfall incidents and rainfall amount. Both values can be varied using noise input. Nevertheless, variability in rainfall occurrence requires some baseline input pattern.

Model Results

Results at different rainfall levels with minimal variation.

A good starting point for examining model outcomes is to assume that rainfall variation is minimal. In this model there are two random components to rainfall: a relatively small affect that determines whether rain falls on a particular day, and a larger, optional affect that adds a user determined variability to rainfall amount. By using only the first random component rainfall varies only slightly.

If we examine the outcome for overall rainfall amounts of 100% 110% 120% and 130% normal we see that the area farmers plant to the drought intolerant crop increases as expected. At low rainfall amounts the drought tolerant crop dominates while at each higher rainfall level a larger proportion of the drought intolerant crop is planted (Figure 7). This is largely due to the differences in crop productivity at the different rainfall levels (Figure 8), as well as to changes in prices as the relative abundance of the crop compared to their normal abundance and to the abundance of the other crop changes.

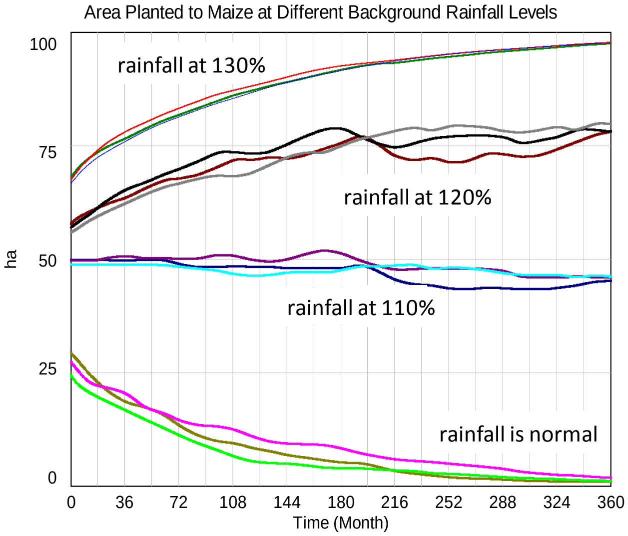

Figure 7. Example output showing area of maize at different background rainfall levels.

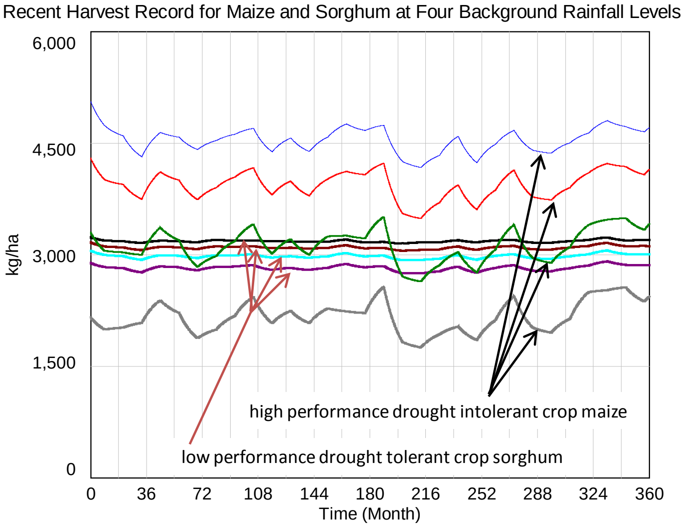

Figure 8. Typical harvests per ha of maize and sorghum at four relatively constant rainfall regimes.

A simple step change in the rainfall by 20% indicates how such changes occur in the model where the financial and food benefits of switching from one crop to another are illustrated (Figure 9).

Effects of increases in natural rainfall variation

Importantly, inter-annual variations in rainfall do occur naturally, and these changes are expected to become larger and more frequent in the future. Wetter and dryer periods are expected to become common. During wetter periods farmers will be incentivized to grow more maize, and less sorghum, hoping that continued rainy periods will support the higher yields of maize. The effects of such variations in rainfall are illustrated in Figure 10, discussed below. There a series of different random sequences of rainfall illustrate the types of patterns that might occur in planting of crops. For a few years one crop will prevail then as the rainfall patterns change the other crop will become more common.

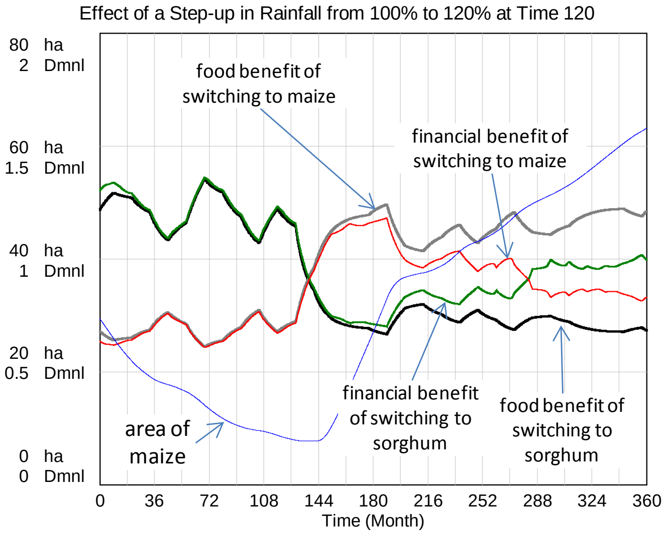

Figure 9. Test effect of a step-up in rainfall at time = 120 months. The relative food and financial benefit of maize under high rainfall conditions are both initially important even though maize's financial benefits eventually drop below that of sorghum as prices of maize, compared to sorghum, drop.

Possible effects of introducing a higher yielding maize variety

During the wetter periods the planting of maize will become more common because of its higher yields under wet conditions. This will incentivize the continued planting of maize until after a dry period occurs leading to crop failures and thereby making maize less attractive, initiating a gradual switchover to sorghum until another wet period occurs. Since a substantial portion of research on improved crop varieties is focused on maize, one has to be concerned about unintended effects of further incentivizing the planting of maize. In the model this question was examined by raising the productivity of maize, from a grain to biomass fraction of 0.4 (which approximates the current actual fraction) to a grain to biomass fraction of 0.5, a hypothetical 25% improvement.

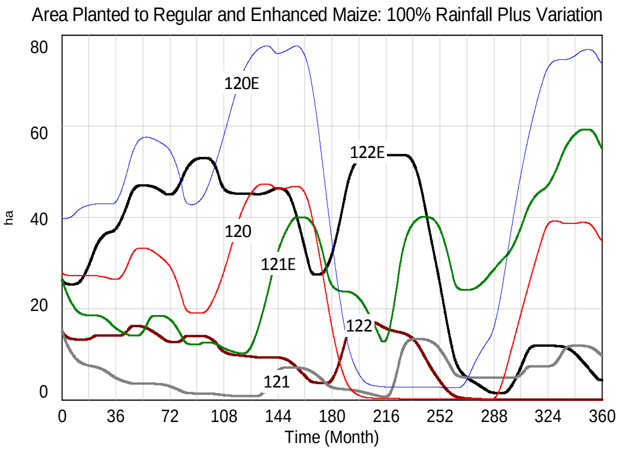

Figure 10. Example runs with pink noise generated rainfall variations. Lines without in "E" indicate runs made with standard maize. Lines marked with an "E" indicate runs made with enhanced maize. Runs with identical numbers use the same random rainfall pattern.

Some example runs of this test, comparing the two different maize varieties under conditions of increased rainfall variation, are illustrated in Figure 10. In these cases we can see that the area planted to maize increases substantially when enhanced maize varieties are used. During periods of good rainfall the enhanced maize will produce more grain, but as rainfall drops maize will continue to be planted and the resulting crop will not produce well if conditions are sufficiently dry.

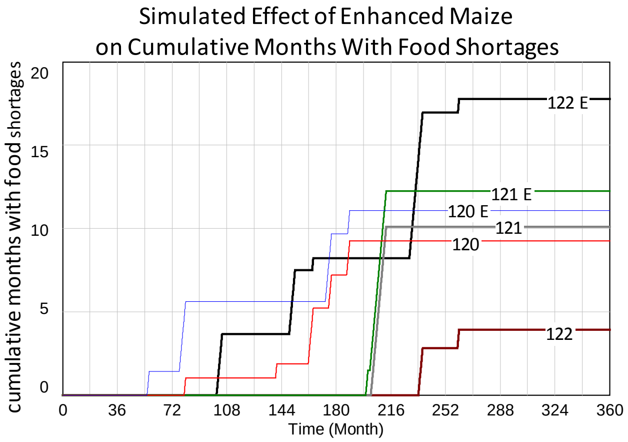

Figure 11. Simulation outputs indicating the cumulative length of food shortages for both standard and enhanced maize for three paired runs. In each case shown here enhanced maize produced more food shortage then did standard maize under the conditions of the paired runs. Also see figure 12.

In the model food shortages are tracked by calculating the number of times the amount of food available in storage drops below a critical amount. By tracking this for various model runs it is possible to determine the amount of food shortages that would be produced under different conditions. A simple illustration of this is provided in Figure 11 where a small series of model runs with and without enhanced maize is presented. In all the cases shown there, runs using enhanced maize produced a more months of food shortage then did runs with normal maize.

In order to test this idea further, 500 paired runs were made, 250 using enhanced maize and 250 using normal maize. The runs were paired by the random number sequence used to create the rainfall pattern. The underlying rainfall was the 100% scenario which would normally favor the planting of sorghum. In all but a few cases enhanced maize caused more food shortage then did normal maize (Figure 12). Under conditions of these runs, using normal maize as the maize option created 6.9 months with food shortages over a 30 year period while the use of enhanced maize, instead of producing more food, created 12.4 months without food over the same period.

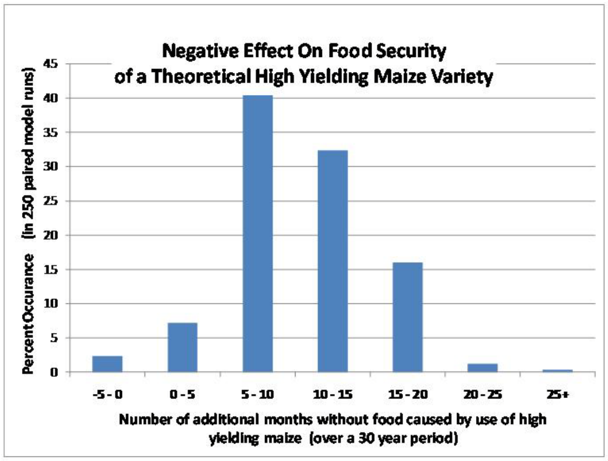

Figure 12. Distribution of the number of *additional* months of food shortage caused by the use of high yielding rather than normal maize, based on paired runs of the model. In only a few percent of the cases was the use of high yielding maize beneficial under the conditions in these model runs.

Conclusions and comments

While this is a preliminary model with a number of elements that need further investigation, the fact that enhanced maize which is intended to produce more food could, under some realistic scenarios, decrease food security is a question of concern that deserves more careful investigation.

For example, the exact nature of the pricing relationships between maize and other crops is critical. In the approach used herein prices of the two grains are fairly tightly bound, making economic incentives to switch from one grain to the other as one becomes scarce somewhat less important. If, on the other hand, the two prices are fairly independent then as maize becomes more dominant its price drops compared to other grains, thereby encouraging farmers to grow more of those. This effect would inadvertently also mitigate the possible effects of prolonged drought on food supplies by incentivizing the planting of the alternate crops albeit with a significant delay. Future investigations will need to reexamine the pricing relationships between maize and other grains (e.g. sorghum, millet, and tef) grown in the area of interest.

In spite of its high productivity and widespread use, there are other potential problems arising from the increasing dependence on maize as a staple crop. One concern (which this model, modified, may be able to address) is the growing interest in sustainable cropping systems, which includes the use of crop residues to increase soil organic matter. Soil organic matter is important because of its role in holding soil moisture, and therefore important for mitigating effects of dry periods within a growing season. Compared to other grain crops, maize produces significantly less excess organic matter that can be put back into the soil. So maize growing is not only risky in drought prone areas, but maize is also less useful at improving soil structure to fight drought. There are also a number of issues related to the use of a single dominant crop over wide areas: dangers related to crop pests, disease and possibilities of regional crop failure.

Nevertheless, in addition to its higher productivity, maize is favored for cultural reasons. In parts of East Africa, even in the face of almost certain failure, people still want to grow maize. Any additional incentive to grow maize will be met with enthusiastic support. Thus maize is a dominant part of the African agricultural landscape and will remain so, but hopefully in a way that improves agricultural production within a diverse agricultural landscape.

Acknowledgments

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