ECONOMIC ANALYSIS TO SUPPORT PRIORITY SETTING FOR INVESTMENT IN AGRICULTURAL BIOTECHNOLOGY FOR WEST AFRICA

ESTIMATES OF THE RETURNS TO EIGHT POTENTIAL BIOTECHNOLOGY INNOVATIONS IN WEST AND CENTRAL AFRICA

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I. Executive Summary

This report focuses on the potential impact of eight specific agricultural biotechnologies for the countries of West and Central Africa that are members of CORAF. They are:

1. *Bt* cotton
2. *Bt* corn/maize
3. Virus resistant cassava (cassava mosaic disease)
4. Virus resistant tomato (poty-virus)
5. Virus resistant rice (rice yellow mottle virus)
6. *Bt* cowpea
7. Fungal resistant cocoa, and
8. Nitrogen use efficiency (NUE) rice.

These crops represent differences in the importance of the crops and the potential returns to farmers and the economy. In addition some of them are closer than others for ready diffusion such as *Bt* cotton. A number of other Bt crops such as maize and cowpea have a head start in the process in that the technology exists but there is still much work to be done breeding it into West and Central African appropriate germplasm. Meanwhile other crops such as fungal resistant cocoa are likely many years away from being deployable in West Africa. Some of the crops on the list, such as the Bt crops and likely NUE rice, are produced through the use of transgenes, moving genes from one crop or species to another, while others are being developed through marker assisted selection techniques which do not transfer genes from one crop to another.

The report proceeds through the individual crops providing, i) basic information on their importance, ii) the degree of problems created by the pest, disease, or fungus that is addressed by the biotechnology innovation, iii) the effectiveness of the biotechnology solution, iv) anticipated adoption rates, and v) results from a simulation using the DREAM model of the biotechnology innovation. These results are then combined to provide a full ranking of the values attributed to the various crops. This is followed by a section that provides a set of policy recommendations.

The analysis uses data to calibrate a series of simulations of the DREAM model which estimates the returns to research. The data used in this analysis for production and consumption figures come primarily from the FAO. The data used to quantify the crop specific qualities of the biotechnologies come from a number of different sources. Where available, this work uses published studies to quantify the problems caused by pests, viruses, and fungi. This was supplemented by information provided by experts in the US and in West Africa who knew the specific crops.

The analysis of technologies presented here overall shows a lot of potential for biotechnology innovations in the West and Central African context. Cassava that is resistant to the mosaic virus is clearly the most beneficial of the technologies considered here, with benefits over the next 30 years of about $20 billion. It is by a factor of 5 the most important of the technologies in this study. Bt cowpeas come next in terms of benefits with broad based benefits across both countries and sectors of society within those countries. Of the crops considered here Bt cowpeas would seem to have the highest probably of success given that it is a market that is primarily internal to the region. It is followed closely by Bt cotton, which is likely to be the first biotechnology to get

widespread use in West and Central Africa, with benefits around $5 billion. After those crops there are three crops that provide a next level of benefits $1 billion over 30 years: virus resistant rice, virus resistant tomato, and nitrogen use efficiency rice. These crops face stiff international competition in the form of low priced rice and low priced tomato paste that may make the technology benefits harder to realize for countries and producers. Following these technologies are a set of smaller benefits from black pod fungus resistant cocoa and Bt maize. These are all estimated in the neighborhood of $500 million over 30 years. Bt maize does not for the moment seem to respond to a key constraint in West and Central African production and so while this same technology shows a lot of promise elsewhere, it does not have the same level of benefits in this region. The fungal resistant cocoa is a beneficial technology, but the time lags in doing the research and in adopting this technology significantly reduce the benefits when it is compared to field crops.

There are also significant differences in the technology rankings by region, particularly since some crops are not grown in all regions. The coastal region receives the largest benefits, driven primarily by the importance of cassava, cowpeas, and cotton in those regions. The central region follows close behind also due to the importance of cassava. The Sahel would gain the lowest level of benefits from the eight technologies considered in this report, although most of this is driven by there not being a lot of cassava grown there.

II. Introduction

A. Overview of the technologies

This report focuses on the potential impact of eight specific agricultural biotechnologies for the countries of West and Central Africa that are members of CORAF.[1] They are:

1. *Bt* cotton
2. *Bt* corn/maize
3. Virus resistant cassava (cassava mosaic disease)
4. Virus resistant tomato (poty-virus)
5. Virus resistant rice (rice yellow mottle virus)
6. *Bt* cowpea
7. Fungal resistant cocoa, and
8. Nitrogen use efficiency (NUE) rice.

These crops represent differences in the importance of the crops and the potential returns to farmers and the economy. In addition some of them are very close to be ready for diffusion such as the *Bt* crops cotton, maize, and cowpea, while others such as fungal resistant cocoa and nitrogen use efficiency rice are likely many years away from being deployable in West Africa. Some of the crops on the list, such as Bt and likely NUE rice, are produced through the use of transgenes, moving genes from one crop or species to another, while others are being developed through marker assisted selection techniques which typically do not transfer genes from one crop to another. These differences in how the technologies are produced could have an impact on farmer acceptance of the technologies, with public opposition much lower for marker assisted technologies than for transgenic crops. However, these technical distinctions are likely to be lost on the average West African farmer, so it is more likely that the actual effectiveness of the technology will be much more deterministic of the eventual adoption rate than how the technology is produced.[2]

B. Overview of biotechnologies in West and Central Africa

The penetration of agricultural biotechnologies in West and Central Africa has been relatively slow compared to East and Southern Africa as well as the rest of the world. There is as yet no officially sanctioned land planted in biotechnology crops on private land holdings, although there are a few experimental plots. Only Burkina Faso has made significant strides in testing biotechnology crops, in that case Bt cotton is being tested on experimental fields and is likely to be released to the public in 2008. Some other countries, notably Mali and Ghana, are also making some strides in passing appropriate legislation and moving toward testing of biotechnologies. Nigeria, which has for more than a decade discussed putting in place a biosafety system to test biotechnology crops, has despite its early efforts lagged behind its neighbors. Some other countries have just begun to consider how they will regulate biotechnologies or conduct the necessary research to consider their use. Most of the countries of

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[1] For simplicity, these countries will be referred to generically as "West and Central Africa" in this report.

[2] One should note that many donors, especially from Europe, as well as many in the African scientific establishment do make a major distinction between marker assisted selection and transgenic transformations of crops. This may imply more enthusiasm and/or more research and extension effort on crops developed through marker assisted selection than for those with transgenic biotechnology.

the region fall into this same category in which they have taken few concrete steps to address biotechnology issues. Regional initiatives to regulate biotechnologies show some promise in speeding up the process and helping countries that are behind in developing their own regulatory framework. It is as yet too early to tell whether CORAF countries can come together either jointly or in regional or agroclimatic groups to produce a set of biosafety protocols. Even with these regional initiatives most of the 22 countries in the region are likely a number of years away from creating the full set of biosafety protocols that would allow them to be prepared to allow biotechnologies in their country.

Along with an official reticence from policy makers to make much of an effort toward allowing use of biotechnologies in their country, there is also a reasonably vocal opposition to biotechnologies in a number of countries. This opposition, often fueled by northern, especially European, NGO's, most often takes the form of a demand for a complete ban on biotechnologies. For example in Mali, the anti-biotechnology groups have stirred up opposition from some farmers and farmer groups through fears of loss of control of seed varieties, the incursion of large US multinationals, and the unknown dangers of genetic engineering. To a certain extent these issues seem to have some resonance with farmer groups. Reports from farmers in Mali and Burkina Faso who have seen Bt cotton in the field, however, suggest that where there are enormous visible benefits available from a biotechnology crop, farmers are very willing to adopt the crop. But this opposition suggests caution with biotechnology crops that provide only marginal benefits, or for those in which the benefits are not readily visible to farmers. Such crops should only be introduced after farmers get used to the idea of biotechnologies.

A further key constraint in the potential spread of biotechnologies in West and Central Africa is the near complete absence of any sort of formal private seed market. There is a significant informal seed system particularly for crops such as cocoa and cassava in some places such as Nigeria. The informal seed markets, though, provide few guarantees of quality and rely almost entirely on local knowledge of buyers and sellers. These incomplete markets imply farmers are unaccustomed to paying for seeds and in most cases farmers are very reluctant to pay for seeds. None of the countries in the region have an effective set of private sector seed propagators or multipliers. In some crops especially cash crops such as cocoa, cotton, and to a lesser extent irrigated rice, the public sector (or quasi-public marketing boards) have typically provided seeds or planting materials as well as done a fair amount of research in the crops. However, even in these crops farmers rarely pay for their seeds. For most other crops including maize, cowpeas, cassava, and rain-fed rice farmers plant seeds they have saved or trade them amongst themselves, usually without explicit pricing. The lack of a market for new varieties is particularly difficult for cassava, in which it typically takes one hectare of cassava to propagate ten hectares of new cassava.[3] Tomatoes are the one crop in which farmers may buy seeds on a more regular basis, but in this case it is often imported seeds bought once and then, if they are not hybrids, replanted in subsequent years.

[3] Note that micro-propagation technology and techniques can reduce this constraint significantly, by making in possible to propagate many hectares from a single cutting. However, farmers have been slow to learn and employ micro-propagation technology, such that one should not expect this problem to disappear in the near future.

C. Analytical approach.

C. 1. Technical approach

The technical approach used in this analysis is to get the best estimates available for the benefits of the technologies and to feed them into the DREAM model elaborated by Alston, Norton, and Pardey (1998) and further developed by IFPRI. The DREAM approach provides a number of advantages in this setting because it is a fairly general model that has been used a number of times in related studies. This allows some sorts of comparisons across models in different studies. The DREAM model also provides a good method to account for different markets within a homogenous product market.

The DREAM model used in this work is explained in detail in Alston, Norton, and Pardey (pp. 386- 440; 1998). It uses the standard models of agricultural research evaluation and simulates the returns to technological innovations for producers and consumers. In this work we concentrate on the producer benefits of the technologies. The model is driven primarily by the quality of the data, the quality of the assumptions made about the future returns and from the quality of elasticity estimates used. To the extent possible we have tested the sensitivity of the results to these assumptions. All models are run for 30 years in order to allow a full adoption of most of the technologies within the time period covered by the model. We run the DREAM model separately for three regions, Coastal, Central, and Sahelian. This has the benefit of providing some consistency in the trade across regions.

While the simulations with the DREAM model include both the producer and consumer part of the market, the benefit data used to evaluate the technologies in this report is only the producer benefit and does not include the consumer benefit. This is driven by a desire to focus on how the new technologies will affect producers. In addition there is a lot of uncertainty in the consumer demand data.

C.2. Data sources:

The data used in this analysis for production and consumption figures come primarily from the FAO. IFPRI researcher, Liang Zhou, was kind enough to share the database that was used for IFPRI's study of strategic alternatives for agricultural led growth in West Africa done for CORAF (IFPRI, 2006). These data were primarily culled from FAO databases, but also contain some proprietary IFPRI analyses of how markets interact. The IFPRI data have the distinct advantage of having reasonably good consumption information, which allows the consumption elasticities to be set at estimated values rather than a default value of 1 as would be the case when there is no information available.

We also supplemented the data where we had other information, such as alternate price estimates, which we considered more reliable. In addition, the IFPRI database did not include tomato production, thus we entered that data from the FAO databases. The reader should note that these FAO data are often of dubious reliability, especially for sub-saharan Africa where they are often estimates based on shaky original data. In addition the inconsistencies of the FAO

tomato data did not allow a thorough estimate of either the consumer demand side parameters or of the trade patterns in tomatoes. This is a particularly glaring weakness for our tomato estimates since much of the trade in tomatoes comes in the form of paste, which is not well accounted for in our data. For tomatoes, it is likely that we have overestimated the market's capacity to absorb increased tomato production, suggesting that we have overestimated the benefits of increased tomato production.

The data used to quantify the crop specific qualities of the biotechnologies come from a number of different sources. Where available, this work uses published studies to quantify the problems caused by pests, viruses, and fungi. This was supplemented by information provided by experts in the US and in West Africa who knew the specific crops. Information of the potential abilities of biotechnologies to combat these pests, viruses, and fungi were rarer to find in the literature (notable exceptions being for Bt cotton, Bt maize, and virus resistant rice). Thus for the quality of the technologies, the analysis rests primarily on interviews with scientists (biotechnologists, crop breeders, and field workers) in West Africa who know these crops. Adoption rate information was culled from interviews with social scientists who have worked on these crops, published work on similar experiences of adoption in these crops, and discussions with field workers and to a lesser extent with growers.

The available data covers the major countries in the region, but not all of them. For most of the models the estimates are based on the following countries: Coastal (Guinea, Sierra Leone, Cote d'Ivoire, Ghana, Togo, Benin, Nigeria), Central (Cameroon, Central African Republic CAR, Gabon, Congo Republic, Democratic Republic of Congo DRC), Sahel (Burkina Faso, Chad, Gambia, Guinea Bissau, Mali, Mauretania, Niger, Senegal). In some cases, especially for tomatoes, data was not available for all countries. In this case it is estimated with the available countries under the assumption that production and consumption in the other countries are both zero.

In the case of the rice data we estimate rice production in both the irrigated and rainfed areas of production. This allows us to have different assumptions for the very different types of production systems and different types of farmers in these areas.

C.3. Maintained assumptions

In order to provide consistency of the analysis across the different crops and to reduce the degrees of complications created by unknown and likely unknowable parameters, this work sets up a number of assumptions of how these biotechnologies will work across countries. The key assumptions we vary across the crops are 1) when the technology is likely to be available, 2) the rate of adoption of the technology, and 3) the effectiveness of the technology. For most other assumptions we maintain a consistent set of assumptions. These are listed below.

First, we do not take into account any country differences in the speed with which they will adopt biosafety protocols and create the necessary legislation for the use of biotechnology crops within these countries. This is not to deny the primary importance of these issues, but to maintain the focus on the qualities of the eight technologies in question. In our estimates we

assume that any necessary biosafety regulations will be in place at the time that the technology becomes available. We thus do not account for the delays one is likely to see in countries where biosafety regulations are still years away. This assumption most affects the estimates for crops such as cotton that could be ready for the market in short order, while has little effect on the cocoa technologies because of their extended timeline.

Second, we do not account for how differences in farmer or consumer acceptance may change the adoption rates for these crops. These are currently unknowable differences between countries and between crops. It is our opinion that the speed of adoption will be driven largely by the agronomic and food qualities of the technologies, with good technologies being adopted rapidly while less successful technologies adopted more slowly. This is particularly important with crops likely to be eaten by the farmers who grow them, such as cassava, rain fed rice, maize. It is less of an issue with crops clearly intended for markets such as cocoa.

The adoption rates used in this report represent what we expect to be actual adoption rates given all of the constraints common in CORAF countries.[4] We use our best guess of the adoption rates of the technologies based on 1) the adoption of new varieties in that particular crop, 2) the infrastructure for diffusion of technologies in that crop, 3) the size of the population that could benefit from the technology, and 4) the size of the benefits the technology provides. The size of the benefits the technology provides may have a particularly large impact on the adoption rate in that a crop that increases yields 100% will have a faster adoption rate than one that increases it only 25%. In particular where a crop is estimated to have only a minor yield benefit, such as for *Bt* corn in the Sahel, we assume no adoption.

Third, we assume that crop production areas increase fairly slowly and consistently. This implicitly assumes that the new technologies studied here will not cause major shifts in crop acreage. For some of the crops discussed below this can be a particularly strong assumption and where appropriate we discuss how these figures might change with an increased size of planting area due to a successful biotechnology application.

Fourth, a single discount rate of 5% is used in the DREAM analysis across models. There is no consensus in the literature about the rate of discount. However there is a tendency to apply a rate around 3% as a lower bound and 6% as a higher estimate. We think that 5% is a reasonable discount rate for this type of analysis because it captures what may be higher discount rates for people in a poorer country. It is also the same as that typically used by IFPRI in its studies of the returns to research (see e.g., IFPRI 2006). Analysis using a lower 3% discount rate show, as expected, higher returns, but did not measurably change the rankings of the technologies. The key exception is that the returns to the cocoa technology which are much farther into the future look relatively better with a lower discount rate.

D. Outline of the rest of the report

The remainder of the report proceeds as follows. In the next section we proceed through the individual crops providing, i) basic information on their importance, ii) the degree of problems

[4] These are best guesses of actual adoption rates and should not be confused with estimates that assume near complete adoption in a fairly rapid period.

created by the pest, disease, or fungus that is addressed by the biotechnology innovation, iii) the effectiveness of the biotechnology solution, iv) anticipated adoption rates, and v) results from a simulation using the DREAM model of the biotechnology innovation. In the section that follows we combine the results from the individual crops to provide a full ranking of the values attributed to the various crops. This is followed by a section that provides a set of policy recommendations.

III. Crop specific information

This section focuses on the potential impacts of the eight specific agricultural biotechnologies for the countries of West and Central Africa. They are considered in the following order:

1. Virus resistant cassava (cassava mosaic disease)
2. Fungal resistant cocoa,
3. *Bt* cotton
4. *Bt* cowpea
5. *Bt* corn/maize
6. Virus resistant rice (rice yellow mottle virus)
7. Nitrogen use efficiency (NUE) rice.
8. Virus resistant tomato (gemini-viruses, in combination with conventional resistance to yellow leaf curl virus)

The description of each crop provides the information about the crop specific assumptions used in the modeling procedures. The modeling assumptions are summarized in appendix table A1.

A. CMD resistant Cassava:

Cassava is one of the major food crops of the coastal and central study zones. In addition it has great potential to be used in a number of different industries because of its ability to produce high quantities of biomass and starches. As a food crop it is especially important to the poor, for whom it is a major source of calories in most of these countries. Much of the cassava is grown as a subsistence crop, but there are still substantial amounts of trade in the crop.

The cassava mosaic virus disease (CMD) is the most significant and damaging disease in cassava throughout the African continent and has become more of a pronounced problem in West and Central Africa in the last decade. An infestation of CMD can destroy all the production in a field. It has the potential to completely destroy a country's production as it did in Uganda in the mid 1990's, where CMD basically destroyed the cassava crop (Bua et al. 1996). In Uganda a program of introducing clean and semi-resistant cassava plant material was successful in restoring the cassava crop and bringing the CMD virus under control, though not in eliminating it.

We estimate the incidence of CMD in West and Central Africa cassava growing regions to be 50% of the growing area. Given that a resistant variety would produce in the 50% area while a non-resistant variety might not produce at all, we estimate that the benefits on average to CMD resistant varieties will be equivalent to a 50% yield boost to production in a country. Obviously for individual farmers production benefits will likely be closer to a doubling of production, which are the estimates from the Donald Danforth CMD resistant cassava project. But if we account for the incidence of the disease a conservative estimate will be the 50% we have chosen.

The adoption of cassava varieties is typically fairly slow in Africa because it is a subsistence crop often not grown explicitly for the market, the slow rate of replication of plant materials (it takes 1 ha of material to propagate 10 ha of plants using traditional methods), and the fact that there is not really any formalized market in cassava plant material. This means that the adoption rate for a new technology, even one with great benefits, is likely to be quite slow. Based on

conversations with cassava breeders and economists at IITA who work on cassava we use an estimate of 20 years for an adoption of cassava varieties with the new technology in them to 80%. Because it is a subsistence crop we expect that it will not pass 80% since farmers will continue to reduce their risks by continuing with their old varieties for some part of their planting.

The DREAM results for cassava that is resistant to CMD are presented below. They show the highest producer benefits of any of the estimates in this study despite only including countries from two of the three regions and the estimates having a relatively slow assumed adoption rate for a field crop. These high returns are due to both the importance of cassava in the economy and the benefits of the technology.

The benefits are largest in the Democratic Republic of Congo, with $9.4 billion in benefits, which alone accounts for nearly half the total estimated benefits. Nigeria accounts for another quarter of the net benefits to producers of cassava. Other countries such as Ghana and Cameroon each have around $2 billion in benefits. Benin also has significantly large benefits. For these countries the benefits make CMD cassava the most important of the technologies in these countries. For some of the coastal countries such as Cote d'Ivoire the benefits of the cassava technology is not the leading technology, but still among the tops.

Producer Benefits to CMD Resistant Cassava

Region	Country	Producer Benefits ($1,000)
Coastal		
	Guinea	123,922.2
	SierraLeone	39,700.4
	CotedIvoire	148,917.4
	Ghana	2,060,873.4
	Togo	138,139.5
	Benin	1,045,178.9
	Nigeria	5,157,417.1
Central		
	Cameroon	1,856,410.1
	CAR	62,843.6
	Gabon	175,078.1
	Congo Rep	637,335.6
	D.R.Congo	9,405,400.0
Coastal	Total	8,714,148.9
Central	Total	12,137,067.4
Sahel	Total	0
	Whole Region	20,851,216.3

Thus overall, CMD cassava is an extremely important technology across the coastal and central regions of West and Central Africa. This importance in the estimates is further increased by cassava being an important crop for the poor, so that these benefits will likely have important distributional impacts on poverty. That is this technology can reduce the risks that poor cassava producers face which should have an impact on overall poverty statistics and on the vulnerabilities that the poor face.

B. Cocoa

Cocoa represents one of the major export crops of West and Central Africa, being a crop for which the region has a major comparative advantage relative to other parts of the world. Cote d'Ivoire and Ghana are two of the world's top three producers of cocoa and both of them derive a significant portion of their foreign exchange earnings from cocoa. Nigeria and Cameroon are also major producers, although because of the importance of oil revenues in each of those countries cocoa plays a lesser role in the overall economy.

Black pod disease is a fungus which affects the pods on cocoa trees. It is most prevalent in Nigeria and Cameroon, where it is found to some extent on almost all plantations, while it is less of a problem in Ghana and Cote d'Ivoire. But Ghana and Cote d'Ivoire are unique in the region, with most of the other cocoa producers having problems with black pod disease on the same scale as Nigeria and Cameroon.

Black pod disease where it is prevalent will destroy a full cocoa crop unless treated with copper insecticides. In areas where it is prevalent, Nigeria and Cameroon, it is estimated that such sprays cost about 10% of the price farmers receive for their cocoa. Despite the sprays, the fungus still can cause some damages, which are on average about 20% of the yield. In Ghana and Cote d'Ivoire farmers tend not to spray for black pod, but do lose some production (about 5%) to its effects.

Thus a cocoa tree that was resistant to black pod disease would in Nigeria and Cameroon reduce costs by 10% and increase yields by 20%, while in Ghana and Cote d'Ivoire it would increase yields about 5%. The research timeline for such a technology is going to be quite slow because of the time lags inherent in tree research. Testing each improvement can take 5-7 years since that is the time a cocoa tree goes from seed to producing its first set of pods. The techniques of biotechnology can increase this speed somewhat through marker assisted selection's ability to reduce the number tests necessary. But even in the most optimistic scenario it will be 15 years before there is an available technology.

In addition adoption rates in tree crops are typically quite slow, since often a farmer will not replant trees until they are 20 to 30 years old. Studies of cocoa farmers in all of the major cocoa growing regions show that they are slow to plant new improved tree varieties, but this may be as much due to problems in the distribution system and the low quality of the "improved" varieties rather than a constant feature of cocoa growers. For this study we have chosen to model the adoption rate as taking 15 years to reach a maximum adoption rate of 50%. This would be the

adoption rate we might expect if the black pod resistant varieties were both successful for farmers and popular.

The DREAM results for the adoption of a black pod resistant cocoa technology are presented below. The overall estimate for a black pod disease resistant cocoa variety that would be available in 15 years is $452 million. The majority of these benefits accrue to two countries Nigeria and Cameroon because they have the combination of the most severe problems with significant acreages in cocoa. Although the benefits of the technology are modest in Ghana and Cote d'Ivoire they both get fairly large benefits just because of the size of the industry. It should be added that with the importance of these crops in those countries for foreign exchange, the levels of benefit might in fact turn out to be higher than for Nigeria or Cameroon where they have oil to trade.

The key factors driving the cocoa results are the length of time that it will take to do the research and the length of time required for adoption of a new tree crop. In addition, because this is a technology that is less useful in the two major cocoa producing countries, the overall regional benefits are more modest than if black pod disease were a major constraint in Ghana and Cote d'Ivoire.

One important caveat for the use of biotechnologies in cocoa production is the importance of the major chocolate firms. It is possible and even likely, given European and to a lesser extent US consumer preferences, that the major cocoa buying firms would not want to buy cocoa from trees that were described as being produced by "biotechnology". The current work on black pod disease is being conducted using marker assisted selection rather than transgenes so should pose absolutely no problem for consumers. But to the extent future work on cocoa uses transgenic biotechnology there is a strong possibility of resistance from the major cocoa buying firms.

Producer Benefits to Fungal Resistant Cocoa

Region	Country	Producer Benefits ($1,000's)
Coastal		
	Guinea	284.1
	SierraLeone	1,000.4
	CotedIvoire	85,121.2
	Ghana	74,997.6
	Togo	10,978.8
	Benin	58.9
	Nigeria	157,021.9
Central		
	Cameroon	115,726.1
	CAR	81.5
	Gabon	726.9
	Congo Rep	1,124.4
	D.R.Congo	5,570.0
Coastal	Total	329,462.9
Central	Total	123,228.9
Sahel	Total	0
	Whole Region	452,691.8

C. Insect resistant Bt Cotton

Cotton has been one of the successful growth crops of West and Central Africa in the last decade. Significant advances particularly in Mali, Burkina Faso, and Cote d'Ivoire in cotton production have made the region an important supplier of cotton in the world. Yet recently the sector has seen declining yields, rising costs of production, and difficulties competing in the world market (Elbehri and MacDonald, 2004).

Bt cotton technology which protects cotton against insect pests has been deployed in most of the world (US, China, India, Argentina, South Africa, among others), but not yet in West and Central Africa. Burkina Faso is poised to plant the first set of Bt cotton in the region in the 2008 growing season. Mali is likely to follow suit in one or two years either officially or through farmers "borrowing" seeds from neighboring Burkina Faso.

Bt cotton research is driven by a strong interest by the private sector in selling seeds and thus is very different from the other crops presented here where most of the research for West and Central Africa will have to be done by the public sector. As such the benefits listed in these estimations are much more likely to be shared between producers and a private company, although evidence from South Africa suggests that African producers are still likely to capture the vast majority of returns (Grouse et al. 2004).

The returns to Bt cotton in West and Central Africa has already elicited a number of studies including Elbehri and MacDonald (2004) and Sanders (2005). The reader is referred to those studies for a full understanding of the potential for adoption of the crop. Here it provides a useful comparison point for the other seven technologies we are considering.

Using the estimates in the literature cited above, it is reasonable to assume that Bt cotton will produce cost reductions and yield increases equivalent to about a 20% increase in production. This figure matches more or less those used by Elbehri and MacDonald (2004). Given that it is a cash crop with fairly good agricultural extension we estimate that it will take 8 years to reach 100% adoption in Bt cotton. While the pace will likely be higher in many parts of Burkina Faso or Mali, it is likely to be slower in places such as Benin. Note that as the first biotechnology deployed in a lot of these countries it may also face some farmer resistance, but our impression from discussions with agricultural professionals in Mali is that if this is a successful technology that resistance will not be very significant. Since the technology is ready for deploying, we use an immediate use in the model presented below.

The results of the DREAM model for Bt cotton technology are presented in the table below. The overall results put Bt cotton as the second most important of the technologies and the most important technology in the Sahel region. Benefits from Bt cotton are largest in the Cote d'Ivoire and Mali, with significant benefits also found in Benin, Cameroon, Nigeria, and Burkina Faso.

Producer Benefit to Bt Cotton

Region	Country	Producer benefits ($1,000)
Coastal		
	Guinea	80,864.8
	SierraLeone	0.0
	CotedIvoire	1,291,797.0
	Ghana	31,079.6
	Togo	0.0
	Benin	777,853.2
	Nigeria	460,900.1
Central		
	Cameroon	418,036.5
	CAR	29,964.3
	Gabon	0.0
	Congo Rep	0.0
	D.R.Congo	19,353.8
Sahel		
	Burkina Faso	498,500.6
	Chad	147,605.6
	Gambia	405
	Guinea Bissau	7,439.5
	Mali	983,279.5
	Mauretania	0
	Niger	1,566.9
	Senegal	27,318.6
Coastal	Total	2,642,494.7
Central	Total	467,354.6
Sahel	Total	1,666,116.7
	Whole Region	4,775,966.2

D. Insect resistant Bt Cowpeas

Cowpea is an important grain legume crop in West and Central Africa both as a subsistence crop and as a cash trade crop between countries. It is indigenous to the region and the region accounts for about 80% of the world trade in cowpea as well as 69% of the production of the crop (Langyintuo and Lowenberg-DeBoer, 2006). As a crop it provides an important source of protein in the local diets and can command a relatively high price in the markets of the region.

In part because cowpea is indigenous to the region, it is beset by innumerable pests which make it a difficult crop to grow and to store. Producing a variety of cowpea that resisted all of the pests that reduce its yield could increase yields over four-fold. In addition there are insects that

eat cowpeas in storage which accounts for another 15-25% loss of the production. In terms of pests there are insects that reduce production at planting, flowering, the first stage of seed production, and the later stages of seed production. The Bt technology addresses the maruca insect that attacks the maturing cowpeas on the plant. There exist within the germplasm of the cowpea some natural resistances to the other insects in the growth of the crop, but none for the maruca. Thus the Bt technology is a necessary addition to the technology mix in order to make cowpea resistant to insects. But in addition to Bt technology, there will need to be a lot of work with other conventional breeding or marker assisted selection techniques to produce the type of four-fold increase in the crop that is possible for cowpea.

In judging the Bt technology by itself it still plays an important role in increasing the potential yield of cowpea in West and Central Africa. We provide two estimates for *Bt* technology because of uncertainty as to how much of the yield boost can be related to the biotechnology improvements and how much would come from other improvements. From discussions with experts we estimate that it can eliminate the maruca problem entirely meaning an increase in yields of 50%. We also provide estimates for a 20% yield increase which would be appropriate if it were only 40% effective against maruca. They represent conservative estimates compared to that proposed in Langyintuo and Lowenberg-DeBoer (2006) where they propose a baseline scenario of a doubling of production 100%. Their estimate would seem appropriate for the kind of cowpea seed that will likely see the market, which will include multiple resistances. But since we are interested in the *Bt* component only, we use a more conservative estimate of the returns. Although both are provided, in comparisons we use the 50% yield increase for our estimates.

The research work on Bt cowpea is reasonably far advanced with the first Bt cowpea ready for field tests in the next year or two. But there is a great variation in individual country preferences for the cowpea, by color, look, and flavor. Thus any successful biotechnology cowpea will need to be one that has been bred by the local NARS to match the local country tastes. We thus choose a 5 year timeframe for the introduction of Bt cowpea on the market.

There is little direct evidence on adoption rates for new cowpea varieties, but given the visible problems that insects produce in cowpea production and the important trade economy in cowpea that makes it somewhat like a cash crop, we estimate a reasonably fast adoption path for this technology. We assume that cowpea adoption will reach 100% within 8 years of its introduction.

The results of running the DREAM model for Bt cowpeas is presented below in the table. Note the estimates use the FAO data on "other pulses" to make these estimates, which in this region is primarily cowpea. This does, however, produce somewhat of an over-estimate of production, to the extent that some other pulses are included in the estimates.

Overall the benefits to producers from producing Bt cowpeas are high in the West and Central Africa region, with the Sahel taking the lead with the highest benefits followed by the coastal region. Benefits are highest in Nigeria and Niger, where much of the cowpea production is intended for trade with Nigeria. Some other countries that have significant benefits include Burkina Faso, Cameroon, and the DR Congo. Overall, cowpea places among the top technologies in these estimations in most countries of the region.

There are fairly low estimates for Mali, much lower than what one would expect from the published literature, which may be because of some measurement problems in the data. Overall the data used here is likely to understate the potential cowpea acreage since the pest problems are so great as to mean that many fields are never harvested. Thus there may well be greater amounts of production that are not fully captured here once there exists an insect resistant variety of cowpea.

Producer Benefits to Bt Cowpea

Region	Country	Producer Benefits: 20% yield increase	Producer Benefits: 50% yield increase
Coastal			
	Guinea	0.0	0
	SierraLeone	36,464.7	96,214.2
	CotedIvoire	2,181.2	5,710.9
	Ghana	3,953.3	10,350.0
	Togo	0.0	0.0
	Benin	0.0	0.0
	Nigeria	709,652.3	1,860,432
Central			
	Cameroon	176,001.2	465850.5
	CAR	0.0	0.0
	Gabon	0.0	0.0
	Congo Rep	7,355.9	19462.8
	D.R.Congo	91,461.1	242028.4
Sahel			
	Burkina Faso	143,846.7	368844.2
	Chad	54,590.0	140103.9
	Gambia	0.0	0
	Guinea Bissau	0.0	0
	Mali	17,497.0	44873.1
	Mauretania	52,404.2	134490.6
	Niger	680,609.6	1746714
	Senegal	33,719.7	86544.4
Coastal	Total	752,251.5	1,972,707.4
Central	Total	274,818.2	727,341.7
Sahel	Total	982,667.2	2,521,570.0
	Whole Region	2,009,736.9	5,221,619.1

E. Insect resistant Bt Maize

Maize is a staple crop for all of the countries in West and Central Africa and particularly important in the savannah zones of the region. It grows best north of the humid forest zones and south of the driest sahelian zones which do not receive enough rainfall for maize cultivation. Maize grows best with abundant sunshine and adequate water availability. Maize yields in the region (around 1-2 tons per hectare) are very low by world standards, often about 10% of the highest yields achieved in the world. The problems in production of maize in the region are myriad, but start with low fertilization, parasitic weeds, and inadequate water. With improvements in these things, maize yields in the savannah climate zones can reach 7-8 tons per hectare with existing technologies and even more with continued breeding programs.

In the forest zones maize is grown as a crop that comes in early in the hungry season and so commands a price to be eaten green (roasted typically). Because of the high amounts of rainfall and low solar radiation, the potential for maize in the forest zones is relatively low. Current yields are 1 – 2 tons per hectare, whereas maximum potential yields are about 3 tons per hectare due to the low solar radiation.

Bt maize can protect the plant from various types of stem borers. In the US Bt maize has been very effective and widely adopted in parts of the central Midwest where stem borers are a major problem, while its adoption has been less widespread in the upper Midwest where insect pressures are lower and farmers rarely spray for insects. In Africa studies in East Africa have shown about a 13% increase in yields from using Bt corn in Kenya to combat stem borers (Smale and DeGroot, 2006).

Stem borer insect problems in maize are only significant in the forest zones of West and Central Africa, since these areas do not have the same pests as in East Africa. There is essentially little or no stem borer pressure in the savannah zones of West and Central Africa where maize grows best. Because of this low insect pressure in the savannah zone it is highly unlikely that farmers would be interested in adopting a new technology that combats such a minor problem. We thus assume that Bt maize will not be adopted in the savannah zone of the region.

In the forest zones of the region, stem borers are, however, quite problematic. Nearly three-quarters of the maize fields in the forest zone are likely to be infested with stem borers. The best estimates are that they reduce production by about 33% in the forest zone. Thus a Bt technology has the potential to increase yields in the forest zone, but is unlikely to have any effect outside the forest zone.

For the estimates, since the forest zone is only a minor part of the growing area of only a few countries we estimate the effects of Bt maize as having a 33% yield increase in all the coastal and central region countries. Because the technology is likely to be effective and is something farmers can see, we assign a fairly fast adoption rate of 10 years. But since the forest zone is only about 10% of the land area of these countries we assign a maximum adoption rate of 10%. The exception is in Gabon and Congo Republic where we assume all of the maize acreage is in the forest zone and assign them a 100% adoption rate. We further assume the Bt technology is

nearly ready for deployment such that it should be ready within 3 years for the first farmers to adopt.

The DREAM model results for Bt model are presented below. Given the overall size of the maize crop in the region these estimates are very modest and put Bt maize at the lowest end of the technologies considered here. In no cases is it among a country's major winners in terms of technologies. The places where it is likely to have the most benefits are Nigeria, Benin, Cameroon, and DR Congo.

Producer Benefits to Bt Maize

Region	Country	Producer benefits ($1,000)
Coastal		
	Guinea	2,453.5
	SierraLeone	339.4
	CotedIvoire	11,121.3
	Ghana	20,706.5
	Togo	8,794.9
	Benin	89,605.0
	Nigeria	123,350.3
Central		
	Cameroon	78,549.6
	CAR	7,661.1
	Gabon	26,045.9
	Congo Rep	5,300.4
	D.R.Congo	63,760.1
Coastal	Total	256,370.9
Central	Total	181,317.1
Sahel	Total	0.0
	Whole Region	437,688.0

The largest benefit of the Bt maize technology may be that it provides a food during the hungry season that might well benefit the poor to a significant extent. This distributional benefit is not well represented by these results and would be particularly difficult to quantify given that the green maize sector is likely poorly measured by available data.

F. Virus resistant Rice

Rice is one of the major grain crops of West and Central Africa. It holds an important role in the economies especially since it is typically a staple food of urban consumers and because in country production of rice can potentially reduce the import of rice from outside Africa. Because rice is an internationally traded good and is produced at low cost in Asia and the US there is a

great deal of price competition in rice. As it currently stands, rice production in West and Central Africa is in terms of costs barely cost competitive with international rice prices. Advances in the technology of growing rice, such as virus resistant rice, can have the potential to improve the competitivity of West and Central African rice growers on the world market.

Rice yellow mottled virus, RYMV, is the most serious problem in rice throughout the world. It has been devastating in rice production in Asia, with some countries such as the Philippines having a near total loss of the crop from the virus. It is most prevalent in irrigated rice areas and much less prevalent in upland rainfed rice. RYMV is prevalent throughout West and Central Africa, with the levels of infestation highest in the irrigated perimeters of the zone.

The features of RYMV make it hard to measure its effect on rice yields directly. When the virus attacks it will in most cases destroys the production of all the affected plants, but the virus shows up in a patchwork because it is spread by insects. In order to measure its effects the best way is to measure the incidence. Again that incidence changes significantly according to location and year. Overall the best estimate from discussions with experts is that in West and Central Africa RYMV has an incidence of 20-30% in irrigated perimeters and on the order of 5-10% in rainfed rice. For the simulations we use the lower figure of infestation, but assume 100% effectiveness.[5] Thus we assume that an RYMV resistant rice variety will increase yields by 20% in the irrigated areas and of 5% in the rainfed rice areas.

One of the key benefits of an RYMV resistant rice variety is to allow a greater use of rice germplasm in the irrigated perimeters. Typically a lot of the better rice varieties in terms of other desirable agronomic features (yield, ease of production, nutrient, water use, etc.) are more susceptible to RYMV. For example the use of the Gambiaka rice variety in Mali's irrigated areas was almost stopped because of its susceptibility to RYMV, even though it had more other desirable agronomic features. Thus one of the yield effects of having an RYMV trait that can be put in a number of different germplasms may be that one can use better germplasm in an area with high RYMV incidence.

The research in RYMV resistance is reasonably advanced in a number of research groups. We use an estimate of a 5 year delay in there being a technology ready to be adopted by farmers. In terms of the expected adoption pattern in rice of a new variety we make separate estimates for the irrigated areas from the rainfed areas. In irrigated areas there are examples of a whole irrigated perimeter changing rice varieties within 3 years. We therefore make an estimate of a 5 year adoption pattern with 80% total adoption at the end for irrigated rice. In the rainfed rice growing areas adoption rates are much slower in part because farmers are much more likely to be growing rice as a subsistence crop. This means that they value the flavor of the rice, are less price sensitive in their choice of variety, and are less likely to buy rice seeds. Based on

[5] One expert interviewed suggested that a biotechnology solution to RYMV will likely solve about 40% of the virus problem with increased resistance, but the other 60% of resisting the virus will have to come from farmer management, the timing of planting, the rotation of varieties, and the use of pesticides against the insects that bring the RYMV virus to the plants. Thus the estimates here of 100% effectiveness assumes existence of the seed technology in conjunction with better farmer vigilance.

discussions with experts and also because of the only marginal yield improvement in the technology we expect that adoption will take 30 years to reach 80% adoption.

We ran the DREAM simulations for RYMV resistant rice for two types of rice, irrigated and rainfed. The results aggregated across those two types to the country level are presented below in the table. Overall, RYMV resistant rice provides fairly high benefits with the major rice growing countries in the coastal and sahel regions dominating. These include high benefits in Nigeria, the leader, in Mali and Senegal where there are large irrigated areas. In terms of regions the coastal region accounts for two-thirds of the total benefits with the sahel accounting for most of the rest. The low levels of rice growing in the central region mean that there is relatively little in terms of benefit for producers there.

Producer Benefits to RYMV Resistant Rice

Region	Country	Producer benefit ($1,000)
Coastal		
	Guinea	141,502.6
	SierraLeone	29,379.1
	CotedIvoire	83,664.3
	Ghana	19,564.3
	Togo	3,091.5
	Benin	40,718.5
	Nigeria	1,082,053.3
Central		
	Cameroon	24,919.5
	CAR	12,120.4
	Gabon	37.6
	Congo Rep	41.1
	D.R.Congo	12,403.2
Sahel		
	Burkina Faso	50,065.9
	Chad	14,461.4
	Gambia	2,058.5
	Guinea Bissau	11,761.1
	Mali	220,753.4
	Mauretania	34,328.7
	Niger	343.3
	Senegal	102,099.9
Coastal	Total	1,399,973.6
Central	Total	49,521.8
Sahel	Total	435,872.2
	Whole Region	1,885,367.6

G. Nitrogen Use Efficiency Rice

As mentioned above rice production is particularly important to the West and Central African regions. The addition of nitrogen use efficiency to rice in the region has the potential to improve production, earnings, and reduce farmer costs. Below we outline the potential benefits of the technology.

Nitrogen use efficiency technology has the potential to reduce the fertilizer requirements of field crops from between 33 – 66% (Arcadia-Biosciences website). In the case of rice these seem like reasonable estimates. However, in the African context it is less clear how the technology will work. In particular there are very low levels of fertilizer use in most of African farming in general and in rice farming in rainfed areas in particular. The NUE technology can reduce what farmers apply on their field, but if they are not applying fertilizer in sufficient quantities it is less clear how the technology would work.

From discussions with experts, the best case scenario for irrigated areas is that a rice variety that was 50% more effective in taking up nitrogen there might be a 10% reduction in costs of production. We chose 10% as the yield benefit in irrigated rice areas, which represents both a 10% reduction in costs and a small increase in yields. In the case of rainfed rice where there is little or no applications of fertilizer, the key is the yield response from a plant that has better access to nitrogen. A number of experts warned of other nutritional constraints that would happen to rice once the nitrogen problem were solved, such as zinc and other soil nutrients. Thus while NUE technology might reduce the nitrogen constraint in rainfed areas, the plants were likely to run into other constraints in terms of nutrients as well as the quality of the germplasm before they got a big yield boost. We therefore choose a conservative 10% increase in rainfed rice.[6]

The anticipated adoption rates used for NUE rice are the same as those for RYMV resistant rice of 5 years to 80% adoption in irrigated areas and 30 years to 80% adoption in rainfed areas. Given the lower assumed benefits of this technology, these may be overestimates of the adoption rate.

We ran the DREAM simulations for NUE rice for two types of rice, irrigated and rainfed. The results aggregated across those two types to the country level are presented below in the table. Overall, NUE rice provides fairly low benefits with the major rice growing countries in the coastal and sahel regions dominating the small benefits. These include some modest benefits in Nigeria, the leader, and in Guinea, Cote d'Ivoire, Mali and Senegal. In terms of regions the coastal region accounts for three-quarters of the total benefits with the sahel accounting for most of the rest. The low levels of rice growing in the central region mean that there is relatively little in terms of benefit for producers there. Because the benefits are assumed to be similar in

[6] With the right complementary germplasm the NUE technology might be a perfect complement. For example with the spread of NERICA rice technology in rainfed areas the potential benefits of NUE technology will likely increase. With better rice varieties and better farmer management, the NUE technology is likely to be much more useful than assumed here. Thus the baseline used here of current rice varieties and current farmer practices, while we believe it represents the likely scenario, underestimates the potential benefits.

irrigated and rainfed areas, the benefits to NUE rice are more evenly spread than RYMV resistant rice even though they are much smaller overall.

Producer Benefits to Nitrogen Use Efficiency Rice

Region	Country	Producer benefits w/ 5% yield increase ($1,000)	Producer benefits w/ 10% yield increase ($1,000)
Coastal			
	Guinea	57,644.3	115,681.1
	SierraLeone	16,080.7	32,268.3
	CotedIvoire	39,802.7	79,923.2
	Ghana	9,324.9	18,723.9
	Togo	1,956.7	3,929.9
	Benin	11,777.3	23,625.9
	Nigeria	382,420.5	607,301.9
Central			
	Cameroon	6,592.4	13,277.0
	CAR	12,121.1	5,999.0
	Gabon	37.6	75.7
	Congo Rep	41.1	82.6
	D.R.Congo	8,455.1	17,001.5
Sahel			
	Burkina Faso	13,881.1	27,816.8
	Chad	5,876.9	11,771.4
	Gambia	1,083.1	2,169.6
	Guinea Bissau	4,614.0	9,242.8
	Mali	57,692.5	115,547.8
	Mauretania	8,460.8	16,953.0
	Niger	1,786.6	3,577.5
	Senegal	27,455.2	55,006.9
Coastal	Total	519,007.1	881,454.2
Central	Total	27,247.3	36,435.8
Sahel	Total	120,850.2	242,085.8
	Whole Region	667,104.6	1,159,976.8

H. Virus resistant tomato

Tomato production is one of the more important fruit/vegetable production crops in the region. One finds tomato cultivation in all of the countries, with significant areas devoted to tomatoes in parts of the Sahel, Mali, Niger, and Burkina Faso and the more populous countries of the coastal central zones, Nigeria, Ghana, and Cameroon. Tomato production in these countries has fluctuated a lot over time in part due to the advent of tomato diseases as well as changes in the

local tomato transformation industry. Because tomatoes are highly perishable, the ability to process tomatoes has a large influence on the market.

The extent of the poty virus problem in West and Central African tomato production is unknown. Current research will likely let us know about its extent within the next year. In the mean time reports from the field suggest it may not yet be a major issue, but as tomato virus problems develop rapidly it may become a major production issue. For this reason we use estimates based on the spread of the Gemini virus in tomato in the region. If the poty virus is found to be, or becomes a serious problem, then the estimates presented here will likely be accurate. If the poty virus is a less serious problem as seems to be the current case, then the estimates will likely be about half of what is presented here. For that reason we present in the table below two scenarios: a 50% yield boost such as would be the case with the Gemini virus technology and a 20% yield gain as would be the case if the poty virus is less of a problem than the Gemini virus.

Gemini viruses are a major problem in the production of tomatoes in the region. In Mali for example where they were not prevalent until the 1990's, they have cut tomato yields in half. The viruses are spread by flies, which means there are some integrated pest management strategies that can reduce the spread and effects. A Gemini virus resistant tomato could have a major effect on tomato yields, with the potential to double yields in most areas.

If we assume the equivalence to the Gemini virus problem we estimate that a poty virus resistant tomato could increase tomato yields by 50% in the region. Since tomatoes are a cash crop for the most part we expect reasonably fast adoption rates of the technology, with a 8 year adoption path to 100% adoption of the new technology. Given the state of research we expect that it will be 5 years before the technology is ready to be used in the field.

Two other caveats are important with the tomato estimates. First the FAO data on tomato production is particularly bad even by the standards of the region. To our knowledge there are a few country studies but no region wide estimates that would allow us to use better data than what is available from FAO. A particularly glaring weakness of the data used and the simulations provided below is that they do not account for the international trade in tomato paste which substitutes for fresh tomatoes. In particular there is currently a large supply of cheap tomato paste and a lot of competition in the tomato paste market that would likely keep prices down lower than they are in this model.

Second tomatoes being highly perishable have a very different market than the other crops considered in this report. The model simulated below estimates a large increase in tomato production, which because of the perishability of the product would require a major increase in either processing capacity or the capacity of markets to absorb product. One should therefore take the estimates of tomato production increases as measures of the potential IF the complementary market inputs were made available. It is hard to predict from the evidence in the region whether a greater supply of tomatoes would help improve the market and processing infrastructure or whether it would lead to large piles of rotting tomatoes.

Results from the DREAM estimation are presented below in the table. They show fairly large benefits across the countries of the region from a virus resistant tomato technology. Nigeria with

the largest market and production of tomatoes shows the largest benefits from the technology, accounting for about one-third of the benefits. Cameroon and Ghana also show major benefits from the technology. In the Sahel the producers in Niger and Mali are likely the largest beneficiaries from a virus resistant tomato.

Producer Benefits to Virus Resistant Tomato

Region	Country	Producer benefits: 50% yield improvement ($1,000)	Producer benefits: 20% yield improvement ($1,000)
Coastal			
	Guinea	0.0	0
	SierraLeone	25,367.6	6,362.9
	CotedIvoire	31,341.9	19,611.9
	Ghana	242,131.3	48,410.7
	Togo	8,691.9	2,021.9
	Benin	0.0	0
	Nigeria	1,108,695.7	214,243.3
Central			
	Cameroon	533,276.2	197,835.9
	CAR	0.0	0
	Gabon	545.2	200.3
	Congo Rep	0.0	0
	D.R.Congo	72,410.4	26,602.2
Sahel			
	Burkina Faso	17,866.1	6,528.9
	Chad	0.0	0
	Gambia	0.0	0
	Guinea Bissau	0.0	0
	Mali	134,378.3	48,962.3
	Mauretania	0.0	0
	Niger	138,194.8	51,486.4
	Senegal	70,381.7	25,633.6
Coastal	Total	1,416,228.4	290,650.7
Central	Total	606,231.8	224,638.4
Sahel	Total	360,820.9	132,643.2
	Whole Region	2,383,281.1	647,932.3

Overall the producer benefits from a poty virus resistant tomato technology if it produces a 50% yield gain is one of the better technologies among the eight considered here. But these results are to a great extent dependent on the very strong assumption that poty-virus effects in tomatoes are the same extent as those of Gemini viruses. If, as preliminary field results suggest, the poty virus problem is less than half the Gemini virus problem, then the $2.3 billion estimate would likely be closer to the 20% yield boost estimate of $0.6 billion instead. In addition any estimates

with tomato production in the region assume there is a market of sufficient size for the increased production of tomatoes. It is not at all clear that such would be the case in the countries of the region outside of a few countries such as Ghana.

IV. Ranking crop technology values

A. Region wide rankings

Running the DREAM model for each crop technology and then aggregating by region allows us to rank the importance of these technologies for all of West and Central Africa. Those results are presented in the table below. Cassava ranks first, by an order of magnitude. It is followed by cotton and then three crops with about the same levels of benefits: virus resistant tomato, Bt cowpea, and virus resistant rice. The nitrogen use efficiency rice ranks next at about one-third the benefits of virus resistant rice. Cocoa and Bt maize come in with about the same value just below $0.5 billion in benefits.

Ranking the Crop Technologies
(Benefits over 30 years in $1,000)

	Total	Coastal	Central	Sahel
Cassava	20,851,216.8	8,714,149.3	12,137,067.5	0.0
Cowpea	5,221,619.1	1,972,707.4	727,341.7	2,521,570.0
Cotton	4,775,966.2	2,642,494.9	467,354.6	1,666,116.70
Tomato	2,383,281.1	1,416,228.4	606,231.8	360,820.9
VR Rice	1,885,369.0	1,399,974.2	49,522.1	435,872.7
NUE Rice	1,159,975.8	881,454.2	36,435.8	242,085.8
Cocoa	452,691.0	329,462.0	123,229.0	0.0
Maize	437,687.8	256,370.8	181,317.0	0.0

In these rankings the virus resistant cassava technology which has benefits of nearly $21 billion is the clear winner by an order of magnitude over the next highest crop cotton. This high ranking exists despite it only be a crop of relevance for two of the zones. Such a big increase in production of cassava as envisioned in this model would probably help foster an industry that transformed cassava into other food or industrial items. Given the high returns of research in cassava one might wonder if it were something that the private sector might invest in. However, since there is no seed market for cassava, it propagates by cutting, it is unlikely that the private sector could capture the returns from this research effort.

After cassava comes Bt cowpeas which provides uniformly high benefits across all regions and is the top crop by value of benefits for the Sahel. For cowpeas the importance of the Nigerian production and market effect drives a lot of the results. In both cases the major producers are either Nigeria or its neighbors which are often producing for the Nigerian market. But cowpeas are perhaps the crop for which it is easiest to see an expansion of area along with an expansion of demand. In addition cowpeas are a crop often grown by the poor and in many countries are

staple foods for the poor due to their high protein content. Thus like cassava there are likely to be positive distributional effects from improvements in cowpea production.

Following closely behind Bt cowpeas is Bt cotton, which is already making in roads in the Sahelian zone. Cotton is one area where the private sector has invested a lot of effort in the technology. It is likely that the private sector will continue to lead in cotton and the needs for public money will be relatively low. Thus while cotton ranks very highly, it should likely be a low priority of public sector investments.

Three technologies virus resistant tomato, virus resistant and nitrogen efficiency rice have relatively similar total benefits and follow cotton. All three of these have broad based benefits spread across all three regions. For tomatoes the importance of the Nigerian production and market effect drives a lot of the results.[7] The major producers are either Nigeria or its neighbors which are often producing for the Nigerian market. In contrast to the other crops in the list the estimates for tomatoes may be an overestimate because they assume there would be some market for the tomatoes. Given their perishability the envisioned expansion of tomato production here would need a concomitant investment in an infrastructure to market or process the extra production. In addition given the problems with the available data on poty-viruses, it is possible that they are not as big a problem as estimated here. If their effect is more akin to a 20% yield cost rather than the 50% used here, the benefits would be more than cut in half.

For rice nitrogen use efficiency rice comes in at about two-thirds the benefits of virus resistant rice. This difference between the technologies is primarily driven by different estimates of the benefits in irrigated rice areas, with NUE rice having lower estimated returns than VR rice. Thus if the costs of the technologies were the same, there would be greater benefits to virus resistant technologies. However, the nitrogen use efficiency technology is likely to be developed for other regions of the world and other crops and might be relatively easier to put into West and Central African rice varieties. In addition while the benefits of VR rice are capped by the extent of the virus, NUE rice could if matched with appropriate complementary technologies (farmer management, fertilizers, and germplasm) have much greater benefits.

The next to last crop in the rankings is black pod fungus resistant cocoa. It ranks low because of the long time to develop the technology and the slow pace of adoption in perennial crops, rather than because of the quality of the technology per se. In addition the importance of cocoa in terms of export earnings might also move this technology up the rankings for certain countries.

Last on the list, though not that different from fungus resistant cocoa, is Bt maize. While Bt maize has a lot of potential in East and Southern Africa, it does not respond to the key problems of maize production in West and Central Africa. It is primarily useful in the forest zones where maize yields are low due to low solar radiation rather than other agronomic constraints. While it ranks low, Bt maize is useful for a type of corn that appears on the market during the hungry season of the coastal and forest zones. Thus it is a food particularly important for the poor, so

[7] Since there is in fact little or no data on poty-viruses, it is not clear that poty-virus problems are equally large across the region. Thus in order for these estimates to be correct the virus would have to be a relatively large problem in Nigeria and its surrounding countries.

that increases in its production and availability could have some benefits for major benefits for poverty.

B. Regional variation in benefits:

There are also significant differences in these rankings by region, particularly since some crops are not grown in all regions. In the table below we show how the benefits would be distributed across the different regions. The coastal region receives the largest benefits, driven primarily by the importance of cassava, cowpeas, and cotton in those regions. The central region follows close behind also due to the importance of cassava. The Sahel would gain the lowest level of benefits from the eight technologies considered in this report, although most of this is driven by there not being a lot of cassava grown there.

Total Benefits across Regions

	Regional total benefits to producers ($1,000)
Coastal	17,612,841.2
Central	14,328,499.5
Sahel	5,226,466.1
Total	**37,167,806.8**

Below we outline the key regional differences between the regions by ranking the crops within the regions.

B.1. Rankings in the Coastal region

The benefits in the coastal region end up ranked almost the same as the whole region. They are in the table below.

Coastal Rankings of Benefits

	Producer benefits ($1,000)
Cassava	8,714,149.3
Cotton	2,642,494.9
Cowpea	1,972,707.4
Tomato	1,416,228.4
VR Rice	1,399,974.2
NUE Rice	881,454.2
Cocoa	329,462.0
Maize	256,370.8
Total	17,612,841.2

In the coastal region, cassava remains the most beneficial of the technologies with cotton continuing in the second position. Cotton's high rankings come from the strong benefits in the Cote d'Ivoire. Cowpeas come next, although the region's consumers are likely to also gain great benefits (that might double these figures) from cowpea technologies in neighboring countries such as Niger and Cameroon. This is because despite the Sahel's comparative advantage in cowpea production, the greatest appetite for them comes from Nigeria and Ghana. Tomato and virus resistant rice are nearly equally ranked, with Nigeria's production of both those crops being an important component of the benefits.

B.2. Rankings in the Central region

In the Central region cassava also takes the lead position by multiple orders of magnitude. After that the other crops have relatively low benefits. Cowpeas and tomatoes, driven by high production in Cameroon, come in second and third. This is followed by cotton as the next crop in the ranking. The main difference in the rankings for the central zone is that Bt maize has relatively significant benefits in this region. Here a larger portion of the maize is in areas with corn borer pressures that would be affected by the technology. Rice technologies have relatively few benefits due to the low production of rice in the area.

Central Region Rankings of Benefits

	Producer benefits ($1,000)
Cassava	12,137,067.5
Cowpea	727,341.7
Tomato	606,231.8
Cotton	467,354.6
Maize	181,317.0
Cocoa	123,229.0
VR Rice	49,522.1
NUE Rice	36,435.8
Total	14,328,499.5

B.2. Rankings in the Sahel region

In the Sahel region there are only five of the technologies that are relevant. This leaves Bt cowpea as the most beneficial crop technology in the region, with major benefits to the region, driven in particular by their importance in Niger. The second ranking for Bt cotton also mirrors the importance of cotton in the foreign exchange earnings for countries in the region, where it can make up to 50% of the country's export earnings. These are followed by virus resistant rice, virus resistant tomatoes, and finally nitrogen use efficiency rice.

Sahel Region Benefit Rankings

	Producer benefits ($1,000)
Cowpea	2,521,570.0
Cotton	1,666,116.7
VR Rice	435,872.7
Tomato	360,820.9
NUE Rice	242,085.8
Total	5,226,466.1

V. Policy implications and recommendations

The analysis of technologies presented here overall shows a lot of potential for biotechnology innovations in the West and Central African context. Cassava that is resistant to the mosaic virus is clearly the most beneficial of the technologies considered here. It is by a factor of 5 the most important of the technologies in this study. It is followed by Bt cowpeas which has broad based benefits in the region both across countries and across sectors of the population. Bt cotton, which is likely to be the first biotechnology to get widespread use in West and Central Africa, comes next in the rankings. After those crops there are three crops that provide a next level of benefits: virus resistant rice, virus resistant tomato, and nitrogen efficiency rice. They all face stiff international competition in the form of low priced rice and low priced tomato paste that may make the technology benefits harder to realize for countries and producers. Following these technologies are a set of smaller benefits from black pod fungus resistant cocoa and Bt maize. Bt maize does not for the moment seem to respond to a key constraint in West and Central African production and so while these same technologies show a lot of promise elsewhere, they do not have the same level of benefits in this region. The fungal resistant cocoa is a beneficial technology, but the time lags in doing the research and in adopting this technology significantly reduce the benefits when it is compared to field crops.

In terms of where the public sector should put its research investment money there are a number of different ways of analyzing these results. The easiest is a straight money ranking in which one would allocate based on the highest returns to the producers. In this case the resources would be devoted to cassava research and then to Bt cowpea, Bt cotton, etc.

It is clear that such a straight monetary ranking would ignore that the private sector might do some of the research work, particularly in Bt cotton. If one considers where the private sector might put in some research and marketing effort, only Bt cotton really drops from the rankings. If the returns to Bt maize were higher or that were a larger market one might think that the private sector would join that market. But given its small size, it is unlikely that a private company would invest in that market. None of the other crops are likely to attract much private sector effort especially because of the poor seed market infrastructures.

Another ranking would be to see where the technologies were likely to have the greatest effects on the poor and potentially on the distribution of income within the countries of the region. In such a ranking cassava would still remain in the first position. Among the next rank of crops, cowpeas would likely move up because it is a food more commonly eaten by the poor as well as a crop grown broadly across the economic spectrum.

A number of the countries in the region might want to prioritize the technologies based on their effect on the overall economy. This would probably not change the rankings much from the straight monetary rankings, except where there were significant foreign exchange implications. This is only the likely the case with cocoa, where its position as a major foreign exchange earner might move it up in the rankings for some countries. But that is likely the case only in Ghana and Cote d'Ivoire where the technology is not a major benefit for their producers because black pod disease is less of an issue.

Complementary investments

It is important to note that these technologies are merely part of a technological package that one would provide a farmer. Without exception they are traits that one adds to existing crops and germplasm and as such are dependent on the existence or creation of quality germplasm. Thus there are key complementary inputs necessary in terms of creating the crops that would carry these technologies. In many of these crops there is a long way to go to create these. These are also traits that solve one of many problems that a crop in West and Central Africa faces. For example while the Bt cowpea solves one of the problems that cowpeas face in high production, there remain a lot of others which are of equal importance in terms of how they would affect cowpea yields. Another example comes from rice. A biotechnology solution to RYMV will solve some of the problem with increased resistance, but the complementary effort of resisting the virus will have to come from farmer management, the timing of planting, the rotation of varieties, and the use of pesticides against the insects that bring the RYMV virus to the plants.

Thus it would be a mistake to invest in these technologies to the exception of other conventional improvements in crops and crop technologies. Each of these biotechnologies is built on the conventional research that has taken place over the years. And the success of these biotechnologies hinges on the success of the parallel conventional research.

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Appendix Table A1
Modeling Assumptions for the DREAM Model

	Cassava	Cocoa	Cotton	Cowpea	Maize	VR Rice	NUE Rice	Tomato
Adoption rate	20 yrs 80% (estimate from Nigeria)	15 years 50%	8 yrs 100%	8 yr 100%	10yr 10% in coastal and central countries, 0% in Sahel	5 yrs 80% irri 30 yr 80% rainfed	5 yrs 80% irri 30 yr 80% rainfed	8 yrs 100%
Technology change rates	100% yield gain where virus present 50% incidence, 50% yield gain	Nigeria, Cameroon, Togo, Benin: 10% cost reduction & 20% yield gain. Ghana, CI, Liberia: 5% yield gain	20% yield increase	50% yield increase, (20% yield increase also provided)	33% yield increase	20% yield increase irrigated, 5% yield increase rainfed	10% yield increase in both irri and rainfed (numbers for 5% also provided)	20% increase in production, (also 50% increase provided)
Technology creation lags	3 years	15 years	0 years	5 years	3 years	5 years	5 years	5 years
Sources	IITA discussions, IITA documents	IITA discussions, J. Gockowski	Academic Literature: Elbehri et al. and Sanders	Mali discussions, IITA discussions, Purdue paper	IITA and Mali discussions, E. Africa papers	Mali, WARDA discussions, Nat Biotech article	Arcadiabiosci website, WARDA discussions	Mali discussions