Assessing NERICA Adoption and Impact:

The Case of The Gambia

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Abstract

Food security is a major concern of West Africa for the often-cited reason that imports are far outstripping local production in the region. This issue is especially critical as it pertains to the staple food of rice in The Gambia. In the midst of these concerns, high-yielding crop varieties have found a growing place in the agriculture of sub-Saharan Africa. The 2008 World Development Report emphasized a growing need for agricultural innovation and specifically mentioned New Rices for Africa (NERICAs), varieties developed by crossing Asian rice with African rice. The report hails NERICA's potential but states that a remaining need for further extension and dissemination of the varieties explains why adoption levels remain modest.

Using data provided by the Africa Rice Center, the organization where NERICAs were created, this Capstone examines what factors influence farmer adoption of NERICAs and what impacts NERICA adoption has on yields, income, and health and education expenditures for a group of farmers surveyed in The Gambia. These issues are analyzed using linear probability regressions and probit regressions estimating the binary choice variable of farmer adoption and several impact variables. The results of these tests indicate that a farmer's level of education and training are significant determining factors of her likelihood to adopt. Another significant estimator of adoption is contact with sources of information, such as TV or extension services. Concerning impact of NERICA adoption, adoption is a significant, positive estimator of rice yields. However, it is not significant in estimating farmers' health and education expenditures. These results indicate that the most important areas for future development and agricultural extension work include education and access to information among rural farmers. Those elements enhance farmers' overall capacity to maximize profits, not only from NERICAs but also from the generally limited resources of the sample population.

1. Agriculture in West Africa and The Gambia: Development of NERICAs

In the small, West African nation of The Gambia, rice is considered the most important staple food and has a long history of cultivation in the region. Every year, rice is consumed at a rate of 117 kilograms per person, which is the third-highest rice consumption rate of the countries of West Africa. But only 12 percent of demand is met through local production (Bittaye et al. 2002). Much of the existing rice demand has been increasingly supplied through imports of foreign rice. As the residents of The Gambia and West Africa continue to rely on foreign imports for food, they also remain susceptible to fluctuations in the global price of rice. The hazards of this state of the rice economy became evident in 2008 when a food crisis in West Africa was largely driven by the escalating world prices. According to the Food and Agriculture Organization's monthly Rice Price Update, the price of rice exported from Thailand, the world's largest rice exporter, nearly doubled from 2007 to the present – going from 550 USD per ton to 1,054 USD per ton in April of 2012 (FAO 2012).

Partially as a result of the trade imbalance in the regional and country rice market, and partially as a result of a burgeoning population, countries and people of West Africa have increased production to meet the rising need for food. However, less than 40 percent of the regional increase in production resulted from improved yields. Instead, over 60 percent of the increase resulted from two changes in agricultural practices: First, more land was cleared and converted for agricultural use (IFAD 2011). The implications of clearing more land are problematic in the West African Sahel, where deforestation has become an increasing problem. Second, land was left fallow for shorter periods of time in order to have more continuous harvests. But declines in soil fertility result from leaving land fallow for shorter periods of time, and though harvests were more frequent when land was left fallow for less time, potential yields in each harvest were likely no realized due to the lower soil fertility.

Trepidation concerning food prices and local agricultural production has prompted many to call for increased domestic agricultural production in the West Africa region and The Gambia (Bittaye et al. 2002). The 2008 World Development Report emphasized the need for sustainable technological innovations for the stability of agricultural production in Sub-Saharan Africa, particularly in agricultural systems like The Gambia that are rain-fed and considered risky. One research outcome of the past couple of decades that has been widely hailed as a triumph in agricultural research and development is the high-yielding varieties, New Rices for Africa (NERICAs) (Linares 2002, Diagne et al. 2011, The World Food Prize 2004).

Touted as a technological success, NERICAs are hybrid rice varieties developed by scientists at the Africa Rice Center and released for use in 1996 (IFAD 2011). NERICAs are crossed between the two species, *Oryza sativa*, Asian-domesticated rice, and *Oryza glaberrima*, African-domesticated rice. The intention of its fabrication was to combine the high-yielding and uniform qualities of the *sativa* with the robust qualities of the *glaberrima*, which is resistant to many environmental stressors and very nutritionally beneficial.[1] Monty Jones and the other NERICA developers received the 2004 World Food Prize, and NERICAs are currently planted on more than 200,000 hectares in Sub-Saharan Africa (IFAD 2011). NERICAs have been hailed as a success story among efforts for food security and agricultural profitability in Africa (Linares 2002, Diagne et al. 2011, The World Food Prize 2004). However, at this point, adoption of the variety

[1] See Appendix for more information.

remains low due to insufficient dissemination and extension, according to the 2008 World Development Report.

Many efforts have been made to introduce NERICAs in several countries across Sub-Saharan Africa through participatory value selection (PVS) trials and other extension efforts. PVS trials are methods through which researchers can accomplish several things. They can take into account farmers' preferences in their efforts to develop and disseminate new seed varieties, and they can observe the performance of those new varieties in the actual ecologies of the farmers' fields. This is considered an effective method of developing and disseminating crop varieties because the farmers' fields are a more realistic context to observe the crop's effects than in the more controlled or ecologically different environment of the research center (Paris et al 2011). The NERICA varieties have also disseminated through farmers' informal channels, but some researchers believe that if more farmers knew about the varieties as a result of extension efforts, there would be a higher rate of NERICA adoption in those countries (Adesina and Baidu-Forson 1995, Diagne 2006 & 2010, Barry et al. 2008, Kijima et al. 2006 & 2011).

1.1 Objective

This paper aims to discern two important factors of NERICA use to guide future extension efforts: the farmer characteristics that most significantly influence adoption and the impact of NERICA adoption on yields, income, health, and education of farming households. The paper intends to determine the predominant socio-economic farmer characteristics that predict NERICA adoption. Furthermore, it seeks to answer the following questions about the impacts of adoption in Gambian farmer households: What changes in rice yields are associated with NERICA adoption? What changes in income from rice are associated with NERICA adoption and resulting rice yields? And finally, what changes in expenditures on health and education are associated with NERICA adoption, resulting rice yields, and rice income?

To answer these questions, the paper tests several hypotheses using Africa Rice Center data from The Gambia. First, the hypotheses regarding the question of adoption specifically address the age, context, experience, capacity for information gathering, and education of farmers who might adopt NERICA. The final hypotheses deal with the impact questions. They predict that farmers who adopt NERICA are more likely to have increased rice yields as well as income from rice. Also, they predict that farmers who adopt NERICA will spend more on health and education as a result of increased rice yields and rice income.

1.2 Previous Gambia Literature

Two other papers have been written using the Africa Rice Center's survey data from The Gambia. Diagne (2010) finds that the NERICA varieties have extremely high adoption potential, but that this adoption potential remains largely unmet in several countries, including The Gambia. He argues that the "adoption gap" could be explained by the "knowledge gap," or extent to which farmers are still unaware of the varieties (Diagne 2010). Diagne (2010) emphasizes the need for further extensions to spread knowledge of NERICAs.

In addition, Dibba (2010), a student at the Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi, Ghana, wrote his master's thesis on the effects of NERICA adoption on rice yield and income, with the aim of examining its effects on overall poverty. Dibba (2010) had similar findings concerning the NERICA adoption gap as Diagne (2010). In addition, he finds that NERICAs did, overall, reduce poverty among adopters, increasing yields by over 100 kg/ha and increased overall income by 10.16 dalasi among adopters, according to his findings.

This paper contributes to this existing literature because neither of the previous studies incorporated the farmer household information on the health and education expenditures, gathered in 2010. This paper aims to take the NERICA impact assessment a step further by incorporating this data to analyze the relationship between NERICA adoption and farmers' expenditures on health and education.

The results of this study have several policy implications for the future extension efforts of the Africa Rice Center and the agricultural departments of West African governments. It indicates what farmer characteristics are the most important when targeting populations for further extension efforts. In addition, it shows what effects the Africa Rice Center, governments, extension service providers, and development workers can expect from farmers who adopt NERICA, as well as general trends regarding the spending decisions made by farmers when they gain a higher level of income.

In general, the need for improved agricultural outputs through investments in agricultural research, development, and dissemination are hoped to have multiplier effects on the communities in which they are extended and have positive externalities on the overall quality of life of rural populations. Poverty can be described as a self-perpetuating trap. Infusions of income-enhancing resources as well as appropriate education and training can be the first steps in reversing the direction of the downward-trending spiral of poverty (FAO 2003). Market-based approaches to economic development do not necessarily take these realities into account, according to the FAO's

Anti-Hunger Programme policy statement (FAO 2003). But infusions of resources can begin to accomplish poverty reversal by bringing about positive multiplier effects on households and communities. This is manifested through enhancing their productive capacities and their participation in economically beneficial activities, e.g., healthcare and child education (Covarrubias et al. 2011). NERICA contributions are not the most liquid form of resource infusions, so there is still an element of farmer economic participation through cost-benefit weighing in the adoption decision and process of growing the varieties. However, the philosophy of infusing resources to encourage growth and stability of present and future household income has been embraced in many anti-poverty initiatives and is what drives studies and efforts for NERICA adoption.

1.3 Paper Plan

The remainder of this paper accomplishes this analysis in several steps. The following section puts the present study in the framework of the long-standing adoption literature, theory, and models. Section 3 outlines the process of technology diffusion and adoption on the aggregate and individual levels. Section 4 describes the data and methodology used in this adoption analysis and impact evaluation. The fifth section enumerates the results from running this analysis. Finally, Section 6 draws conclusions from these results and details the implications for policymaking and future research on the topic of agricultural innovations.

2. Conceptual Framing: Adoption

2.1 Modeling Adoption

In conducting an empirical analysis of adoption, it is first necessary to define adoption and how it will be encapsulated as a variable in the model. Adoption can be measured on both the aggregate or community level and the individual level, on both the dichotomous and continuous scale. At the aggregate level, adoption is measured as a continuous variable measuring the rate of adoption across an entire population. At the individual level, a discrete variable represents the adoption choice, while a continuous variable represents the intensity to which that person implements the technology, e.g. the amount of land dedicated to growing a certain crop or variety (Feder et al. 1985). At the individual level, the type of variable used in measuring adoption also changes based on the type of technology in question – e.g., “divisible” and “non-divisible” technologies.

2.1.i. Aggregate Adoption

At the aggregate level, the variable for adoption necessarily becomes continuous to measure the degree of adoption within a community (Feder et al. 1985). There are several stages of aggregate-level adoption. In early stages, adoption among a population is low because of lack of knowledge of the technology, combined with an initial hesitance to face the costs associated with adopting a new technology. In the case of NERICA adoption, a specific explanation for this initial adoption lag would be that the farmers in the sample population have limited resources with which to feed and generate income for themselves and their households. They would naturally be highly risk-averse and so would wait to adopt until they felt they had sufficient information to ensure the success of their harvest.

In general, several models of aggregate adoption show that there are some common personal characteristics that can predict early and late adopters of innovations. Rogers's (2003) seminal work on diffusion of technology through populations outlined the following five "ideal" categories for researchers to classify adopters: (1) *innovators*, (2) *early adopters*, (3) *early majority*, (4) *late majority*, and (5) *laggards*. Citing numerous adoption studies completed in the U.S. and elsewhere, Rogers generalized that a graphical illustration of the number of new adopters over time follows a bell-shaped curve, which approaches normal distribution. Tracking cumulative adoption, or adoption on the aggregate level, over time, follows along an S-shaped curve. This curve illustrates the different stages of adoption, including initial adoption lag and subsequent adoption "take-off," described above (Rogers 2003).

The "innovators" are those individuals with the most resources and access to information about the technology, as well as the personality traits that would make them want to be on the cutting edge and try new innovations. They will be among the first to adopt, and theoretically other members of the community could follow in learning about the technology and adopting it. Eventually, aggregate adoption levels reach a "critical mass" at which adoption is so widespread among the community that its continuation is self-perpetuating (Rogers 2003).

Rogers (2003) exemplifies aggregate adoption patterns with a study of hybrid corn adoption in Iowa communities in the U.S., conducted by Ryan and Gross (1943). As illustrated in Figure 1, which is recreated from Rogers (2003 p. 273), cumulative adoption observed over time followed nicely along the theoretical S-shaped adoption curve, while the number of new adopters over time formed the classic bell-shaped curve of normally distributed data. However, in this case, the curve shows skewness to the left, meaning that the initial time it took for the technology to "take off" among the last of the early adopters and among the early majority adopters was longer than it took for the final laggards to adopt (Rogers 2003). This skewness makes sense, considering that there would be less community-wide information about the technology available for "early adopters" than for "late adopters" and "laggards" (Rogers 2003).

The same model and logic follows for NERICA adoption in The Gambia. West African farmers have a similar hesitance to adopt because of lack of information and risk aversion due to limited resources. So the rice farming populations in several countries across the region are still in the early stages of adoption (Diagne 2010). According to Diagne (2010), they remain in the stage of seeking knowledge about the varieties. The "adoption gap" that can be found in these countries is largely explained by lack of awareness of the varieties or lack of information about the varieties. This explanation for the adoption lag is consistent across the adoption literature. Foster and Rosenzweig (1995) found that imperfect knowledge about high-yielding varieties being spread in India during the Green Revolution was a major barrier to adoption.

The Africa Rice Center released NERICAs more than a decade ago. But in The Gambia, specifically, PVS trials only began in 1998, and concerted extension efforts among this sample population started in 2004 – only two years before collection of the adoption data. Therefore, it could still take time for adoption of the innovation to "take off." Tracking hybrid corn adoption from Ryan and Gross' 1943 study (Figure 1) reveals that it took more than six years for the innovation to "take off," i.e., have more than six people adopt it per year, in the case of Iowa farmers.

Movement along the adoption curve is expedited by several factors, all related to access to information about the technology. Studies have shown that there is significant evidence that learning about innovations does not only occur through formal channels of information spreading (in the case of NERICA, through extension workers from The Gambia's National Agricultural Research Institute (NARI) and the government's Department of Agricultural Services (DAS)) but also through the informal channels of learning from neighbors and community members by word-of-mouth. A study in India by Foster and Rosenzweig (1995) tested the hypothesis that farmers learn through both own and others' experience in the process of deciding whether to adopt new technologies. They found evidence of "learning spillovers," in which the experience of neighbors and other community members significantly affect profitability of high-yielding varieties, in turn affecting adoption and intensity of high-yielding variety implementation on Indian farms. So farmers with neighbors who have the resources or inclination to be among the initial adopters of a new technology would benefit from their neighbors' experience using the innovation.

2.1.ii. Individual Adoption

Rogers (2003) also describes the stages of the individual-level adoption decision, illustrated in Figure 2. For potential adopters, there are five stages in the "innovation-decision process," which include (1) *knowledge* about the innovation, (2) *persuasion* about the innovation's attributes (and disadvantages), (3) *decision* whether or not to adopt, (4) *implementation* of the technology, and (5) *confirmation* of the decision to adopt and implement, at which point the individual seeks more information after adoption and implementation and may choose to discontinue use of the innovation. Many of the factors described above influencing macro-level adoption rates similarly reflect the adoption decision for individuals.

Measurements of individual-level adoption change based on the type of technology considered. Technologies utilized in agriculture can be classified as “divisible” or “nondivisible” (Feder et al. 1985). Nondivisible technology, such as a piece of agricultural machinery, can only be measured as a dummy variable on the individual level. That variable represents the choice of whether or not a farmer adopts the machinery. However, adoption of a divisible technology, such as high-yielding seed varieties – can be represented as a continuous variable on the individual level because it shows the intensity of an individual’s use of that particular technology. A continuous variable measuring individual-level adoption could show, for example, the proportion of available land a farmer dedicates to planting the new variety. As mentioned above, the variables for both divisible and nondivisible technologies become continuous on the aggregate level to represent the adoption rate across an entire community (Feder et al. 1985).

2.2 Farmer Decisions and Adoption of NERICAs

The methods used to analyze this adoption assume a variety of factors come into play in a farmer’s decision to adopt. They assume that farmers are risk-averse, are profit maximizing, and have resource limitations. For example, there are finite amounts of land available for planting and income available for investing in agriculture and information seeking. Many farmers included in this study would not have enough spare resources to engage in experimentation with part of their land in order to determine the merits of the NERICA varieties. However, other farmers would have certain characteristics that would make them particularly innovative and willing to try the seeds on (part of) their land. As farmers in the community engage in greater experimentation and spread the information about its results, more neighboring farmers will be able to benefit from the information because the level of uncertainty associated with adopting NERICA is lower.

Since Feder et al. (1985) would classify the technology considered in this study as "divisible," adoption of NERICAs could theoretically be represented by a continuous variable on the individual level. However, the Africa Rice Center's data for NERICA adoption in The Gambia only includes a binary variable that represents individuals' choice of whether or not to use the technology at all. Therefore, this study analyzes the characteristics that predict the outcome of this binary choice variable.

Any number of specific socio-economic characteristics can affect an individual farmer's level of risk aversion and innovation, discussed above, and hence her likelihood to adopt a new technology. The characteristics examined in this study include age, context of a farmer's residence in her village, experience, education, and access to information-gathering resources such as extension services and information media. These are the interesting farmer characteristics available for analysis from the Africa Rice Center, and this analysis can add valuable new information to adoption literature.

2.2.i. Age and Context

Age would presumably have a negative effect on adoption because older farmers are likely to be more risk-averse. As a farmer grows older, she could possibly feel that she has invested so much time, effort, and knowledge in her way of doing things, that the costs of changes – in terms of time, learning, effort, etc. – would not likely outweigh the benefits. In addition, as a farmer grows older she is more likely to be caring for more dependents. As described below, a larger household size is hypothesized to decrease probability of adoption because of the increased risk aversion of a farmer who has more mouths to feed. While age has not been found to be significant in most other country studies of NERICA adoption, in general adoption literature increased age is commonly considered to have a negative effect on likelihood to adopt (Diagne 2006, Diagne 2010, Feder et al. 1985). Therefore, concerning age, the null hypothesis in this study is that age would significantly, negatively correlate with adoption, i.e. older farmers would be less likely to adopt NERICAs.

In addition, several other contextual characteristics of farmers' living situations and households could also have a significant bearing on adoption. First, farmers who have lived in their villages for a longer period of time may be more likely to adopt, just as farmers who are natives of their villages may also be more likely to adopt. These hypotheses reflect the idea that farmers are more willing to adopt when they are more familiar with the available resources, e.g. the land available for cultivation, with which to implement the proposed technology, i.e. NERICAs. Diagne (2006) saw a similar finding in his study of NERICA adoption in Côte d'Ivoire.

Third, as mentioned above, it would follow that farmers with larger households are less likely to adopt because of the increased risk aversion that would result from having more mouths to feed. Therefore, the null hypothesis tested is that household size has a negative, significant coefficient on likelihood to adopt.

2.2.ii. Experience

This study furthermore hypothesizes that farmers with more years of experience in rice cultivating are less likely to adopt NERICA. The reasoning behind this hypothesis is similar to the reasons for the decrease in likelihood to adopt accompanying increased age. Farmers who have already invested considerable time and resources in learning and implementing certain technologies (for example, an array of traditional rice varieties to be planted in their fields) may find that the potential costs of resources, time, and effort necessary in learning a completely new technology outweigh the potential benefits.

Kijima et al. (2006 and 2011) conducted studies over several years in Uganda with conclusions that seem contrary to this hypothesis. They found that previous farmer experience in rice growing was a significant, positive predictor of adoption in Uganda (2006). In addition, previous experience in rice growing significantly affected yields as well as continuation of adoption. However, even among farmers with previous experience, rice was a generally less profitable crop relative to others grown. So Kijima et al. (2011) observed a dropout rate of over 50 percent in farmers who were originally NERICA adopters.

However, the dynamics of rice cultivation in Uganda are extremely different from those in The Gambia because rice is not a native or traditional crop of Uganda, whereas in West Africa, it has been grown for thousands of years. Implementing NERICA rice in Uganda requires the additional adoption costs of learning how to cultivate an entirely new crop, in addition to learning about the technology of the high-yielding variety, itself. This is not the case among targeted farmers of West Africa, who are already rice farmers. Furthermore, rice is planted in Uganda for use primarily as a cash crop, rather than a subsistence crop, whereas in The Gambia it is largely a subsistence crop. Therefore, adoption and continued use of NERICA in Uganda is based on yields and income, which is affected by previous rice growing experience. But this may not directly reflect the dynamics of adoption in The Gambia.

Indeed, Diagne (2010) found experience in rice farming to have a negative coefficient in studies of both The Gambia and of Guinea. However, he only found these results to be significant for Guinea. Nevertheless, this outcome follows logically, so the hypothesized outcome from the models used in this analysis of The Gambia is that more years of experience in rice farming would correlate negatively with likelihood to adopt the new technology of NERICA varieties.

2.2.iii. Information Gathering

Among sources for gathering information, extension efforts comprise an important element because they can help farmers to overcome the barrier of unawareness of new technologies, which can be a significant inhibitor to adoption (Diagne 2010, Rogers 2003, Foster and Rosenzweig 1995). In addition, Adesina and Baidu-Forson (1995) found that in some cases, farmers' subjective perceptions of a technology, regardless of its basis on information or experimentation, have a significant effect on adoption rate. That is to say, when the farmers reach the "persuasion" stage of the innovations-adoption process, they can at times form an unfavorable opinion about the technology, regardless of whether they have gathered correct or comprehensive information about it. So at this step in the adoption decision they could decide not to adopt (Rogers 2003).

Extension can occur in many other, less direct, forms, as well. Use of TV and radio is one example of an activity with positive externalities that contribute to extension efforts. Some extension programs purposely harness the radio in an attempt to spread information to farmers. In 2007 the Bill and Melinda Gates Foundation funded the Farm Radio Research Initiative with Farm Radio International, which used radio stations in Tanzania, Uganda, Ghana, Mali, and Malawi to spread agricultural information. The radio program in Ghana was intended specifically to spread awareness of NERICAs (Gates Foundation 2010). Radio and television can also serve as informal means of spreading information. Any implementation of media as a forum for agricultural extension necessitates an assessment of whether the farmer characteristics of listening to the radio and watching TV are important indicators for NERICA adoption. Furthermore, Diagne (2010) found contact with extension services to be a very important determinant of NERICA adoption across the countries he studied.

This study's hypothesis tested concerning farmer information gathering is that farmers with access to more tools with which to gather information about NERICA varieties are more likely to adopt them. The variables used to measure access to information in this study include media consumption (specifically, radio and TV), receiving extension services through contact with NARI and DAS, and receiving vocational training. All five of these variables are hypothesized to correlate positively with likelihood to adopt NERICAs.

2.2.iv. Education

Finally, the role of education in farmer adoption of and benefit from high-yielding seed varieties is generally considered a very important determinant of a farmer's ultimate adoption decision. Senegalese rice farmer Abibatou Goudiaby, from the Casamance region just south of The Gambia, said it best:

> When you are educated you can understand and do certain things yourself...It can improve the life of a peasant. Any knowledge you have from your education can help you be more efficient in your work...For instance you get to know what fertilizers or what seeds to use or how to use them. (IFAD 2011 p. 66 & 146)

Indeed, adoption studies have shown that higher levels of education can enhance farmers' likelihood to adopt by enabling farmers to better harness new technologies in several ways (Diagne 2010, Rogers 2003, Feder et al. 1985). First of all, a higher expectation of success with the technology would make a farmer more likely to adopt. Expectation of success is highly influenced by a farmer's perceived complexity of the technology. This perceived complexity is likely to be lower if the farmer has a higher level of education because that would mean she probably has had more experience with gathering and processing new information.

Second, farmers are less able to become aware of new technologies without an educational background that gives them cognitive tools, such as literacy, with which they can learn about them. Education generally leads to an enhanced ability to gather information, but the varying forms of education available in The Gambia have interesting implications on farmer adoption. The types of education received by farmers surveyed for this data collection include Islamic education, various levels of education at secular schools, and "other." A dummy variable was generated to encompass "yes" responses for primary and secondary levels of education secular schools. In addition, a dummy variable for Islamic education was created. In this study, education of all forms is hypothesized to have a positive, significant correlation with adoption.

3. Conceptual Framing: Impact

3.1 Modeling Impact Evaluation

To measure the impact of any initiative or project, researchers must study a sequence of events that plausibly shows a causal relationship from its implementation to its expected long-run outcome or impact. This sequence is referred to as a "theory of change," often modeled as a "results chain" in impact evaluations (Gertler et al. 2011). With this model, a researcher can trace a project from the initial resource inputs with which it began, all the way through to accomplishment (or not) of its long-term goals. The researcher can thus determine if the desired outcomes were achieved and perhaps even where along the chain the breakdown in desired causal effects occurred.

A traditional results chain involves tracking the project through several stages referred to as "implementation" to the several final stages indicating its "results" (Gertler et al. 2011). The implementation stages include initial inputs of resources, activities by the project team, and outputs of goods or services produced by that team for use by a target population. The results stages include initial and final outcomes. The first outcomes of disseminating these products or services are the population's use of the product or service and the immediate effects of that use. The results stages to be measured also include the final outcomes, which involve determining more widespread, long-term community or societal effects achieved by the project (Gertler et al. 2011).

3.2 Evaluating NERICA Impact: The Results Chain

The present study specifically examines the impact of NERICA adoption on the final outcomes of farmers' expenditures on education and health. So the theory of change tested in this study is represented as a results chain, illustrated in Figure 3. The procession of that results chain starts with adoption of NERICA rice varieties and eventually ends with better health and education of the farmers who adopt. The final outcomes measured are farmer expenditures on health and education several years after the initial extension efforts of the NERICA varieties in The Gambia. The underlying philosophy that drives the modeling of this results chain is the idea of the positive externalities of innovations on the lives of rural households, as discussed in Section 1. The following sections outline the NERICA results chain and describe the desired household effects of NERICA adoption.

3.2.i. Implementation Stages

Before the NERICA dissemination project took place in The Gambia, researchers at the Africa Rice Center invested the inputs of time and money toward research and development of the new rice varieties. These initial investments represent the beginning of the implementation stages of the results chain. Subsequently, NARI extension workers specifically targeting populations in The Gambia invested time and resources in the design and implementation of the extension program, intending to spread knowledge of NERICAs to rice farmers throughout various regions of The Gambia. The outputs of these implementation efforts were that 256 rice farmers were exposed to NERICA varieties.

3.2.ii. Results Stages

The results stages of the project include the preliminary and final outcomes. The preliminary outcome is adoption, i.e., whether farmers chose to adopt NERICA for planting on their fields. In addition, the results include any subsequent changes to rice yields and rice income. The final outcomes measured are the impact of NERICA adoption on farmers' spending on health and education. The theory of change tested in this impact analysis (Figure 3) hypothesizes that a farmer's initial decision to adopt brings about higher yields from her rice crop, leading to a farmer gaining more rice income. In order to improve both her life and that of her dependents, the farmer will invest this extra income in her household's health and education. Each step of this theory of change must be tested in order to determine the impact of the program and its effectiveness in achieving the final outcome of better health and education for rural Gambians.

3.3 Theoretical Basis of the NERICA Results Chain

3.3.i. Rice Yields

Agricultural extension programs can improve a farmer's crop yields through increased access to knowledge, labor cooperation, seeds, and other agricultural inputs. The Senegalese farmer, Goudiaby, mentioned above, had contact with agricultural associations, one of which gave her high-quality rice seeds. She reported that she harvested her best crop ever from those seeds (IFAD 2011, p. 146). NERICA varieties, specifically, have been shown to have better yields than other rice varieties used in Sub-Saharan Africa. In 2006, Kijima et al. found that the average yield of NERICA is 2.23 tons per hectare – twice the average rice yield for sub-Saharan Africa.

However, various factors can cause a farmer's yield from improved varieties not to match potential yields from that variety. This yield gap can constitute a difference in size of yields of over 100 percent for rice (IFAD 2011). The main determinants of NERICA yield found in the study by Kijima et al. (2011) included education, rainfall, cropping patterns, soil fertility, and previous experience growing rice. The fourth determinant, soil fertility, which is directly influenced by fertilizer use, is important because NERICA is responsive to soil nutrients, so its yields are directly related to fertilizer application. When the success of agricultural innovations is contingent on adoption of other technologies, especially ones that could impose extra cost, this could present not only a barrier to adoption but also a decrease in the resulting income from adoption. Despite this potential constraint, NERICAs planted without fertilizer, still show large improvements in yields.

However, there also remains the possibility of bias in estimating the relationship between NERICAs and yields. It is possible that yields are higher due to greater farmer capacity – either resource-wise or talent-wise in regards to their farming capabilities. Thus, it is possible estimates may capture farmer characteristics and not NERICA impacts. This is partially managed by including the control variables reflecting different farmer characteristics, but not entirely. Non-measurable farmer personality characteristics, e.g., the entrepreneurial spirit that makes someone an innovator, are not included as controls.

3.3.ii. Rice Income

In order to invest more in expenditures on education and health, farmers must have a higher income. The challenge becomes identifying whether this increased income is derived from the higher yields gained from the adoption of NERICAs. Unrelated circumstances could also affect rice income, making it difficult to isolate NERICA adoption as the only possible explanation for the change. One example of a change that could cause increased yields is more labor used in the planting cycle when NERICA was implemented. If a farmer hires more labor, it would follow that yields would increase;

however, an increase in income will only be observed if the change in income an increase, net of any payments for additional labor. Though there are potential biases in the rice income resulting from NERICA adoption, this study evaluates impact by reporting rice income, rather than rice revenue, so this number should encapsulate income net of any resulting expenses from NERICA adoption.

3.3.iii. Health and Education Expenditures

The very poor face the choice of what to do with an increase in disposable income. It could go toward products for immediate consumption or toward investments that could enrich the quality of life of the earners, themselves, or their dependents. In this case, the results chain model of the theory of change tests whether that increased income from NERICA adoption will lead to higher expenditures on health and education – two examples of the types of investments that would further quality of life for the poor, as stated above. An ongoing debate among development agents and project implementers involves whether gains in areas of life such as education and health follow changes in the situation of the poor through infusions of resources or through market-based approaches (FAO 2003). In this case, the former is assumed in the theory of change – NERICA farmers gain increased yields, which garner increased income. With this income, they are able to spend more on health and education, investments that improve the likelihood of fundamentally changing their economic situations.

<u>4. Data Description and Methodology</u>

4.1 Survey and Data

The data used in this paper comes from an Africa Rice Center survey conducted on both the village and the farm level with 600 rice farmers from 70 villages throughout the agricultural regions of the Gambia. The Africa Rice Center first introduced NERICAs in The Gambia in 1998 through participatory varietal selection (PVS) trials (Dibba 2010). Diffusion throughout the population took place through farmers' informal channels of communication. Later in 2004, The Gambia's National Agricultural Research Institute (NARI) implemented an extension program as a formal method to spread knowledge of NERICAs to selected villages. The survey data was then collected, from November of 2006 through September of 2007, from a sample of 600 farmers in 70 villages. The sample purposely included the villages where NERICA extensions took place, as well as villages where it did not. The survey data observes adoption of NERICA and farmer household characteristics throughout this sample population (Diagne 2010, Dibba 2010).

Village and farmer selection for the survey sample took place through a multi-stage stratified random sampling method. NARI provided a list of rice-growing villages where it introduced NERICA seeds through its extension efforts (dubbed "NERICA villages"). NERICA villages to be included in the sample were randomly drawn from NARI's list. Then, "non-NERICA villages" were chosen randomly out of villages within a five- to ten-kilometer radius of the sample NERICA villages. However, the sample selection process for the survey was not entirely random because villages that had previously undergone NERICA PVS trials were purposely included. Overall, 35 NERICA villages and 35 non-NERICA villages, covering all of the agricultural regions of The Gambia, were selected. Five or ten farmers were randomly selected from sample villages for household-level questioning (Diagne 2010).

The data collection process consisted of two questionnaires – the village questionnaire and the farmer questionnaire. The village-level questionnaire was administered to people with comprehensive knowledge of each village and included questions on known varieties in that village and details about them, such as the type of ecology where they are grown and what post-harvest processing they require (Dibba 2010). In addition, the village-level survey included questions about infrastructures and community variables (Diagne 2010).

The farmer-level survey gathered socio-demographic data for each sample household. These data include the notable variables of age, number of people in the household, the number of years the farmer had been a resident of the village, whether the farmer was a native of the village, number of years of experience the farmer had in rice farming, whether the farmer engaged in non-agricultural activities, whether the farmer listened to the radio, whether the farmer watched TV, the farmer's exposure to vocational training, and the farmer's level of education (Diagne 2010). These variables are used in the present study to test the hypotheses detailed above about the socio-economic characteristics that are important in predicting farmers' adoption choice. Several years later, another survey was conducted to gather more socio-economic information about the farmers in the sample. This information gathered in 2010 includes total expenditures made by farmers on health and education that year. The impact hypotheses detailed above test whether this information indicates significant longer-term effects of NERICA adoption on the issues facing farming households outside of its agricultural activities – the health and education of household members.

Other data collected at the farmer level determined what varieties the farmers knew about, out of the varieties found to be known at the village level. Farmers were also asked if they had recently (within the past five years) cultivated the varieties about which they were aware, among other detailed questions (Dibba 2010). However, the variables resulting from these stages of the survey are not implemented in the present study.

4.1.i. Data Constraints

Several potential biases and threats to internal validity in the results of the analysis arise due to constraints in the robustness of the data. First, as in all data gathered through surveys or other methods that could involve human error, there is some degree of errors-in-variable bias. Overall, the data depicts a sample population of 600 farmers, but out of those, only 516 farmers responded to most of the questions in the survey. One farmer responded to only a few of the questions, so quite a few variables remain unobserved for the 517th farmer (farmer code 561, village code 6102). Several other variables had lower number of observations, as well, because they were questions for which no response was logged during the survey – a common implementation problem with survey data that is largely unavoidable. However, one assumption made about non-response answers is that no responses to the radio and TV questions are treated equivalently to the "no" answers in this analysis. Overall, the analysis remains at the mercy of the available data, which was determined by the survey conducted throughout the country, which means there is the possibility of human error in logging survey data.

Secondly, and importantly, there is sample selection bias that confounds the analysis of this study. Specifically, according to Dibba (2010) and Diagne (2010), the villages selected for the survey from which this data is gathered were not completely random. They were specifically chosen among villages that had undergone PVS trials with the Africa Rice Center since the release of NERICAs in The Gambia. Therefore, the condition of complete randomness in allowing for controls to conduct the analysis is violated.

4.2 Descriptive Statistics

Though the sample size for the survey was 600 farmers out of 70 villages in various regions of The Gambia, for reasons discussed above, the analysis reflects responses from only about 516 farmers. Out of those 516, 256 live in NERICA villages, and 260 in non-NERICA villages, so NERICA village farmers make up 49.61 percent of the observations. However, the percentage of farmers who knew about NERICAs in 2006 is lower in NERICA villages than non-NERICA villages – about 62.11 percent and 31.92 percent, respectively, at the one-percent significance level. Over the entire sample, about 46.9 percent of farmers said they were aware of NERICAs. Overall adoption of NERICAs is lower than knowledge of NERICAs, at 40.31 percent over the entire sample. In NERICA villages, only a little more than half (55 percent) of the farmers adopted, whereas farmers in non-NERICA villages adopted at a rate of about 25.77 percent. The fact that there is any adoption, at all, in non-NERICA villages can be explained by the diffusion of information about NERICAs through farmers' informal channels. Table 2 includes the averages of the observations for each variable over the entire sample population. In addition, it includes the means for each variable observed specifically in

NERICA and non-NERICA villages, as well as the significance test for the difference in means between these groups. Summary statistics for the key variables analyzed in this study are summarized below.

4.2.i. Age and Context Variables

The farmers in the sample population ranged in age from 15 years old to 85 years old, but the average farmer age is about 45 years old. Farmers had lived in their villages for an average of about 35 years by 2006, but this number ranged from one year living in the village to 85 years (entire life lived in the village). Interestingly, there was a statistically significant difference in the means of farmer age in NERICA and non-NERICA villages. NERICA village farmers were about five years older than non-NERICA village farmers, on average, at the one-percent significance level. A little over half (about 56.59 percent) of farmers were natives of their villages. Any difference between NERICA and non-NERICA villages concerning village natives was not statistically significant. Farmers' household sizes ranged from two all the way to 100 inhabitants, reported by two farmers. However, the household size reported on average was about 16 people.[2] Again, there was no statistically significant difference between household sizes in NERICA and non-NERICA villages.

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[2] One explanation for a 100-person household is that the household was a type of boarding school. In West Africa, there is a tradition for boys receiving an Islamic education to move away from the home at an early age and live in an Islamic school, called a *daara* in Wolof, one of The Gambia's native languages, and learn the Koran from an Islamic teacher, called a *marabout*. So a household of a *marabout* could report 100 members. Indeed, the two farmers reporting 100 household members also reported that the type of education they received was Islamic education. In addition, there are 16 farmers in the population sample who reported a household of over 50 inhabitants. Twelve of those farmers also reported receiving Islamic education. So the presence of village *daaras* could be the likely explanation for what may seem like extremely large households.

4.2.ii. Experience Variables

Farmers' previous years of experience with rice cultivation did show statistical significance in the difference of means for NERICA and non-NERICA villages at the 5-percent level for lowland rice and the one-percent level for upland rice. The difference of significance in the overall effect of each type of rice planting may indicate some geographical bias in the location of chosen NERICA villages. For both variables, the average for years of experience in NERICA villages was higher than in non-NERICA villages. The average number of years of experience in lowland rice farming was 13.66 years, while the average number for upland rice farming was approximately 8.42 years. Over the entire sample, years of experience ranges from zero to 25. If farmers reported having more than 25 years of experience, their years of experience were logged as 25 during the survey (Table 2).

4.2.iii. Information Gathering Variables

The farmers' information-gathering characteristics consist of the following variables: receiving vocational training, contact with NARI, contact with DAS, listening to the radio, and watching TV. Nearly 30 percent of the farmers surveyed reported receiving some form of vocational training. A very large portion – 87 percent – of farmers listen to the radio, while less than half – 42.55 percent – watch TV. There is no statistically significant difference in these means for NERICA and non-NERICA villages.

In addition, about 30.8 percent of farmers reported having had contact with The Gambia's DAS. However, only 5.43 percent of farmers had contact with NARI. This seems like a very low number, considering that about half of the farmers surveyed were from NERICA villages, i.e. villages where NARI performed extension efforts. There are multiple possible explanations for this low number. First of all, just because a farmer is from a NERICA village does not guarantee that he or she had individual contact with a NARI worker. In addition, it is possible that farmers mistakenly reported contact with DAS workers when, in fact, they had interacted with NARI workers. Since DAS is The Gambia's government agricultural department, it seems to engage in farmer outreach and extensions more often than NARI, a non-governmental organization. So a farmer could plausibly be under the impression that a meeting with a NARI extension worker was a meeting with a DAS worker. As would be expected, the difference in means for having had contact with NARI was significantly different at the one-percent level for NERICA and non-NERICA villages, with non-NERICA villages reporting lower contact with NARI, on average (Table 2).

4.2.iv. Education Variables

A little over half (53.38 percent) of the farmers surveyed reported that they received Islamic education, while about 10 percent received traditional schooling at the primary or secondary level. Two farmers were illiterate, and about 36 percent said they received a form of education logged as "other" in the survey because it was not originally listed as an explicit option. Neither of the variables for Islamic education or secular education had significantly different means for NERICA and non-NERICA villages (Table 2).

The question remains of which variables play a significant role in predicting the adoption decision and which, if any, of the impact variables, show a significant correlation to NERICA adoption on the individual level. The sections that follow include a note on some constraints on the analysis from the data, a description of the methods used to perform the tests for this analysis, the results of the tests, and the implications and policy recommendations concluded from these results.

4.3 Methodology

4.3.i. Adoption Methodology

The empirical tests of NERICA adoption hypotheses are conducted using an Ordinary Least Squares linear probability model and probit model to determine what independent variables significantly predict the binary choice independent variable, *aner06*, which represents the adoption decision. The OLS model (Equation 1) tests the correlation of available socio-economic farmer characteristics with adoption and the significance of that correlation.

(1)

$$
\begin{aligned}
\Pr(aner06=1 \mid age06, hhsize06, \ldots, islamic) &= \beta_0 + \beta_1(age06) + \beta_2(hhsize06) \\
&+ \beta_3(nanres06) + \beta_4(origv06) + \beta_5(nanbf06) + \beta_6(nbanc06) + \beta_7(nonfarm) \\
&+ \beta_8(listradio) + \beta_9(wattv) + \beta_{10}(nar06) + \beta_{11}(das06) + \beta_{12}(formpr06) \\
&+ \beta_{13}(primsec) + \beta_{14}(islamic) + u
\end{aligned}
$$

However, linear probability models are not the best fit for binary dependent variables. One important reason for this is that the linearity of the model causes probability to exceed one for high values and to fall below zero for low values, which is impossible for a probability. The linear probability model is generally a weak representation of the real-world interpretation of the variables in question (Stock and Watson 2007). Therefore, it is important to also test the significance of farmer socio-economic characteristics with a probit regression on the adoption binary choice variable, with the same regressors as in Equation 1.

In addition, it is important to observe the effects of controlling for extension efforts in the adoption models. Therefore, Equation 2 shows the linear probability model used to control for the NERICA village variable, which represents whether or not the farmer making the adoption choice was from a village where NARI had executed extension efforts or not. The same control is made in order to observe its effects in a second probit regression. The results from the linear and probit regressions controlling and not controlling for NERICA are listed side-by-side in the results tables in order to compare the effects of instating this control. Table 1 lists the labels for each of the variable names used in Equations 1 and 2.

(2)

$$
\begin{aligned}
&\Pr(aner06=1 \mid age06, hhsize06, \ldots, islamic) = \beta_0 + \beta_1(age06) + \beta_2(hhsize06) \\
&+\beta_3(nanrec06) + \beta_4(origv06) + \beta_5(nanbf06) + \beta_6(nbanc06) + \beta_7(nonfarm) \\
&+\beta_8(listradio) + \beta_9(watttv) + \beta_{10}(nar06) + \beta_{11}(das06) + \beta_{12}(formpr06) \\
&+\beta_{13}(primsec) + \beta_{14}(islamic) + \beta_{15}(vgener06) + u
\end{aligned}
$$

4.3.ii. Impact Methodology

Assessing impact entails testing the initial outcomes on the NERICA results chain, which is the correlation and its significance between a farmer’s rice yield and NERICA adoption, as well as between rice revenue and NERICA adoption. Then, final outcomes on the results chain are tested with OLS models to correlate NERICA adoption with farmers’ total spending on health and education. The same controls for NERICA village that were placed on the adoption regressions were also placed on impact regressions in order to control for the effect of various household characteristics on the impact indicators. Also, the additional control of living in a NERICA or non-NERICA village was added in a second regression in order to observe the difference in the outcome of the impact indicators of controlling for NARI extensions in the village, which impact literature has shown to have spill-over effects, even if individual farmers did not directly come into contact with extension workers (Equations 3 and 4) (Foster and Rosenzweig 1995).

(3)

$$Y = \beta_0 + \beta_1(anew06) + \beta_2(age06) + \beta_3(hhsize06) + \beta_4(nanres06) + \beta_5(origvi06)$$
$$+ \beta_6(nanbof06) + \beta_7(nbanco06) + \beta_8(nonfarm) + \beta_9(listradio) + \beta_{10}(wattv) + \beta_{11}(nari06)$$
$$+ \beta_{12}(das06) + \beta_{13}(formpr06) + \beta_{14}(primsec) + \beta_{15}(islamic) + u$$

$$(Y = rdriz06, revriz06, tscfees10, thealthexp)$$

(4)

$$Y = \beta_0 + \beta_1(anew06) + \beta_2(age06) + \beta_3(hhsize06) + \beta_4(nanres06) + \beta_5(origvi06)$$
$$+ \beta_6(nanbof06) + \beta_7(nbanco06) + \beta_8(nonfarm) + \beta_9(listradio) + \beta_{10}(wattv) + \beta_{11}(nari06)$$
$$+ \beta_{12}(das06) + \beta_{13}(formpr06) + \beta_{14}(primsec) + \beta_{15}(islamic) + \beta_{16}(vgenew06) + u$$

$$(Y = rdriz06, revriz06, tscfees10, thealthexp)$$

<u>5. Results</u>

5.1 Adoption

The adoption regressions (Tables 3 and 4) indicate that the linear probability models and the probit models both yield approximately the same results concerning the significant farmer characteristics for predicting adoption. The characteristics that are statistically significant include the variables for years of experience in the two types of rice farming (upland and lowland), watching TV, contact with NARI, vocational training, receiving primary or secondary education, and, for the models that control for it, NERICA village. A further discussion of the findings from the analyses is below.

5.1.i. Farmer experience

None of the variables demonstrating farmer socio-economic and contextual characteristics were significant in predicting probability to adopt in either model. However, the variables indicating farmer experience were significant for both the linear probability model and the probit model. But an interesting outcome is that the coefficient on the variable for years of experience has the opposite sign, depending on the type of rice farming the variable represents. It is positive for upland rice farming experience and negative for lowland rice farming experience. In addition, the significance of the variable for number of years in upland rice farming decreases when the model controls for NERICA village, and the significance for the number of years of experience in lowland rice farming increases in both the probit and the linear probability models. As mentioned in the discussion of sample selection bias above, these changes could indicate some regional bias in choosing villages where extensions took place, or “NERICA villages.” In addition, this result could also indicate that NERICAs are generally better adapted to the upland rice ecological system.

5.1.ii. Information gathering

Three of the information-gathering variables also provided interesting results. In the probit model, watching TV is a positive predictor of adoption at the 10-percent significance level, both before and after controlling for NERICA villages. In the linear probability model, watching TV is only statistically significant at the ten-percent level before controlling for NERICA villages, but not after. However, the probit model is generally considered a stronger fitted model when predicting a binary dependent variable, so it is fair to generally conclude that watching TV improves the probability for NERICA adoption at the 10 percent significance level.

In addition, vocational training also shows significance at the 10 percent level – before and after controlling for NERICA villages in the probit model but only after controlling for NERICA villages in the linear model. Finally, contact with NARI is very significant at the one- and five- percent levels before and after controlling for NERICA villages, in both models. This outcome is not surprising, however, since NARI conducted the extensions to make farmers aware of NERICA varieties. The expected outcome of the regression is that farmers with greater access to information about the varieties and techniques of growing them would have a higher likelihood of adopting, and that was generally shown to be true in the adoption models.

5.1.iii. Education

Finally, education also fulfilled the expectation of significantly increasing the probability of NERICA adoption. In the linear probability model, education at the primary and secondary level is significant at the five- and 10-percent levels, before and after controlling for NERICA villages, respectively. In the probit model, it is significant at the five-percent level with and without the NERICA village control. Since education empowers farmers with the tools of learning with which they can more easily acquire new information, it makes sense that this variable would show significance in predicting adoption.

However, this role of education in NERICA adoption was only true for primary and secondary education and not for Islamic education or the “other” specification for a farmer’s type of education. While the coefficient on the “Islamic education” variable is positive, it is not significant at any conventional level. This outcomes does make sense because Islamic education in West Africa would not necessarily supply the explicit tools with which one would be able to more easily acquire information in the setting of agricultural extensions. Islamic education is mostly conducted in Arabic and entails memorizing verses of the Koran. Learning to read in any language helps a person's ability to process new information. However, learning to read and recite in Arabic, when the national language is English and the local language could be any number of native languages, may not be particularly useful in the process of communicating and receiving new agricultural knowledge.

5.2 Impact

5.2.i. Rice Yields

The linear regression testing the significance of NERICA adoption on rice yields (Table 5) reveals that NERICA adoption does, indeed, positively correlate with rice yields at the one-percent significance level, by a coefficient of around 100 kilograms per hectare, both before and after controlling for NERICA villages. Other significant variables in the model included farmer age, years of experience in lowland rice farming, participation in a nonfarm activity such as commerce or artisanship, contact with the DAS, and receiving primary or secondary education. Household size was also a significant predictor of rice yields at the 10 percent level, but only before controlling for NERICA villages.

Receiving primary and secondary education and contact with the DAS were both the variables with large coefficients for predicting NERICA yields. Primary and secondary education is correlated with an increase of about 120-122 kg per hectare in rice yields. Also, as would be expected, the number of years of experience (specifically, in lowland rice farming) is positively correlated with rice yields at the ten-percent significance level.

However, oddly, contact with DAS corresponds with a loss of about 90 kg per hectare – a result that is significant at the one-percent level. One explanation for this could be that DAS gave advice that conflicted with that of NARI and caused lower yields when implemented with the NARI-extended technology. However, that is simply speculation, and the true reason remains a mystery. Another variable with a significant, negative coefficient on rice yields is nonfarm activity. This variable is negative at the ten-percent significance level, both before and after controlling for NERICA villages. However, this result makes sense because dedication of time and resources in activities off the fields would naturally take away from the potential yields to be had from farming activities.

The findings on the control variables are interesting and of note; however, the main finding from this is regression is that NERICA adoption does, in fact, play a significant role in rice yields. So the first step of the results chain hypothesized above is fulfilled.

5.2.ii. Rice Income

The linear regression on rice income (Table 6) marks a break in the predicted results chain expected from NERICA adoption. NERICA adoption was significant in increased rice yields, but this model shows that NERICA adoption is not significant in predicting rice income at any conventional level. It even has negative coefficients in the rice income regression, but these cannot be generalized as a common effect of adoption since they are not significant. Nevertheless, this break in the results chain is interesting because it could indicate that farmers need to use extra resources when they implement NERICAs on their fields, i.e. extra agricultural inputs like labor, fertilizers, pesticides, etc. These extra inputs could draw away from the potential income from planting the rice. That is to say, even though farmers' yields (and possibly rice revenues) are higher, their net income from rice could be deteriorated through payments on these extra needed inputs. This could indicate an important constraint on NERICA varieties, which is further discussed in the conclusions of this paper.

Concerning controls on the regression of NERICA adoption on rice income, household size, years of experience in rice farming, and nonfarm activities were all positively correlated with rice income. The positive coefficient on household size could indicate that having a large household size increases the available labor for planting and harvesting NERICAs. This labor would not incur extra cost, since it would include members of the household, so it would increase rice income. If this is the true explanation for the positive correlation between household size and rice income, then one of the aims of enhancing economic production through infusions of resources fails in the case of NERICAs. Programs that entail transfers of resources to the very poor are meant to, among other things, reduce the incidence of pulling children from school in order to engage them in income-generating activities. However, if members of the household (which could include dependents) are engaged in generating rice income, the opposite of the desired outcome of resource transfers has occurred (Covarrubias et al. 2011). In the case of NERICAs, the coefficient on household size for estimating rice income is smaller after controlling for NERICA villages, indicating that the issues described above may not be exacerbated by NERICAs. However, this difference in the coefficients is only slight.

In this regression estimating rice income, the variables for number of years of experience in rice farming played an even more significant role in positively predicting the outcome. Number of years of experience in lowland rice farming was significant at the one-percent level both before and after controlling for NERICA villages. In addition, number of years of experience in upland rice farming was significant at the five-percent level, both before and after NERICA village controls.

It makes sense that engaging in a nonfarm activity would increase rice income at the 10-percent level. This is because someone who reports engaging in non-farm activities could report selling her wares at the market as "commerce" – an activity outside of farming. Since this hypothetical farmer is engaged in this secondary activity and is not just producing rice for subsistence, it makes sense that her income from rice would increase.

Another important outcome in this regression is that Islamic education had a very significantly, highly negative influence on rice income. Islamic education is negatively correlated with income by about 1,500 dalasi, at the five-percent significance level, both before and after controlling for NERICA villages. The explanation for this outcome could be tied to the discussion above about the practice of *daaras* in West African education. A farmer who has received Islamic education could be a *marabout* and run a rural *daara*, in which case the number of mouths to feed in the household might have a depressing effect on potential income from rice. This downward effect could be caused by the fact that the rice is being used as subsistence, rather than as a commercial crop. However, one confounding aspect to this hypothesis is that presumably, the *marabout* would report a larger household size. So, household size would also have the same negative effect on rice income, like Islamic education. But this is not the case, so other explanations for this highly negative correlation between Islamic education and rice income could be possible.

5.2.iii. Education Expenditures

The results chain was broken at the stage when NERICA adoptions were tested as estimators of rice income. Additionally, NERICA does not play a significant role in estimating education expenditures (Table 7). The variables that were significant, however, included participation in a nonfarm activity, listening to the radio, and contact with NARI.

Engaging in a nonfarm activity was positively correlated with education expenditures by a coefficient of around 360 dalasi at the five-percent significance level, both before and after controlling for NERICA villages. This could be because a nonfarm activity is a channel for supplementary income, which could be the determinant income for paying for school fees.

Listening to the radio was highly significant in predicting education expenditures, with a coefficient of 480-490 dalasi at the one-percent significance level. One reason this outcome could follow logically is that a farmer who listens to the radio may highly value information acquisition, in general, so may also be more likely to enroll her children in school. In addition, owning a radio may indicate that a farmer has a certain level of disposable income, with which she might be more able to pay for school fees. Interestingly, contact with NARI is negatively correlated to education expenditures at the five-percent level before controlling for NERICA villages and at the 10-percent level afterwards. Perhaps the explanation for this outcome is that NARI focuses its efforts on poorer farmers who would not have the extra income necessary to send their children to school, which could possibly explain this outcome.

5.2.iv. Health Expenditures

The model estimating health expenditures (Table 8) is even less revealing than that for education expenditures and consists of only one significant variable – engagement in a nonfarm activity. According to the model, a nonfarm activity is positively correlated with health expenditures at the 10-percent significance level. Engaging in a nonfarm activity has a coefficient of around 250 dalasi of health expenditures. The explanation for this could be similar to that for the same effect observed on education expenditures – nonfarm activities may be the only source of income generation for a subsistence farmer, so it may be the only source she has for income to be spent on healthcare.

6. Conclusions, Policy Implications, and Areas for More Research

In general, one of the most significant and socially important results to emerge from this study is the profound role played by a farmer's level of education and exposure to extension efforts in her decision of whether or not to adopt NERICAs. Concerning the impact of this adoption, this study did not reveal that adoption of NERICAs has a significant effect on rice income or health and education expenditures. However, no definitive answer can be given at this early stage concerning the effects of NERICA adoption on health and education expenditures. The intensity of individual-level NERICA adoption is likely still low at this point, as farmers continue to experiment with the variety. So, its full potential to generating income and augmenting the allocation of income toward health and education expenditures by farmers may not yet be realized.

Much remains to be learned about the situations and populations with the highest potential for NERICA adoption and about the overall impact of NERICAs on farming populations. In addition to the adoption and impact analyses left to be done, it will also be important to address the benefits and downfalls of NERICA adoption to contribute to the broader discussion of the role of hybrid high-yielding seed varieties in the agricultural systems of West Africa. Though NERICA has many attributes and benefits, discussed in Section 1, it also has several constraints, discussed in Section 6, which should be addressed by policymakers and researchers.

One of the central issues in the discussion of agricultural technology adoption is whether demand for the technology is sustainable for the long-term in the face of the difficult economic choices made by farmers with finite land, labor, and other resources. As the results indicate, there are cases at this time in which NERICA adoption actually correlates negatively with rice income. Adopting a new agricultural technology is often accompanied by the need to increase inputs, e.g., fertilizer and labor, which require higher costs and often increased access to credit (Kijima et al. 2011; Feder et al. 1985). Even if initial adoption rates are high, Kijima et al. (2011) find that dropout rates can also be very high later on due to low profitability of the crop compared to alternatives in Uganda. Indeed, when agricultural initiatives seek to alleviate the poverty trap, they could, instead, leave farmers in a debt trap, in which they are constantly taking out loans or over-spending to obtain the inputs to make certain crops profitable (Thompson 2007).

In addition, there are environmental concerns to be considered in promoting agricultural development for Sub-Saharan Africa. Because NERICAs incorporate the genes of *sativa* rice varieties, they are more susceptible to drought or other instable water conditions than the original native African rice species, *Oryza glaberrima*. Kijima et al. (2011) found that NERICA cultivation in areas with variable rainfall was a significant reason for adopters to “drop out,” or cease use of the varieties in Uganda.

Responsible evaluation of the constraints of NERICAs is especially important because NERICAs have received considerable press attention in recent years. For example, a 2007 *New York Times* article highlighted the great promise of NERICAs, as well as downfalls in their adoption and income-generating potential (Dugger 2007). In addition, Monty Jones was named a TIME 100 Most Influential Person of the Year in 2007 for his and his team’s work developing the genetic cocktail that yielded non-sterile NERICA varieties (Sachs 2007). Aid and development groups have taken interest in the varieties, as well. The Bill and Melinda Gates Foundation has contributed funding directly to the Africa Rice Center over the years (Africa Rice Center 2008). What is in danger of being lost is the social and market values of traditional African crop varieties that already provide so much in terms of genetic diversity and environmentally resistant traits.

The question becomes, is there a limit to the number of technologies and behaviors that can be proposed to farmers for adoption by outside agricultural development actors? And is there a point at which the benefits of promoting this adoption cease to outweigh the costs of implementation, both on the supply and demand side for agricultural innovations?

References

Adesina, A.A., and Baidu-Forson, J., 1995. Farmers' perceptions and adoption of new agricultural technology: evidence from analysis in Burkina Faso and Guinea, West Africa. *Agricultural Economics*, 13, 1-9.

Africa Rice Center, 2008. News Brief. <http://www.africaricecenter.org/warda/newsbrief 08.asp>, accessed 03 May 2012.

Bill & Melinda Gates Foundation, 2010. Profiles of Progress: Farm Radio. <http://www.gatesfoundation.org/agriculturaldevelopment/Pages/farm-radio-profile-of-progress.aspx>, accessed 24 Feb. 2012.

Bittaye, A., Jones, K., and Drammeh, E, 2002. Economic Impact Assessment of the Rice Research Program in The Gambia. National Agricultural Research Institute (NARI) and Institute du Sahel (INSAH).

Covarrubias, K., Davis, B., and Winters, P., 2011. From Protection to Production: Productive Impacts of the Malawi Social Cash Transfer Scheme. Food and Agriculture Organization of the United Nations: Protection to Production. Food and Agriculture Organization of the United Nations: From Protection to Production. <http://www.fao.org/economic/ptop/publications/en/>, accessed 30 April 2012.

Diagne, A., 2006. Diffusion and Adoption of NERICA Rice Varieties in Côte d'Ivoire. *The Developing Economies*, 44(2), 208-231.

Diagne, A., 2010. Technological change in smallholder agriculture: Bridging the adoption gap by understanding its source. *The African Journal of Agricultural and Resource Economics (AfJARE)*, 5(1), 261-286.

Diagne, A., Midingoyi, S.G., Wopereis, M., and Akintayo, I., 2011. Chapter 15: Increasing Rice Productivity and Strengthening Food Security through New Rice for Africa (NERICA). In P. Chuhan-Pole and M. Angwafo (Ed.) *Yes Africa Can: Success Stories from a Dynamic Continent*. Washington, DC: World Bank, 253-267.

Dibba, L., 2010. Estimation of NERICA adoption rates and impact on productivity and poverty of the small-scale rice farmers in The Gambia. Master's Thesis submitted to Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana.

Dugger, C.W., 2007. In Africa, Prosperity from Seeds Falls Short. *New York Times*. <http://www.nytimes.com/2007/10/10/world/africa/10rice.html?_r=1>, accessed 23 April 2012.

Feder, G., Just, R.E., and Zilberman, D., 1985. Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change*, 33(2), 255-298.

Food and Agriculture Organization of the United Nations. 2012. FAO rice price update. <http://www.fao.org/economic/est/publications/rice-publications/the-fao-rice-price-update/en/>, accessed 14 April 2012.

Food and Agriculture Organization of the United Nations, Office of Knowledge Exchange, Research and Extension, 2003. Anti-Hunger Programme: A twin-track approach to hunger reduction: priorities for national and international action. <http://www.fao.org/docrep/006/j0563e/j0563e00.htm#Contents>, accessed 03 May 2012.

Foster, A.D., and Rosenzweig, M.R., 1995. Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture. *The Journal of Political Economy*, 103(6), 1176-1209.

Gertler, P.J., Martinez, S., Premand, P., Rawlings, L.B., Vermeersch, C.M.J., 2011. *Impact Evaluation in Practice*. Washington, DC: World Bank. <http://www.worldbank.org/pdt>, accessed 27 March 2012.

International Fund for Agricultural Development, 2011. *Rural Poverty Report 2011: New realities, new challenges: new opportunities for tomorrow's generation*. Rome: IFAD.

Kijima, Y., Otsuka, K., and Sserunkuuma, D., 2011. Inquiry into Constraints on a Green Revolution in Sub-Saharan Africa: The Case of NERICA Rice in Uganda. *World Development* 39(1), 77-86.

Kijima, Y., Sserunkuuma, D., and Otsuka, K., 2006. How Revolutionary is the "NERICA Revolution"? Evidence from Uganda. *The Developing Economies*, 44(2), 252-267.

Linares, Olga F. 2002. African rice (*Oryza glaberrima*): History and future potential. *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, 99(25), 16360-16365.

Paris, T., Manzanilla, D., Tatlonghari, G., Labios, R., Cueno, A., and Villanueva, D. 2011. *Guide to participatory varietal selection for submergence-tolerant rice*. International Rice Research Institute.

Rogers, E.M., 2003. *Diffusion of Adoptions*. (5th ed.). New York: Free Press.

Sachs, J. 2007. Scientists & Thinkers: Monty Jones. The TIME 100. <http://www.time.com/time/specials/2007/time100/article/0,28804,1595326_1595329_1616316,00.html>, accessed 03 May 2012.

Stock, J.H., and Watson, M.W., 2007. *Introduction to Econometrics* (2nd ed.). Boston: Pearson Education, Inc.

Thompson, C., 2007. Africa: Green Revolution or Rainbow Evolution? *Review of African Political Economy*, 34(113), 562-565.

The World Bank, 2007. Chapter 7: Innovating through science and technology. *The World Development Report, 2008: Agriculture for Development.*

The World Food Prize. 2004. Dr. Monty Jones and Yuan Longping. <http://www.worldfoodprize.org/en/laureates/20002009_laureates/2004_jones_and_yuan/>, accessed 3 May, 2012.

Tables and Figures

Figure 1. Visualizing Aggregate-Level Adoption. Source: Ryan and Gross (1943), cited in Rogers (2003).

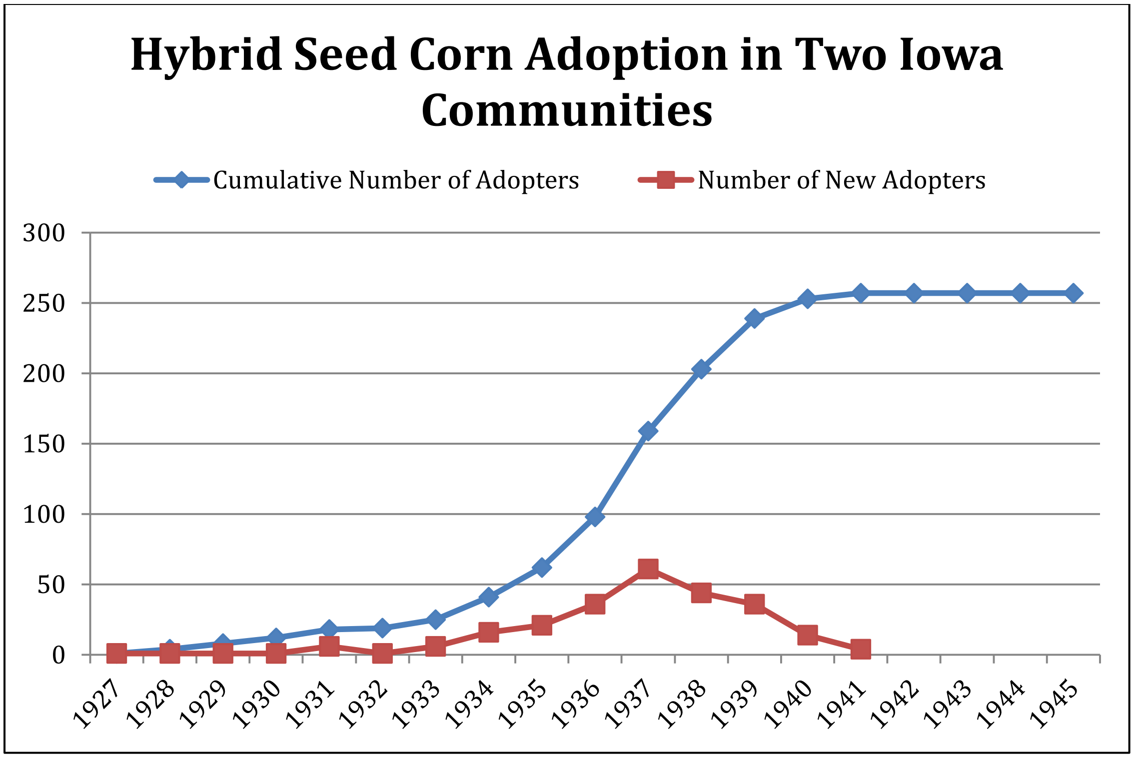


Figure 2. The Individual Adoption Decision. Source: Rogers (2003).

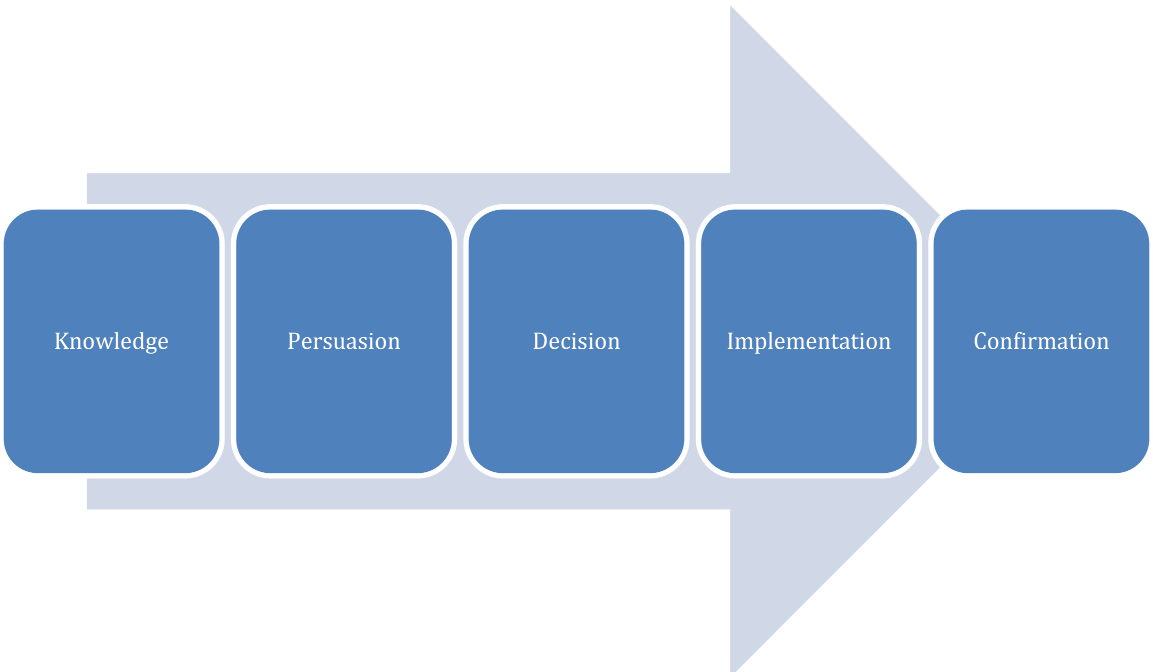


Figure 3. Theory of Change: Results Chain Model of NERICA Impact

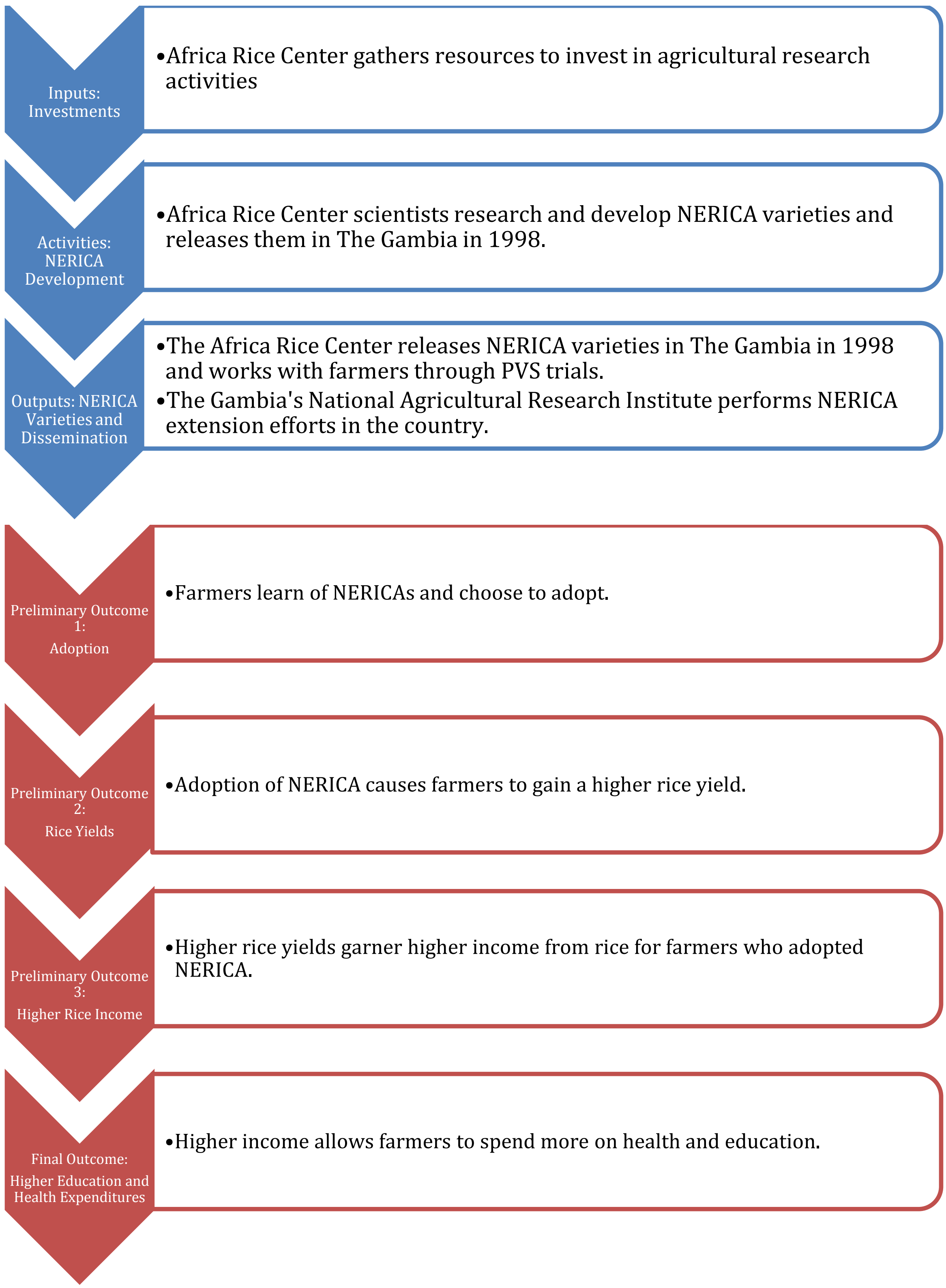


Table 1. Variable names and labels used in Equations 1-4.

Variable name used in equations	Variable labels
aner06	Adoption of NERICAs
age06	Farmer age in 2006
hhsize06	Household size in 2006
nanres06	No. years residence in the village in 2006
origvi06	Native of the village (d)
nanbf06	No. years of experience in lowland rice farming
nanbanco06	No. years of experience in upland rice farming
nonfarm	Nonfarm activity as main occupation or secondary activity (d)
listradio	Listens to the radio (d)
wattv	Watches TV (d)
nari06	Contact with NARI (d)
das06	Contact with Department of Agricultural Services (d)
formpr06	Received vocational training in 2006 (d)
primsec	Received primary or secondary education (d)
islamic	Received Islamic education (d)
vgener06	NERICA village (d)
rdriz06	Total yield from rice in 2006
revriz06	Total income from rice in 2006
tscfees10	Total expenditures on education in 2010
thealthexp	Total expenditures on health in 2010

The abbreviation "(d)" signifies a dummy variable in this and all following tables.

Table 2. Observation group means, conditional means for NERICA and non-NERICA villages, and the test of significance for the difference in means.

Variable	Mean (total observations)	Mean (NERICA village)	Mean (non-NERICA village)	Test of significance (two-tailed p-value)	*<.10 **<.05 ***<.01
Adoption of NERICAS	0.4031	0.5508	0.2577	**0.0000**	***
Farmer age in 2006	44.9186	47.2461	42.6269	**0.0002**	***
Household size in 2006	16.4457	17.2031	15.7000	0.2071	
No. years residence in the village in 2006	34.9593	35.9961	33.9385	0.1728	
Native of the village (d)	0.5659	0.5430	0.5885	0.2981	
No. years of experience in lowland rice farming	13.6647	14.6953	12.6500	**0.0218**	**
No. years of experience in upland rice farming	8.4186	10.3398	6.5269	**0.0000**	***
Nonfarm activity as main occupation or secondary activity (d)	0.7853	0.7734	0.8000	0.4623	
Listens to radio (d)	0.8704	0.8672	0.8769	0.7412	
Watches TV (d)	0.4255	0.4531	0.4000	0.2232	
Contact with NARI (d)	0.0543	0.0859	0.0231	**0.0016**	***
Contact with Department of Agricultural Services (d)	0.3081	0.3281	0.2885	0.3302	
Vocational training in 2006 (d)	0.2965	0.2969	0.2962	0.9857	
Received primary or secondary education (d)	0.1006	0.1172	0.0846	0.2199	
Received Islamic education (d)	0.5338	0.5195	0.5500	0.4888	
Rice yield in 2006	941.6719	966.5952	917.1505	0.1306	
Rice income in 2006	5935.2850	5327.4600	6553.0740	**0.0341**	**
Total education expenditures in 2010	464.4554	376.4531	551.1038	0.1996	
Total health expenditures in 2010	265.2483	365.2863	153.2440	**0.0650**	*
Total yield from NERICAs	491.1333	607.3312	354.5344	**0.0010**	***
Knowledge of NERICAs	0.4690	0.6211	0.3192	**0.0000**	***

Table 3. Linear Probability Models Predicting Adoption of NERICAs, with robust standard errors.

Adoption of NERICAs	coefficient	Significance (two-tailed p-values)		coefficient + NERICA village	Significance (two-tailed p-values)	*<.10 **<.05 ***<.01
Farmer age in 2006	0.0025	0.3800		0.0001	0.9680	
Household size in 2006	-0.0006	0.6990		-0.0012	0.3880	
No. years residence in the village in 2006	-0.0025	0.3860		-0.0011	0.6810	
Native of the village (d)	0.0289	0.7000		0.0127	0.8600	
No. years of experience in lowland rice farming	-0.0039	**0.0980**	*	-0.0048	**0.0370**	**
No. years of experience in upland rice farming	0.0046	**0.0350**	**	0.0024	0.2810	
Nonfarm activity as main occupation or secondary activity (d)	0.0224	0.7010		0.0187	0.7340	
Listens to the radio (d)	0.0622	0.3140		0.0659	0.2560	
Watches TV (d)	0.0793	**0.0820**	*	0.0695	0.1180	
Contact with NARI (d)	0.2700	**0.0050**	***	0.2132	**0.0330**	**
Contact with Department of Agricultural Services (d)	0.0362	0.4590		0.0377	0.4290	
Received vocational training in 2006 (d)	0.0784	0.1040		0.0785	**0.0820**	*
Received primary or secondary education (d)	0.1757	**0.0300**	**	0.1404	**0.0630**	*
Received Islamic education (d)	0.0089	0.8500		0.0111	0.8060	
NERICA village (d)				0.2763	**0.0000**	***
Constant	0.2084	0.1170		0.1909	0.1320	
Number of obs	516.0000			516.0000		
F(14, 501)	3.3100	F (15, 500)		7.8000		
Prob > F	0.0000			0.0000		
R-squared	0.0718			0.1443		
Root MSE	0.4796			0.4610		

Table 4. Probit Regressions Predicting Adoption of NERICAs, with robust standard errors.

Adoption of NERICAs	coefficient	Significance (two-tailed p-values)		coefficient + NERICA village	Significance (two-tailed p-values)	*<.10 **<.05 ***<.01
Farmer age in 2006	0.0069	0.3500		0.0003	0.9670	
Household size in 2006	-0.0017	0.6740		-0.0041	0.3330	
No. years residence in the village in 2006	-0.0069	0.3540		-0.0033	0.6580	
Native of the village (d)	0.0799	0.6860		0.0228	0.9090	
No. years of experience in lowland rice farming	-0.0108	**0.0830**	*	-0.0144	**0.0250**	**
No. years of experience in upland rice farming	0.0124	**0.0320**	**	0.0069	0.2610	
Nonfarm activity as main occupation or secondary activity (d)	0.0646	0.6840		0.0593	0.7120	
Listens to the radio (d)	0.1931	0.2880		0.2295	0.2080	
Watches TV (d)	0.2147	**0.0740**	*	0.2055	**0.0980**	*
Contact with NARI (d)	0.7286	**0.0080**	***	0.6012	**0.0420**	**
Contact with Department of Agricultural Services (d)	0.1070	0.4090		0.1164	0.3900	
Received vocational training in 2006 (d)	0.2131	**0.0970**	*	0.2230	**0.0850**	*
Received primary or secondary education (d)	0.4708	**0.0260**	**	0.4288	**0.0450**	**
Received Islamic education (d)	0.0247	0.8460		0.0453	0.7280	
NERICA village (d)				0.7797	**0.0000**	***
Constant	-0.8055	**0.0290**	**	-0.9026	**0.0150**	**
Number of observations	516.0000			516.0000		
Wald chi2(14)	37.0400			80.4700		
Prob > chi2	0.0007			0.0000		
Pseudo R2	0.0548			0.1141		
Log pseudolikelihood	-328.8453			-308.2307		

Table 5. Linear Regression Predicting Impact on Rice Yields, with robust standard errors.

Rice Yields	coefficient	Significance (two-tailed p-values)		coefficient + NERICA village	Significance (two-tailed p-values)	*<.10 **<.05 ***<.01
Adoption of NERICAs	102.7098	**0.0030**	***	95.4903	**0.0040**	***
Farmer age in 2006	-4.9619	**0.0050**	***	-5.1695	**0.0040**	***
Household size in 2006	2.3349	**0.0960**	*	2.2929	0.1000	
No. years residence in the village in 2006	1.1190	0.5080		1.2270	0.4680	
Native of the village (d)	-0.6370	0.9900		-2.1024	0.9680	
No. years of experience in lowland rice farming	2.8418	**0.0750**	*	2.7192	**0.0890**	*
No. years of experience in upland rice farming	2.3590	0.1210		2.1871	0.1550	
Nonfarm activity as main occupation or secondary activity (d)	-77.7325	**0.0620**	*	-77.6959	**0.0610**	*
Listens to the radio (d)	43.9717	0.2900		45.0646	0.2830	
Watches TV (d)	45.6872	0.1890		45.2316	0.1940	
Contact with NARI (d)	-73.5358	0.2440		-76.4048	0.2240	
Contact with Department of Agricultural Services (d)	-91.1166	**0.0030**	***	-90.4847	**0.0040**	***
Received vocational training in 2006 (d)	30.9034	0.4410		31.3320	0.4350	
Received primary or secondary education (d)	122.4858	**0.0630**	*	120.0747	**0.0660**	*
Received Islamic education (d)	17.8727	0.6280		17.9324	0.6270	
NERICA village (d)				25.5778	0.4290	
Constant	989.6798	**0.0000**	***	989.4056	**0.0000**	***
Number of observations	492.0000			492.0000		
F (15, 476)	3.4700	F (16, 475)		3.3100		
Prob > F	0.0000			0.0000		
R-squared	0.0982			0.0993		
Root MSE	349.7200			349.8800		

Table 6. Linear Regression Predicting Income from Rice, with robust standard errors.

Rice Income	coefficient	Significance (two-tailed p-values)		coefficient + NERICA village	Significance (two-tailed p-values)	*<.10 **<.05 ***<.01
Adoption of NERICAs	-23.5643	0.9690		-321.0417	0.6020	
Farmer age in 2006	-81.0471	**0.0090**	***	-89.6027	**0.0050**	***
Household size in 2006	68.9700	**0.0200**	**	67.2365	**0.0210**	**
No. years residence in the village in 2006	21.1818	0.4780		25.6307	0.3920	
Native of the village (d)	109.1422	0.8990		48.7588	0.9550	
No. years of experience in lowland rice farming	107.1786	**0.0010**	***	102.1254	**0.0010**	***
No. years of experience in upland rice farming	70.8570	**0.0250**	**	63.7728	**0.0410**	**
Nonfarm activity as main occupation or secondary activity (d)	-1607.0210	**0.0950**	*	-1605.5110	**0.0910**	*
Listens to the radio (d)	516.0138	0.5070		561.0469	0.4680	
Watches TV (d)	378.9718	0.5180		360.1993	0.5390	
Contact with NARI (d)	310.0202	0.8250		191.8036	0.8900	
Contact with Department of Agricultural Services (d)	-1232.9180	**0.0530**	*	-1206.8810	**0.0600**	*
Received vocational training in 2006 (d)	190.5190	0.7700		208.1792	0.7480	
Received primary or secondary education (d)	804.3199	0.5470		704.9687	0.5900	
Received Islamic education (d)	-1336.7870	**0.0380**	**	-1334.3260	**0.0380**	**
NERICA village (d)	1.0000			1053.9220	**0.0630**	*
Constant	7199.3420	**0.0010**	***	7188.0430	**0.0010**	***
Number of observations	492.0000			492.0000		
F (15, 476)	2.8600	F (16, 475)		2.7100		
Prob > F	0.0003			0.0004		
R-squared	0.0956			0.1013		
Root MSE	6201.6000			6188.7000		

Table 7. Linear Regression Predicting Total Education Expenditures, with robust standard errors.

Total Education Expenditures	coefficient	Significance (two-tailed p-values)		coefficient + NERICA village	Significance (two-tailed p-values)	*<.10 **<.05 ***<.01
Adoption of NERICAs	-27.3152	0.8660		30.2926	0.8390	
Farmer age in 2006	-8.5922	0.1520		-6.9867	0.2420	
Household size in 2006	2.7079	0.5710		3.2121	0.5050	
No. years residence in the village in 2006	8.9449	0.1240		8.1055	0.1610	
Native of the village (d)	-290.7261	0.1660		-280.3691	0.1760	
No. years of experience in lowland rice farming	5.5993	0.4160		6.4814	0.3340	
No. years of experience in upland rice farming	5.9964	0.3460		7.3921	0.2640	
Nonfarm activity as main occupation or secondary activity (d)	360.1913	**0.0260**	**	361.6234	**0.0260**	**
Listens to the radio (d)	473.1424	**0.0000**	***	466.8556	**0.0000**	***
Watches TV (d)	-136.6070	0.3410		-133.8724	0.3490	
Contact with NARI (d)	-358.2702	**0.0350**	**	-331.8681	**0.0550**	*
Contact with Department of Agricultural Services (d)	239.8740	0.1750		236.6275	0.1790	
Received vocational training in 2006 (d)	69.6222	0.6780		65.0413	0.7000	
Received primary or secondary education (d)	30.3307	0.9080		46.2773	0.8600	
Received Islamic education (d)	-267.4401	0.1180		-269.6080	0.1150	
NERICA village (d)				-203.9895	0.1140	
Constant	-31.2115	0.9310		-30.2894	0.9330	
Number of observations	516.0000			516.0000		
F (15, 500)	2.5000	F (16, 499)		2.3400		
Prob > F	0.0015			0.0024		
R-squared	0.0418			0.0455		
Root MSE	1535.3000			1533.9000		

Table 8. Linear Regression Predicting Total Health Expenditures, with robust standard errors.

Total Health Expenditures	coefficient	Significance (two-tailed p-values)		coefficient + NERICA village	Significance (two-tailed p-values)	*<.10 **<.05 ***<.01
Adoption of NERICAs	73.4429	0.5420		38.2013	0.7610	
Farmer age in 2006	9.7470	0.1260		8.8797	0.1380	
Household size in 2006	4.8235	0.5360		4.3692	0.5780	
No. years residence in the village in 2006	0.6897	0.9080		0.9734	0.8710	
Native of the village (d)	189.3192	0.1090		187.9919	0.1100	
No. years of experience in lowland rice farming	0.9629	0.8030		0.6538	0.8680	
No. years of experience in upland rice farming	-3.4035	0.6590		-3.8952	0.6110	
Nonfarm activity as main occupation or secondary activity (d)	254.7062	**0.0630**	*	249.5532	**0.0630**	*
Listens to the radio (d)	116.9071	0.2460		123.5123	0.2280	
Watches TV (d)	-40.5819	0.7630		-48.5283	0.7160	
Contact with NARI (d)	742.2455	0.2550		724.8943	0.2670	
Contact with Department of Agricultural Services (d)	61.8615	0.6530		62.0999	0.6530	
Received vocational training in 2006 (d)	100.9757	0.4550		107.8500	0.4340	
Received primary or secondary education (d)	83.4042	0.7700		74.5550	0.7930	
Received Islamic education (d)	-83.5083	0.5030		-80.7973	0.5190	
NERICA village (d)				114.4731	0.1850	
Constant	-731.2545	0.1000		-731.3696	0.1000	
Number of observations	443.0000			443.0000		
F (15, 427)	0.4400	F (16, 426)		0.4100		
Prob > F	0.9655			0.9793		
R-squared	0.0535			0.0553		
Root MSE	1195.4000			1195.7000		

<u>Appendix</u>

The Domestication of *Oryza glaberrima* in a World of *Oryza sativa*
Honors Supplement: Political Ecologies of Food and Agriculture
Professor T. Garrett Graddy
November 24, 2011

> Africa is seen by many observers as a basket case – a vast region incorporating more than 40 nations that appears unlikely to be able to feed its burgeoning population in the coming years. (Lost Crops of Africa XIII, 1996)

During a time of seemingly daily confrontation with images of tragedy and disaster coming from the African continent, it may be difficult for the common observer not to think of this vast continent as "a basket case." There are some who believe the countries of Africa have lost any hope of sustainable security for its people without the intervention of the outside, "developed," world. Indeed, many lives have been needlessly lost in times of drought and failed harvest. Currently, the world is witnessing famine on a catastrophic scale in the Horn of Africa, and only recently, a major increase in the volatility of food prices sent many who were getting by into a state of increasingly precarious food security. In the hearts of many outsiders, there was the natural impulse to act and do something about it, which gives rise to a string of questions: "What can I do to help?" "What is missing that 'they' need?" "What is wrong with 'their' current situation?" Perhaps these are the wrong questions. Perhaps the right questions would lead one to ask, "What is *right* with the situation that can be strengthened and perpetuated?" Cue the ancient agricultural systems that have been in place across the continent of Africa for centuries.

This paper aims to readjust the discussion of Africa's needs regarding agricultural success and food security. The goal is to change the axis of the discussion to address the Africa's needs not from the perspective of directing resources from the West, but rather with resources that already exist there. Perhaps those resources can also be a solution for the needs of the rest of the world. What historically has been ignored and only recently received attention is that for millennia, before the intervention of outsiders, Africa had its own successful methods to guarantee food security – including in its rice agriculture. But this is not the Asian rice found throughout the global market. This rice is unique to Africa and is arguably tastier, hardier, and more nutritious than its highly processed Asian cousin. But it has been phased out of mass-scale agricultural production in preference of this higher-yielding cousin. This paper will address these issues by describing the current state of African rice production, the history of its domestication and subsequent marginalization, how it compares to Asian rice in quality, and the implications that its marginalization has for agriculture in Sub-Saharan Africa.

A.1. West African Rice Agriculture

Presently, Africa's crop yields remain incredibly low, especially considering its long history. Annual output of cereals was only about 50 million tons or 11 kilograms per person in 1996 (Lost Crops of Africa 6-7). As a result, Africa needed 14 million tons more grain each year than it was producing – clearly, to be obtained through imports (Lost Crops of Africa 7). In Sierra Leone, 245 varieties of rice were in use in 1996, only

24 of which were African (Lost Crops of Africa 28). This is particularly alarming when one considers that on average, the yield of African grains (i.e. the efficiency, or amount able to be produced per unit of land) can even outpace the yields of some crops developed by modern science (Lost Crops of Africa 13). Despite this strength and robustness, crops like African rice, or *Oryza glaberrima*, declined in production drastically over the course of the past century. Currently, farmers growing the plant as an actual subsistence crop are few and far between. "In most locations, [*glaberrima* rice] lingers only as a weed in fields of its foreign relative. Soon it may be gone" (Lost Crops of Africa 17).

However, there are still areas where *Oryza glaberrima* remains – not only as a subsistence crop but also as a crop with great religious and traditional importance. It can now be found between Senegal and Sierra Leone, Guinea, and on the shared border of Ghana and Togo. The area where it is most densely cultivated is in Nigeria's floodplains and in the Niger River inland delta in Mali. While African rice can only be found in these select places, the amount of land in Africa allocated to planting Asian rice is the fourth largest on the continent. Not only does the planting of Asian rice flood the fields of Africa, but also the processed Asian rice imports flood the markets. In 1996, ninety percent of the world's rice was grown in Asia, and West Africa absorbed a quarter of the world's rice exports (Lost Crops of Africa 17 and 24).

A.2. History of *Oryza glaberrima*

A.2.1. What Really Happened – Domestication and Cultivation

Before the globalization of the food market and the establishment of massive aid organizations and food supplies, there was food in Africa. And before the engineering of super-nutritious Asian rice varieties to spread throughout the continent to "feed Africa," Africa had its own rice far more nutritious than common Asian rice. The rice genus, *Oryza*, is an ancient grass species of which at least twenty have been found on other continents, such as South America and Australia (Lost Crops of Africa 17). The only two that were domesticated were Asian and African *sativa* and *glaberrima* (Carney *Black Rice* 1 & 38). For *Oryza glaberrima*, the African center of domestication is thought to be the flood basin of the central Niger, where the Mande people first domesticated it along the wetlands at least 1,500 years ago (Lost Crops of Africa 7 and 17, Carney "Antecedents" 5). From there, it was carried west to Senegal, south to the Guinea coast, and east to Lake Chad, proving that "some West African countries have, since ancient times, been just as rice-oriented as any Asian one" (Lost Crops of Africa 17).[3] This evidence serves as further proof that rice was, indeed, cultivated in West Africa long

[3] Another interesting argument made to prove the existence of rice in Africa before the introduction of *sativa* involves linguistics: several languages arising from areas of rice domestication in West Africa have words for "rice" completely unrelated to Arabic or European words. On the other hand, languages from other areas of the continent employ words like "erruz," "eruz," "arroz," "riz," "rijst," etc., with great similarity and direct traceability to European and Arabic origins. Words in West Africa languages (Mandinka, Peulh, Gamian Wolof etc.) for rice are phonetically similar to each other – e.g. "mano," "marro," "malloh," – but not to European and Arabic languages and dialects (Carney "African Rice in the Columbian Exchange" 386 & *Black Rice* 36). In addition, in the Wolof currently spoken in Senegal, the word "ceeb," pronounced "cheb," means "rice." While not bearing much phonetic resemblance to other languages' words used for "rice" in the region, this word, too, does not evoke the sounds of Arabic and European words.

before any Portuguese ships could have brought *Oryza sativa* varieties of rice along the West Africa coast or even before the Arabian traders could have brought it down the East African coast. Yet, nevertheless, for centuries, Western scholarship espoused to the massive assumption that any rice grown there must have been brought from the outside. Hence began the universal colonial amnesia, perpetuating the myths about the inferiority of African subsistence and giving rise to the marginalization of its native rice.

A.2.2. Colonial Marginalization

Examples abound of European scholars blatantly discounting the possibility that African native knowledge systems and expertise could have been in place before the entrance of colonial powers. The nineteenth century West African crop collections of two French botanists, Francois Mathias Rene Leprieur (Senegal from 1824 through 1829) and Edelstan Jardin (Guinea Conakry from 1845 through 1848) acknowledged the rice in their collections as *Oryza sativa* (Carney *Black Rice* 33). Furthermore, Europeans assumed the African rice planting methods were taught them by the Portuguese traders who came down the coast. “Even the French botanist August Chevalier, who had done so much to substantiate an independent center of rice domestication in Africa, did not question the irrigated coastal systems as the product of Portuguese tutelage” (Carney *Black Rice* 37). Hence, even before the Middle Passage, Africans were deprived of their claim to their own native agricultural knowledge.

It was not until 1855 that scholars began to acknowledge that this rice was, in fact, not *sativa*, but something else. Moravian botanist Ernst Gottlieb Steudel reexamined Jardin’s collections and remarked the differences in certain grains of rice. So Steudel dubbed the African rice with the nomenclature *glaberrima* to acknowledge the smooth hulls (Carney *Black Rice* 33). Later in 1914, Chevalier’s research advanced the hypothesis that this rice was not just different from *sativa* but was even native to Africa, itself (Carney *Black Rice* 34). While the debate over this hypothesis continued for many decades, the “developed” world was eventually – finally – forced to acknowledge the native-to-Africa qualities in this rice (Carney “Role of African Rice and Slaves” 528).[i]

Until recently, not only was there general disregard for the African rice in prevailing scholarship, but there was also a political and economic disregard for this rice specie – an imperialism that still casts its shadow over agricultural research today. At the time of colonization, local crops like the *glaberrima* rice “[lacked] the interest and support of the authorities (most of them non-African colonial authorities, missionaries, and agricultural researchers),” and “could not keep pace with the up-to-the-minute foreign cereals” (Lost Crops of Africa 1). That story is repeated today, as Africa’s food supply is increasingly imported and semi-subsistence crops remain an “informal,” unrecorded economy. “There are no statistics on production or costs. A plant may be helping to feed millions, but in the international figures on area sown, tonnage produced and exported, and prices paid it never shows. It is as if it doesn’t exist” (Lost Crops of Africa 13).

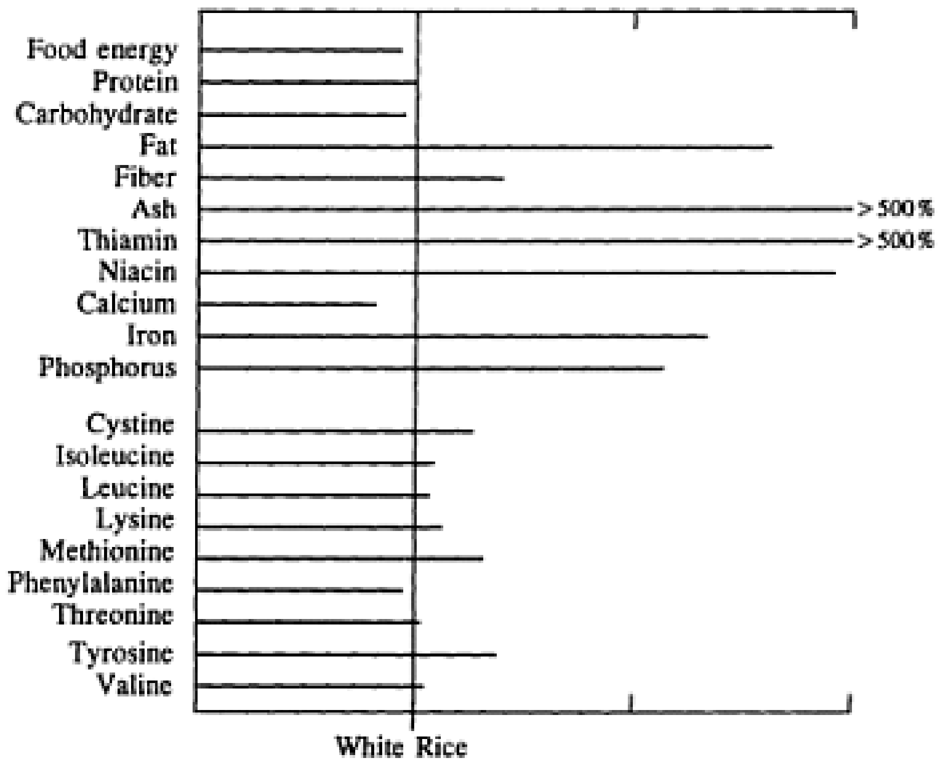
The imperialist search for profit gains in the global market went hand-in-hand with the increased need to industrialize agricultural production, both leading to the marginalization of *Oryza glaberrima*. Once it became preferable to produce crops on a mass scale, the need arose to process crops through industrial means. But the *glaberrima* grain shatters when handled roughly and is far more difficult to polish, and as such is easily damaged when run through a mill. The European priority was to produce a large, uniform crop yield with industrial power. All of these characteristics caused the European colonizers to favor *sativa* rice (Lost Crops of Africa 1, 17).

In addition to the technological, economic, and scholarly imperialism that resulted in the decline in the use of *glaberrima* rice, there was also a social or psychological component to this shift. As the profit-seeking methods of capitalist industrial agriculture hedged out traditional crops, myths began to arise about their inherent quality. "Eventually, they took on a stigma of being second-rate...that the local grains were not as nutritious, not as high yielding, not as flavorful" (Lost Crops of Africa 1). They soon became classified as the "foods of the poor and the rural areas," not just by white colonizers, but also by Africans (Lost Crops of Africa 1). These beliefs were "illogical, ill-conceived, and even dangerous...Cultural bias is a tragedy; the plants poor people grow are usually robust, productive, self-reliant, and useful – the very types needed to feed the hungriest mouths on the planet" (Lost Crops of Africa 12-13)." Traditional religious beliefs surrounding the practices of growing African rice very well may have been the only forces perpetuating its growth.

A.2.3. *Oryza sativa* and *Oryza glaberrima*: A Comparison

Oryza glaberrima is, indeed, an extremely robust plant with a lot of advantages over the *sativa* specie. Its advantages are extremely pertinent to issues of food security and production (Lost Crops of Africa 21). In several ways, *glaberrima* could very well guarantee food security better than *sativa*. First, *glaberrima*'s yield could have a higher potential than *sativa*'s. African rices rival certain Asian rice in productivity levels – a remarkable feat, "considering the 5,000 years of intense effort that has been invested in improving Asian rice" (Lost Crops of Africa 22). A second characteristic vital for food security is that *glaberrima* not only will yield well, but also will yield quickly – up to 10-20 days earlier than the *sativa* plant (Lost Crops of Africa 24). This trait is important not only in times of food shortage when a crop is needed quickly, but also in areas where rains are sporadic and unreliable. For example, during the last decades of the twentieth century, the rains in northern Sierra Leone would stop abruptly and early. For this reason, farmers cultivated the *glaberrima* on their lands in order to guarantee a harvest (Lost Crops of Africa 24). Even in southern Sierra Leone, where Asian rice is predominant, two particularly quick varieties of African rice, *pende* and *mala*, are kept around in case of emergencies. The only problem is that sometimes farmers do not have access to these seeds, as *sativa* seed is much more predominant in the market. The third aspect of the *glaberrima* that makes it helpful for food security needs is its nutritional quality higher than that of *sativa*. While this does not result from any inherent difference in the grain, itself, it is a product of the greater difficulty in removing the *glaberrima* husk. Since this process can be done mechanically with *sativa* rice, *sativa* rice is polished to a higher degree and so loses some important vitamins like thiamine (Figure 1). In a survey of 500 farmers in Sierra Leone, an important comment was made about the feeding capabilities of the *glaberrima*: it is preferred not only for its taste and nutritional superiority, but also because it is "'heavy in the stomach' and keeps hunger at bay far longer" (Lost Crops of Africa 28). These merits to this grain have been overlooked for quite some time in discussions of how to sustainably feed Africa.

Figure 1. Comparative Quality of *glaberrima* and *sativa*. Source: *Lost Crops of Africa*, p. 27.



The second aspect of *glaberrima* qualities that gives it an advantage involves certain characteristics concerning the process of its production. *Pende*, the quick-yielding *glaberrima* variety mentioned above, has another important benefit, shared by other varieties: it is valued for its ability to smother weeds on its own (Lost Crops of Africa 24). Indeed, the *glaberrima* grows so "rambunctiously" that its "spreading canopy... [suppresses] weeds and resists local diseases and pests by itself," a quality that will be exceedingly valuable in a post-Green Revolution era (Lost Crops of Africa 21). "The grains of Africa still retain much of the hardy, tolerant self-reliance of their wild savanna ancestors" (Lost Crops of Africa 6). Another example of the hardiness of *glaberrima* rice is its broad genetic base, maintained through cross breeding with wild varieties. While this cross breeding can give rise to pest weeds, it also "enhances its ability to resist drought, pests, diseases, and other hazards" (Lost Crops of Africa 30).

Lastly, this genetic robustness found in the *glaberrima* rice has important ecological implications for its production – particularly concerning water and land use.

> The threat of famine acted as an incentive for developing one of the world's most ingenious cultivation systems…The practice of wetland farming throughout the West African rice region represents an imaginative adaptive strategy to regional climatic and topographic differences. (Carney *Black Rice* 44 and 46)

Concerning water use, varieties of *glaberrima* have demonstrated the ability to grow in wider varieties of habitats than *sativa*. The ancient African farmers of this rice selected cultivars that could grow in different depths of water (including “floating” varieties for water several meters deep), whereas *sativa* varieties often require a uniform water depth, carefully controlled through irrigation. Other *glaberrima* varieties can survive in rain fed conditions, also precluding the need for irrigation. In the northern areas of West Africa between Senegal and Chad, rainfall can be as limited as 10-20 inches annually, and yet this variety of rice spread and flourished in these areas (Carney *Black Rice* 44). Even despite aridity and sporadic rainfall, the peoples of the region domesticated this *Oryza* species, discovering that it can flourish in the swamp-like areas surrounding the arid stretches of Sahel (Carney *Black Rice* 45).

In addition, the rice cultivation techniques of West Africa were highly integrated with the other agricultural needs, exhibiting skilled land use in a complex, holistically integrated system. First of all, the rice fields were co-managed with sorghum, millet, a second rice crop, other vegetables, and even cattle management to guarantee food security, a nutritionally complete diet, and efficient soil management.

> Following the rice harvest during the fall and every winter, cattle enter the fields to graze upon crop residue, their manure fertilizing the soil. This seasonal rotation between rice cultivation and pastoralism embraces a clever land-use strategy that satisfies both cereal and protein…needs...The underlying rationale of the system eluded Europeans until well into this century. (Carney *Black Rice* 47 and 48)

The imposition of the European irrigation systems for rice production (previously used for the *sativa* rice) managed to supremely interfere with these well-established systems. And yet they continued to assume that an inherent inferiority existed in the African system. Even in 1939, French agronomist Pierre Viguier remarked, “Rice cultivation by irrigation and rice cultivation by submersion; this is the difference between Asian and African civilizations” (qtd. in Carney “Antecedents” 11 and *Black Rice* 49). Indeed, “Europeans never considered that the cultivation of rice by river tides might form part of a clever land-use strategy for a drought-prone region” (Carney *Black Rice* 37).

While the *glaberrima* rice variety possesses these characteristics giving it a clear advantage over *sativa*, the reality is that the Asian type was extensively developed over thousands of years and did spread throughout West Africa. It has certain key advantages for large-scale commodity trade. First of all, *sativa* simply has a better yield record in most locations than *glaberrima*. It also does not possess certain traits that are a nuisance for *glaberrima* farmers, e.g. scattering its grains on the ground, weak stalks that are easily toppled, and brittle, easily shattered grains. Therefore, processing the *glaberrima* grain for a large supply for trade and export is much more difficult – the grains cannot be put through mills for polishing like the *sativa* rice, or else they will likely break. For this reason, it is hard to produce a uniformly white grain supply with *glaberrima*, posing a disadvantage for it as a globally traded crop commodity. In addition, growing *glaberrima* outside its native areas can prove difficult – it is not suitable for either extreme of arid climates or wet climates, since it is susceptible to fungi, some parasites, and viral diseases. For this reason, it cannot be grown well in Southeast Asia – including the Philippines, where the International Rice Research Institute is located. This lack of adaptability to the climate where the world’s major rice research occurs does not help *glaberrima*’s prospects. The IRRI is developing websites for each of its satellite offices, including three in Africa, none of which are in West Africa ("Country Profiles"). Finally, due to societal (mis)perceptions, there is a greater demand for Asian rice. "Everywhere, consumers have fallen in love with processed Asian rice" (Lost Crops of Africa 22).

A.3. Conclusion

The world-wide love affair with Asian rice has many implications for the global rice economy as well as for the African rice economy and African development efforts. In the age of mass agricultural industrialization, widespread seed genetic modification, an ever-growing population, and the threats of climate change and resource depletion, *glaberrima* provides an important piece to the puzzle of the world's food security. Development efforts have brought forth new ideas and seed innovations in attempts to "feed Africa." Scientists have tried to combine traits in *Oryza sativa* and *Oryza glaberrima* to provide "New Rice for Africa" (NERICA) – a variety with *sativa* high yield combined with the genetic robustness of *glaberrima*. While this has been developed at the Africa Rice Center – the research center in Western Africa dedicated to rice research – with the best intentions, any *ex situ* genetic engineering of crops must proceed with caution. In addition, the emerging research about *glaberrima* and the recognition of the importance of its role in African semi-subsistence history played a vital part of this development. Hence, it is vital that modern scholarship get past "the Atlantic slave trade and its legacy of racism, combined with the inherent sense of Western superiority during colonialism, [which] conditioned European perceptions of African rice systems" (Carney *Black Rice* 49).

Appendix Works Cited

Carney, Judith A. “African Rice in the Columbian Exchange.” *Journal of African History*, vol. 42. 2001: Cambridge University Press. (377-396).

Carney, Judith A. “The African antecedents of Uncle Ben in U.S. rice history.” *Journal of Historical Geography*, vol. 29. 2003: Elsevier Science Ltd. (1-21).

Carney, Judith A. *Black Rice: The African Origins of Rice Cultivation in the Americas*. Cambridge: Harvard University Press, 2001.

Carney, Judith A. “The Role of African Rice and Slaves in the History of Rice Cultivation.” *Human Ecology*, 26.4. 1998. (525-545).

“Country Profiles.” *International Rice Research Institute*. 22 Nov. 2011 <http://irri.org/partnerships/country-relations>.

National Research Council. “African Rice.” *Lost Crops of Africa*, vol. 1. Board on Science and Technology for International Development. 1996: National Academy Press.

“NERICA: Rice for Life.” West Africa Rice Development Association. 2001. 22 Nov. 2011 <http://www.warda.cgiar.org/publications/NERICA8.pdf>.