FOOD SECURITY RESEARCH PROJECT

Factors Contributing to Zambia's 2010 Maize Bumper Harvest

by

William J. Burke, T. S. Jayne, and Antony Chapoto

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Any views expressed or remaining errors are solely the responsibility of the authors.

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EXECUTIVE SUMMARY

Zambia's maize crop grew by roughly 48% between the 2009 and 2010 harvests, leading to the largest crop recorded in recent history. The 2009 maize harvest was also very good, making the 48% rise in 2010 even more remarkable. The forces driving that increase, however, remain widely debated. Many in government and media have attributed the recent production increase to the government's fertilizer subsidy program as well as to the state's recent efforts to raise maize prices through the operations of the Food Reserve Agency. Others have argued that the bumper harvest is partially due to the adoption of conservation farming techniques by farmers. Still others attribute the maize production growth mainly to favorable weather. Unfortunately, none of these claims have been backed up by solid evidence-based research.

This study measures the contribution of these various factors to the jump in maize production in 2010. The analysis will benefit policy makers and other stakeholders by providing an empirical foundation for future discussions in Zambia about the importance of government programs and other factors in driving the recent maize production growth. A companion FSRP working paper is assessing the impacts of these programs – which have been primarily oriented to encourage maize production – on the production of other crops and on total net income in Zambia's smallholder farm sector.

Using calculus based methods analogous to those derived by Minot (2003), we decompose the growth in Zambian maize production from 2009 to 2010 into contributions from three possible sources: yield increases, increased area planted to maize, and increased ratio of harvested to planted land. More specific determinants of production such as fertilizer use, type of seed, etc. can only affect production through one of these sources of growth.

The study is carried out using several years of nationally representative survey data from Crop Forecast Surveys, which are collected annually by the Ministry of Agriculture and Cooperatives (MACO) in collaboration with the Central Statistical Office (CSO).

We find that yield growth accounted for the majority (59%) of the maize production growth between 2009 and 2010. Expansion of area planted to maize explains an additional 23%, while the remaining 18% can be attributed to a rise in the ratio of harvested to planted land.

Following this decomposition, regression analysis and subsequent simulations are employed to understand the factors driving the rise in maize yields. Results suggest the largest factor contributing to yield growth has been weather, which explains 61% of the rise in maize yields between 2009 and 2010. Increased fertilizer use from both the private sector and the subsidy program explains an additional 32% of the yield increase, while increased hybrid seed use can be attributed with another 5%. When assessing the factors accounting for the 2010 maize yields compared to the four previous years, the combination of favorable weather, increased fertilizer use, and the beneficial interactions between good weather and fertilizer application accounts for over 90% of the yield gains achieved over this period.

Maize yield response rates to fertilizer application rose from about 3 kg of additional maize for each kg of fertilizer applied in 2006 to just over 4 kg/kg in 2010. This rise in yield response to fertilizer use over this period is due largely to favorable weather in both the 2008/09 and 2009/10 growing seasons.

Unfortunately, data was not available in the Crop Forecast Surveys to carry out the same analysis of the growth in maize area planted and the ratio of harvested to planted area. Improvements in the types of information contained in future Crop Forecast Surveys would make it possible to more accurately assess the contribution of various factors to changes in maize area and the proportion harvested to planted area. For the time being, if we assume that the factors driving yield growth also explain the change in the ratio of harvested to planted land, then we can conclude that 47% of the difference in production from 2009 to 2010 was due to weather, 25% was due to increased fertilizer use from both the private and public sectors, and 23% was due to area expansion. The remaining 5% can be explained by increased hybrid seed use and improved management.

The implication of these findings is that, although Zambia had a good harvest in 2010, policy makers and other stakeholders should not overlook that the country remains largely vulnerable to major shifts in maize production in the future. Weather fluctuations are one major source of production variability. Maize production instability may be exacerbated because of problems that the government has faced in trying to meet smallholders' marketing needs during the 2010 bumper harvest. For example, the Food Reserve Agency (FRA) announced a producer price in 2010 far above market prices, but has yet to put the financing in place to pay many farmers or to transport the crop from open air satellite depots to covered storage facilities. As a result, many farmers remain unpaid several months after delivering their maize to FRA, a large proportion of FRA's accumulated maize is at risk of damage once the rains start, and market prices remain relatively low. The problem of low maize prices has been exacerbated by the continued focus on government led exports and limiting the number of export licenses for the private sector. Moreover, if FRA continues to price maize above import parity levels while Zambia is a surplus producer with low domestic prices, there is no way to avoid the fact that there will be a substantial cost to Treasury when the FRA attempts to sell its accumulated stocks.

For all of these reasons, farmers' planting behavior in the coming 2010/11 crop season may be very different from the 2009/10 season. Specifically, if farmers' response to unpredictable maize policy is to plant less area to maize next year, it could stimulate increased (and increasingly unpredictable) government intervention going forward. The long run risk is highly volatile maize production levels and prices in the future. Unpredictable government policies on maize generate uncertainty for participants in the marketing system and create unintended consequences for the performance of maize and other food markets. Therefore, predictable and transparent rules dictating the government's involvement in the maize market would reduce market risks and enable greater coordination between private and public decisions in the market. Also, greater policy stability is necessary for sustained maize surplus production and may contribute to broader grain market development in the country.

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ACRONYMS

CFS	Crop Forecast Survey
CSO	Central Statistical Office
FISP	Farmer Input Support Program
FRA	Food Reserve Agency
FSP	Fertilizer Support Program
FSRP	Food Security Research Project
GRZ	Government of Zambia
MACO	Ministry of Agriculture and Cooperatives
MET	Zambia Meteorological Service
MSU	Michigan State University
OPV	Open Pollinated Varieties
USAID	United States Agency for International Development

1. INTRODUCTION

Following the Zambian Crop Forecast Survey (CFS) for 2010 a record harvest has been predicted, with production estimates roughly 48% higher than in 2009, which was itself a very good harvest. Many in Zambia have attributed the recent production increase to the government's fertilizer subsidy program and maize marketing policies, in which the Food Reserve Agency (FRA) buys maize from farmers at prices above the market. Others have attributed the bumper harvest to the adoption of conservation farming techniques by farmers. Unfortunately, none of these claims are backed up by evidence-based analysis. It is against this backdrop that this paper decomposes the maize production growth in 2010 to changes in area planted, yield, and the proportion of area planted that was harvested. We further assess the contribution to yield growth of increased fertilizer use, use of hybrid maize seed, adoption of conservation farming techniques, weather, and their interactions. The analysis will benefit policy makers and other stakeholders who will then be able to evaluate the effectiveness of government programs and make more informed conclusions about Zambia's food security status.

The 2010 maize bumper harvest follows several years of substantial interventions in both the input and output markets for maize by the Government of Zambia (GRZ). In 2002, the GRZ began distributing an increasing amount of subsidized fertilizer each year through the Fertilizer Support Program (FSP). Up until the 2009 planting season this program alone has regularly accounted for more than one third of the overall public budget to agriculture (Xu et al. 2009; Chapoto 2009). At the beginning of the 2009/10 agricultural season FSP was reformed and re-named the Farmer Input Support Program (FISP). Under FISP, beneficiary farmers received less fertilizer (two 50kg bag of basal dressing and two 50kg bags of top dressing compared to four bags of each type in previous years), but this allowed the program to reach more beneficiary farmers for a given total quantity of subsidized fertilizer to be distributed. Also, local organizations were involved in the targeting of farmers who would not otherwise have purchased fertilizer. Better targeting, it is thought, will not only result in more fertilizer going to those in the greatest need, but would also enable the private sector to sell more commercial fertilizer to farmers who could afford to buy it.

Undeniably, fertilizer use has increased from the 2008/09 agricultural season to the 2009/10 season. The FISP distributed approximately 25% more subsidized fertilizer (69,100 metric tons in all) than it did a year earlier.[1] Moreover, the private sector fertilizer sales in 2010 also increased by 62% (selling more than 94,000 metric tons). All told, fertilizer use in Zambia increased from 2009 to 2010 by more than 50,000 metric tons.

In light of the controversy surrounding the causes of the 2009/2010 bumper harvest in Zambia, the objective of this study has three objectives:

1. To determine the relative contributions of yield growth, area expansion, and changes in the ratio of maize area harvested to planted to the growth in maize production from the 2009 to 2010 harvest seasons.

[1] The official target was a higher increase in FISP distribution to more than 100,000 tons, but data from the nationally representative 2010 Crop Forecast Survey indicates that only 69,100 tons were received by farmers.

2. To identify the factors driving the changes in these sources of overall production growth in order to assess the relative contributions of fertilizer, weather, seed use and other factors.

3. To examine the sources of the longer-run growth in maize production between 2010 and the prior four production seasons using Crop Forecast Survey data.

The remainder of this paper is organized into five sections as follows: Section 2 and 3 describes the conceptual framework and data respectively. Section 4 presents and discusses the findings, while Section 5 presents the conclusions, implications for maize policy, and issues to consider for future studies.

2. CONCEPTUAL FRAMEWORK

In order to determine what share of production growth can be attributed to changes in yields per harvested hectares, changes in the ratio of harvested to planted area and to changes in the total area planted, we must first derive a model for how a change in production comes about. Mathematically, total production (*prod*) can be written as the product of yield per hectare harvested (*y*) and total area harvested (*ah*):

$$prod = y \cdot ah \qquad (1)$$

However, equation 1 does not consider the fact that some crops are lost or abandoned after planting. This could occur due to drought or flooding, or it could be a behavioral decision on behalf of the farmer who feels that market prices are not worth the harvesting effort. To add this element of total production, we can multiply and divide equation 1 by the total area planted (*ap*) at the beginning of the season without losing equality:

$$prod = y \cdot \frac{ah}{ap} \cdot ap \qquad (2)$$

Borrowing from Minot (2003), who presented a multiplicative functional form for farmer income in Vietnam, we can take the total derivative of equation (2) in order to obtain:

$$\frac{\partial prod}{\partial prod} = \frac{\partial y\left(\frac{ah}{ap} \cdot ap\right)}{\partial prod} + \frac{\partial \frac{ah}{ap}\left(y \cdot ap\right)}{\partial prod} + \frac{\partial ap\left(y \cdot \frac{ah}{ap}\right)}{\partial prod} \qquad (3)$$

We now clearly see that changes in production ($\partial prod$) will come from either changes in yield, changes in the ratio of harvested to planted area, or changes in area planted. While this expression describes marginal changes, we only observe large changes from one year to the next. To make (3) operational (i.e. to calculate relative contributions) we can substitute marginal changes for actual changes and add a residual term (η) to allow for the fact that the equality no longer holds:

$$\Delta prod_t = \Delta y_t\left(\overline{\frac{ah}{ap}} \cdot \overline{ap}\right) + \Delta \frac{ah_t}{ap_t}\left(\overline{y} \cdot \overline{ap}\right) + \Delta ap_t\left(\overline{y} \cdot \overline{\frac{ah}{ap}}\right) + \eta \qquad (4)$$

where $\Delta x_t = x_t - x_{t-1}$ is the change in *x*, and $\overline{x} = \left(x_t + x_{t-1}\right)/2$ is the two-period mean for each *x* variable. Inclusion of the residual term, η, essentially acknowledges that, due to the fact that these effects are not additively separable (except for marginal changes), there may be some share of the growth from one year to the next which cannot be attributed to any of the sources. Minot (2003) referred to this as the *interaction term* because if it cannot be attributed to any one source, it must be attributable to the interaction between various sources over time. Nevertheless, calculations should endeavor to minimize this term since it only exists to account for noise stemming from the fact that we are forced to use large changes to approximate contributions from a formula based on marginal changes. This is done through the choice of base values used to make equation (3) operational. As it happens, this is always accomplished using the time-averaged values as in equation (4).[2] Now we can calculate the relative contribution of increases in yield (γ_t^y), for example, as:

$$\hat{\gamma}_t^y = \frac{\Delta y_t \left(\frac{\overline{ah}}{\overline{ap}} \cdot \overline{ap} \right)}{\Delta prod_t} \tag{5}$$

and, by construction the equality will hold:

$$1 = \hat{\gamma}_t^y + \hat{\gamma}_t^{ah/ph} + \hat{\gamma}_t^{ap} + \eta^* \tag{6}$$

where $\eta^* = \eta / \Delta prod$. These values can be calculated at national or provincial levels to examine how the relative contribution to growth from each source varies geographically.

Our calculations will be used to inform the follow-up regression analysis for the determinants of the most important of these sources.

[2] Other options include using the base year or final year values. It can be shown, however, that using the means over time is equivalent to using these and all other possible methods, then averaging results. In this way, choosing the time-average base is analogous to a multiple imputation method.

3. DATA

To study the sources of growth we use data from the Zambian Crop Forecast Survey conducted annually by the Central Statistical Office. These nationally representative samples provide data on 14,122 and 14,034 maize fields grown by 11,518 and 11,224 farm households in 2009 and 2010, respectively. Analysis comparing the 2010 harvest to the average of prior years uses data from CFS 2006, 2007, and 2008, with 8,367, 13,521, and 13,390 observations on maize plots.

CFS surveys each year ask a randomly-selected set of respondent farmers to provide information about their area, production and yield outcomes. A unique feature of the CFS is that it asks respondents about both maize area planted as well as maize area harvested. We find that a minority of farmers abandon their fields at some point after planting, either due to drought, flood, and a variety of factors related to labor shortages. In an average season, roughly 20% of the maize area planted nationally is not harvested. For this reason, the ratio of area harvested to planted, which is influenced primarily by weather outcomes, is included in this production decomposition analysis.

4. RESULTS AND DISCUSSION

Table 1 presents the results of the decomposition analysis of the growth in production from 2009 to 2010 harvest seasons by source. Note that the residual terms, or the share of the change in production that cannot be attributed to any source is very small (less than one half of one percent of the total change in maize production) for all provinces and at the national level.

For Zambia as a whole, yield growth can be attributed with 59% of the increase in total maize production from 2009 to 2010. The ratio of harvested to planted land and area expansion can be credited with 18% and 23% of the remaining production growth.

The importance of yield growth in driving maize production growth is fairly consistent across provinces. With the exception of Copperbelt and Northern provinces, where area expansion explains the majority of the production growth, and Western province, where the improved ratio of harvested to planted land explains the majority of the increase, yield is the most important source of production growth. Even in the three exception provinces, yield is a major contributing factor to growth, accounting for 39-47% of overall growth.

The ratio of harvested to planted land contributed practically nothing to production increases in many of the provinces. This can be explained by the fact that the ratio in those provinces was quite high in 2009, leaving little room to improve over rates that were already at or above 90%. In the Eastern province area expansion also contributed very little to production growth (actually, area planted declined), which means yield increases can be credited with all of the growth in production for that province.

Table 1. Contributions to Maize Production Growth by Province (2010 vs. 2009)

Province	Relative Contribution to Production growth between 2009-2010 harvests from changes in: Yield	Ratio of Harvested to Planted land	Area Expansion	Residual (unexplained share)
	-------------Percent-------------			
Central	45	24	31	0.0
Copperbelt	47	02	51	0.0
Eastern	102	00	-2.0	0.0
Luapula	59	01	40	0.0
Lusaka	51	16	32	0.0
Northern	39	1.0	60	0.0
North Western	56	7.0	37	0.0
Southern	45	31	24	0.0
Western	47	58	-4.0	0.0
All Zambia	59	18	23	0.0

Source: Central Statistics Office Crop Forecast Survey 2008/09 and 2009/10

This begs the question, what can explain the difference in *yield* from 2009 to 2010, a period that saw average yields nationwide increase from around 2 metric tons of maize per hectare (mt/ha) to just over 2.5 mt/ha? To examine this we estimate a linear model of the determinants of yield from 2006 to 2010. Then, similar to the way we were able decompose the contributions to growth in total production, we will be able to decompose the contributions to yield itself through simulation analysis.

The model for yield incorporates, as much as possible, the agronomic principles to identify the determinants of yield, which are weather, management, and soil nutrient composition (including fertilizer application), as well as how these determinants may interact. Management variables available for this study include binary indicator variables for whether purchased hybrid seed is used[3], whether maize was planted with a nitrogen fixing legume (which we expect to have a positive effect), whether the maize was planted alongside some other, non-nitrogen fixing crop (which we expect to have a negative effect), and whether the tillage was done before the rains. We expect pre-rain tillage to have a positive coefficient as this implies the seed would be in the ground for the annual *nitrogen flush* that comes when a large amount of organic nitrogen is released into the soil with the first rains (Haggblade and Tembo 2003). Additional management dummy variables are included for the type of tillage that is used, which in Zambia is either hand hoeing, planting basins, zero tillage, plowing, ripping, ridging or bunding. The effect of hand hoeing will be subsumed into the intercept term. Finally, the field size overall is included as a proxy variable for unobserved management factors, such as how thinly labor must be spread at the field level.[4]

For weather variables we will use total rainfall over the growing season (November to March) derived from data collected at 34 rainfall stations throughout the country by the Zambia Meteorological Service (MET). One does not expect the benefits of rainfall to be linear, and indeed too much rainfall could be detrimental, so the model will include a quadratic term for rainfall to allow for diminishing returns. From the MET data we can also obtain a rainfall *stress* variable, defined as the number of 20 day periods during the growing season with less than 40 mm of rainfall, which we would expect to have a negative effect on yield.

There are many other aspects of weather that will impact yield in a given field throughout the year. For example, the amount of sunlight available to each plant will vary with cloud cover. Prevailing temperatures during and between rains also influences a plant's growth and production, along with many other weather related factors. Unfortunately, these factors are very difficult to enumerate. In agronomic studies these factors are controlled for by planting control and treatment crops in the same field, thereby subjecting them to the same weather conditions. For nationally representative data, on the other hand, we will take advantage of the fact that, while these factors are time variant, they will be relatively homogenous geographically within a given time period. That is, if we include year dummy variables, interacted with geographic dummy variables, we can safely claim that they are capturing the net effects of less enumerable weather conditions. Specifically, in our model we will include year dummy variables, agro-ecological zone dummy variables and a full set of their interactions, all of which will be considered weather variables. Agro-ecological zone dummy

[3] This variable includes purchased improved open pollination varieties, which may not technically be a hybrid.
[4] This is an admittedly incomplete proxy for labor and other management variables. For example, if the field is large, but there is an excess of family labor, this would be a very poor proxy. That said, data limitations prevent us from developing a better proxy. Furthermore, the coefficient on this proxy is statistically significant and of the expected (negative) sign, so it will remain in the model.

variables will also be controlling for various soil types throughout the country, which one might argue is comingling weather and soil effects. In terms of contributions to changes in yield, however, this argument is moot since soil type is a time-constant determinant.

The final soil nutrient variable is fertilizer application. There are two main types of fertilizer used in Zambia. First is the primarily phosphoric basal dressing, and second is nitrogen rich top dressing. Ideally these would enter the model separately as they contribute to growth in organically different ways.[5] For better or worse, these inputs are used in largely equal proportions for most fields in Zambia. The correlation between the rate of basal and top dressing applications is 0.88 (significant at 0.0% level). Practically speaking this is a positive result, since agronomic studies indicate that response rate to each is higher when they are used together. Statistically, however, this presents a collinearity problem. In short, if too few farmers are using only one type and not the other, regression analysis is not able to efficiently allocate yield response to one or the other. To resolve this issue, we must lump the two types of fertilizer together and include fertilizer application rate as one variable in our model.

Table 2. Mean Value of Maize Yield Determinants Over Time (2006-2007)

	Harvest year				
	2006	2007	2008	2009	2010
Yield Determinants	------------------------Mean----------------------				
Rainfall					
Total Rainfall (mm)	1029	1118	1029	1083	1078
Rainfall Stress[a]	1.56	2.29	2.18	1.27	0.99
Tillage					
% of plots tilled before the rains	32%	28%	30%	29%	29%
Planting basins	2%	2%	1%	1%	2%
Zero tillage	4%	3%	4%	4%	2%
Plowing	34%	35%	37%	34%	37%
Ripping	0%	0%	0%	0%	1%
Ridging	22%	28%	30%	29%	19%
Bunding	3%	3%	2%	3%	2%
Management					
Hectares planted (ha)	0.68	0.79	0.86	0.76	0.83
Planted with N-fixer	3%	3%	3%	5%	4%
Planted with other crops	4%	4%	3%	4%	3%
Used purchased hybrid seed[b]	35%	39%	42%	39%	46%
Rate of fertilizer application (kg/ha)	100.19	112.63	97.93	111.28	147.58

Source: Zambian Crop Forecast Survey data 2006, 2007, 2008, 2009 and 2010.
Notes: a) Rainfall stress is defined as the number of 20 day periods with less than 40 mm of rainfall during the rainy season. b) This variable also includes open pollinated varieties with purchased hybrids.

[5] See Eckert (2010) and Griffith (2010) for a thorough explanation of how each contributes to plant growth and production.

In reality, the effect of fertilizer will depend on a number of factors. For example, when weather is favorable, one could expect response rate to fertilizer to increase. Plants grown from hybrid seed are known to be more responsive to fertilizer application. To accommodate this characteristic in the model, fertilizer application rate is interacted with all other variables in the model (including having a quadratic term for fertilizer application rate). In other words, the partial effect of fertilizer application will be modeled as a function of all other variables.

Note that this implies that the partial effect itself can change over time, by region and so on, which will be demonstrated after the discussion on contributions to yield changes. Table 2 presents the means over time for the variables that are to be used in the regression. Full regression results can be found in Appendix A.

Having obtained our coefficient estimates, we now turn to simulation analysis in order to determine what factors have driven the differences in yield from 2009 to 2010. That is, using regression results we can plug in specific values for each explanatory variable and simulate what the outcome would be. Results from several such simulations are presented in Table 3.

To begin, we will simulate the expected average maize yield in 2009 by plugging all of the 2009 national mean values for each of the determinants (row *i*). This results in a predicted yield of 2,079 kg/ha. If we replace all of the 2009 values with the national means from 2010 (row *ii*), the simulation results in a predicted yield of 2,522 kg/ha, or a 21.3% increase. It is worth noting that these predicted values are quite close to the actual mean yield estimates from their respective years (off by 6% and 2% respectively). Now, in rows *iii* through *vii* we return all values to their 2009 levels, then change only certain variables to ascertain the relative contributions from various factors such as weather, fertilizer use, and so on to total yield changes.

First consider row *iii*, where all weather variables are changed to their 2010 values. This predicts a yield of 2,346 kg/ha, or an increase of 12.9% over 2009. In other words, if nothing else had changed from 2009 to 2010 except for the weather, yields would have increased by 12.9%. Put into the context of a 21.3 percent change in the prediction overall, this translates into a .61 share of the total change being attributable to weather.

If all variables are held at 2009 values and the fertilizer variable is changed to the 2010 value (row *iv*), the predicted yield is 2,219 kg/ha, or a 6.7% increase in yield. This means that the increase in fertilizer use can be attributed with a 32% share of the increase in yield from 2009 to 2010. It is important to note that the source of fertilizer is not considered in these simulations (i.e. increases in both FISP distribution and commercially purchased fertilizer have contributed to the increase in yield). Finally, the simulation in row *v* demonstrates that the increase in the share of fields planted using hybrid or open pollinated varieties (OPV) seeds accounts for an additional 5% share of the change in yield (or a 1% increase in yield itself). Jointly these three factors explain nearly all (a 98% share) of the explained increase in yield from 2009 to 2010. The remainder can be explained by improved field management.

Also note that the sum of the individual effects is not the same as the joint effects. For example, if we simulate a change in both weather and fertilizer use (row *vi*) the increase in yield is 19.9%, while the sum of their individual effects is 19.6%. This is possible because the model's incorporation of interactions allows for conditional yield response. Therefore, we can say that a yield increase of about 0.3% (or a contribution to total change of about .01) can be attributed to the interactions between the changes in weather and fertilizer use.

Table 3. Factors Driving Increased Yield from 2009 to 2010

Simulations changing specific factors from their 2009 to 2010 values.[a]	Results: Yield Prediction (kg/ha)	% change vs. 2009	Percent of contribution to total change[b]
i) Predicted yield using all 2009 values for weather, fertilizer, hybrid seed use, and others.	2,079	-	-
ii) Predicted yield using 2010 values for weather, fertilizer hybrid seed use, and others.	2,522	21.3%	100%
iii) changing weather from 2009 to 2010 values. All other variables held at 2009 levels.	2,346	12.9%	61%
iv) changing fertilizer from 2009 to 2010 value. All other variables held at 2009 levels.	2,219	6.7%	32%
v) changing purchased hybrid seed use from 2009 to 2010 value[c]. All other variables held at 2009 levels.	2,099	1.0%	5%
vi) Weather and fertilizer	2,493	19.9%	94%
vii) Weather, fertilizer and seed use	2,514	20.9%	98%

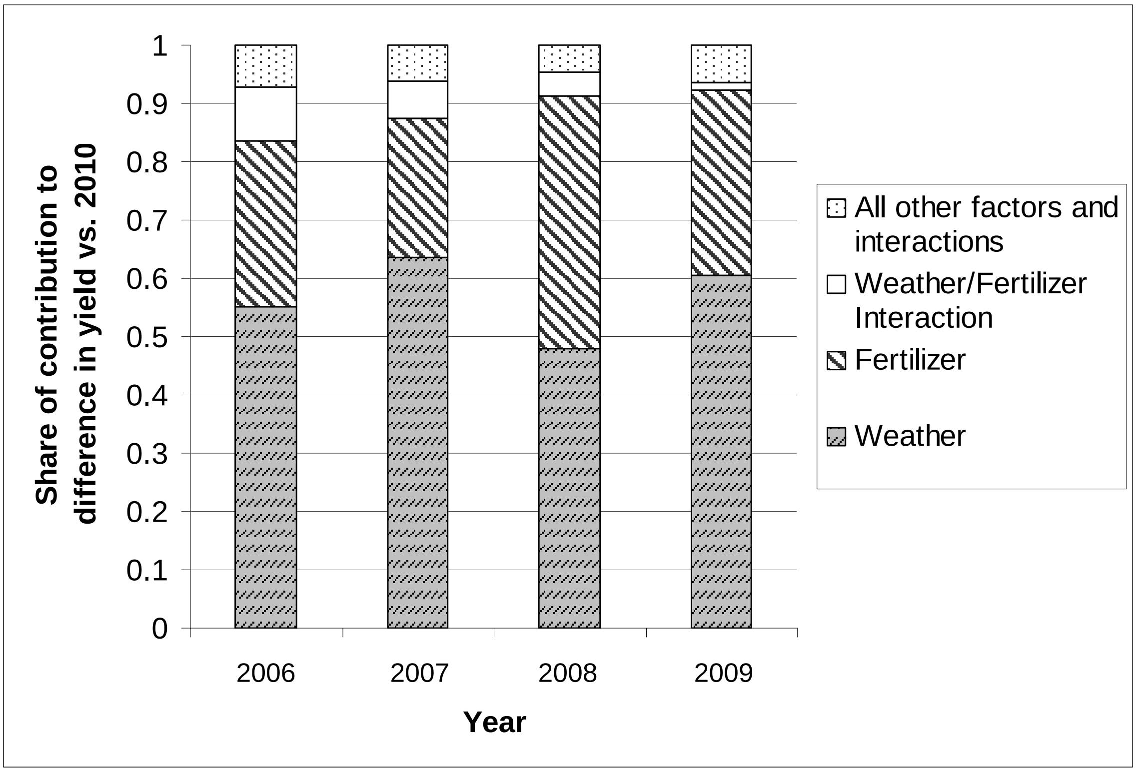
Source: Zambian Crop Forecast Survey data 2006, 2007, 2008, 2009, and 2010.
Notes: a) Values refers to the national Crop Forecast Survey means from 2009 unless otherwise indicated (e.g. in row *iv* the values of all variables in the simulation are 2009 national means, except the fertilizer application rates, which are set to the 2010 national mean. In addition to weather, fertilizer and seed use, factors controlled for are timing and method of tillage, other crops in the field (nitrogen fixing legumes and other crops controlled separately), and field size as a proxy for management. b) Contribution to total change is calculated as the percent change vs. 2009 from each simulation, divided by the percent change vs. 2009 for the 2010 simulation in row (*ii*). c) Measured as the share of fields under cultivation using purchased hybrid seed (including improved open pollinated varieties).

This result, which may be a surprising to some, should be interpreted carefully since this analysis is focused on contributions to *changes* in yield. In other words, the fact that the interaction effect contributes little to the change from 2009 to 2010 does not imply that the interaction has a small effect on the determination of yield itself. Moreover, if we were to compare the 2010 harvest to years preceding 2009, the interaction effects are more prominent. Figure 1 illustrates how the difference in yield between each year and 2010 can be attributed to differences in either weather, fertilizer, the interaction between those two factors, and all other determinants. Once again, we can see that the majority of the differences (57% on average) are attributable to changes in weather and changes in fertilizer use contribute an additional 32% on average.[6] The plain white section of each bar represents the contribution of the interaction effects between weather and fertilizer. Again, we see this contribution is rather small for 2009, but is as high as 9.4% as 2010 compares to 2006, and is 5.3% on average.

Another interesting trend emerging from these results is the change in yield response to fertilizer over time. Figure 2 plots the marginal yield from fertilizer application over the past five survey years in terms of kg of maize per kg of fertilizer (kg/kg), which has steadily increased from just over 3 kg/kg for the 2006 harvest to nearly 4 kg/kg for the 2010 harvest.

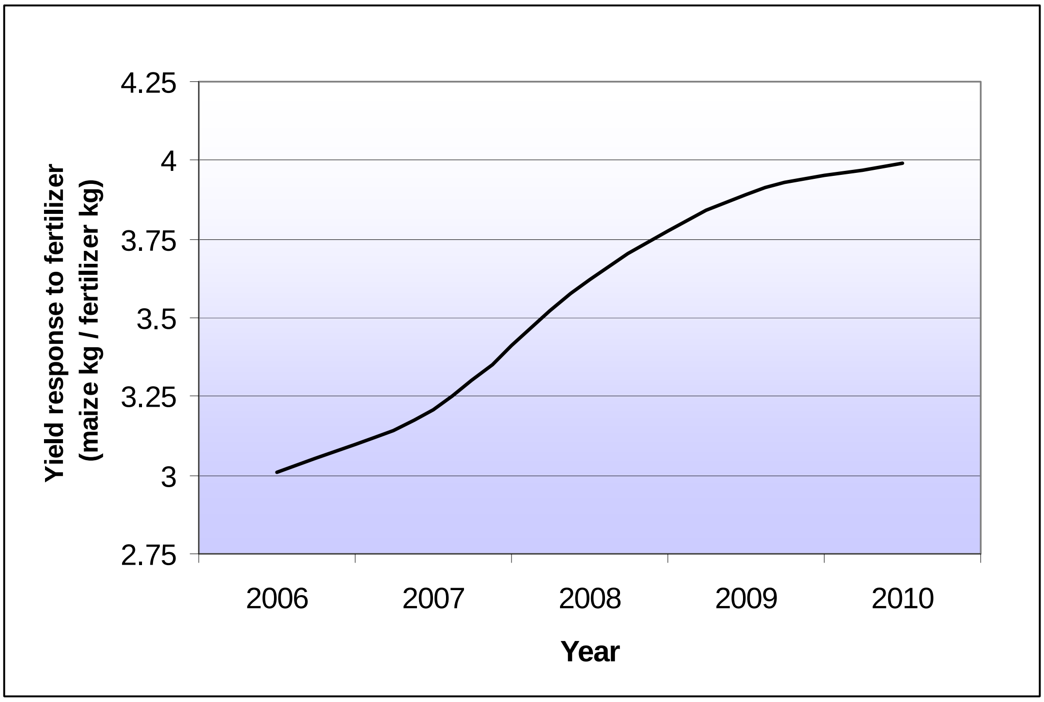
[6] The relatively large contribution from differences in fertilizer use as compared to 2008 is explained by greater than average use in 2010 in addition to lower than average use in 2008, as demonstrated in Table 1.

Figure 1. Factors Behind High Zambian Maize Yields (2010 vs. 2006 through 2009)



Source: CFS 2006, 2007, 2008, 2009, 2010 and author's calculations

Figure 2. Marginal Yield from Fertilizer Use over Time



Source: CFS 2006, 2007, 2008, 2009, 2010 and author's calculations

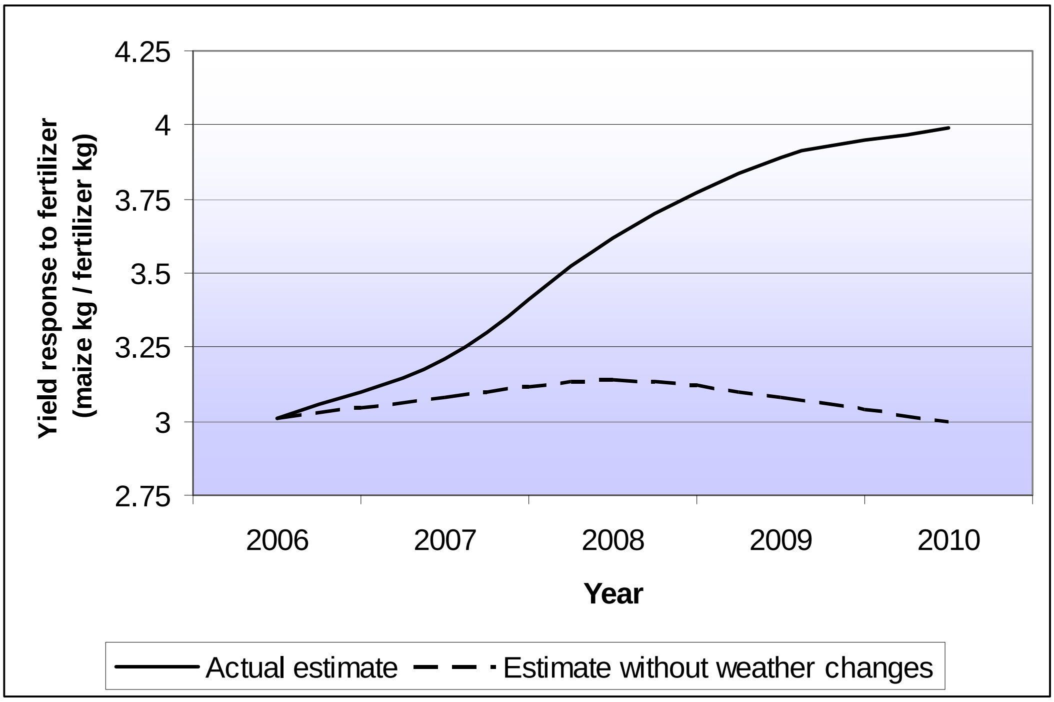
Since the response rate to fertilizer (or the partial derivative of yield with respect to fertilizer) is a function of all other determinants of yield and the level of fertilizer itself, we can conduct simulation analysis similar to that used to identify the sources of yield growth to identify the driving force behind increasing response rates.

Figure 3 presents the actual estimates for marginal response to fertilizer applications, as well as a counterfactual estimate of what response rates would have been if everything else changed, but weather variables are held constant at 2006 levels. This simulation indicates that without weather changes, response rates would have been fairly flat over time, with the 2010 response estimated as nearly identical to that of 2006.

Unfortunately, we are not able to estimate models for the ratio harvested or the total area planted due to data limitations. Since these are behavioral decisions, we would need much more information about the household and market environment than is available in the CFS.[7]

That said, if we assume the trends that are true for yield also explain the change in the ratio of harvested to planted land[8], then we conclude that 47% of the difference in production from 2009 to 2010 was due to weather, 25% was due to increased fertilizer use from both the private and public sectors, and 23% was due to area expansion. The remaining 5% can be explained by increased hybrid seed use and improved management.

Figure 3. Marginal Yield from Fertilizer Use over Time without Changes in Weather



Source: CFS 2006, 2007, 2008, 2009, 2010 and author's calculations.

[7] These include detailed price data on inputs and outputs (including substitute crops), more detailed household demographic information and some indication of the household's social capital, to name a few.
[8] At least in terms of the significance of weather effects, this is supported by anecdotal evidence from farmers. When asked why fields were not harvested, the largest changes in reasons from 2009 to 2010, in terms of the percent of respondents answering were for drought, floods and water-logging. A full summary of these responses are found in Appendix A2.

5. CONCLUSIONS

In this study our objective has been to understand the factors driving Zambia's record bumper harvest of 2010 versus the 2009 harvest and earlier years. We find that yield increases contribute a majority of the growth, explaining 59% of the difference from 2009 to 2010 at the national level. Area expansion explains an additional 23%, while the remaining 18% can be attributed to improvements in the ratio of harvested to planted land.

Following this decomposition, regression analysis and subsequent simulations were employed to identify the factors driving change in the dominant source for growth, yield improvements. Results suggest the largest factor contributing to yield growth has been weather, which explains 61% of the increase. Increased fertilizer use from both the private sector and subsidy distribution explains an additional 32% of yield increase, while increased hybrid seed use can be attributed with another 5%.

Another trend emerging from the results in an apparent increase in yield response rates to fertilizer use which rose from about 3 kg of additional maize for each kg of fertilizer applied in 2006 to just over 4 kg/kg in 2010. Once again, evidence strongly suggests this is due largely (if not solely) to increasingly favorable weather patterns over the past 4-5 years.

5.1. Implications for Policy

Zambian policy reforms have successfully contributed to raising maize production over the past year. A companion FSRP working paper to be released shortly shows that the total value of crop output has also risen over the past 4 years, although there have been shifts out of some other crops (most notably cassava, cotton, and groundnut) in response to the greater production incentives for maize. This is an achievement and should not be minimized.

However, though Zambia had a good harvest in 2010, policy makers and other stakeholders should not overlook that the potential exists for huge swings in maize production over the coming years. First, the country remains vulnerable to major shifts in weather conditions. Second, maize production instability may be exacerbated because of problems that the government has faced in trying to meet smallholders' marketing needs during the 2010 bumper harvest. For example, the Food Reserve Agency announced a producer price in 2010 far above market prices, but did not have the financing in place to pay many farmers or to transport the crop from open air satellite depots to covered storage facilities. As a result, many farmers remain unpaid several months after delivering their maize to FRA, a large proportion of FRA's accumulated maize is at risk of damage once the rains start, and market prices remain relatively low. The problem of low maize prices has been exacerbated by the continued focus on government led exports and limiting the number of export licenses for the private sector.

For all of these reasons, farmers' planting behavior in the coming 2010/11 crop season may be very different from the 2009/10 season. Specifically, if farmer response to unpredictable maize policy is less production next year, it could stimulate increased (and increasingly unpredictable) government intervention going forward. The long run risk is highly volatile maize production levels and prices in the future. Unpredictable government policies on maize generate uncertainty for participants in the marketing system and create unintended consequences for the performance of maize and other food markets. Therefore, predictable and transparent rules dictating the government's involvement in the maize market would reduce market risks and enable greater coordination between private and public decisions in the market. Also, greater policy stability is necessary for sustained maize surplus production and may contribute to broader grain market development in the country.

Furthermore if FRA is pricing maize above world prices while Zambia is a surplus producer, there is no way to avoid the fact that there will be a substantial cost to Treasury when that surplus is exported.

5.2. Considerations for Future Research

The findings outlined in this study are useful to policy makers and other agriculture stakeholders; however there are some shortcomings in the current study that should be acknowledged in order to improve the work in the future. First, with the possible exception of the field size, there are no labor control variables in our model due to a lack of data. Beginning with the 2010 survey attempts have been made to start collecting information on the number of man hours spent on various activities such as land preparation, fertilizing, weeding, etc. Without a series of these observations over time, however, these data will not be useful in understanding the determinants of changes in production from one year to the next. This substantial limitation should emphasize the importance of continuing to collect specific labor data in future Crop Forecast Surveys.

Secondly, one might argue that our weather variables (year dummy variables) are picking up increasing farmer ability over time due to improved extension. The merits of this argument would be very difficult to test given the lack of data on extension services, though we contend that these effects are more likely to impact long-run changes in production, not production from one year to the next. That said, one possible method to test for an *ability trend* would be to include a linear time trend in the model. Assuming the average farmer is getting better at farming gradually (or that the number of farmers having ever received training from an extension worker increases over time), than a linear time trend would be a good way to pick this up. In that model, the effects of the dummy variables represent the deviations from this trend that are explained by weather changes.

Unfortunately, there would be a number of problems with this approach. First, if weather has had an improving trend over the past five years (which it has), these effects would be comingled. Second, the simulations upon which we base our post-estimation analysis would become difficult to interpret. Intuitively, this is because we would be trying to change weather variables (time dummies), while holding the *ability trend* (another time variable) constant. It would be analogous to estimating the ceteris paribus effect of a change in x without changing x^2. That said, while ceteris paribus simulations wouldn't make much sense, results from such a regression would show whether the time trend is a significant variable, and if the annual trends hold up.

Inclusion of the time trend (and it's interaction with fertilizer) does not have any measurable effect on the annual yield predictions (changes of less than 0.0 kg/ha), and the trend for increasing marginal yield response to fertilizer application is the same, though the rates for each year vary slightly. Interestingly, the coefficient on the trend itself is significant and suggests that non-fertilizer users are experiencing *decreasing* yields over time.[9] Finally, the coefficient on the fertilizer interaction term wasn't significant, which supports the argument that the increase in fertilizer productivity is more a function of weather than some unobserved *ability trend*. In future studies, however, it would be beneficial to explicitly control for access to extension advice.

[9] One possible cause could be soil mining which, in the absence of fertilizer, causes land to lose natural productivity. Also, as fertilizer use increases, more productive farmers are self-selecting into the fertilizer user group. Full results from this regression are available upon request.

APPENDIX

Appendix A. Full Regression Results

One should interpret these regression results carefully since the coefficient estimates (and their significance levels) do not represent the partial effects themselves. Given the large number of interaction terms, the partial effect of a given variable will be a function of the levels of other variables. To analyze partial effects, one would be better informed by computing average partial effects and conducting delta-method inference to ascertain significance. That, however, is beyond the scope of this study.

Table A1. Full Regression Results

Explanatory variables	Maize yield
2007 (1=yes)	-385.6***
2008 (1=yes)	-674.2***
2009 (1=yes)	-211.5***
2010 (1=yes)	203.6***
Agro-ecological zone 1 (1=yes)	-75.71
Agro-ecological zone 1*2007	184.7
Agro-ecological zone 1*2008	631.3***
Agro-ecological zone 1*2009	142.8
Agro-ecological zone 1*2010	15.16
Agro-ecological zone 2a (1=yes)	428.7***
Agro-ecological zone 2a*2007	250.3***
Agro-ecological zone 2a*2008	637.9***
Agro-ecological zone 2a*2009	21.82
Agro-ecological zone 2a*2010	-27.94
Agro-ecological zone 3 (1=yes)	318.8***
Agro-ecological zone 3*2007	513.8***
Agro-ecological zone 3*2008	860.7***
Agro-ecological zone 3*2009	456.0***
Agro-ecological zone 3*2010	127.8
Growing season rainfall (mm)	0.629**
Rainfall squared	-0.000268**
Number of 20 day periods with <40 mm rain	96.15***
Hectares planted	-121.0***
Planted with nitrogen fixing crop (1=yes)	149.0***
Planted with non-nitrogen fixin crops (1=yes)	70.35
Used purchased hybrid or OPV seed (1=yes)	288.4***
Tillage done before the rains (1=yes)	27.13
Tillage using planting basins (1=yes)	162.6
Zero tillage used (1=yes)	-147.2***
Tillage using plow (1=yes)	206.6***
Tillage using ripping (1=yes)	183.3

Table A1 (Continued). Full Regression Results

Tillage using ridging (1=yes)	-103.2***
Tillage using bunding (1=yes)	-199.6***
Fertilizer application rate (kg/ha)	3.122**
Fertilizer application rate squared	-0.000693***
Fertilizer application rate*2007	0.646
Fertilizer application rate*2008	-0.844
Fertilizer application rate*2009	0.0776
Fertilizer application rate*2010	-0.145
Fertilizer application rate*Zone 1	0.742
Fertilizer application rate*Zone 1*2007	-1.132
Fertilizer application rate*Zone 1*2008	0.591
Fertilizer application rate*Zone 1*2009	1.040
Fertilizer application rate*Zone 1*2010	0.189
Fertilizer application rate*Zone 2a	0.605
Fertilizer application rate*Zone 2a*2007	-0.0844
Fertilizer application rate*Zone 2a*2008	1.768
Fertilizer application rate*Zone 2a*2009	1.019
Fertilizer application rate*Zone 2a*2010	1.782**
Fertilizer application rate*Zone 3	1.236**
Fertilizer application rate*Zone 3*2007	-1.098
Fertilizer application rate*Zone 3*2008	1.151
Fertilizer application rate*Zone 3*2009	0.537
Fertilizer application rate*Zone 3*2010	0.875
Fertilizer application rate* rainfall	-0.00204
Fertilizer application rate*rain squared	7.46e-07
Fertilizer application rate*rain stress	0.0548
Fertilizer application rate*hectares planted	0.569***
Fertilizer application rate*nitrogen fixing mix	0.276
Fertilizer application rate*other mix	0.175
Fertilizer application rate*hybrid seed use	-0.0105
Fertilizer application rate*pre-rain tillage	0.0133
Fertilizer application rate* basin tillage	-0.677
Fertilizer application rate*zero tillage	0.169
Fertilizer application rate*plowing tillage	-0.0474
Fertilizer application rate*ripping tillage	-0.593
Fertilizer application rate*ridging tillage	0.438**
Fertilizer application rate*bunding tillage	0.651*
Constant	811.8***
Observations	60477
R-squared	0.100

Notes: *Significant at 10%, ** Significant at 5%, ***Significant at 1%

Table A2. Reasons for Not Harvesting Part of a Field (% of Respondents)

Reason Given:	2009	2010	Difference
Water logging	15.4	8.0	-7.4
Wilting due to drought	5.4	22.4	17.0
Animal/bird destruction	4.9	3.1	-1.8
Field not weeded, weeded late	2.1	2.1	0.0
Pests and diseases	1.9	2.9	0.9
Fire	0.0	0.0	0.0
Theft	0.1	0.4	0.2
Floods, heavy rain	24.7	9.5	-15.2
Soils generally bad	3.1	3.3	0.2
Lack of fertilizer	36.9	38.7	1.8
Lack of management experience	1.4	0.5	-0.9
Received bad advice	0.1	0.0	-0.1
Not enough labor	0.0	0.8	0.7
Seeds not good	0.1	2.0	1.9
Planted late	0.6	3.4	2.8
Eaten fresh	0.0	2.0	2.0
Other (specify)	3.1	0.4	-2.7
Don't know	0.0	0.5	0.4
Total	100	100.0	0.0

Source: CFS 2009, 2010

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