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Economic Impact on Food Security of Varietal Tolerance to Cassava Brown Streak Disease in Coastal Mozambique

by

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Research Reports

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SUMMARY

Maize and cassava are the staple food crops in Mozambique. Drought is the main source of production instability in maize. Cassava is widely touted as being drought resistant but disease exacts a heavy, often hidden, toll on edible production. In the lowland coastal regions of Central and Northern Mozambique, Cassava Brown Streak Disease (CBSD) is the most important source of biotic stress. Compared to drought, CBSD is unlikely to make headlines because damage is chronic and does not appear to fluctuate sharply from year to year, damaged production does not enter the market, and the yield consequences of infection are not transparent. Yet brown streak annually costs poor cassava-consuming households in Mozambique tens of millions of dollars in damaged production and foregone consumption.

Brown streak is a problem that can be addressed by effective agricultural research and extension. Indeed, a partial solution to brown streak can be found in the region in the form of several sweet varieties that succumb to the disease but do not express root symptoms. The economic impact of these so-called tolerant varieties is the subject of this paper. We assess the impact of a focused five-year effort to multiply and distribute the tolerant-variety Nikwaha by the USAID-funded NGO Save the Children and its partners in six districts in coastal Nampula Province. Among the countries of the region affected by brown streak, such a concentrated program to combat CBSD via tolerant cultivars is only found in Mozambique.

The analysis of the economic impact of Nikwaha is based on two data sources: the national rural household surveys in 2002 and 2003, and field- and household-level surveys conducted by Save the Children in participating communities. Although not providing definitive evidence, the national survey data attested to the potential for brown streak to adversely affect food security. The national survey data also pointed to a paucity of effective options to adjust to risk of CBSD which affected (an astonishing) 57% of the roots sampled over four years in the Save the Children field surveys. The demand for Nikwaha is strong because it tolerates root damage and scores favorably on consumption characteristics. Based on comprehensive field-survey data and conservative assumptions, the economic superiority of Nikwaha is reckoned at 25% per plant which is equivalent to about $70 per hectare at a median planting density of 3,000 plants.

The Nikwaha project by Save the Children and its partners is projected to generate a 75% rate of return on investment and a total economic impact between 29 and 65 million USD in net present value. By the end of 2006, about 100,000 rural households are expected to have benefited from the project which started in 2002. The economic impact of this project is very high even in comparison to other successful agricultural research and extension projects for which the modal rate of return is between 40% to 60%. The project quickly identified a solution that addressed a major problem. Such a high rate of return epitomizes research that borrows technology with limited adaptation and testing. Both serendipity in finding a solution and focus on getting material to farmers played major roles in making the project a success.

These high expected returns point to the potential for replicating two to three extension projects of similar intensity and recommendation domain in Mozambique. Other countries afflicted with brown streak in southern and East Africa should consider investing in similar propagation projects patterned after the Save the Children experience.

A sensitivity analysis shows that the projected rate of adoption is the parameter that conditions the results of our cost-benefit analysis. Survey responses suggest that the early

acceptance of Nikwaha is strong, but more research is needed to determine the coverage of Nikwaha. In particular, the extent of adoption is projected to be about 15% in 2006. Determining the accuracy of this prediction will tell us a lot about the size of economic impact. Knowledge about the rate of return on this relatively low-cost investment is more certain. Even a low adoption performance of 15% by 2015 generates a rate of return on investment approaching 50%.

In addition to research on the diffusion of tolerant varieties, such as Nikwaha, several other lines of investigation warrant priority. The ongoing commitment to the breeding and testing of varietal resistance/tolerance needs to be maintained and strengthened. Breaking the apparent linkage between sweetness and tolerance could be targeted as a strategic breeding priority as varietal tolerance/resistance in a bitter background is highly desirable.

Prospects for successful research are bright. Recent research has led to expanded knowledge about CBSD on a number of frontiers. Earlier research on CBSD in the 1940s and 1950s in Tanzania was technically successful and resulted in appreciable impact which was never documented. Sustained funding for research on CBSD is warranted. The pay-off to research in breeding and pathology is expected to be extremely high.

The brown streak story in coastal Nampula also illustrates the potential for ill-informed relief efforts to compromise future food security and economic development. Information on disease susceptibility should figure prominently on the choice of cultivars targeted for relief efforts so that responses to the present calamity do not result in a future calamity.

Our study also has illustrative value as one of the first impact assessments of agricultural technology conducted in Mozambique since the return of peace in 1992. We take pains to discuss the case study approach to impact assessment, particularly the generic concepts and assumptions that underlie the analysis.

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LIST OF ACRONYMS

CBSD	Cassava Brown Streak Disease
DFID	Department for International Development of the United Kingdom
IAF	National Household Consumption Survey
IIAM	Institute of Agricultural Research of Mozambique
IITA	International Institute of Tropical Agriculture
INIA	National Institute for Agronomic Research
MPF	Ministry of Planning and Finance
NGO	Non-governmental Organization
NRI	National Resources Institute
SARRNET	Southern African Roots Crops Research Network
TIA	National Agricultural Survey
USAID	United States Agency for International Development

1. INTRODUCTION

In the late 1990s, the incidence of cassava brown streak disease reached pandemic proportions along Mozambique's northern coast (Hillocks et al. 2002). The direct consequences of brown streak for food security are unmistakable: severe yellow-brown, corky necrosis that makes infected areas inedible especially for moderately to heavily damaged roots. In its simplest terms, brown streak results in farmers harvesting a crop that they can only partially eat.

The threat of brown streak to food security has not abated (Zacarias, Cuambe, and Maleia 2004). Since 2002, repeated sampling of plants in farmers' fields suggests that the infection rate among commonly grown varieties approaches 85%. Most plants of existing farmer varieties show symptoms of necrosis of at least one root in severely affected villages (McSween 2004).

Although scientific information about brown streak is still sparse (Legg and Hillocks 2003), tolerant varieties are a practical means to make a large dent in the brown streak problem. Except for Mozambique, the regional resurgence of brown streak in eastern and southern Africa did not result in a widespread campaign to identify and disseminate tolerant varieties (Katinila, Hamza, and Raya 2003). In Mozambique, a brown streak tolerant variety named Nikwaha was quickly identified, multiplied, and disseminated to farmers in six coastal districts of Nampula Province where cassava brown streak disease had become a serious threat to household food security. In this paper, we document the economic impact of the introduction of this tolerant variety.

Estimating the economic impact of a new variety may seem to be a simple exercise, but impact assessment is never as straightforward as it first seems. Telling a persuasive story requires detailed information on context: the specific circumstances, characteristics, and impact of the problem and the solution. Making an effort to getting the context 'right' is central to this case study. This evaluation also has a context. It represents one of the first 'formal' assessments of the economic impact of a successful project combining research and technology transfer in Mozambique since hostilities ended in 1992. We also exploit a richer data set for drawing inferences than is usually available in similar studies on returns to investing in agricultural research and extension (Alston, Norton, and Pardey 1995).

This paper begins with a brief description of the importance of cassava in Mozambique, the incidence and consequences of brown streak, and the scope of the NGO Save the Children/U.S. program to propagate brown streak tolerant cassava planting material that is largely responsible for the dissemination of Nikwaha. Benefits are discussed extensively; a reasonable and conservative estimate of the per plant benefits of Nikwaha is the key parameter in the analysis. The early acceptance of Nikwaha is reviewed, and its diffusion over time is projected. The intervention is cast as a project and is appraised in the setting of a cost-benefit analysis. In the conclusions, we examine the limitations of our calculation on economic impact, identify areas for research, evaluate the prospects for more investment in extension, and draw lessons from Save the Children's Nikwaha experience.

1.1. Cassava and Brown Streak in Mozambique

Maize and cassava are the staple food crops in rural Mozambique (Table 1). They also dominate the value of agricultural production, each with a 25% share. In general, cassava is the primary staple in the coastal belt and is mainly consumed in four of Mozambique's ten provinces: Nampula, Zambezia, Cabo Delgado, and Inhambane. Of the more than 1.2 million households in the rural population who state that cassava is their staple food crop in Table 1, the largest share (about 43%) live in Nampula. Cassava is consumed throughout Nampula, but its role as the staple food crop is heightened in Nampula's eight coastal districts.

Table 1. **Most Important Staple Food for Rural Households in Mozambique in 2003**

Staple Food	Percent of Total Observations[a]
Maize	49
Cassava	40
Rice	8
Sorghum	3
Millet	<1
Sweetpotato	<1

Source: Estimated from the National Agricultural Survey (TIA 2003)
[a] Weighted estimates based on 4,935 observations

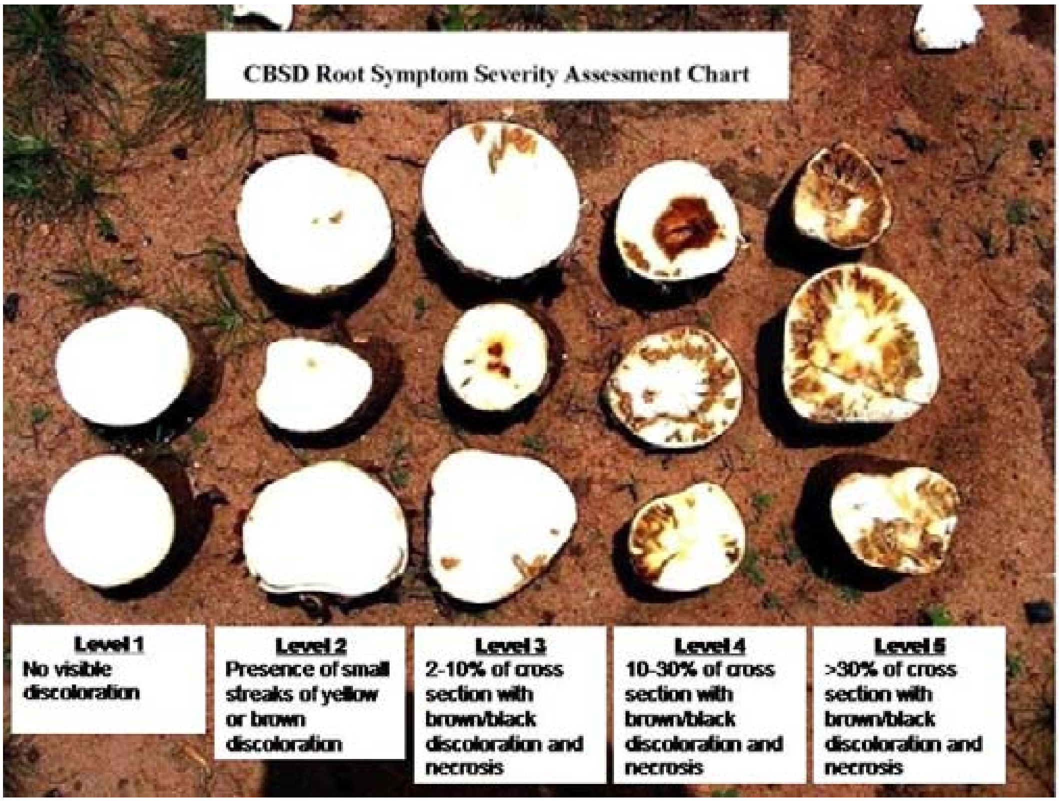
Cassava brown streak disease (CBSD) was first reported in 1936 in Tanzania (Thresh 2003). The disease was observed in several countries of eastern and southern Africa in the 1950s. Following 40 years of waning scientific activity and economic interest in brown streak, CBSD was 're-discovered' in Tanzania, Kenya, and Malawi in the 1990s. The disease gained prominence as a threat to food security in coastal Nampula in the late 1990s.

Cassava brown streak virus was identified as the cause of the increasingly severe problem of dry root rot in coastal Mozambique in 1999 (Hillocks et al. 2002**).** Since 1939 whitefly was the prime suspect for transmission of the virus, and, recently, definitive scientific evidence was marshaled to show that whitefly is the vector (Maruthi et al. 2005). In contrast, a strong inverse correlation of the incidence of CBSD with altitude is well-documented (Hillocks 2004). Within Mozambique and Tanzania, disease prevalence is highest on the Coast (0-200 meters above sea level). But recent surveys in 2004 suggest that neighboring intermediate districts that share boundaries with the coastal districts have rates of infestation (exceeding 40%) that are not significantly different from the coastal districts of Nampula and Zambezia provinces (Zacarias, Cuambe, and Maleia 2004). In more upland, interior districts, the estimated incidence of necrotic roots falls to about 15%.

Why the disease apparently flared up in the 1990s is still unknown. In Nacala and Nacala-a-Velha Districts, where the disease symptoms were first reported in 1998, farmers almost unanimously report that the first signs of the root rot appeared following Hurricane Nadia. The 1994 hurricane had devastated agricultural production. As a response to the emergency, new cassava planting material was distributed to farmers. One variety, named "Calamidade," because it was made available in response to a 'calamity' was widely distributed, and became particularly well liked by farmers because of its high yields. By the late 1990s, the only variety many farmers grew was Calamidade. Although all common local varieties on the coast are susceptible to the disease, the level of expression of root symptoms varies by cultivar (McSween 2004). Unfortunately, Calamidade quickly proved to be a calamity all its own, since it is one of the most highly brown streak susceptible varieties.

The immediate consequences of brown streak for food security are unmistakable: severe yellowish-brown, corky necrosis that makes infected areas inedible, especially for roots with damage scores of 3, 4, or 5 (Figure 1). The 1-5 scoring scale in Figure 1 is based on a classification used by the International Institute of Tropical Agriculture (IITA) and focuses on the most damaged root from each plant. Over the past four years, the average score for Calamidade was 3.5, with 96% of 4,000 plants sampled in farmers' fields showing root damage with scores greater than or equal to 2.0. Four of the less susceptible/tolerant farmer varieties have averaged about 2.6. In 2004 and 2005, the tolerant variety Nikwaha had a mean score about 1.3. (The surveys that were conducted to assess the root necrosis severity are discussed later in the paper.)

Figure 1. Classification of Root Symptoms Severity



Source: Save the Children illustration of IITA's root symptom severity classification using on-farm cassava samples

Brown streak is not the only important yield reducer in cassava in Mozambique. Mealy bug and mosaic virus can also exact a heavy toll on production (INIA 2003). But brown streak is clearly the main source of biotic stress in coastal Nampula, the heartland of cassava production and consumption in Mozambique (Thresh 2001).

1.2. Evidence of Adverse Consequences from Brown Streak from Survey Data

Given its presumed importance, the consequences of brown streak should be visible in national survey data, but using secondary data to confirm the importance of its impact is not an easy task. The disease largely remains hidden since most cassava is produced for home consumption (only about 5% of cassava production is marketed). Collecting accurate data about cassava production and usage is also complicated because cassava is harvested at multiple times throughout the year, and reliable production estimates require considerable interviewer training and supervision. Additionally, brown streak primarily affects root quality and only secondarily yield.

In spite of these difficulties in measuring the economic impact of the disease, the latest national agricultural surveys in 2002 and 2003 (called the TIA 02 and TIA 03) provide evidence that households in coastal Nampula are more food insecure than those in the uplands where brown streak is not a major concern. This evidence comes from a comparison between households covered by the TIAs in three coastal districts and eight upland/interior districts sampled from Nampula Province.

During both 2002 and 2003, the survey indicated that coastal households were significantly more likely than upland cassava-consuming households to buy cassava during the hungry season, and to have purchased cassava during the 30 days preceding the interview (Table 2). Somewhat surprisingly, the coastal households were also more likely to buy maize (Table 3). The importance of this is that many coastal households are net consumers of both cassava and maize, and thus for them, the opportunity cost is the retail price in the local market, and not the lower producer harvest price. This finding has implications for valuing benefits in the next section.

The estimates in Tables 2 and 3 are consistent with a flow of cassava and maize from the interior to the coast. We expect to see higher prices on the coast. In 2003, this prediction rang true as prices were 45% higher on the coast. In the recent past, the interior has sent dried cassava to the coast in response to this price differential.

Interestingly, prices in the TIA 2002 were at the same level for both cassava-consuming regions (Table 4). The difference in price behavior between the two years suggests a shortfall in production on the coast in 2002-03 compared to 2001-02.

Table 2. **Relative Importance of Buying Cassava in Rural Nampula by Period, Year, and Region**

Period	Year	Region[a]	Proportion Buying	95% Confidence Interval	t Value
Hunger season	2002	Coast	0.49	0.41-0.57	2.71
		Interior	0.37	0.33-0.42	
Hunger season	2003	Coast	0.55	0.47-0.64	4.36
		Interior	0.35	0.31-0.40	
Last 30 days	2002	Coast	0.26	0.19-0.33	5.50
		Interior	0.09	0.06-0.12	
Last 30 days	2003	Coast	0.29	0.21-0.36	4.98
		Interior	0.12	0.09-0.15	

Source: Estimated from TIA 2002 and TIA 2003
[a] Based on 604 observations in the TIA 2002 and 569 observations in the TIA 2003

Table 3. Relative Importance of Buying Maize in Rural Nampula by Period, Year, and Region

Period	Year	Region[a]	Proportion Buying	95% Confidence Interval	t Value
Hunger season	2002	Coast	0.59	0.51-0.67	3.96
		Interior	0.41	0.36-0.45	
Hunger season	2003	Coast	0.61	0.53-0.69	4.68
		Interior	0.39	0.34-0.44	
Last 30 days	2002	Coast	0.43	0.34-0.50	6.73
		Interior	0.16	0.13-0.20	
Last 30 days	2003	Coast	0.31	0.23-0.38	4.80
		Interior	0.13	0.10-0.17	

Source: Estimated from TIA 2002 and TIA 2003
[a] Based on 604 observations in the TIA 2002 and 569 observations in the TIA 2003

Table 4. **Mean Prices of Dried Cassava in Rural Nampula by Year and Region**

Year	Region	Mean Price ('000 meticais/kg)	95% Confidence Interval	t Value
2002	Coast	0.96	0.65-1.26	0.17
	Interior	0.93	0.82-1.04	
2003	Coast	2.25	1.76-2.75	2.28
	Interior	1.69	1.51-1.87	

Source: Estimated from the community questionnaires of the TIA 2002 and TIA 2003; based on group interviews with 55 communities in 2002 and 64 in 2003

Documenting that coastal households face higher prices for their staple food crop and are more likely to enter the market to buy their staple food requirements is consistent with, but not proof positive, the increased infestation of brown streak has resulted in food insecurity. Prior to the renewed onslaught of the disease, the coastal areas could already have been more food insecure than the uplands. Nonetheless, the national agricultural survey data draw attention to the potential of the disease to generate adverse consequences on household food security.

The likely adverse impact of cassava brown streak disease on household food security is also supported by the fact that in the sandy, low-fertility soils of coastal Nampula Province, the scope for crop substitution is limited, leaving farmers with few production alternatives. Although a coping survey has not been formally carried out to see how families have adjusted to the disease, farmers say that they are planting more sorghum or other crops to compensate for brown streak damage on cassava; but maize, sorghum, and millet are all more at home in the uplands. Indeed, the TIA data suggest that production levels of maize and sorghum are also lower on the coast than in the interior (Table 5).

Production of rice is higher on the coast than in the uplands, but rain-fed lowland rice is very localized and notoriously unreliable. The TIA data suggest that only one household in four produces rice on the Nampula coast. The comparative advantage of the lowlands is in tree crops and annual roots and tubers, and not in cereals that apparently substitute for cassava.

The limited scope for crop substitution and the relatively high incidence of market purchases of food crops support the hypothesis that cassava-consuming households have coped with the disease by allocating more labor to off-farm income-generating activities such as fishing, trade, and other forms of local self-employment. Off-farm income is highly responsive to education, particularly if a person completes the "basic level" of five years of primary school (Walker et al. 2004), and for better-educated households, increasing off-farm self-employment could be an effective way to adjust to the increased risk of brown streak. For the poorly educated or those with less ability, increasing off-farm income could be a costly exercise with a low probability of success.

The TIA data support the hypothesis that coastal households have higher off-farm income than their counterparts in the interior; however, the difference in off-farm income is not statistically significant (Table 6). In general, off-farm income is much more important to households in the southern provinces of Mozambique, such as Gaza Province, than in the northern provinces like Nampula.

Table 5. **Mean Household Production of Cassava, Maize, and Sorghum in Rural Nampula by Region in 2003**

Crop	Region	Production (kgs)	t Value
Cassava	Coast	2,112	-2.07
	Interior	2,694	
Maize	Coast	120	-2.30
	Interior	187	
Sorghum	Coast	28	-2.17
	Interior	49	

Source: Estimated from the TIA 2003

Table 6. **Mean Household Off-farm Income in Rural Nampula by Region in 2002**

Region	Off-farm Income in US$	t Value
Coast	125	1.10
Interior	92	

Source: Estimated from the TIA 2002

Another way that farmers could compensate for the disease losses is by increasing the planting density of cassava. However, brown streak is borne in the planting material from one generation to the next. Hence, planting more area to cassava is an ineffective solution even if land and labor were available.

More typically, farmers cope with the disease by harvesting earlier (at around six months of age), before the disease has begun to visibly affect root quality. Although disease-free roots can be harvested in this way, yield potential is sacrificed because of the preponderance of immature, smaller roots.

Early harvesting in May-July also creates problems for propagation during the dry season. Cuttings have to be stored two to three months longer before the onset of the rains in November than when the main harvest was traditionally in August and September (Hillocks and McSween 2003). Moreover, the practice of leaving cassava in the field for the proverbial “rainy day” has all but disappeared because older plants almost always succumb to CBSD.

1.3. Technological Options and Save the Children's Propagation Project

Two broad technological options, clean planting material and tolerant varieties, are available to manage brown streak. A technically sound program could incorporate elements of both healthy stem cuttings of farmer varieties and new tolerant cultivars. Implementing a clean 'seed' propagation program would be the technologically optimal response. Farmers would positively select for clean material and would follow rigorous selection procedures to diminish the incidence of the disease. Elements of such a program have recently been tried in Tanzania (Hillocks 2004). Success of a clean propagation program would likely result in a large per plant benefit because the economic losses in the form of root quality and yield could be recovered fully. But clean seed programs for vegetatively propagated crops are typically not successful in developing countries especially those as poor as Mozambique. Success usually depends on having a well-defined commercial seed sector operating in an institutionally developed economic environment. Moreover, brown streak pressure in these severely affected districts is so high that a clean seed program by itself is unlikely to be successful.

An introduced variety that resists infection or that tolerates infection has a better chance for success as the cornerstone of a CBSD management strategy in coastal Nampula. Resistance breeding based on inter-specific hybrids and symptoms of CBSD in stems and roots was carried out in Tanzania in the 1940s and early 1950s (Jennings 2003). That program generated a variety that is still popular in Tanzania. The need for a breeding program featuring inter-specific crosses suggests that resistance was not readily visible or available in the local germplasm. Fortunately, recent screening has uncovered one or more regional cultivars that display tolerance to CBSD since the 1990s outbreak of the disease. Although resistance is preferable to tolerance, tolerance can still provide a basis for an emergency intervention similar to the project that is discussed in the next section.

The reality of the rampant infestation of brown streak in coastal Nampula was recognized in reports in 1998. The first research trial of potential tolerant cultivars was conducted by the National Agronomic Research Institute (INIA) on the Nampula coast in 1999 (Mangana 2003). An entry called Nikwaha from the interior of Nampula looked promising and appeared to demonstrate field tolerance to brown streak. Since the mid-1990s, USAID had funded the NGO Save the Children to carry out agricultural, health, and nutrition extension in rural Mozambique. The next cycle of funding was scheduled for 2002 to 2006 and targeted six of the eight districts of coastal Nampula. Brown streak loomed large as a problem to be addressed in agricultural extension.

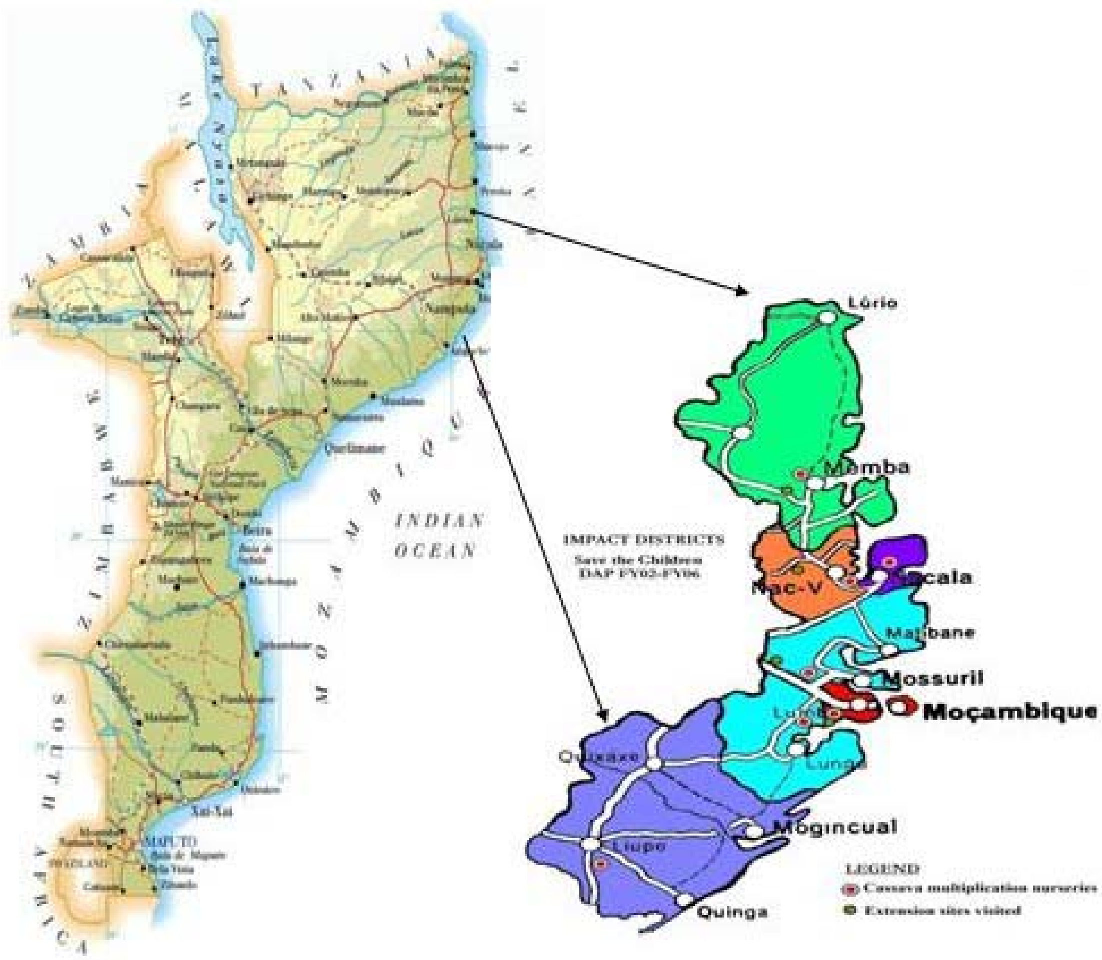
The head of agriculture for Save the Children was confronted by a risky decision: multiply and disseminate Nikwaha or wait until a more suitable variety was identified via agricultural research. Nikwaha was a risky choice, because it is a sweet variety. Farmers on the Nampula coast produce bitter varieties that, in general, are higher yielding than sweet varieties. Nikwaha was well adapted to upland Nampula, but it had not been grown on the Nampula coast. Waiting for a better variety also entailed risks. Cassava is easier to propagate than other root and tuber crops, such as potatoes, but cassava is also characterized by a low multiplication ratio of 10:1. Delaying too long could forego any opportunity for effective multiplication in the project.

With hindsight, the decision to disseminate Nikwaha was a good one. Tolerant bitter varieties have yet to be identified although some farmer varieties seem less susceptible than others. Primary multiplication centers were established in one location in each district (Figure 2).

Distribution of cuttings started in December 2002. By December 2005, the multiplication of material should have been sufficient for 250,000 households to plant 2,500 plants each. Another sweet variety, Nachinyaya, which has given good results in farmer-to-farmer propagation in Tanzania (Mtunda et al. 2003), has also been multiplied and is being evaluated by farmers. Early results indicate that it may be heavier yielding and earlier maturing than Nikwaha on the sandy soils of coastal Nampula.

Save the Children has received the help of several partners in their effort to make Nikwaha available to farmers in coastal Nampula. SARRNET (the Southern African Roots Crops Research Network coordinated by IITA and funded by USAID via Proagri) was instrumental in the early multiplication of Nikwaha. Without this impressive amount of initial material, Save the Children could not have made as much progress on multiplication as it did. The contribution of the INIA was mentioned above. Technical advice to the Save the Children program was provided by the National Resources Institute (NRI) in the United Kingdom with financial support from the DFID Crop Protection Program. The Provincial Department of Agriculture has also assisted in the distribution of Nikwaha, particularly in those areas that are outside of the project's mandate.

Figure 2. **The Location of the Project Districts and the Primary Multiplication Sites**



Source: Adapted from Africa, Central and South, Michelin, PNEU, Paris 1996

2. BENEFITS

The results of almost all economic impact assessments that focus on the adoption and impact of a specific technology hinge on two aspects: per unit benefits and adoption levels (Walker and Crissman 1996). Estimating per unit benefits is the focus of this section.

2.1. Root Symptom Severity Surveys

Estimating per plant value with-and-without the project is the first step in benefit estimation. Data from root symptom severity surveys are the basis for our with-and-without comparison. These surveys were carried out by Save the Children in August of each year in the project communities in the six districts over four years from 2002 to 2005 (McSween 2004). About 250 farms were surveyed annually. On each farm, 20 plants in a line were selected and harvested. The roots of the sampled plants were cut transversally into small sections to estimate the incidence of necrosis. Each root was examined and the incidence of symptoms was recorded along with the root weight of the plant. As described earlier, a CBSD score for a plant was assigned based on the root with the most severe symptoms of necrosis.

For our purposes, the two most important pieces of information from the surveys are the estimated root weight per plant in kgs and the determination if the root was undamaged or damaged. Each year more than 50 varieties appeared in the surveys across the villages, but 14 common varieties represented about 85% of sampled plants each year. These varieties showed some variation in their susceptibility to or tolerance of brown streak. McSween (2004) classified 'best bet' local varieties as those that met two criteria: (1) at least half of their plants with CBSD-symptom mean scores of two or less from 2002 to 2004, and (2) not having a mean score of three or more in any one year. Four local varieties, M'pacua, Nassuruma, Nivalapua, and Namacarolina, qualified for best bet recognition. The more susceptible or less tolerant common varieties included Cocoro, Buana, Nacuali, Calamidade, N'lapa, Tomo, Carita, Taliana, Guerra, Namuiche, and Mphovatacua.

Over time we expect to see farmers replace the more susceptible varieties with the best bet varieties. It is important to recognize that gradations in varietal tolerance exist among the local varieties and that our *without* scenario is a moving target conditioned by the pace of farmers' substitution of one local varietal type for another. In 2004, Nikwaha started to appear in the surveys that are also the basis for estimating the introduced variety's performance. Therefore, we have survey data on the agronomic behavior of the main local varieties for four years and on Nikwaha for two years in farmers' fields.

2.2. Root Weight per Plant and the Incidence of Root Damage

In the tables and figures that follow, we describe the average data of the common varieties by year. Fourteen varieties by four years gives 56 average observations for analysis.

Contrary to expectations, the movement towards best bet varieties does not appear to be that fast (Table 7). Throughout the period, the frequency of the more tolerant local varieties has hovered at around 20%. However, the increasing presence of some of the best bet varieties was noticed in specific locations during the 2005 survey. For example, Namacarolina is rising in popularity in Nacala-a-Velha. Nonetheless, damage levels in the more tolerant varieties are still high, indeed, too high to be managed without introduced resistant/tolerant material.

Based on Table 7, 2002 appeared to be a particularly bad year with low plant yields. In contrast, 2005 seemed to offer some respite with somewhat higher yields and lower damage levels. The best-bet varieties seem to be heavier yielding and show less root damage than the other common cultivars.

Table 7. Relative Importance, Weight, and Percent Root Damage of Sampled Plants in Farmer's Fields by Varietal Susceptibility and Year

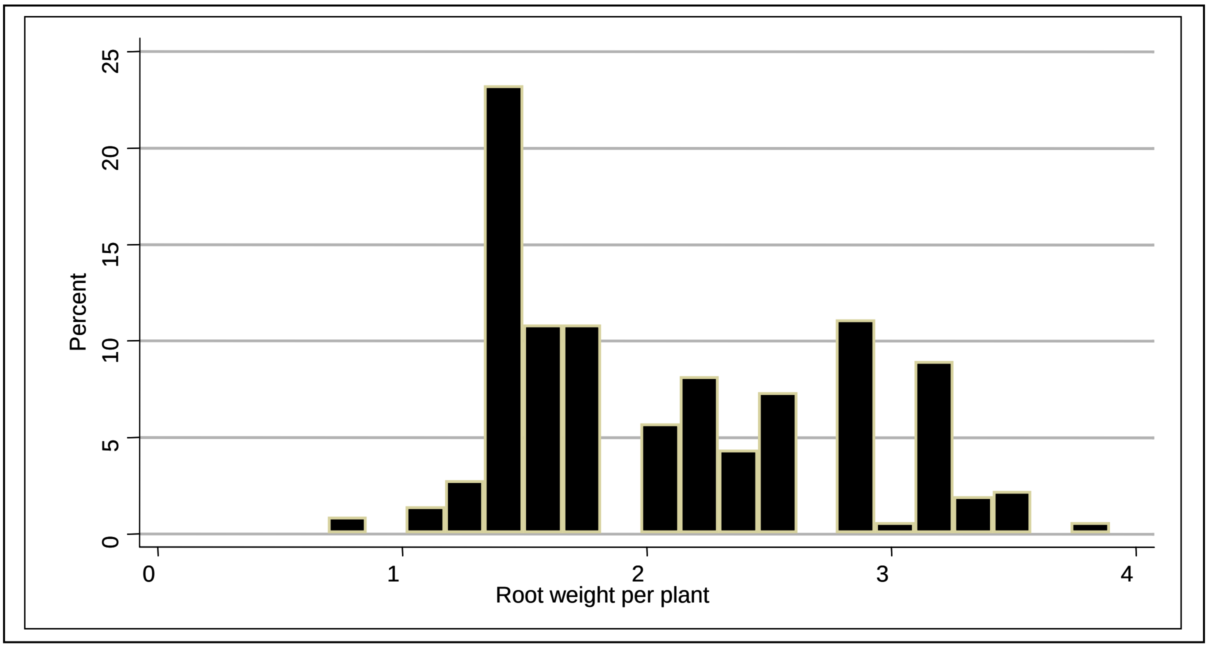
	Relative Importance	
Year	Less Tolerant	More Tolerant
	% of Sampled Plants	
2002	79	21
2003	82	18
2004	83	17
2005	79	21
Mean	81	19
	Yield	
	Less Tolerant	More Tolerant
	kgs/Plant	
2002	1.55	2.06
2003	2.00	1.92
2004	2.26	2.18
2005	2.52	2.86
Mean	2.08	2.26
	Damage Level	
	Less Tolerant	More Tolerant
	% Damage by Root	
2002	66	52
2003	59	38
2004	67	42
2005	49	38
Mean	60	43

Source: Save the Children Root Symptoms Severity Surveys; based on 56 mean common variety observations

Mean yield per plant tended to cluster between values of 1.3 and 1.8 kgs (Figure 3). Percent root damage by variety by year was distributed uniformly suggesting widespread variation from field to field and plant to plant (Figure 4). The on-farm level of root damage is higher than most, if not all of the reported literature (Legg and Hillocks 2003). Root weight of many plants fell below 2.0 kgs, and damage averaging over 60% of the roots was common.

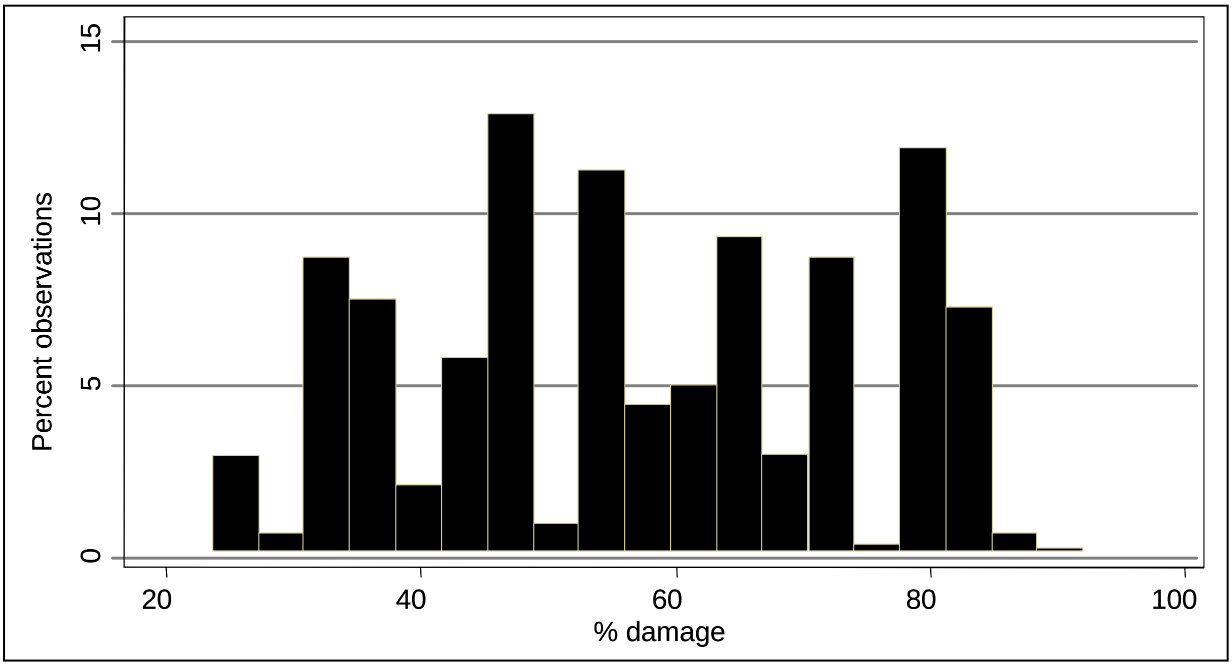
Additive differences over time and by varietal type are more formally tested with a regression approach in Table 8. Each observation is weighted by its frequency in the survey. The results show that best-bet varieties do not confer a significant advantage in yield, but they do result in a reduction in root damage of 17%. The results also confirm that 2002 was a low-yielding year, about 0.6 kgs less per plant than in the base year of 2004.

Figure 3. The Distribution of Cassava Root Weight (kgs/plant) by Main Variety by Year from 2002 to 2005 in Six Coastal Districts of Nampula Province



Source: Save the Children Root Symptom Severity Surveys

Figure 4. **The Distribution of Percent Damage of Sampled Roots by Main Variety from 2002 to 2005 in Six Coastal Districts of Nampula Province**



Source: Save the Children Root Symptom Severity Surveys

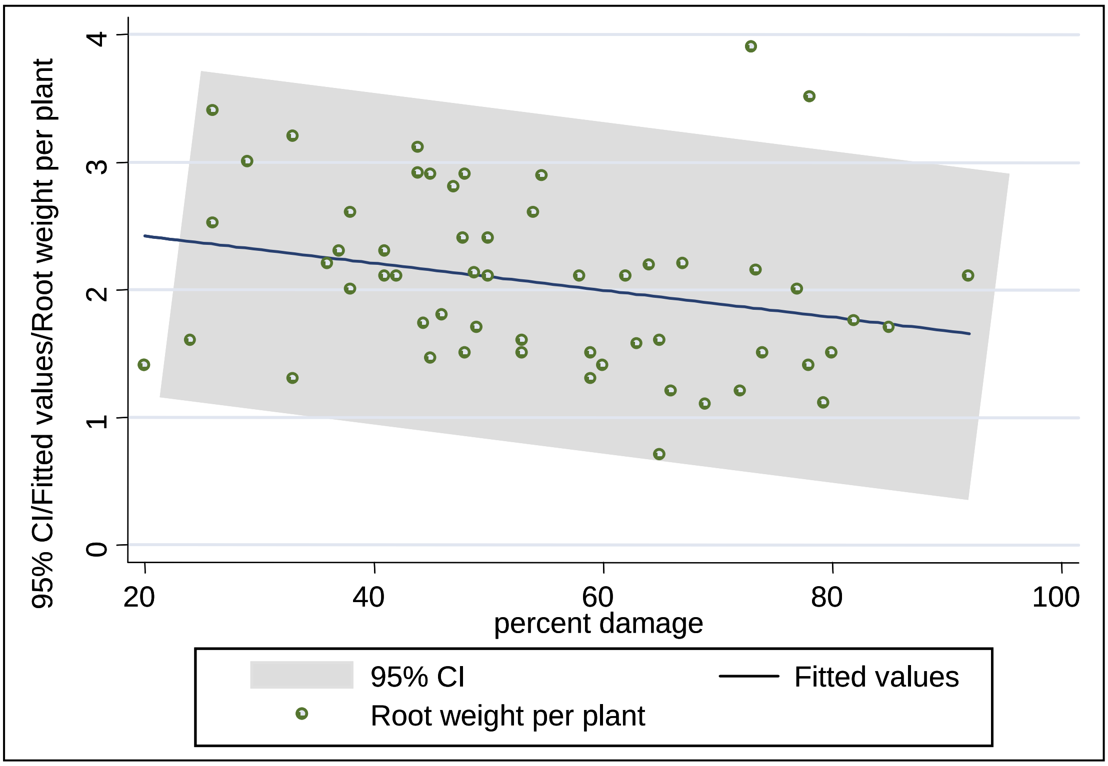
Table 8. Regression Results of Root Weight and Percent Damage by Year and Variety Type

Independent Variable[a]	Root Weight (kgs/Plant) Estimated Coeficients	t Value	Percent Damage (%) Estimated Coeficients	t Value
2002	-0.60	-2.17	0.67	0.09
2003	-0.26	0.88	-7.96	-0.97
2005	0.34	0.81	-16.27	-1.76
Variety type	0.19	0.79	-17.44	-4.23
Constant	2.21	9.17	66.29	10.47
R^2	0.26		0.35	

Source: Estimated from Root Symptom Severity Surveys
[a] Relative to 2004

The effect of brown streak on yield has given mixed results in Kenya and Tanzania (Bock 1994; Hillocks et al. 2001). The on-farm data weakly support the results of Hillocks's experiments that CBSD can cause reductions in yield in highly susceptible varieties. Level of damage is negatively associated with root weight in Figure 5. If we redo Table 8 and include percent damage as a regressor in the first equation on root weight, the estimated coefficient is statistically significant and negative implying a loss of about one-half of a percent in yield for each one percent increase in damage at a mean yield level of 2.1 kgs/plant and a mean percent damage of 57%.

Figure 5. Relationship between the Root Weight and the Percent Damage



Source: Save the Children root symptoms severity surveys

2.3. Per Plant Benefits

Estimating the change in net benefits per plant is the basis for our impact evaluation. The expected benefit per plant $E(b_p)$ is the difference between the mean expected value of Nikwaha per plant minus the weighted expected value of replaced varieties. This relationship is described in (1) below where v_n is the expected per plant value of Nikwaha and v_f is the expected per plant value of all the farmer varieties.

(1) $$E(b_p) = E(v_n) - E(v_f)$$

From the perspective of partial budgeting, we interpret the expected values in (1) as net benefits, i.e., the on-farm costs of producing Nikwaha and the susceptible varieties do not vary. The assumption of identical production technologies seems reasonable because farmers produce cassava in extensive, assorted intercropping with no use of fertilizers or pesticides. The local bitter varieties require processing for consumption, but this advantage of Nikwaha is not quantified.

We also do not value what farmers pay for Nikwaha planting material that is distributed and subsidized by the project. We assign costs to multiplication and distribution of material to the project in the next section, but, once stem cuttings are in the hands of the farmers, we assume that there are no differences in propagation costs or that expenses for propagation material can be recovered by the same farmers in the private market. Sales of Nikwaha planting material have been reported in a few markets, but for the most part, farmer-to-farmer distribution is characterized by unmonetarized transactions.

The expected value of Nikwaha is based on data from farmers' fields in 2004 and 2005 when the variety began appearing in the sample plots. The expected value in (2) is the simple average of all plant observations for that cultivar in the past two years.

(2) $$E(v_n) = 0.5\bar{v}_{n,2004} + 0.5\bar{v}_{n,2005}$$

In equation (3), we describe the main piece of information needed to quantify the without scenario: the expected value of the farmers' varieties. That expected value is equal to the mean weighted value of all main varieties over the four years when samples were taken.

(3) $$E(v_f) = \sum_{i=1}^{14}\sum_{j=1}^{4} w_{ij}\,\bar{v}_{ij}$$

where w_{ij} = the sample proportion of farmer variety i in year j

$\bar{v}_{ij}$ = the mean value of variety i in year j

In principle, with five states of damage in the pathologist's scoring of CBSD severity in Figure 1, the mean value of a variety should be defined by

(4) $$\bar{v}_{ij} = \sum_{k=1}^{5} p_k \bar{r}_{ij} \bar{d}_{ijk}$$

where p_k = the price of cassava in damage state k in meticais;

$\overline{r}_{ij}$ = the root weight of variety i in year j in kgs per plant, and

$\overline{d}_{ijk}$ = the proportion of roots in damage state k.

In practice, we have complete information on the mean root weight in kgs per plant and the frequency of undamaged roots. Therefore, we need to make some reasonable assumptions about prices by damage level and on the frequency of the four damage states.

2.3.1. Cassava Price

As we saw in the previous section, damaged cassava is rarely traded in the market. Purchases of fresh cassava are also infrequent. Dried cassava is commonly traded in localized markets because of the high transportation cost of this bulky commodity. We have argued that net consumers of cassava who buy more than they sell outnumber net producers along Nampula's coast. Increasing the relative importance of net consumers is undoubtedly one of the effects of the disease that has reduced the supply of edible cassava. Hence a reasonable price should be between an average rural farm-gate and retail price for fresh cassava, which is the main form of sales and purchases of the sweet variety Nikwaha.

A national consumer expenditure survey was carried out in 2002-03, and it provides information on the purchase prices of several commodity products in rural Nampula (MPF 2004). For example, the median price of cassava flour was about 3,700 meticais in rural Nampula, dried cassava was purchased at 2,100 meticais per kg, and fresh cassava was transacted for 2,250 meticais. These data refer to 45-75 transactions per product (Table 9).

The producer price data in Table 4 for 2003 are broadly in agreement with the national consumption survey data in Table 9. The estimated producer price for dried cassava in 2003 was about 2,500 meticais on the coast that seemed to be in a scarcity situation relative to 2002 when presumably a more abundant supply prevailed and prices were considerably lower. Higher prices in 2003 are also consistent with the regression results in Table 8 that show a significant fall in yield per plant in 2002 relative to the other years. Hence, prices in 2003 were presumably higher than in other years.

Table 9. Transactions and Cassava Prices by Region and Product

Region	Fresh Cassava		Cassava Flour		Dried Cassava	
	Trans-actions (no.)	Median Price ('000 meticais/kg)	Trans-actions (no.)	Median Price ('000 meticais/kg)	Trans-actions (no.)	Median Price ('000 meticais/kg)
Niassa e Cabo Delgado-rural	161	1.39	203	4.18	49	3.43
Niassa e Cabo Delgado-urban	126	2.40	44	5.72	6	2.27
Nampula-rural	60	2.25	98	3.70	72	2.10
Nampula-urban	53	2.24	37	4.81	127	3.94
Sofala e Zambézia-rural	134	1.79	163	5.22	16	5.40
Sofala e Zambézia-urban	47	2.64	33	6.95	2	3.94
Manica e Tete-rural	71	1.43	2	4.72	5	1.60
Manica e Tete-urban	131	1.48	-	-	3	1.48
Gaza e Inhambane-rural	344	2.41	18	6.56	30	5.02
Gaza e Inhambane-urban	145	2.73	16	4.57	10	2.24
Maputo província-rural	68	3.89	-	-	2	2.43
Maputo província-urban	66	4.94	-	-	3	5.14
Maputo City	86	8.22	5	26.55	-	-

Source: Data from Inquerito dos Agregados Familiares, Ministry of Finance 2004

In neighboring rural Cabo Delgado, the purchase prices in 2003 may better reflect recent normalcy than in rural Nampula, which was characterized by scarcity in 2003. In rural Cabo Delgado, we document the expected relationship in terms of processing: more highly processed products are dearer. We also see more transactions of fresh cassava, which is presumably sweet and enjoys greater popularity, in Cabo Delgado than in Nampula. Rural consumers purchased fresh cassava at 1,390 meticais per kg. Dried cassava was sold for 3,430 meticais per kg. And cassava flour was the most expensive product at 4,200 meticais per kg.

Although fresh cassava in the project villages on the Nampula coast has sold for as much as 5,000 meticais/kg, we feel that a price of 1,300 meticais/kg reflects the scarcity value of cassava for purposes of this analysis. In 2002 prices and exchange rates, a valuation of 1,300 meticais/kg is equivalent to about $55 per metric ton of fresh cassava.

In (4) above, the prices vary by the severity of damage as shown in Figure 1. Our assumed price of 1,300 meticais refers to undamaged cassava that scores 1.00. For the four damage categories 2.0-5.0, we assume that 90% of damage category 2.0 is edible, 50% of each root scoring 3.0 can be consumed, only 10% of root weight in category 4.0 is available for consumption, and that roots scoring 5.0 have no economic value. These assumptions are equivalent to assigning prices of 1,300, 1,170, 650, and 130 meticais to roots scoring 1.0, 2.0, 3.0, and 4.0, respectively.

2.3.2. Transforming the Scoring Data on Worst-root Damage per Plant

The damage classification in Figure 1 may be effective for a pathologist/breeder searching for varietal resistance/tolerance, but it leaves a lot to be desired in valuing crop loss. We have information on the incidence of damage by root and the distribution of the scoring classification *by plant*. But we need information on the frequency of damage *by root.* In other words, we have root estimates on the first (undamaged) category, but we only have plant estimates for four (damaged) categories.

Using per plant estimates based on the most affected root in each category will overestimate the value of damage. A hypothetical example illustrates this point. Suppose, in the sample, we harvest a plant that yields 2.1 kgs with seven roots of equal weight. On cutting the roots, we find that four are damaged and the root with the most damage scores 5.0. The damage level of the other three damaged roots was not recorded. At one extreme, we could assume that the other three damaged roots belonged to category 5.0, resulting in a per plant value of 1,170 meticais. On the other hand, we could also assume that the other three damaged roots scored 2.0, resulting in a per plant value of 2,223 meticais. Hence, the real value of the plant lies between 1,170 and 2,223 meticais in our hypothetical example. Using the per plant scores result in the lower limit of 1,170 meticais. Rather than take the simple average of the upper and lower bounds, it is efficient to use as much information from the damage categories as possible. Therefore, we adjust the per plant frequencies downward from the more severely damaged category with scores of 3.0, 4.0, and 5.0 to increase the frequency of the least severely damaged category 2.0 to transform the data from per plant distribution based on the worst root to a root damage distribution.

Our transformation assumptions are described in equations (5) to (8) below for each damage category. This transformation is arbitrary, but it seems to fit the experience in root sampling from 2002 to 2005. The transformation can be explained by working our way backwards from equation (8) to equation (5). The worst damage score (5.0) is divided equally into two parts, one-half stays in the same category and one-half is equally divided ($0.17\bar{l}_{j5}$) and assigned to the previous three categories. Applying the same rule of one-halfs gives the modified results for scores 3.0 and 4.0 in equations (6) and (7). The per plant estimates for the first damage category (2.0) are retained and are joined by contributions from the three more severe categories to substantially increase the incidence of root damage in this category relative to its frequency in the worst-root per plant classification.

(5) $d_{ij2} = \bar{l}_{j2} + 0.17\bar{l}_{j5} + 0.25\bar{l}_{j4} + 0.50\bar{l}_{j3}$

(6) $d_{ij3} = 0.5\bar{l}_{j3} + 0.17\bar{l}_{j5} + 0.25\bar{l}_{j4}$

(7) $d_{ij4} = 0.5\bar{l}_{j4} + 0.17\bar{l}_{j5}$

(8) $d_{ij5} = 0.5\bar{l}_{j5}$

where $\bar{l}_{jk}$ = the mean frequency of the worst-root per plant scoring classification by variety *j* and damage score *k*.

A comparison of the mean frequency data across all common varieties by the untransformed per plant and transformed per root classifications is presented in Table 10. Multiplying by the prices of each category gives a value of loss attributed to CBSD of 23% based on the per root transformed row in Table 10 compared to a clean value of 1,300 meticais.

The loss estimate of 23% is only based on the replacement value of damaged production and does not include yield losses *per se*. As a point of reference, Gondwe et al. (2003) found that 65% of a sample of 418 plants belonged to category 1.0 in Malawi, that is, significantly less damage than in the project villages. They also observed "that fewer roots were produced by affected plants …. and that some affected plants had smaller roots than plants without CBSD symptoms" [p.32]. Based on affected and non-affected plant comparisons and farmer interviews, their mean total yield loss estimate ranged from 20% to 24%. Although the project samples indicated about 50% more damage than the Malawi sample, the loss estimates are roughly the same size. Hence, our value loss estimates appear to be conservative and most likely substantially understate the magnitude of the true losses occasioned by CBSD.

However, our estimates do not systematically understate the value of Nikwaha which is compared to local susceptible varieties in farmer-field conditions. But these estimates would understate the yield advantage of an effective clean propagation program (if such a program could be implemented) or a resistant variety that is as heavy yielding as the local bitter varieties. In other words, Nikwaha "recovers" part of the loss but is not a total solution to the problem of CBSD.

Table 10. **Relative Importance of Damage by Classification**

Classification	Damage Score (% Frequency) 1.0	2.0	3.0	4.0	5.0
Per plant untransformed	43.0	16.4	17.4	12.3	10.9
Per root transformed	43.0	30.0	13.5	8.0	5.4

Source: Save the Children Root Symptoms Severity Surveys; based on 56 mean common variety observations by year observations

2.3.3. Adjusting for Cultivar Change in the Local Varieties

Over time, farmers should switch to more tolerant local varieties in response to CBSD. As we discussed at the beginning of this section, we see some specific examples of this change, but we have yet to see significant differences in the results of the root symptom surveys where the incidence of the more tolerant local varieties has been relatively constant at 20% from 2002 to 2005. Nevertheless, we assume a more dynamic scenario for the medium term, that is, the relative importance of the more tolerant varieties will double to a level representing 40% of the total. The dynamic scenario provides a more conservative estimate of impact than the projection of the current situation, i.e., the static scenario.

2.3.4. Years for Inclusion

The results in Table 8 suggest that the first year was unusually low yielding and its inclusion could result in estimates that overstate the economic impact of Nikwaha. If we had data for Nikwaha during the first two years, then inclusion of the four years would be warranted. But we only have data for Nikwaha during its early acceptance in 2004 and 2005. We also know that 2005 seemed to be a year of somewhat lower severity of CBSD in terms of root damage. Ignoring the first two years, in effect restricting the analysis to a strict with-and-without comparison of Nikwaha, could significantly understate benefits. To address year-to-year variability, we have decided to provide two estimates over time: one includes all four years, and the other is based on the last three years. Therefore, the value of our expected without scenario ranges from a low of 2,168 meticais per plant with static varietal change and 2002 included to a high of 2,420 meticais with dynamic varietal change and 2002 omitted (Table 11).

Table 11. Mean Expected Variety Value by "Without" Scenario (meticais/plant)

	Varietal Change	
Years	**Static**	**Dynamic**
2002 included	2,168	2,259
2002 omitted	2,348	2,420

2.3.5. Expected Value of Nikwaha per Plant

By 2005, Nikwaha was the third most frequently sampled variety in the project communities. In 2005, the mean Nikwaha yield from 443 plants was 2.9 kgs and was significantly higher than 'traditional' varieties. In 2004, the mean yield of Nikwaha was 1.6 kgs, which was significantly lower than the 14 common varieties. In both years, CBSD root damage was only 5% to 6% for Nikwaha, which was more tolerant to CBSD by a wide margin. The mean expected value for Nikwaha for 2004 and 2005 was 2,855 meticais per plant. The net benefit per plant ranges from about 435 to 685 meticais per plant, that is, 1.8-2.9 cents per plant in U.S. dollars. Depending on the without scenario used in Table 11, this gain is equivalent to a varietal increase in per plant value of production ranging from 18% to 32%.

2.4. Net Benefits per Hectare

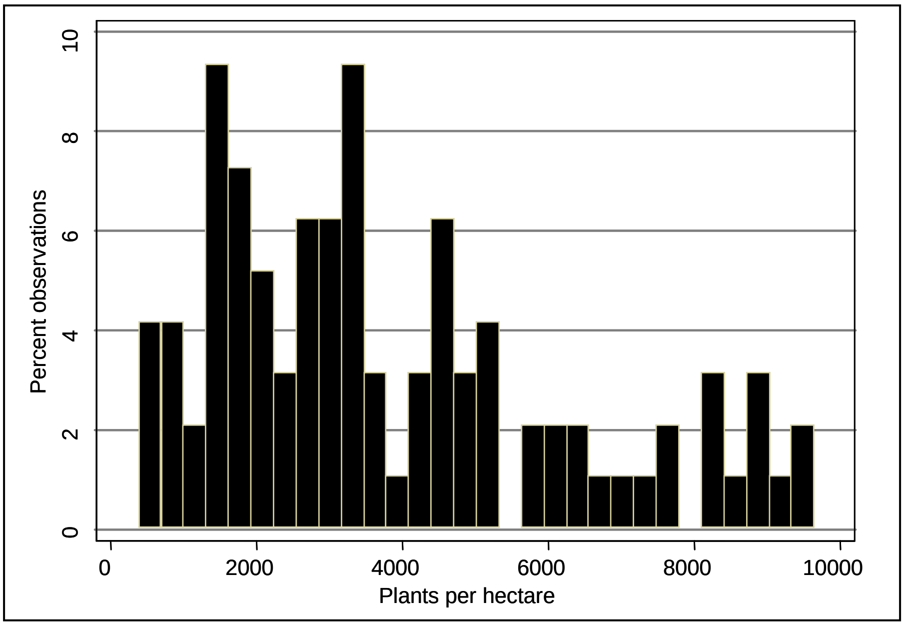
On-farm benefits equal the net benefit per hectare multiplied by the adopted area. Therefore, we need to translate our benefits per plant into benefit per unit of area that is the basis for estimating adoption. Algebraically, our focus shifts from b_p in equation (1) to b_h in equation (9) where p equals plant population per hectare.

$$(9)\ E(b_h) = E(b_p)p$$

Cassava is commonly grown with several other crops; few fields are sole-cropped and, in most fields, line sowing is not practiced. Sampling planting densities in the project communities suggests widespread variation from field to field (Figure 6).

In principle, a sole-cropped field would be planted at a square spacing of a meter between rows and plants in a row. Only about 10% of the fields approach a monoculture cropping density of 10,000 plants in Figure 6. The median spacing with the data in Figure 6 is estimated at about 3,000 plants per hectare, and this is the density we use to define a typical hectare of cassava. At prices and exchange rates prevailing in 2002, an assumed planting density of 3,000 plants per hectare gives a per hectare net benefit of about $70 for the average of the four without scenarios in Table 11.

Figure 6. The Distribution of Plant Density of Cassava in the Sampled Fields



Source: Save the Children Root Symptom Severity Surveys

3. ADOPTION

Estimates of adoption strongly influence the outcome of the analysis. No adoption is the same as saying no impact. Evaluations of the early acceptance of agricultural technologies are necessary for persuasive impact assessment.

Since December 2002, Save the Children, with strong assistance from SARRNET, has annually distributed stem cuttings of Nikwaha to farmers via community-level multiplication nurseries. In July 2005, Save the Children conducted an evaluation to determine the fate of the material that was initially distributed to 120 villages where community nurseries were established in December 2002 (McSween 2005). Three hundred households, about equally divided between community-nursery participants and non-program households, were interviewed in ten villages.

3.1. Results of the Rapid Appraisal on the Early Acceptance of Nikwaha

The rapid appraisal confirmed a strong demand for Nikwaha. Of 162 program participant households, about three-fourths said that they had planted Nikwaha on their farms. About two-thirds of those who planted Nikwaha had given or sold cuttings to someone else. Of the 138 non-program participant households, about two-fifths said that they grew Nikwaha and half of these had distributed Nikwaha cuttings to others. On average, each farmer who had distributed cuttings gave them to three other farmers. Based on these figures, McSween (2005) estimated that the initial distribution of Nikwaha to about 6,000 project beneficiaries in 2002 had spread to over 30,000 farmers by the end of 2004.

Farmers reported that Nikwaha planting material had disseminated thoroughly in their own communities, and in many cases, had spread to other communities through traditional networks as gifts to family and friends, and, in a minority of cases, via sales. Farmers praised Nikwaha as having the best tasting leaves of any variety they grew. They also said that Nikwaha's roots were tasty and easy to cook.

Another message from the early acceptance appraisal focused on the continuing role of the susceptible bitter varieties (McSween 2005). Although farmers were glad to have a sweet variety that could be harvested and eaten fresh, they reconfirmed the need for bitter varieties. Sweet cassava is harvested and boiled fresh and is usually eaten in the morning or during the day as a snack food. Bitter cassava is dried, pounded into flour, and cooked into a stiff porridge to provide the starchy base for the main meals of the day. Sweet cassava is harvested more frequently, but in lesser quantities per harvest than bitter cassava.

3.2. Projecting the Adoption of Nikwaha

The early acceptance appraisal provides two key pieces of information that are important for projecting the adoption of Nikwaha: (1) the initial uptake of Nikwaha is strong; major weaknesses that could result in significant disadoption are not apparent, and (2) Nikwaha and other tolerant sweet varieties are unlikely to totally replace susceptible bitter varieties. These findings are consistent with a projected adoption that is fast (for a vegetatively-propagated crop) in terms of the speed of diffusion and that is substantially less than a ceiling level of 100%.

The cost-benefit analysis is structured on the basis of adopted area and net benefit per adopted area. The total cassava area in the six project districts is reported at 75,000 hectares in Provincial Department of Agriculture publications. This area is equivalent to sole-cropped cassava planted at one meter by one meter. Our plant population of 3,000 plants/ha gives an equivalent area of about 235,000 hectares of cassava in associated mixed intercropping under farmers' field conditions as the size of the recommendation domain. We assume a ceiling adoption level of 50% when diffusion of Nikwaha finally peaks.

We also know how much material was distributed by the project in 2002, 2003, 2004, and 2005. Early acceptance effectively started in 2003. Although technically it is possible to multiply cassava at a rate of 10:1 and although stem cuttings have no alternative use other than for planting material, we prefer to use a more modest rate of dissemination equivalent to a 5:1 multiplication ratio. This conservative multiplication ratio gives an area estimate of 200 hectares in 2003 equivalent to 0.08% of total area. Using the same procedure yields an estimate of 0.56% for 2004 and 3.13% for 2005.

Sufficient material was distributed through the project to support these low estimates of initial adoption. Other sources would give significantly higher estimates. For example, Nikwaha was the third most popular cultivar in the root severity symptom surveys in 2005 representing 13% of the sampled plants. Of course, the incidence of Nikwaha in the project communities is likely to be higher than in the rest of the districts. The calculations from the rapid adoption appraisal also give higher numbers than those from our 5:1 multiplication estimates. The December 2002 distribution by itself was reckoned to account for 4.6% of the total cassava-growing area in 2005.

We also need to specify the length of the project in order to project an adoption profile. Unlike cereals, cultivars of vegetatively propagated crops have long lives in farmers' fields even in developed countries. For instance, the average varietal age of potatoes in the United States exceeds 40 years. This observation argues for a longer length of project, which we assume is 30 years from the time costs are first incurred.

Armed with information on initial adoption and with assumptions on the adoption ceiling and project life, we can now project adoption by fitting a logistic curve to our early acceptance estimates consistent with our assumptions. That the diffusion process often results in a logistic adoption curve is one of the stylized facts of the adoption literature (Griliches 1957; Rogers 1995). The formula for a logistic is given in (10).

(10) $$\hat{a}_t = \frac{k}{1 + e^{-(a+bt)}}$$

where $\hat{a}_t$ = the projected level of adoption in year t
k = the ceiling level of adoption
a = the initial start of adoption
b= the speed of diffusion

Estimates that give a reasonable fit to our data include a speed of diffusion (b) of 0.5 and a starting value (a) of –3.0. With a 50% ceiling level and a 30-year length of project, adoption of Nikwaha is projected to account for 15% of the cassava-growing area in the six target districts in 2006 and 20% in 2007. Adoption reaches 49% by 2015.

4. PROJECT COSTS

The Nikwaha project is not a costly exercise, and even egregious errors in assigning costs are not going to unduly affect our results. Moreover, the project is self-contained; hence, the cost data are transparent and reliable. We do have to make many assumptions about how the different institutional actors who contributed to the project allocated their time.

Costs were tabulated for 11 categories for direct expenses incurred by Save the Children. Staff costs included salaries of extensionists, of permanent labor and guards for nurseries, and of supervisory and administrative personnel. Staff costs were pro-rated according to time spent in multiplying and distributing tolerant varieties vis-à-vis other activities in the larger Save the Children Project. Cost of vehicles were the main expense on equipment. Operating costs included gasoline and temporary labor for land clearing and planting, weeding, harvesting, and the management of collaborative variety trials. Initial expenses on planting material for nurseries also figured in operating costs. Partner expenses by SARRNET and IIAM in supporting the project were estimated and included.

We also included the cost of the DFID-funded work by NRI during phases 1 and 2 of that program. All expenses in Mozambique of this work were charged to the project.

Investment in the project started in 1999 and is expected to finish in 2006. Purchase of vehicles to support multiplication and dissemination were the largest cost item. Costs peaked in 2002 at slightly under $400,000.

As trivial as it sounds, the main problem in assigning costs in a research-related project is choosing the correct starting date. Because we are evaluating the identification, multiplication, and distribution of Nikwaha as a research and extension project, we should begin to tabulate costs when varieties were first screened for brown streak tolerance/resistance. Varietal screening was first reported in trials planted in 1999 (Gondwe et al. 2003) and that is the date we use to start the project.

5. COST-BENEFIT ANALYSIS

The groundwork for a cost-benefit analysis of the "Nikwaha project" has been laid in the previous sections. Our estimates are summarized in a net benefit stream for the project that is defined in (11).

(11) $N_t = b_h \hat{a}_t h - C_t$

where N_t equals net project benefits in year t with t varying from 1 to 30. b_h are net benefits per hectare and are described in equations (1) to (8) and in equation (10). $\hat{a}_t$ is the projected area of adoption expressed as a proportion of total cassava-growing area (h) defined above assuming a plant population of 3,000 plants per hectare. C_t refers to total project cost in year t.

Both benefits and costs are expressed in constant 2005 prices. Prior to 2005, we inflate all net benefits, which are mainly costs, back to the first year of the analysis in 1999. We based this deflation procedure on a food price index for urban Nampula from the Mozambican National Statistical Agency. From 2005 onwards, we assume that the inflation rate for both benefits and costs is the same, which is a common supposition about future price trends in cost-benefit analysis.

The estimated net benefit stream is presented in Table 12 for our baseline scenario. This project net benefit stream applies to the base scenario where b_h = \$70/ha, k = 50%, and t = 30 years. Characteristic of success stories, if we graph the net benefit stream over time, negative net benefits in the initial years are scarcely visible and are dwarfed by positive net benefits from 2006 onwards.

We want to compare the results of the Nikwaha project to similar success stories of agricultural research and extension, and we also want to determine how robust the results are to changes in the assumptions that underlie the analysis. Two measures make economic sense in describing the results of cost-benefit analysis (Boardman et al. 2001). These criteria are the internal rate of return and net present value. Both can be explained by formula (12), which says that net present value equals the sum of discounted net benefits. Discounting is a way to standardize results across projects of different durations and to recognize that time has an opportunity cost that is reflected by s the social discount rate for public-sector projects or those supported by donor funding.

(12) $PV(N) = \sum_{t=1}^{t=30} \frac{N_t}{(1+s)^t}$

As its name implies, net present value says how much the project is worth today over and above an investment at a fixed interest rate. The internal rate of return is the interest rate that drives net present value to zero. Net present value conveys information on the size of economic impact. The internal rate of return reflects the profitability of capital invested in the project.

As expected, the Nikwaha project performs well on both criteria (Table 12). The estimated internal rate of return slightly exceeds 75% and net present value approaches 30 million dollars in our base scenario at a 10% social discount rate which is high even for developing countries. A social discount rate of 5% results in a project value to society of 60 million dollars.

Table 12. Estimated Net Benefit Stream for the Nikwaha Project by Save the Children and Its Partners

Year	Adoption Rate (%)	Total Benefits ($US)	Total Cost ($US)	Net Benefits ($US)	Deflator	Deflated Net Benefits ($US)
1999			22,440	-22,440	1.71	-38,372
2000			23,266	-23,266	1.76	-40,948
2001			22,199	-22,199	1.58	-35,074
2002			381,210	-381,210	1.28	-487,948
2003	0.08	13,190	127,381	-114,190	1.19	-135,886
2004	0.56	91,457	115,457	-23,999	1.11	-26,639
2005	3.13	515,326	110,413	404,913	1.00	404,913
2006	15.50	2,549,959	102,160	2,447,799	1.00	2,447,799
2007	21.89	3,601,098		3,601,098	1.00	3,601,098
2008	28.72	4,724,789		4,724,789	1.00	4,724,789
2009	35.03	5,762,164		5,762,164	1.00	5,762,164
2010	40.11	6,597,962		6,597,962	1.00	6,597,962
2011	43.77	7,200,548		7,200,548	1.00	7,200,548
2012	46.21	7,601,066		7,601,066	1.00	7,601,066
2013	47.74	7,853,086		7,853,086	1.00	7,853,086
2014	48.67	8,006,239		8,006,239	1.00	8,006,239
2015	49.22	8,097,350		8,097,350	1.00	8,097,350
2016	49.55	8,150,865		8,150,865	1.00	8,150,865
2017	49.74	8,182,064		8,182,064	1.00	8,182,064
2018	49.85	8,200,173		8,200,173	1.00	8,200,173
2019	49.91	8,210,658		8,210,658	1.00	8,210,658
2020	49.95	8,216,719		8,216,719	1.00	8,216,719
2021	49.97	8,220,220		8,220,220	1.00	8,220,220
2022	49.98	8,222,241		8,222,241	1.00	8,222,241
2023	49.99	8,223,408		8,223,408	1.00	8,223,408
2024	49.99	8,224,081		8,224,081	1.00	8,224,081
2025	50.00	8,224,470		8,224,470	1.00	8,224,470
2026	50.00	8,224,694		8,224,694	1.00	8,224,694
2027	50.00	8,224,823		8,224,823	1.00	8,224,823
2028	50.00	8,224,898		8,224,898	1.00	8,224,898

Results
Internal Rate of Return = 77%
Net Present Value ≈ $29 million (at 10% discount rate)
Net Present Value ≈ $65 million (at 5% discount rate)

The rate of return on investment from the Nikwaha project is high even in comparison to other successful agricultural research and extension projects for which the modal rate of return is between 40% and 60% (Alston et al. 2000). The project quickly identified a solution that addressed a major problem. Such a high rate of return epitomizes research that borrows technology with limited adaptation and testing. Both serendipity in finding a solution and focus on getting material to farmers played major roles in making the project a success.

A sensitivity analysis of the assumptions underlying the base scenario suggests that the profitability of investing in Nikwaha is robust (Table 13). (We assume a high discount rate of 10% that increases sensitivity to changes in assumptions.) Scenarios 2 and 3 test the sensitivity of the results to assumptions about our estimated per hectare benefits extrapolated from the per plant data in Table 11. Assuming a lower net benefit in Scenario 2 does not change the results that much. The estimated internal rate of return falls by about 10% and net present value decreases by about 25%. Likewise, assuming a higher net benefit in Scenario 3 does not substantially increase social profitability above the baseline.

In contrast to plausible assumptions on net benefits, a lowering of the ceiling rate of adoption to 15% does have a large effect on project outcomes, particularly the net present value which declines to 8.5 million dollars (Scenario 4). Based on good information, we project Nikwaha coverage to be around 15% of the project area in the recommendation domain by 2006. Clearly, information to test this assumption and on future adoption is critical in determining the ultimate profitability of the project.

Economic outcomes are not sensitive to a shortening the life of the project to 20 years in Scenario 5. Results in the next five to ten years are crucial to determining the economic fate of the project. What happens after that will not affect material impact. Nikwaha could be entirely replaced by another tolerant/resistant variety after 10 to 20 years, and the project would still be highly profitable.

Of the first five scenarios in Table 13, one of the most interesting is number 4 with a 30% adoption ceiling. This scenario approximates the full replacement of the super-susceptible Calamidade by Nikwaha. Full replacement of Calamidade would be quite an achievement, equivalent to 15-20 million dollars in discounted benefits.

The final scenario (number 6) illustrates the capacity of a success story to cover the costs of a wider initiative or several such initiatives. Nikwaha is only a sub-component, admittedly a very important one, of the agricultural extension and extension component of the overall rural production, health, and nutrition project by Save the Children in the six districts of coastal Nampula. Can the Nikwaha sub-component support the total costs of the wider initiative? The answer to that question is a resounding yes, provided our expectations are eventually confirmed. The economic consequences of transferring Nikwaha met the costs of the total initiative and still left a tidy sum of 26 million dollars as a real gain in food security to the residents of coastal Nampula. High returns from this one sub-component of the Save the Children broader project should also be sufficient to absorb the costs of several other NGO initiatives in USAID's rural income portfolio.

Table 13. Results of the Sensitivity Analysis by Scenario

Scenario	Description	IRR (%)	NPV ($ million)[b]
1. Base	$70/ha 50% adoption ceiling 30-year project life	77	29.1
2. Low Net Benefit	$54/ha (dynamic, 2002 included)[a]	70	22.3
3. High Net Benefit	$87/ha (static, 2002 omitted)[a]	83	36.4
4. Low Adoption	30% adoption ceiling 15% adoption ceiling	65 50	17.3 8.5
5. Short Project Life	20-year project life	77	21.6
6. Illustrative High Cost to Determine Program Coverage	Add $1.0 million/year in project costs from 2002-2006	41	25.9

[a] Without scenario described in Table 11
[b] Discounted at 10%

6. CONCLUSIONS AND IMPLICATIONS

Since the late 1990s, information from field surveys suggests that cassava brown streak is the most important plant disease that threatens food security in Mozambique. Based on four years of field data and on what we believe are conservative assumptions, we show that the multiplication and dissemination of a tolerant variety can be a cost-effective way to combat this disease. The value of getting Nikwaha out to poor farm households in six districts on Nampula's coast is expected to result in net annual benefits of over 8 million dollars with a 75% rate of return on investment. Ingredients for success included the rapid identification of a tolerant variety that also looked good on other traits, such as consumption preferences, a focus on low-cost methods to multiply and distribute material as widely as possible, a rigorous monitoring program of the incidence of the disease and the uptake of the material, and a five-year project duration that afforded sufficient time to get the job done.

Two aspects of the Nikwaha project by Save the Children and its partners warrant comment. The first concerns the need for the project. In spite of the severity of the disease, farmer-to-farmer propagation by itself is not effective in multiplying material even when tolerant varieties may be available in other regions of the same province or in neighboring provinces. A multi-year, focused intervention is needed to jump-start and sustain the presence of tolerant varieties in the informal seed system. Cassava's low multiplication ratio partially explains the need for special attention.

Secondly, the Nikwaha project focuses squarely on food security, and this emphasis is another characteristic that requires more description from the perspective of evaluation. A major concern in agricultural technology projects is that successful agricultural research rapidly expand supply leading to falling prices that in turn diminish the prospects for success. This market scenario is not relevant because most of the cassava-eating households are net consumers, and the main effect of Nikwaha is to replace (inedible) cassava that would have been eaten if it were not damaged by the disease. It is unlikely that the Nikwaha project will be curtailed by market outcomes generated by the seeds of its success. Indeed, the Nikwaha project represents one of those rare but important opportunities where success does not depend on knowing much about market demand.

It is also important to point out that severe brown streak infestation substantially reduces the potential for cost-effective cassava processing into expanding alternative uses. Without an effective brown-streak control program that increases supply and reduces the cost of raw material, cassava-consuming households in Mozambique will not be able to participate in the silent revolution of cassava processing that is gathering momentum in several countries of Sub-Saharan Africa (Nweke, Spencer, and Lynam 2002).

The main limitation of our analysis is the projected rate of adoption. More research is needed to determine the extent of diffusion of Nikwaha. In particular, the extent of adoption is projected to be about 15% in 2006. Determining the accuracy of this prediction will tell us a lot about the size of economic impact. Knowledge about the rate of return on this relatively low-cost investment is more certain. Even a low adoption performance of 10% by 2015 generates a rate of return on investment greater than 40%.

Our results suggest that serious consideration be given to trying the Save the Children project model in other parts of the country. Perhaps two to three multi-district repetitions of the same project size and intensity could be desirable in central and northern Mozambique. A recent rapid appraisal of plants with root symptoms in 30 districts of Cabo Delgado, Nampula, and

Zambezia Provinces found that two-thirds of the districts – those located on the coast or neighboring the coast – showed a 40% incidence of brown streak (Zacarias, Cuambe, and Maleia 2004). Although these levels of root symptoms are not as high as those encountered in the project villages, they indicate that the current project does not exhaust the scope for the transfer of tolerant varieties. Prior to launching a project patterned after the Save the Children experience, several issues need to be examined in any proposed multi-district multiplication area. Are the tolerant varieties new to the area? Will they be readily consumed? Is CBSD the biggest biotic source of crop loss in cassava? Is CBSD increasing in importance? Affirmative responses to these specific questions for several contiguous districts point to the desirability of replicating the project.

The previous comments about replication of the project do not apply solely to Mozambique. Other countries afflicted with brown streak in southern and East Africa should also seriously consider investment in similar propagation projects patterned after the Save the Children experience.

The tolerant sweet varieties make an important contribution to solving the problem of CBSD. But they are only a partial answer to the problem. The desirability of research is transparent. For almost all intents and purposes, no research was conducted for 40 years between 1955 and 1995. Being a regional problem, CBSD has largely escaped the attention of the international research community. Drought in maize is several orders of magnitude more visible than CBSD in cassava. CBSD is also not on the policy makers' radar screen because its effects on markets are not perceived. For agricultural research, CBSD is a significantly more tractable problem than drought, which is the major cause of relief efforts in Mozambique.

Recent research has a good track record in contributing knowledge to combat CBSD. For example, the DFID-funded research by NRI has mapped disease distribution and incidence in Tanzania, Malawi, and Mozambique and was instrumental in calling attention to the gravity of CBSD as a threat to food security in coastal east and southern Africa. That work also showed that a form of tolerance existed in some local land races and that cassava brown streak virus is whitefly transmitted. More recently, research has reversed the conventional wisdom that CBSD is mainly a lowland disease: an outbreak of CBSD in upland Uganda was associated with the deployment of two mosaic-resistant varieties highly susceptible to CBSD.

The earlier research on CBSD in the 1940s and 1950s was also technically successful. The success of the colonial research in Amani in Tanzania suggests that more strategic plant breeding has a role to play in solving the CBSD problem. Cassava is of sufficient economic importance in Mozambique to justify a more strategic breeding approach, particularly since IITA has established in Tanzania a strong regional research team for cassava improvement. A recent investment in tissue culture facilities potentially enhances the ability of Mozambique to exploit elite materials coming from the IITA regional program.

The Nikwaha experience suggests that tolerance/resistance in a bitter background would be highly desirable. A major research challenge would be to break the apparent linkage between sweetness and tolerance. Failure to find tolerant bitter cultivars would amplify the need to search for mosaic resistance in the sweet materials. Research on the yield effects of CBSD in Mozambique is another priority. The interaction between soil fertility and severe-symptoms expression also merits attention to more quickly identify sustainable solutions to this increasingly important problem.

Reluctance to use bitter materials by plant breeders largely stems from the cyanide risk posed by the direct consumption of those varieties. Scientists are wary that, in times of hunger, farmers were more likely to harvest and consume these varieties directly without drying and further processing which equates to a human health risk. However, the introduction of sweet varieties into these food systems means that this risk is diminished because farmers' production from sweet varieties should reduce the likelihood of direct consumption of bitter varieties, which satisfy an important role in cassava food systems and which are less prone to theft and damage from animals, particularly monkeys, in distant fields.

The brown streak story in coastal Nampula illustrates the potential for poorly designed relief efforts to compromise future food security and economic development. Calamidade is very susceptible to brown streak, and its widespread distribution in the wake of the mid-1990s cyclone set the stage for the recurrence of the brown streak epidemic. In the aftermath of a catastrophe, disease susceptibility rarely looms large as a criterion in relief efforts that focus on the quantities of seed material delivered and the number of families benefited. In sexually propagated crops, such as cereals, errors in cultivar adaptation and disease susceptibility in the choice of variety can be rectified relatively rapidly because multiplication rates are high. In vegetatively propagated species, such as roots and tubers, multiplication rates are low and so is variety turnover. The "wrong" variety can stay in farmers' fields for a long time.

With hindsight, it may have been too much to expect that "Calamidade" could be identified as "super-susceptible" ten years ago because brown streak was not then recognized as a problem. But it is not too much to expect that now crop scientists are more intimately involved in decision-making on the selection of varieties for multiplication in relief efforts and that information on agricultural research from disease screening contributes to decision making in both relief and development.

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