32 Impact of Rice Research on Income, Poverty and Food Security in Africa: An *Ex-ante* Analysis[1]

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Introduction

Rice has always been an important staple in many African countries. Since the 1960s, it has also become the most rapidly growing food source across the continent. However, local production is largely insufficient to meet consumption needs. In 2009, Africa imported 10 million tonnes (Mt) of milled rice, at a cost of US$5 billion. With high food and fuel prices predicted to last well into the 2010s, relying on imports is no longer a sustainable strategy for Africa. Rice-sector development can become an engine for economic growth across the continent, contribute to eliminating extreme poverty and food insecurity within Africa, and improve the social well-being of millions of poor people. Development of the rice sector and related sectors will have considerable impact on the competitiveness of African economies and reduce the need to divert valuable foreign currency exchange to imports. Enhanced local production, processing and marketing will also mean that Africa's cities will have access to affordable food. Rice production will create employment along the value chain and in related sectors, and lead to improved nutritional and health status of the rural agricultural poor. It will allow financing of better education that will give the next generation greater opportunities to break the remaining shackles of under-development (AfricaRice, 2011).

Africa's rice sector faces a large number of biophysical and socio-economic constraints. These generally translate into low productivity of rice produced in Africa. Research areas to address these are numerous and need to be prioritized because resources are scarce – basic economics and general knowledge recognize that this scarcity of resources causes many needs to remain unsatisfied.

Ex-ante assessment of the impact of rice research in Africa is important to: (i) adequately identify priority research themes and target populations; (ii) efficiently allocate scarce resources to priority research themes; (iii) better target research outputs to where they will have the maximum impact; (iv) enhance research relevance and positive impact on the livelihoods and well-being of the target population; and (v) enhance the efficiency of public research organizations (Diagne *et al*., 2009).

Several assessments have been made of the potential benefit of rice research in Africa. Many of these were conducted by the Africa Rice Center (AfricaRice), one of the 15 members of the CGIAR Consortium and an association of

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24 African member states. The Center has a long tradition of priority-setting dating back to the 1990s (see Diagne *et al.*, 2009, for a detailed review of previous priority-setting exercises). The Center's research priority-setting since 1990 has involved a broad base of rice research and development stakeholder constituencies at different policy- and decision-making levels. Priority-setting is a continuing process and the methodology used has changed over time.

In early 1990, AfricaRice (then the West Africa Rice Development Association, WARDA), conducted a systematic priority-setting[2] exercise that served for both the Center's Strategic Plan for the period 1990–2000 and its Medium Term Plan 1994–1998 (WARDA, 1993). The exercise was implemented through a three-step process. The first step consisted of data-gathering on the relative importance of rice-growing environments (area, production, etc.), and the relative importance of constraints per environment. The second step comprised an analysis of rice-growing environments and main stresses to determine the priority environments and stresses that needed to be addressed, assessment of countries' research capacities for each constraint, and AfricaRice's comparative advantages. The third and final step consisted of validation of the methodology used and the major findings by a task force.

In 2000, a new priority-setting exercise was initiated for the Strategic Plan 2003–2012 (WARDA, 2004a,b). This exercise was essentially based on the outcomes of the previous priority-setting. The earlier constraints analysis was updated through task forces, working groups, surveys and at the meetings of the AfricaRice National Experts Committee (NEC).[3] On the basis of the results of this exercise, revised strategic and medium-term plans were drafted and validated by the NEC, Board of Trustees and Council of Ministers[4] (WARDA, 2004a,b).

Another priority-setting exercise was conducted for the 2005–2007 Medium-Term Plan by a commissioned internal task force (WARDA, 2004b; Diagne *et al.*, 2009). It included a number of innovative features in its methodology – namely, a review of priority-setting methods and approaches adopted by other agricultural research centres (both those inside and outside of the CGIAR), the sub-regional agricultural research organizations (SROs) and national agricultural research systems (NARS). It used a scoring method based on criteria established by the task force, discussed and approved through consultation with a wide range of major stakeholders.

This chapter presents the approach used to assess the potential impact of rice research in sub-Saharan Africa for 2011–2020 and discusses the major findings. The priority-setting exercise for which this *ex-ante* analysis was conducted has borrowed much from the previous one in terms of processes.[5] But in terms of methodology, a number of innovative features were introduced. First, an in-depth farm-household survey was conducted in 21 countries in sub-Saharan Africa to gather data on rice-growing environments, constraints to rice production, and adoption of improved varieties. Second, the research to address the identified production constraints were elicited from scientists through consultation during a 2-day workshop during the 2010 AfricaRice Science Week. Third, econometric models derived from the agricultural household conceptual framework were used to assess expected productivity, poverty and environmental impacts of the proposed research.

The rest of the chapter is organized as follows. We first review the theoretical and conceptual framework that underlies the evaluation of the impact of agricultural research on farmers. Next, we present the methods used to assess the impact on other actors such as processors, traders and consumers, followed by an overview of the different data sets used for the analysis. We then present and discuss the main findings of the analyses and their implications in terms of thematic and geographic priorities for research on rice-based systems in Africa for the period 2011–2020, before concluding the chapter.

Estimation of the Impact of Rice Research on Farmers

This section presents the theoretical and conceptual framework that underlies the models used to assess the potential impact of rice research in Africa. We describe the general framework and then derive the model that explains household decision-making to adopt rice technologies and their impact on household outcomes, and the model that explains how a change in household production environment can affect its outcomes.

The agricultural household model

To identify the impact of rice research on poverty and income at the farmer level, we follow the agricultural household framework (see Deaton and Muelbauer, 1980; Singh *et al*., 1986; Taylor and Adelman, 2002, for a review of the literature). This framework is summarized in Fig. 32.1.

An agricultural household makes decisions to maximize its utility in the face of some constraints. The decision set, represented by the variables d^* and x^* in Fig. 32.1, includes investment, crop and varietal choices, and resource allocation (seed, land, labour, fertilizer and other inputs), which the agricultural household chooses to maximize the satisfaction it derives from the consumption of food and non-food items represented by the variables c in the figure. The optimal consumption bundle that maximizes the household's satisfaction is determined by a utility function that embodies the household decision-maker's preferences, beliefs and expectations, and by a budget constraint that balances income from all sources as represented

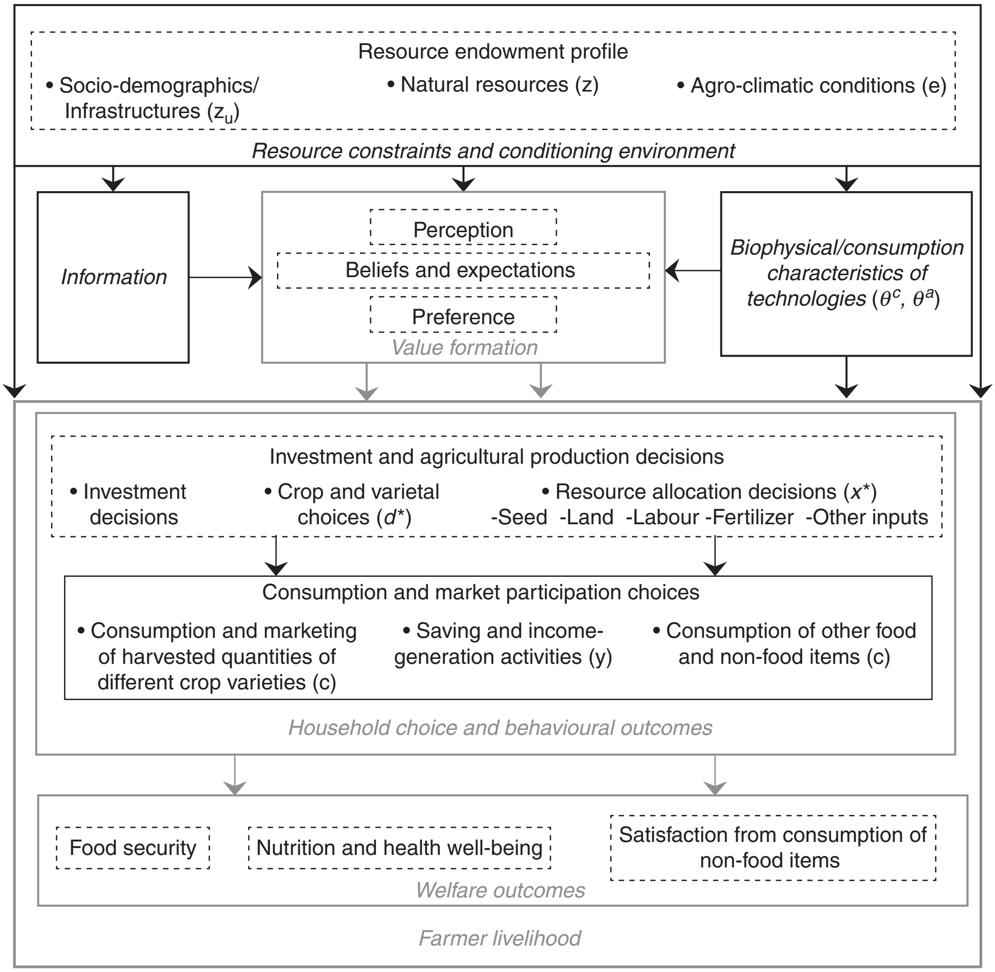

Fig. 32.1. Agricultural household framework (symbols explained in text).

by the variable y in the figure and the cost of acquiring the optimal quantities of the production inputs in d^* and x^* and the non-produced consumption items in c. The maximum utility of consumption attained by the household depends on many factors that are outside of its control. These include the characteristics of the technologies chosen as represented by the variable θ in the figure; the agro-climatic conditions (represented by e in the figure); the household socio-demographics and resources endowment profile, which include the public and private infrastructures and natural resources; the prices of commodities and the information available to the household on all these factors (all represented by z_u in Fig. 32.1).

From the graphical illustration of the agricultural household model in Fig. 32.1 one can see how household decisions (adoption of crop or varietal and agronomic technologies) and the change in the agro-climatic conditions (reduction of yield loss caused by stresses) can affect the household outcomes of interest and permit the identification and estimation of the causal effects. Here we limit the analysis to household total income and village poverty headcount. Note that the impact on income and production is assessed at the household level, while the impact on poverty and food security is assessed at the community level.

Two sets of technologies are assessed. The first relates to adoption of new varieties and is assessed through structural models of farmer demand for varietal characteristics and its relationship to total household income, production or village poverty headcount. The second set relates to adoption of agronomic (including integrated pest management (IPM)) and postharvest technologies assessed through a reduced form model of effect of reduction in yield loss or increase in yield due to farmer adoption of the agronomic or postharvest technologies on total household income or production or village poverty headcount.

Impact of adoption of new varieties

Let us start from the general setting of the agricultural household model as illustrated in Fig. 32.1 and described in the section above and assume that rice-farming households choose among J rice varieties (that include traditional and improved varieties) to produce rice and maximize the utility of consumption of food and non-food items. Thus, the agricultural household's maximization problem can be formally written as:

$$\underset{x\in S(z)}{max}\{U(x,z_u): subject\ to: p_c.c = p_r.\textstyle\sum_{j=1}^{J} f(x_j,z_j) - \sum_{k=1}^{K} p_k \sum_{j=1}^{J} x_{jk}\} \qquad (32.1)$$

where c is the consumption vector of food and non-food items, with p_c the corresponding price vector, $x_j = (x_{jk})_{k=1,\dots,K}$, with x_{jk} being the quantity of input k used in producing rice with variety j (one of the inputs being seed); p_k is the price of input k; z_u is a vector of household socio-demographic variables that affect utility; z_j is a vector of exogenous technological and environmental variables conditioning the production of rice using variety j (variety characteristics, plot soil characteristics, weather, etc.); f is a production function; and p_r is the price of rice. There is no loss of generality by assuming a common production function for all varieties because any variety-specific technological parameter can be included in the z_j vector.

There are several rice varieties distinguished by their respective contents of agronomic and consumption characteristics. Farmers make their choice of which varieties to grow and consume on the basis of their preference for these characteristics. The agronomic characteristics are those that affect the rice yield in the field, during harvest and during postharvest grain processing. The most important of these are yield potential, levels of resistance to various biotic and abiotic stresses and other characteristics such as plant height and tillering ability. The consumption characteristics of varieties include grain quality, shape, colour, aroma, taste, and various cooking and eating characteristics (cooking time, swelling capacity, degree of stickiness, storability after cooking, etc.).

Each variety has a fixed constant vector of consumption characteristics $\theta_j^c = (\theta_{jk}^c)_{k=1,\dots,K}$, with K_c the number of consumption characteristics, and a fixed constant vector of agronomic characteristics $\theta_j^a = (\theta_{jk}^a)_{k=1,\dots,K}$ with K_a the number of agronomic characteristics. Let also $\theta^c = (\theta_j^c)_{j=1,\dots,J}$, $\theta^a = (\theta_j^a)_{j=1,\dots,J}$, $\theta_j = (\theta_j^c,\ \theta_j^a)_{j=1,\dots,J}$ and $\theta = (\theta^c,\ \theta^a)$. Hence, θ_i is the combined vector of agronomic and consumption characteristics of variety j with dimension $K = K_a + K_c$ and θ is the $J \times S$ matrix of agronomic and consumption characteristics of all varieties. Varieties are distinguished and identified uniquely by their full vector of observed and unobserved characteristics θ_j and not by their names or labels (e.g. WABxx, NERICAxx, IRxx, 'traditional', 'improved').

Reformulating the utility function and the production function to take into account variety characteristics, we have: $U(c, z_u) = U(c, \theta^c, z_{u(\theta)})$ and $f(x_j, z_j) = f(x_j, \theta^a, z_{j(\theta)}, e)$. If the focus of the analysis is on the incidence of adoption (i.e. where there is adoption or not) instead of the intensity of adoption, then we define the variable $d^* = I_{\left[x_{j0}^* > 0\right]}$ expressing whether the farmer chooses to adopt a variety j by using its seed. As a direct implication from the model described in Fig. 32.1, the farmer optimal choice depends on the conditioning variables e, θ_j and z_u. Taking the expectation conditioning to these variables, we have:

$$P(d_j^* = 1 \mid \theta_j, z_u, e) = g(\beta, \theta_j, z_u, e) \qquad (32.2)$$

with $P(d_j^{**} = 1 \mid \theta_j, z_u, e)$ being the probability of a randomly selected rice farmer adopting variety j when the vector of characteristics of the variety is θ_j, the farmer socio-economic characteristics are z_u, and the vector of agro-climatic conditions is e; β stands for the vector of parameters to be estimated; and g is a function taking value in the interval [0, 1].

Farmers in a village are not often universally exposed to agricultural technologies. Equally, therefore, a variety as a technology is not often universally exposed to all farmers (Diagne and Demont, 2007; Diagne, 2009). This introduces an important bias if one estimates adoption rates and adoption determinants by using traditional methods (Diagne and Demont, 2007). Therefore, to consistently estimate the village variety adoption rate and its determinants, we follow Diagne and Demont (2007) and use the Average Treatment Effect (ATE) estimation framework (see Imbens and Wooldridge, 2009, for a review).

For each characteristic k, we define $\hat{\theta}_k = max\left\{\theta_{jk}\right\}$, the maximum performance of this characteristic across all known varieties. The maximum characteristic value represents for the farmer the 'known technological frontier' for the characteristic. Also, let us define $\bar{\theta}_k = \frac{1}{J_a}\sum_{j=1}^{J}\theta_{jk} \times d_j^*$, the average performance of characteristic k across all varieties adopted by the farmer, with J_a the number of varieties adopted. This is the farmer's 'observed demand' of the characteristic k.

Taking the expectation conditional to e, θ_j and z_u, we obtain the 'predicted demand':

$$E(\bar{\theta}_k \mid e, \theta, z_u) = \tilde{\theta}_k = \frac{1}{J_a}\sum_{j=1}^{J} P\left(d_j^* = 1 \mid \theta_j, z_u, e\right)\theta_{jk} \qquad (32.3)$$

Because varieties are uniquely identified by their varietal characteristics vectors, the introduction of a new variety is equivalent to a change in the set of varietal characteristics vectors of all known varieties and the improvement in a varietal characteristic k is equivalent to the introduction of a new variety that pushes the farmer's known frontier for that characteristic higher. Equation (32.2) shows how this change affects the probability of adoption of a village variety, and equation (32.3) shows theoretically how the demand for characteristic k changes taking into account the adoption.

The structural causal relationships among varietal characteristics, varietal adoption decision, varietal demand and outcome of interest are described in Fig. 32.2, which shows how a change in a given varietal characteristic due to breeding research affects household total income and production and village poverty headcount through adoption and demand.

Impact of adoption of good agricultural practices

The impact of adoption good agricultural practices is assessed through changes in the effects of rice production stresses. These stresses in some cases affect 100% of the harvested area and cause high yield losses. The magnitude and effect of the stresses could be attenuated when the farmer adopts varieties that have the attribute of resistance to the stress. But another important way to reduce losses is for the farmer to adopt good agricultural practices. Such practices can help to overcome

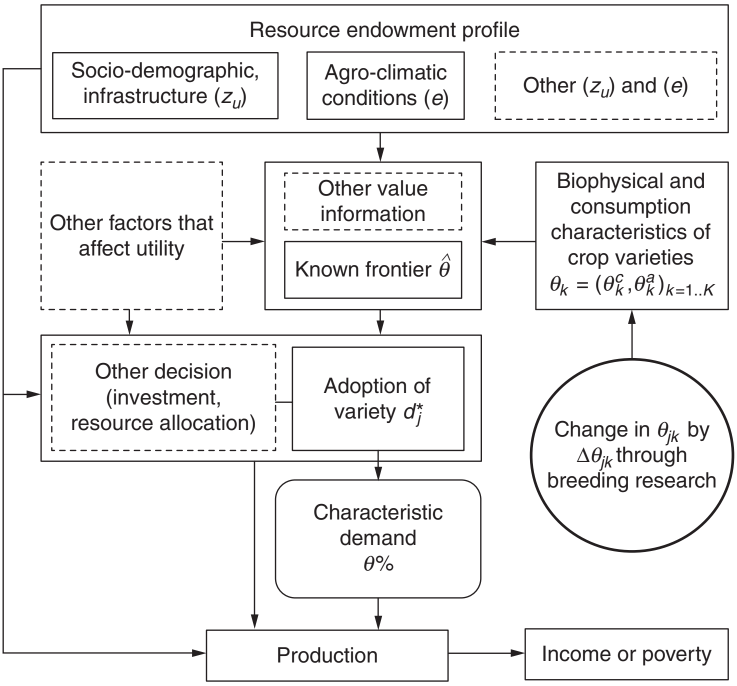

Fig. 32.2. Causal structural relation for the analysis of the impact of adoption of varieties.

stresses during the growing season or tackle postharvest losses. We have not modelled the adoption rate and determinants for this kind of ‘agronomic technology’. Using experts’ opinions after consultation with AfricaRice agronomists and postharvest specialists, we assume the adoption of non-varietal technologies follows a logistic diffusion curve with a 35% peak adoption rate. The logistic distribution is the most common for technology adoption variables.

The structural relation that shows how agronomic research has impact on income or poverty is described in Fig. 32.3 (the conventions are the same as above). The reader is referred to Diagne *et al.* (Chapter 4, this volume) for a formal derivation of the relationships. The channel linking technologies to impact on farmer outcomes is straightforward compared to adoption of new varieties. When the farmer takes the decision to adopt a good agricultural practice, it is expected that the negative effects that will be faced when the stress hits will be less than if he or she did not have this, or any other, suitable technology.

Specification, identification and estimation of the impact model

To be able to project impact of adoption of a technology derived from research over time, we use an autoregressive (AR) model of the outcomes of interest. The AR model is reasonably realistic in most economic settings. Because of the limited data, we use AR model of order one (AR1). Thus, the general impact model equation that will be estimated is:

$$Y_t^h = \alpha Y_{t-1}^h + \beta D_t^h + \gamma X + \varepsilon_t^h \qquad (32.4)$$

where Y is the outcome variable, D stands for the proxy for the technology that is assessed and x is a vector of variables other than D and which affect Y^t. In such regression, the main econometric concern is the possible biases that would be generated by the possibility that D may not be exogenous.

Breeding research

For the breeding research impact model, D is the demand for a given varietal characteristics k. The impact models are estimated separately for each varietal characteristic. Each equation is

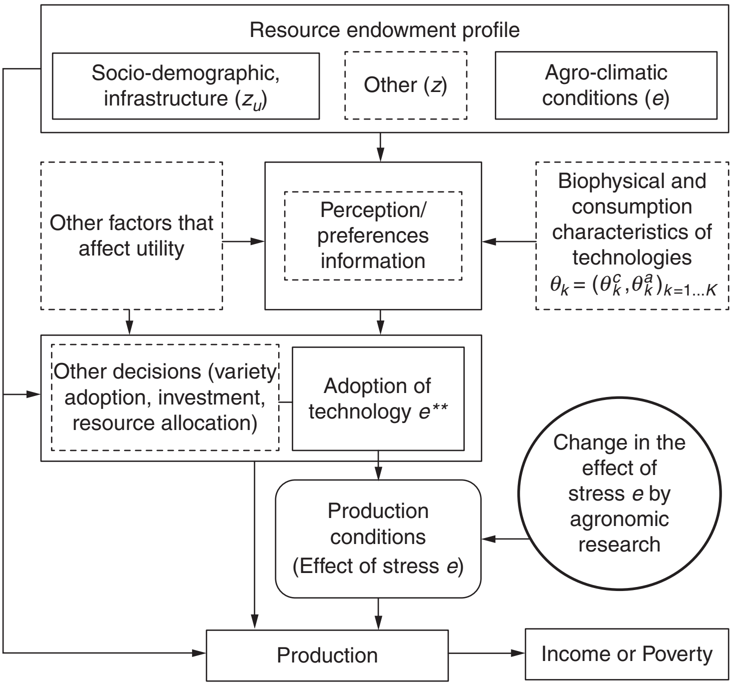

Fig. 32.3. Causal relation for the analysis of the adoption of good agricultural practices.

estimated by the Instrumental Variable method (e.g. Wooldridge, 2002). The varietal technology demand and the outcome (income, production or poverty) can be confounded as shown in the structural causal relation presented in Fig. 32.3. Thus, $D = \widetilde{\theta}_k$ is endogenous in equation (32.4) and Ordinary Least Squares will yield inconsistent parameters. To address this problem, we use the Instrumental Variable estimation method with known frontier ($\hat{\theta}_k$) as instrumental variable for the demand $\widetilde{\theta}_k$. The validity of the frontier as instrument is tested by weak instrument test (see Wooldridge, 2002). The estimated parameter is the total effect of the demand for varietal characteristics on the outcome. Chalak and White (2011) show that in such a regression, the first-stage regression coefficient need not be identified. Each technology is associated with a corresponding varietal characteristic (see Appendix, Table 32.A.1).

Agronomic research

For the agronomic research impact model, D is the yield loss caused by a given stress, when it is experienced by the farmer. We assume that the occurrence of stresses and the yield losses they cause to farm households are exogenous to their decisions. Thus, $D = e$ is exogenous in equation (32.4). So, estimation of the AR1 model by Ordinary Least Squares yields consistent estimates of the parameters. The other variables included in the model are socio-demographic variables, environment and country fixed effect to capture the heterogeneity among environments and countries of stress effect (see Appendix, Table 32.A.1, for complete details of variables used in each model).

From research to impact: methodology

The two diagrams of the structural impact model (Figs 32.2 and 32.3) show how technological options are linked to household- and village-level models. This section explains how the linkage was done. As discussed above, there is a slight difference between how technologies derived from breeding research and agronomic research are assessed. Hence, we distinguish them in the linkage procedure.

Breeding research

STEP 1: TRANSLATING THE SCIENTIST'S ESTIMATE OF PERCENTAGE YIELD GAIN INTO PERCENTAGE INCREASE IN $\hat{\theta}_K$. The average expected yield loss reduction (%) for each proposed research option was converted into an increase in the performance of the characteristic corresponding to the stress that the research option addresses (see Appendix, Table 32.A.1, for correspondence between stress and varietal attribute).[6]

STEP 2: USING PERCENTAGE INCREASE IN $\hat{\theta}_K$ IN THE ADOPTION MODEL TO GET THE PERCENTAGE CHANGE IN VARIETAL DEMAND $\bar{\theta}_K$. By changing the known frontier of characteristic *k*, the new technology from breeding research (i.e. variety) will induce a change in the farmer's portfolio of adopted varieties. The change $\Delta\bar{\theta}_k$ is captured through the adoption model estimated and the demand function derived from this model (equation 32.3) by plugging in $\Delta\hat{\theta}_k$. This change in demand (as population parameter) already accounts for the adoption of the technology. To account for the uncertainty, the change is multiplied by the probability of success of the research φ_k, and the true impact of the research on demand is $\varphi_k\Delta\bar{\theta}_k$.

STEP 3: PLUGGING $\varphi_K\Delta\bar{\theta}_K$ IN THE IMPACT MODEL TO GET IMPACT AT STARTING YEAR. The induced change in the farmer pool of adopted varieties (demand) is plugged into the impact model corresponding to characteristic *k*. The impact $\overline{\Delta y} = \beta\,\varphi_k\Delta\bar{\theta}_k$ is then the average impact on farmer income or production or village poverty headcount in the starting year of availability of the technology across adopting and non-adopting farmers.

Agronomic research

An appropriate impact model is estimated for each stress. If the technology is derived from agronomic research, we use the yield loss reduction impact model with the corresponding loss due to the stress that the technology addresses as explanatory variable. If the technology is derived from postharvest research, we use the impact model that has loss caused by postharvest as explanatory variable. Where the technology does not have a specific nature (and is labelled 'other'), we used the impact model that has average yield loss as explanatory variable.

The linkage of technologies derived from agronomic research to impact models is straightforward by plugging the yield loss reduction expected (r_e, %) directly into the impact model and multiplying the result by the probability of success (φ_e) to account for uncertainty. Thus, the impact is $\overline{\Delta y} = \beta\,\varphi_e r_e$ and corresponds to the average impact at farmer or village level in the first year of availability of the technology across adopting and non-adopting farmers.

Projection over time and aggregation across technologies

Projection of impact over time

At the end of the process described above, we had the impact for the first year of availability of the technology. This year corresponds to $t_0 = 2010 + t_d$ with t_d the estimated number of years needed to develop the technology (from 2010) as given by scientists. However, we are interested in projecting impact over time to 2020.

The AR1 models estimated are enough to allow us to forecast the mean impact starting in a given year t_0 and any subsequent year $t_0 + \rho$ as:

$$\begin{aligned} E\Delta y_{t_0+\rho} &= \beta \sum\nolimits_{j=0}^{\rho-1} \alpha^j E(\Delta y_{t_0+\rho-j}) \\ &= \overline{\Delta y}\,\frac{1-\alpha^\rho}{1-\alpha} \quad \rho = 1,2,\ldots \end{aligned} \qquad (32.5)$$

where $\overline{\Delta \mathrm{y}}$ is the impact in the starting year ($\beta\varphi_k\Delta\bar{\theta}_k$ for breeding research and $\beta\varphi_e r_e$ for agronomic research). This formula enables us to forecast the impact at ρ – period ahead forecasted value for the outcome *y*. Finally, the annual nominal income gained was discounted at the rate of 5% and cumulated to get gross benefit at farmer level.

Aggregation across technologies

The impact parameters calculated, as described above, are for each technology that addresses a specific stress or varietal attribute. These technologies were grouped in major research themes (shown in Appendix, Table 32.A.1):

- Alleviate biotic stresses.
- Alleviate soil-related constraints.
- Alleviate climate-related constraints.
- Alleviate postharvest-related constraints.
- Raise the genetic yield potential.

For each major research theme, the impact parameters were aggregated across all stresses. For the income or production parameters, the aggregation function used was the mean across technology in a given major research theme and was interpreted as the average impact of any technology within that group. For poverty parameters, the mean does not make sense because one individual cannot be lifted out poverty at the same time by two different technologies. Thus, we used a maximum across technologies in a given major research theme as aggregation function so that the result can be interpreted as the minimum number of people that will be lifted out of poverty by any technology within the particular research theme.

Extrapolation from farmer or village level to country level

Number of rice farmers and rice-farming population

The extrapolation from farmer and village level to country level is based on the estimation of the total number of rice farmers in each country. Because of the lack of national estimates of the total number of rice farmers per country, we combined household-survey and secondary data to provide estimates.[7]

The total number of rice-farming households N_h in each of the countries included in our analysis was estimated by taking the ratio of the country's total rice harvested area S (obtained from FAOSTAT, 2010) and the average rice area per household s_h (estimated from the farm-household surveys) and projected over time assuming constant population growth of $g = 2.5\%$ (average rural population growth in sub-Saharan Africa from the World Development Indicators [World Bank, 2010]).[8] The formula used is $N_h = \frac{S}{s_h} \times (1+g)^{\rho}$, where ρ stands for time.

To get the distribution across rice-growing environments, we multiplied the proportion of rice farmers by environment (estimated from the household survey) by the total number of rice farmers in the country (see Diagne *et al.*, Chapter 3, this volume, Appendix, for details). This assumes that the structure of the rice farmers by environment will remain stable over time. The total rice-farming population size in the country was estimated by multiplying the total number of rice-farming households (as estimated above) by the average household size. Missing values for average area and household size were estimated by taking the average across neighbours.

From farmer to country level

The potential benefit of rice research and its expected poverty impacts for rice-producing farmers in sub-Saharan Africa were assessed for 38 rice-producing countries. The household- and village-level impacts estimated from data on 16 countries were used to extrapolate impact at national level for the 38 countries. The 38 countries included are: Angola, Benin, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Comoros, Congo Republic, Côte d'Ivoire, Democratic Republic of Congo (DRC), Ethiopia, Gabon, The Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Sudan (including South Sudan), Swaziland, Tanzania, Togo, Uganda, Zambia and Zimbabwe. The total rice area harvested in these countries in 2009 was about 9.9 million hectares, which represents 99.3% of the total harvested area of sub-Saharan Africa. Their total paddy rice production for the same year was 19.1 Mt (99.1% of the sub-Saharan African total). Thus, the results of this analysis can be considered to be applicable for all of sub-Saharan Africa.

For each country included in the analysis, the impact on individual farmers' income or production was extrapolated to country level by multiplying the average impact estimates by the estimates of total number of adopting farmers in the country. To see that this provided a consistent estimate of the total benefit to rice farmers at the national level, we let $\bar{y}_h$ be the increase in the average household income, N the average population size of rice farmers in the country and A the adoption rate, so that the total benefit at country level is $T = A \times N \times \bar{y}_h$. Now, the total number of adopting rice farmers, $N^a = A \times N$ and $T = N^a \times \bar{y}_h$.

From village to country level

The poverty impact estimated at the village level was multiplied by the total rice-farming population size in the country. To show that this provides a consistent estimate of the reduction in the total number of poor rice farmers at the national level, let P_v be the reduction in the average village poverty headcount and N_v the average population size of rice farmers in a village, so that the average number of rice farmers in a village lifted out of poverty is $Q_v = N_v \times P_v$. Now, if Q is the total number of people living in rice-farming households lifted out of poverty in the whole country, N the total number of people living in rice-farming household in the country, N^a the total number of adopting rice farmers, K^a the total number of rice-farming villages with adopters, N_v^a the average population size of adopting rice farmers in a village, then we have $N^a = K^a \times N_v^a$, so that $Q = K^a \times Q_v = \frac{N^a}{N_v^a} \times Q_v = \frac{N^a}{N_v^a} \times N_v \times P_v$. If A is the adoption rate (assumed to be the same at both village and national levels), then we have $N^a = A \times N$ and $N_v^a = A \times N_v$. So that $Q = \frac{N^a}{N_v^a} \times N_v \times P_v = N \times P_v$. This extrapolation to country level was done for each proposed research options using the calculated estimate of individual farmer- or village-level impact.

Aggregation

For each proposed research options all income gain and poverty reductions were summed to get the gross income benefit and total poverty reduction for all countries. The income benefit by region, rice environment and research discipline was obtained by summing the benefit across all proposed research options and restricting the sum to the level of disaggregation of interest. The poverty levels by region, rice environment and research discipline were obtained by calculating new parameters at the level of interest using a max aggregation function. The new parameters were then used to obtain impact by country or rice environment and summing the result at the disaggregation level of interest.

Estimation of the Impact of Rice Research on Rice Processors, Traders and Consumers

Rice processors and traders

Rice processing involves several activities. At each step significant numbers of farmers and processors experience significant losses (see Futakuchi *et al*., Chapter 25, this volume). Postharvest losses in rice can be divided into quantitative and qualitative losses due to the rudimentary handling methods used in many sub-Saharan African countries. It is estimated that, on average, quantitative postharvest losses of rice at farm level in Africa are in the order of 15–20% (AfricaRice, 2010).

In addition, if rice paddy is not harvested and stored on time, or is dried too quickly, the proportion of rice grains that break during the milling process is usually high. Suboptimal drying and storage practices by farmers often result in good-quality paddy rice being mixed with damaged paddy, weed seeds, insect residues, sand and stones. Separation of broken from whole grains and removal of impurities is possible, but only with equipment available in large-scale rice milling operations. Farmers also tend to mix paddy from different varieties when harvesting, drying or storing rice. But, different rice varieties have different milling characteristics.

As a consequence, there is a significant quality gap between locally produced and imported rice. The locally produced rice that is sold on African markets tends to be made up of a mixture of broken and whole-grain rice of different varieties, sizes and colours. Rice grains are also often mixed with weed seeds, stones, sand and insect residues (Lançon *et al*., 2003). Thus, qualitative losses, estimated by the price differential between imported and locally produced rice, range from 15% to 50%, with an average of 30% in many countries.

To address these constraints, scientists have proposed a set of research options that would generale technologies of good harvest and postharvest handling and timing practices that will be made available to farmers and processors to increase milling performance and the overall quality of locally produced rice. Improved handling practices and technologies can significantly reduce rice paddy and grain losses due to poor harvesting and rice processing technologies (Wadsworth, 1991; Wang and Luh, 1991; Hosokawa, 1995).

We assumed that with adoption of improved processing practices and technologies by rice processors, the milling rate will significantly increase from its current average value of 60% (Totté, 1995) to almost 67% starting from 2013. We further assumed that the percentage of head rice after milling will increase from 11% to 20% and the percentage of broken rice will significantly decrease from 59% to 50%. These estimates are conservative. For the traders, the assessment is done by assuming that the quality of local rice will increase. The increase is measured as the reduction of the price gap between local and imported rice.

In the absence of survey data on rice processors and traders, we made the assumption that the percentage of rice paddy that will be processed using the improved technologies proposed by scientists will follow a logistic curve with an initial adoption rate of 0.5% in starting year 2013 and a peak adoption rate of 35% in 2020. For each year, we forecast the total paddy production and then applied the new technical parameters to compute the increase in milled rice resulting from the adoption of these technologies. The increase in milled rice is valued at processor margins to estimate the income benefit for rice processors. The price increase attributed to the increase in rice quality is used to estimate the benefit for rice traders.

Rice consumers

For rice consumers, it is assumed that the expected increase in production and quality of local rice through adoption of the technologies generated by the proposed research options will be translated into a decrease in rice price compared to the level it may reach in the absence of research.

Using an econometric model with the price of milled rice at each village level as dependent variable and the proxy for the technologies generated by each proposed research option and other village characteristics as covariates, we estimated the level of this price effect. This price effect combined with poverty data from the World Development Indicators (World Bank, 2010), rice expenditure shares provided by the African Development Bank (Koffi Marc Kouakou, AfDB, Tunis, Tunisia, 20 August 2010, personal communication) and estimated population of non-rice farmers in sub-Saharan Africa (obtained by subtracting the number of rice farmers estimated above from the total country population from World Bank, 2010) projected over time, we calculated the expenditure savings on rice by poor consumers. This aggregated expenditure saving has been redistributed to estimate the number of poor consumers that will be lifted out of poverty. Translation into additional rice that can be bought enabled us to calculate the amount of additional caloric consumption and the number of people that could be lifted out of hunger among poor consumers.

Presentation of the Data

The data used for the priority-setting exercise come from various sources, both primary and secondary: (i) household- and community-level surveys conducted in 21 countries in 2009 (AfricaRice, 2010); (ii) a rice experts survey conducted during the AfricaRice Science Week in 2010; and (iii) secondary sources such as FAOSTAT (2010) and World Development Indicators (World Bank, 2010). This section describes the data used and the various transformations made.

Household and community data

Rice data system for sub-Saharan Africa: overview

The rice data system for sub-Saharan Africa was a project funded by the Government of Japan to address the need for better-quality rice data, research and development (R&D) priority-setting and monitoring. Household and community surveys were conducted in 21 countries, members of the Coalition for African Rice Development (CARD)[9] by AfricaRice in collaboration with NARS and national agricultural statistics services. This work aimed to collect household- and community-level data on the biotic, abiotic and socio-economic constraints to rice production. In addition, other data were gathered – farmer knowledge of varieties and their adoption, the farmers' perception of the characteristics of varieties, household demographics, access to seed, area harvested and total production, assets, access to infrastructure, etc. The sample sizes ranged from 370 (The Gambia) to 10,500 (Nigeria) rice-farming households per country in the household surveys.

A wide range of constraints were identified across growth environments. For each constraint, farmers were asked whether they knew it or not. They were also asked to rate the constraint when it occurred in terms of intensity on a three-point scale (high, medium and low). After rating all constraints, they identified the five major ones and were then asked three questions: (i) Have you experienced the constraint in the past 5 years? (ii) What was the proportion of area affected by the constraint in the past 3 years? (iii) What was the yield loss (%) on a whole-field basis when the constraint was experienced in the past 3 years? (See Diagne *et al.*, Chapter 4, this volume, for more details.)

A single list of known traditional and modern varieties was compiled for each village via focus groups. In a given village, each surveyed farmer was asked whether he or she knew each village variety; whether he or she had grown it during the past 5 years; and, if grown, what was the area allocated, the quantity of seed used, the quantity of paddy produced, and other pertinent questions.

A pool of varietal attributes was identified by AfricaRice scientists. Because of the relatively large number of traditional varieties known and cultivated in many of the villages surveyed, the variety performance was evaluated at community level. Measuring the characteristics intrinsic to a variety is complex. Instead of having the exact measure, we used a ranking method to assess varietal characteristics. Each variety's performance for all attributes identified was assessed on a three- or five-point scale by a focus group of rice farmers in the village. The score was then used as a proxy for the varietal attribute. The scores given by the farmers were normalized by dividing by the maximum possible score (3 or 5) to give an index of between 0 and 1. Some of the grouped varietal characteristics scores (e.g. for diseases, insects) were obtained by aggregating the scores of the individual components making up the group using geometric mean (see Appendix, Table 32.A.1). These scores, from village level, were integrated into the household-level file by matching by variety and village. Missing values were corrected using averages by country, village, variety type and rice environment.

Data were collected for 21 countries, but completely processed for only 16 countries.[10] Thus, the models are estimated using only 16 countries' data. The estimated parameters were then used for all the countries included in the analysis. The survey questionnaire was almost the same for the 21 countries, except a few aspects that varied across countries. The data for the 16 countries were pooled.

To assess the probability of adoption of a given variety in a village, we pooled the data as an unbalanced panel. One observation is defined by a pair (h, j), where h is the index for household and j for variety of the village. Thus, the data were balanced at village level in each country.

The income variable used in the impact model was total household income. The survey captured household income from various sources and for the previous 3 years. A household's income comes from rice production, other crop production, livestock production and non-agricultural activities (handicrafts, commerce, work as labourers, formal employment, extraction, processing, etc.). The total household income was obtained as the sum of income from the sources identified for all household members.[11] For uniformity, the incomes were converted from local currency to US dollars using the exchange rate of each currency (from World Bank, 2010). The household total paddy production was obtained by summing the household paddy production across varieties and plots. We calculated each village poverty headcount by using household per-capita income and the poverty line used was the $1.25 per day poverty line multiplied by each country's purchasing power parity (PPP) value (World Bank, 2010).

Rice data system for sub-Saharan Africa: results

A detailed descriptive analysis of the household and community survey data is available in AfricaRice (2010). Here we present some of the key descriptive findings related to the farmers' knowledge and adoption of varieties and the demand for varietal characteristics.

VARIETAL ADOPTION. For a given variety in a village, about 47% of farmers knew it and 29% cultivated it. Among the 'exposed' population (i.e. those who knew it), the adoption rate was estimated at 62.4%. The average treatment effect of adoption of a village variety in the overall population was 61.4%, while it was 60.5% in the population of farmers not exposed to the village variety (see Appendix, Table 32.A.2). The population selection bias was only 1% (see Appendix, Table 32.A.2). This low selection bias may be due to the fact that we focused on any village variety, not on a particular variety. The gap between the potential probability of village variety adoption and the actual adoption rate was estimated at 32.3% (Table 32.A.2).

VARIETAL CHARACTERISTICS DEMAND. Because of the relatively large number of varietal attributes evaluated (27), we grouped some of them using their geometric mean (see Appendix, Table 32.A.1). This geometric mean is the most suitable aggregation function due to the nature of the varietal characteristics to be grouped, the values of which are in the interval 0–1. For all the varietal attributes, the known frontiers, the maximum value of the attribute for the known varieties, are low. The demands, measured as the average value for the adopted varieties, are on average medium and close to the frontier (see Appendix, Table 32.A.3). Thus, there is a need to improve the varietal characteristics by developing improved varieties with higher performance than the existing ones (see also the estimates of the characteristics demand elasticities in the Appendix, Table 32.A.4).

IMPORTANCE OF MAIN RICE PRODUCTION CONSTRAINTS. Constraint analysis focused only on biophysical constraints. The socio-economic constraints are not considered here and will be analysed in later work. Some grouping was made to reduce the number of constraints assessed (see 'sub-category' in Appendix, Table 32.A.1). The yield loss of a given group is the average across the constraints in that group. Also, a farmer experiencing at least one constraint in a group is assumed to have experienced this group of constraints (see Diagne *et al.*, Chapter 4, this volume, for more details on the methodology and findings).

On average, more than 30% of the harvested area of farmers who experienced at least one major constraint was affected. Soil-related constraints, climate-related constraints and weeds were the most common, with 37%, 36% and 33% of the area affected, respectively. The yield losses caused by the constraints when experienced were high and depended on the environment. Climate-related constraints caused on average 28% yield loss in irrigated and upland environments (see Appendix, Table 32.A.5).

Scientist survey

Priority-setting workshop: overview

A 2-day priority-setting workshop was organized during the 2010 AfricaRice Science Week. During this workshop, a questionnaire-based survey developed by the AfricaRice Priority-setting Task Force was conducted. The survey was addressed to AfricaRice experts to elicit research options to address rice production constraints. Scientists proposed research options by rice environment and type of research. The expected impact in terms of yield loss reduction, narrowing of the yield gap or increase in the yield potential under researcher-managed conditions was provided by the experts for each proposed research option. The yield loss reduction R given in tonnes per hectare was turned into a percentage using the formula:

$$r = 100 \times R \times \left(1 - \frac{l}{100}\right) \times \frac{1}{y} \qquad (32.6)$$

in which y is the actual on-farm yield, l the actual average yield loss as perceived by the farmer, r the yield loss reduction (%) expected from the technology. This implies that with the adoption of the technology, resulting from the research option the yield loss perceived by the farmer will be reduced from $l\%$ to $(l - r)\%$. Experts were also asked to indicate associated research costs, probability of success, and the expected year of delivery of the technologies from the proposed research option.

Priority-setting workshop: results

The analysis of the data from the survey of rice experts revealed a wide variety of proposed research options across research disciplines (breeding, agronomy, postharvest) and rice environments. The average yield loss reductions expected from research options mitigating the effects of various biotic and abiotic stresses are 0.6 t/ha in irrigated, 0.5 t/ha in rainfed lowland and 0.45 t/ha in upland environments. The average yield potential increases for research options raising yield potential are 1.5 t/ha for irrigated, 1 t/ha for upland and 1.4 t/ha for rainfed lowland environments. Estimates of yield gains from research options refer to conditions in researcher-managed trials. The average time to delivery of the technologies from the proposed research was slightly more than 4 years and the average probability of success was slightly above 60% (see Appendix, Tables 32.A.6 and 32.A.7 for details of scientists' estimates).

Patterns of Expected Income Benefits and Poverty Reduction

This section presents the main findings of the *ex-ante* analysis of the impact of rice research in sub-Saharan Africa. The results focus on income, poverty reduction and food security. Disaggregation across rice value-chain actors, research option, rice environment, research nature and region are made. The first sub-section focuses on gross income benefit, while the second sub-section presents impact on poverty reduction and food security. The parameter estimates of the model used to project impact are presented in the Appendix, Table 32.A.8. The results disaggregated by country are also presented in the Appendix for reference (Tables 32.A.10 to 32.A.12).

Income benefits

Aggregated income benefits by actors and region

The estimation of the potential impact of research targeted to reduce yield loss due to the major production constraints identified by farmers, to raising the yield potential and to adding quality to rice is a global cumulative 5%-discounted benefit of $10.6 billion over the 7-year period 2014–2020 for the 38 countries included in the analysis, with an average annual benefit of $1.8 billion.

The disaggregation of the income gain across the value-chain actors and per region is presented in Table 32.1.

The estimated potential impact of research targeted to reduce the yield gap and increase grain quality through better crop management and postharvest practices, and to raising the yield potential through higher-yielding varieties is an annual income benefit of $1.1 billion for rice farmers, corresponding to a global cumulative 5%-discounted benefit of $6.9 billion over the 7-year period 2014–2020.

As a result of increased rice supply, domestic prices in major rice-producing countries in Africa are expected to be on average 7.2% lower than the baseline level (i.e. without research). Translating this price effect, it is expected that annual expenditure on rice by non-rice-farming consumers under the $1.25 poverty line will be reduced by $650.6 million (PPP) by 2020 (holding consumption constant), corresponding to a global cumulative 5%-discounted benefit of $3.3 billion.

By improving rice processing technologies and reducing losses, it is expected that the quality of locally produced rice will be increased, generating more revenue for rice processors and rice traders. These benefits are estimated at $64.2 million annually (cumulative 5%-discounted, $323.7 million) for rice processors and $30.8 million annually (cumulative 5%-discounted, $155.3 million) for rice traders.

In terms of regional distribution on income gain, West Africa would have the highest impact, followed by East Africa, Central Africa and finally Southern Africa. This pattern is almost the same for all rice value-chain actors. Country-specific detail is provided in the Appendix, Table 32.A.9.

Income benefits for farmers by type of research

The impact on farmers' income by type of research grouped into major research themes for all sub-Saharan African countries and across rice environments is presented in Table 32.2.

For all types of research and for all sub-Saharan African farmers, the expected gross discounted benefit on farmer income is estimated at $851.7 million in 2014 (starting year of adoption of the research-generated technology by farmers), reaching $6.9 billion in 2020. These benefits correspond to an annual discounted benefit of $1.1 billion from 2014 to 2020. The main assumption underlying these figures is that the impact of the types of research is additive (as explained in the methodology section). Consequently, the gross benefits for all types of research were obtained by summing the individual benefits for each types of research.

Disaggregation across types of research shows that the share of gross discounted cumulated benefits attributable to research that addresses major biophysical production constraints are the most important, with $336.5 million annually for research that addresses major biotic constraints, $320.5 million annually for research to alleviate climate-related constraints, and $220.1 million annually for research addressing soil-related constraints (Fig. 32.4).

Research that raises genetic yield potential is expected to generate an annual income gain of $126.6 million, representing 11.5% of the total gross benefit. Research that alleviates postharvest loss at farmer level will generate $94.8 million annually, about 8.6% of the total annual income gained due to successful research in sub-Saharan Africa till 2020.[12]

The corresponding gross cumulative discounted benefits in 2020 are $2.2 billion for alleviating biotic constraints, $2.0 billion for alleviating climate-related constraints, $1.3 billion for alleviating soil-related constraints, $0.8 billion for raising yield potential and $0.7 billion for postharvest loss reduction.

Table 32.1. Benefit of research on value-chain actors' income by region ($ million discounted at 5%) for 2014–2020.

Region	Farmers	Consumers	Processors	Traders	All actors
Gross annual benefit					
Central Africa	109.4	66.6	7.7	3.75	187.5
East Africa	274.3	183.1	18.7	8.97	485.0
Southern Africa	2.6	16.8	1.5	0.77	21.7
West Africa	712.1	384.1	36.3	17.34	1,150.0
sub-Saharan Africa	1,098.5	650.6	64.2	30.80	1,844.2
Gross cumulative benefit					
Central Africa	697.5	333.0	38.6	18.90	1,088.1
East Africa	1,714.0	915.4	94.3	45.19	2,768.8
Southern Africa	16.5	84.1	7.8	3.86	112.3
West Africa	4,458.5	1,920.7	183.0	87.39	49.6
sub-Saharan Africa	6,886.6	3,253.2	323.7	155.30	10,618.7

Table 32.2. Gross discounted income benefits of research options as grouped by major research theme ($ million).

	Starting year (2014)	End year (2020)	Annual
Biotic constraints	253.6	2,161.9	336.5
Soil-related constraints	159.9	1,349.8	220.1
Climate-related constraints	260.2	2,004.9	320.5
Postharvest-related constraints	87.9	649.0	94.8
Yield potential	90.0	720.8	126.6
All research options	851.7	6,886.6	1,098.5

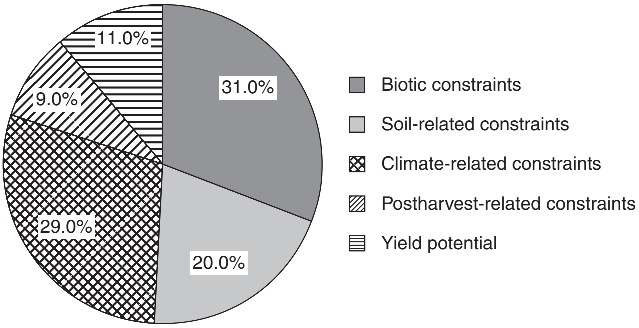

Fig. 32.4. Share of gross annual benefit attributable to technologies as grouped by major research themes.

Income benefits for farmers by rice environment

In terms of rice-growing environment, the rainfed lowland environment comes in first position for all research options with annual income benefit of $497.8 million, upland comes in second place with annual benefit of $430.1 million, irrigated follows with annual benefit of $145.4 million and then other environments with annual benefit of $24.8 million (Fig. 32.5). The high potential impact observed in rainfed lowlands is mainly driven by Nigeria, where this is the major rice environment (70% of rice farmers) (see also Appendix, Table 32.A.10).

Gross cumulated discounted benefit in 2020 will reach $3.0 billion for the rainfed lowland environment, $2.8 billion for upland environment, $0.9 billion for irrigated environment and $0.1 billion for the other environments (Table 32.3).

The impact varies across rice environments for each region (Fig. 32.6).

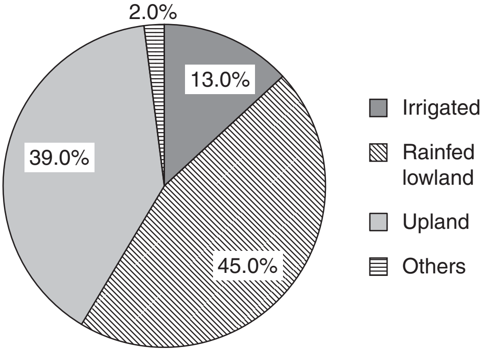

Fig. 32.5. Share of gross annual benefit attributable to each rice-growing environment.

In general, rainfed lowland is the major rice environment in West Africa, mainly in Nigeria. The annual income benefit for lowland in this region represents 49.8% of the total annual income benefit, while the upland environment has a share of 42.0%, the irrigated environment 6.2% and the other environments 2.0%. In East Africa, the trend is different, with rainfed lowland annual income benefit share equal to 47.3%, irrigated second with 30.7%, upland third with 18.6% and the other rice environments 3.4%. In Central Africa, the dominant environment in terms of annual income benefit is upland (71.6%), followed by irrigated (15.4%), rainfed lowland (12.0%) and the others (1.0%). Southern Africa income benefits come mainly from the upland environment (92.0%) and to some extent from the irrigated environment (8.0%).

The benefit in terms of value by region and environment is presented in Table 32.4.

Income benefits for farmers by research discipline

In terms of research discipline, breeding research comes in first position with annual income benefits of $426.8 million, followed by agronomic research with annual income benefits of $303.4 million. Postharvest research will have an annual income benefit of $166.0 million, and all other types of research are expected to have an annual income benefit of $202.2 million (Fig. 32.7).

Table 32.3. Income benefits ($ million) of research options as grouped by major research themes and rice environments.

	Irrigated	Rainfall Lowland	Upland	Others	All rice environments
Impact on income in first year of adoption					
Biotic stresses	36.1	114.8	97.3	5.5	253.6
Soil-related constraints	19.7	79.2	56.7	4.3	159.9
Climate-related constraints	36.3	115.0	99.6	9.2	260.2
Postharvest-related constraints	8.3	41.7	36.7	1.3	87.9
Yield potential	11.6	43.8	34.6	0.0	90.0
All research options	112.0	394.5	324.8	20.3	851.7
Aggregate (gross cumulated) discounted impact on income in 2020					
Biotic stresses	303.2	958.7	851.0	49.1	2161.9
Soil-related constraints	185.4	609.2	522.2	33.0	1349.8
Climate-related constraints	263.8	860.1	824.9	56.2	2004.9
Postharvest-related constraints	61.7	305.3	272.5	9.5	649.0
Yield potential	112.3	314.2	294.3	0.0	720.8
All research options	926.3	3047.6	2764.9	147.8	6886.6
Annual discounted impact on income in 2020					
Biotic stresses	47.6	149.4	131.7	7.7	336.5
Soil-related constraints	28.6	104.3	81.5	5.7	220.1
Climate-related constraints	42.6	140.8	127.1	10.0	320.5
Postharvest-related constraints	9.1	44.6	39.8	1.4	94.8
Yield potential	17.5	58.7	50.5	0.0	126.6
All research options	145.4	497.8	430.5	24.8	1098.5

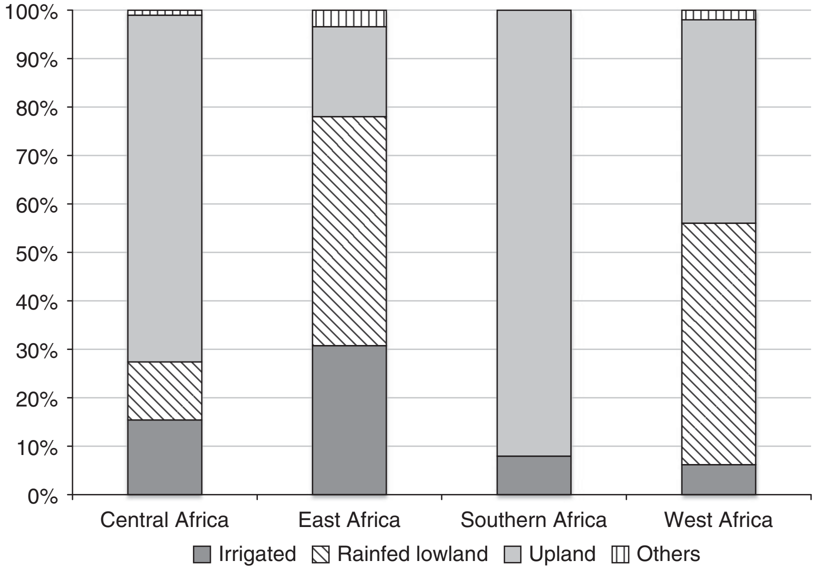

Fig. 32.6. Share of gross annual benefit attributable by rice environment and region.

These annual income gains, aggregated over time to 2020, would yield a gross cumulative discounted benefit of $2.3 billion for breeding research, $2.0 billion for agronomic research, $1.2 billion for postharvest research and $1.4 billion for other research.

Comparison across major research themes shows that the contribution of breeding to research alleviating soil-related constraints will be slightly greater than its contribution to research alleviating biotic stresses and research alleviating climate-related constraints

Table 32.4. Income benefits ($ million) by region and rice environment.

	Irrigated	Rainfed lowland	Upland	Others	All rice environments
Impact on income in first year of adoption					
Central Africa	13.0	10.4	59.1	0.9	83.4
East Africa	64.9	102.8	38.4	7.7	213.8
Southern Africa	0.2	0.0	1.8	0.0	1.9
West Africa	34.0	281.3	225.6	11.7	552.4
sub-Saharan Africa	112.0	394.5	324.8	20.3	851.7
Aggregate (gross cumulated) discounted impact on income in 2020					
Central Africa	107.3	80.4	502.9	6.8	697.5
East Africa	536.9	794.3	326.8	56.0	1714.0
Southern Africa	1.3	0.0	15.2	0.0	16.5
West Africa	280.8	2172.9	1919.9	84.9	4458.5
sub-Saharan Africa	926.3	3047.6	2764.9	147.8	6886.6
Annual discounted impact on income in 2020					
Central Africa	16.8	13.1	78.3	1.1	109.4
East Africa	84.3	129.7	50.9	9.4	274.3
Southern Africa	0.2	0.0	2.4	0.0	2.6
West Africa	44.1	354.9	299.0	14.2	712.1
sub-Saharan Africa	145.4	497.8	430.5	24.8	1098.5

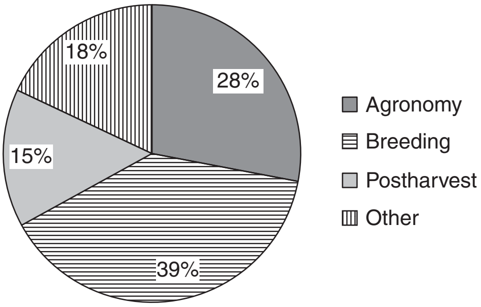

Fig. 32.7. Share of gross annual benefit attributable by research discipline.

(Fig. 32.8). Only breeding research can help in raising yield potential. Table 32.5 provides more details on impact by research theme and research discipline.

Poverty reduction and food security

Giving these income gains, corresponding (i) poverty reduction in terms of number of people lifted out of poverty and (ii) improvement in food security in terms of number of people that can afford to reach caloric sufficiency were also estimated (only for rice-farming households and non-rice-farming consumers).[13] As explained in the methodology, aggregation of poverty reduction across research options was done by using 'max' as aggregation function (to count for the fact that being lifted out of poverty is a one-time event – excluding the possibility of drop back into poverty). So, the results presented here are the minimum yearly poverty reduction.

Aggregated poverty and food-insecurity reduction by actor and region

The results in terms of poverty reduction and food-insecurity reduction are presented in Table 32.6 (see Appendix, Table 32.A.11 for the results disaggregated by country).

As a result of the rice research in sub-Saharan Africa, at least 4.2 million people in rice-farming households will be lifted above the $1.25 poverty line (in 2005 PPP) in 2020. Also the expenditure saving realized by non-rice-farming consumers will equate to 6.8 million urban and rural rice consumers (excluding rice-producing farmers) being lifted above the $1.25 poverty line in 2020. In total, at least 11 million people in the 38 sub-Saharan African rice-producing countries will be lifted out of poverty in 2020, reducing the overall number of poor by 4%.

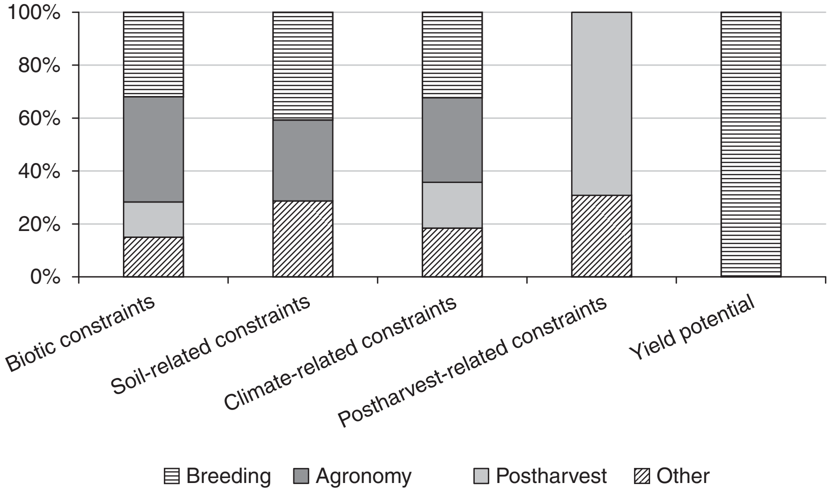

Fig. 32.8. Share of gross annual benefit attributable to research disciplines as grouped per major research theme.

Table 32.5. Income benefits ($ million) of research options as grouped by major research themes and disciplines.

	Agronomy	Breeding	Postharvest	Other	All types
Impact on income in first year of adoption					
Biotic stresses	93.2	74.1	46.5	39.9	253.6
Soil-related constraints	48.5	73.7	0.0	37.7	159.9
Climate-related constraints	86.3	74.2	56.4	43.2	260.2
Postharvest-related constraints	0.0	0.0	63.7	24.3	87.9
Yield potential	0.0	90.0	0.0	0.0	90.0
All research options	228.0	312.0	166.6	145.0	851.7
Aggregate discounted impact on income in 2020					
Biotic stresses	927.1	604.9	308.9	321.0	2161.9
Soil-related constraints	470.5	436.5	0.0	442.8	1349.8
Climate-related constraints	627.3	584.6	388.7	404.4	2004.9
Postharvest-related constraints	0.0	0.0	459.3	189.8	649.0
Yield potential	0.0	720.8	0.0	0.0	720.8
All research options	2024.9	2346.7	1156.9	1358.1	6886.6
Annual discounted impact on income in 2020					
Biotic stresses	133.6	107.4	44.9	50.5	336.5
Soil-related constraints	67.2	89.6	0.0	63.3	220.1
Climate-related constraints	102.6	103.2	55.5	59.2	320.5
Postharvest-related constraints	0.0	0.0	65.6	29.2	94.8
Yield potential	0.0	126.6	0.0	0.0	126.6
All research options	303.4	426.8	166.0	202.2	1098.5

Table 32.6. Poverty and food-insecurity reduction for rice farmers and consumers by region in 2020 (millions of people).

Region	Farmers	Consumers	Total
Number of people lifted above the PPP $1.25 poverty line			
Central Africa	0.3	0.7	1.0
East Africa	1.0	1.6	2.7
Southern Africa	0.0	0.5	0.5
West Africa	2.8	4.0	6.8
sub-Saharan Africa	4.2	6.8	11.0
Number of people no longer undernourished			
Central Africa	0.1	0.4	0.5
East Africa	0.4	1.0	1.4
Southern Africa	0.0	0.1	0.1
West Africa	0.7	2.9	3.6
sub-Saharan Africa	1.2	4.4	5.6

It is anticipated that the improved purchasing power generated by the uptake of improved rice technologies will help undernourished people in Africa to be able to afford to reach caloric sufficiency and more balanced diets. As a result of increased availability and reduced prices, 5.6 million undernourished people will reach caloric sufficiency in Africa, reducing the number of food-insecure people by 6%.

In terms of regional distribution of poverty reduction, it is expected that by 2020 some 6.8 million people will be lifted out of poverty in West Africa, 2.7 million in East Africa, 1.0 million in Central Africa and 0.5 million in Southern Africa.

In terms of regional distribution of reduction of undernourished people, it is expected that by 2020 some 3.6 million undernourished people will be able to afford to reach caloric sufficiency in West Africa, 1.4 million in East Africa, 0.5 million in Central Africa and 0.1 million in Southern Africa (see Appendix, Table 32.A.12 for the results disaggregated by country).

Poverty reduction for farmers by research theme

Analysis for the major research themes shows a wide divergence in their impact upon farmer poverty (Table 32.7).

Poverty reduction will be greatest for research that addresses biotic constraints, followed by research that addresses climate-related constraints, research to alleviate soil-related constraints, research to reduce postharvest losses and finally research to raise yield potential (Table 32.7). Only the most effective research theme contributes to the overall value to avoid double counting.

Poverty reduction for farmers by environment

As noted earlier, the major environment in terms of number of farmers is rainfed lowland. It is also in this environment that the expected poverty reduction will be highest. The general picture in poverty reduction is almost the same as the distribution of farmers across major rice-growing environments. The number of people living in rice-farming households that will annually be lifted out of poverty will be 2.0 million in the rainfed lowland environment; 1.4 million for upland, 0.7 million for irrigated and 0.1 million for other environments (Fig. 32.9).

Poverty reduction for farmers by research discipline

Agronomic research will yield the highest poverty reduction in the early years (2.5 million people), followed by breeding (0.83 million), postharvest research (0.31 million) and other research (0.24 million). By 2020, this trend will change as the starting year and growth of impact significantly differs from one research discipline to another. Thus, breeding will come in first position, followed by agronomy, postharvest and finally other research types (Fig. 32.10).

Table 32.7. Poverty reduction for farmers by major research theme (millions of people).

	First year (2014)	End year (2020)
Biotic stresses	2.47	3.51
Soil-related constraints	0.66	3.34
Climate- and water-related constraints	1.66	3.85
Postharvest-related constraints	0.31	1.43
Yield potential	0.82	4.37
All research themes	2.47	4.37

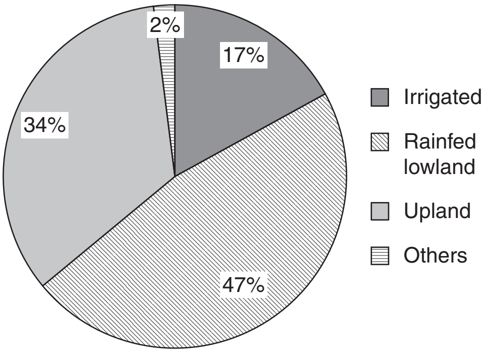

Fig. 32.9. Share of poverty reduction for farmers by rice environment.

As with income impact, there is a significant difference among research types when one differentiates by major research options. Poverty impacts of research to alleviate major stresses (biotic, climate-related, soil-related) derive mainly from agronomic research and to some significant extent from breeding. On the other hand, poverty reduction due to raising yield potential derives solely from breeding. Impact of research alleviating postharvest losses is due to postharvest research and 'other' types of research that could not be clearly classified (Table 32.8).

Research, economics and financial results and impact on production

This section presents the estimation of the direct and indirect research costs. It also describes the methods used to calculate economic and financial indicators.

Estimation of research costs and economic and financial indicators

This research and development (R&D) will be conducted mainly within the framework of the Global Rice Science Partnership (GRiSP), a CGIAR Research Programme on rice, led globally by the International Rice Research Institute (IRRI) in the Philippines and by AfricaRice for the African continent. Research costs include the GRiSP budget for Africa for the period 2011–2015 and a forecasted value for 2016–2020 – a total of about $420 million. They also include indirect costs of dissemination of the technologies (estimated from various past projects at about $1.2 billion).

The benefits and costs were aggregated and discounted to derive the rate of return and the benefit–cost ratio indicators. The financial rate of return for all research activities within the period 2011–2020 is estimated at 84% and the economic rate of return (assuming 20% price distortion) is 61%, showing that rice research in Africa within GRiSP is financially and economically very profitable.

SUMMARY IMPACT ON PRODUCTION AND RELATED INDICATORS.

Impact on rice production. By 2020, Africa's rice paddy production will have increased from 18.4 Mt in 2010 to 46.3 Mt. Without the R&D proposed and assessed in this chapter and projecting each country's production on the basis of 1980–2010 growth rate, the baseline level of paddy production would be 31.7 Mt (20.6 Mt of milled rice) in 2020. Thus, the research and its associated technology dissemination activities will result in a rice production increase of 14.6 Mt of paddy (9.5 Mt of milled rice), corresponding to a 46% increase over the baseline scenario.

Impact on rice imports. Simple projection of rice consumption under the baseline scenario using each country's rice consumption for the period 1980–2010 shows that rice consumption will rise from 19.8 Mt in 2010 to 35.0 Mt by 2020. Under the baseline scenario of no R&D,

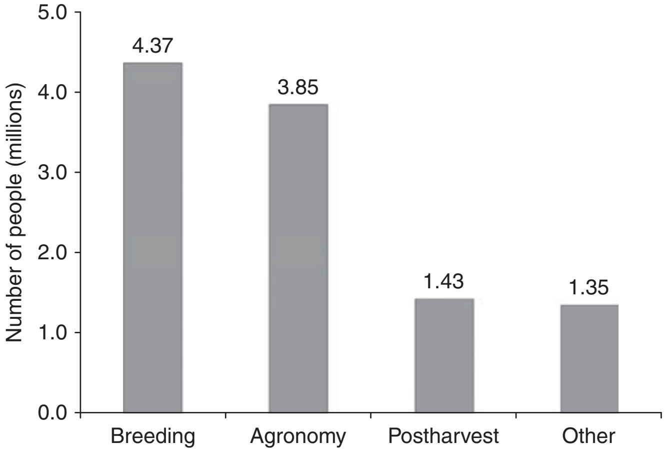

Fig. 32.10. Poverty reduction for farmers (numbers of farmers lifted above the $1.25 PPP poverty line) by research discipline by 2020.

Table 32.8. Number of people (millions) lifted out of poverty through adoption of technologies as grouped by major research themes and disciplines.

	Research discipline				
Research theme	Breeding	Agronomy	Postharvest	Others	All types
Impact on poverty in first year					
Biotic stresses	0.32	2.47	0.20	0.24	2.47
Soil-related constraints	0.38	0.66	0.00	0.20	0.66
Climate-related constraints	0.35	1.66	0.21	0.22	1.66
Postharvest-related constraints	0.00	0.00	0.31	0.22	0.31
Yield potential	0.82	0.00	0.00	0.00	0.82
All technologies	0.82	2.47	0.31	0.24	2.47
Impact on poverty in 2020					
Biotic stresses	1.48	3.51	0.86	1.26	3.51
Soil-related constraints	1.63	3.34	0.00	1.35	3.34
Climate-related constraints	1.86	3.85	0.96	1.24	3.85
Postharvest-related constraints	0.00	0.00	1.43	1.14	1.43
Yield potential	4.37	0.00	0.00	0.00	4.37
All technologies	4.37	3.85	1.43	1.35	4.37

Africa would have to import about 14.0 Mt of milled rice in 2020. But, with this proposed R&D and the production increase it will generate, imports will no longer reach this level, but rather 4.9 Mt in 2020 – corresponding to a reduction of 67%.

The production increase and the increase in quality of local rice attributed to the technologies generated by this research should lead to an increase in the continental rice self-sufficiency ratio from the current level of 60% to at least 83% in 2020. Under the baseline scenario, this ratio would remain close to 60%. In 2011, only five countries had a self-sufficiency ratio greater than 70% (Tanzania, 90%; Madagascar, 89%; Mali, 84%; DRC, 84%; Guinea, 74%); with the production increases predicted, at least nine more countries should reach this level, and all countries will increase their self-sufficiency ratios by 2020.

Contribution to agricultural GDP. The share of rice in agricultural gross domestic product (GDP) of sub-Saharan African countries should increase from the 2010 level of 3.82% to 5.19% in 2020. This corresponds to a 26.5% increase from the baseline scenario, which assumes that the agricultural GDP will maintain its current trend. Thus, R&D on rice in Africa will contribute to achieving the Comprehensive Africa Agriculture Development Programme target of 6% per year agricultural growth.

Conclusion

This chapter presents the AfricaRice research priority-setting exercise for 2011–2020. It covers methodology and presents the projected impact on income and poverty reduction from 2011 to 2020. The methodology used for this priority-setting borrows a lot from the methodologies used in the past, but also includes a number of innovative features.

We used a systematic approach and various data and econometric methods. The data on rice-growing environments, constraints to rice production, varietal characteristics and adoption of improved varieties were collected from household and community surveys. Secondary data were also collected from FAOSTAT, the World Bank and the African Development Bank. Research-based technologies were elicited from scientists, together with their expected efficacy (yield loss reduction), projected costs, probability of success and year of delivery. Econometric models were developed to assess: (i) farmer demand for rice traits and impact on adoption; (ii) impact of varietal technology demand on household total income and village-level poverty headcount; and (iii) impact of reduction of negative effects of production constraints on household total income and village-level poverty headcount. The model parameters were used to estimate impact at country level and for countries for which survey data were not available. Estimations were projected over 10 years, but taking into account the projected year of delivery and the probability of success. In total, the results of the exercise covered 38 major rice-producing countries, which represent more than 99% of the total sub-Saharan African rice area and production.

The priority-setting showed that the total cumulative discounted income benefit expected for all research and all sub-Saharan African countries will be $0.9 billion in 2014 and $10.6 billion in 2020, corresponding to an annual income gain of $1.8 billion. As a consequence of these income gains, 2.3 million people will be lifted above the $1.25 PPP poverty line in 2014 and 11.0 million in 2020. These figures hide important differences across research options and disciplines, regions and rice environments.

In terms of type of research, the impact of research to alleviate major biophysical constraints is most important. Thus, the main focus should be given to this area of research. However, the significant share of research that addresses postharvest constraints in the total benefit suggests that there is a need to consider this area in the future research agenda. Also, research that raises yield potential needs to continue to be undertaken. In terms of research discipline, breeding is the most important, followed by agronomy. Postharvest research, even though coming in last position, provides a significant share of the total benefit.

In terms of geographical area, the main rice-producing region in sub-Saharan Africa is West Africa, which accordingly will receive the highest research benefit. Research efforts need to continue to be focused in this region, with a specific focus on Nigeria, Guinea, Sierra Leone and Côte d'Ivoire. East Africa will be the second major beneficiary region and Central Africa third.

In general, the rainfed rice-growing environments predominate on the continent. This understanding was reinforced by the priority-setting results that showed that the rainfed lowlands will receive the greatest benefit from research, closely followed by the uplands. Irrigated environments, whose importance is increasing, will be the third major environment. The picture is slightly different across the regions. Rainfed lowlands and uplands are the major rice environments in West Africa and of almost equal importance. In East Africa, the two major rice environments are rainfed lowlands and irrigated. In Central Africa, upland is the major environment, followed by irrigated and rainfed lowlands in almost the same proportion.

Notes

[1] An earlier version of this chapter was presented at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18–24 August 2012. The results of this study have also been used in the AfricaRice Strategic Plan 2011–2020 (AfricaRice, 2011).

[2] See WARDA (1993, 1997, 2001a,b) for more details on priority-setting at WARDA during the 1990s.

[3] The National Experts Committee (NEC) is composed of the directors general of the national agricultural research systems (NARS) of AfricaRice's member states; the NEC meets once a year at AfricaRice headquarters to discuss research progress and new directions (i.e. strategic decision-making).

[4] Like other CGIAR-supported centres, AfricaRice has a Board of Trustees composed of nominees from member states and from non-member states. The Council of Ministers (COM), composed of Ministers of Agriculture or Scientific Research of member states is the highest governing body of the Center with statutory meetings being held once every 2 years.

[5] As in the priority-setting exercises conducted in 1990 and 2000, this one also involved a broad range of rice research and development stakeholder constituencies at different policy- and decision-making levels.

[6] Example: a breeding research solution addressing weed competitiveness by reducing the losses due to weeds by x% will result in an improved variety with a weed-competiveness performance $\frac{x}{100}$ higher than the average weed-competiveness of existing varieties.

[7] The extrapolation weight in the rice statistics data that is needed to estimate the total number of rice farmers is available for only a few countries (Guinea, Nigeria, Senegal and Sierra Leone).

[8] This assumes that the rice cropping intensity is once per year. Dawe *et al*. (2010) use the same method for some African and Asian countries.

[9] The 21 member countries of CARD in which household and community surveys were conducted were: Benin, Burkina Faso, Cameroon, Central African Republic, Côte d'Ivoire, DRC, The Gambia, Ghana, Guinea, Kenya, Liberia, Madagascar, Mali, Mozambique, Nigeria, Rwanda, Senegal, Sierra Leone, Tanzania, Togo and Uganda (see www.riceforafrica.org).

[10] Data for Guinea, Liberia and Mozambique were not in the right format and had not been aggregated with the others. Data for The Gambia and Tanzania were not completely processed.

[11] The survey does not directly measure income at household-member level. During the interviews, the enumerators evaluated the income of each member and summed these to get the income of the household.

[12] These do not include postharvest-research benefits at processor level.

[13] Processors and traders are considered as non-rice-farming consumers.

References

AfricaRice (2010) Rice data systems for sub-Saharan Africa: contribution to the Japan–AfricaRice Emergency Rice Project Synthesis Report. Africa Rice Center, Cotonou, Benin.

AfricaRice (2011) *Boosting Africa's Rice Sector: A research for development strategy 2011–2020*. Africa Rice Center, Cotonou, Benin.

Chalak, K. and White, H. (2011) An extended class of instrumental variables for the estimation of causal effects. *Canadian Journal of Economics* 44, 1–51.

Dawe, D., Pandey, S. and Nelson, A. (2010) Emerging trends and spatial patterns of rice production. In: Pandey, S., Byerlee, D., Dawe, D., Dobermann, A., Mohanty, S., Rozelle, S. and Hardy, B. (eds) *Rice in the Global Economy: Strategic research and policy issues for food security*. International Rice Research Institute, Los Baños, Philippines, pp. 015–025.

Deaton, A. and Muelbauer, J. (1980) *Economics and Consumer Behavior*. Cambridge University Press, Cambridge.

Diagne, A. (2009) Technological Change in Smallholder Agriculture: Bridging the adoption gap by understanding its source. *CEGA Working Paper* No. AfD-0905. Center of Evaluation for Global Action, University of California, Berkeley, California.

Diagne, A. and Demont, M. (2007) Taking a new look at empirical models of adoption: average treatment effect estimation of adoption rates and their determinants. *Agricultural Economics* 37, 201–210.

Diagne. A., Kormawa, K., Youm, O., Keya, S. and N'cho, S. (2009) Priority assessment for rice research in sub-Saharan Africa. In: Raitzer, D.A. and Norton, G.W. (eds) *Prioritizing Agricultural Research for Development*. CAB International, Wallingford, UK, pp. 116–135.

FAOSTAT (2010) http://faostat.fao.org/site/452/default.aspx (accessed November 2010).

Hosokawa, A. (1995) Introduction. In: Hosokawa, A. (ed.) *Rice Post Harvest Technology*. The Food Agency, Ministry of Agriculture, Forestry and Fisheries, Japan.

Imbens, G.M. and Woodridge, J.M. (2009) Recent developments in the econometrics of program evaluation. *Journal of Economic Literature* 47, 5–86.

Lançon, F., Erenstein, O., Akande, S.O., Titilola, S.O., Akpokodje, G. and Ogundele, O.O. (2003) Imported rice retailing and purchasing in Nigeria: a survey. Project report. The Nigerian rice economy in a competitive world: constraints, opportunities and strategic choices. West Africa Rice Development Association, Bouaké, Côte d'Ivoire.

Singh, I., Squire, L. and Strauss, J. (1986) The basic model: theory, empirical results, and policy considerations. In: Singh, I., Squire, L. and Strauss, J. (eds) *Agricultural Household Models*. The Johns Hopkins University Press, Baltimore, Maryland, pp. 17–47.

Taylor, E.J. and Adelman, I. (2003) Agricultural household models: genesis, evolution, and extensions. *Review of Economics of the Household* 1(1–2), 33–58.

Totté, A. (1995) *Les étapes de l'après-récolte du riz et le suivi de la qualité*. Food and Agriculture Organization of the United Nations, Rome.

Wadsworth, J.I. (1991) Milling. In: Luh, B.S. (ed.) *Rice Production*, 2nd Edn, Vol. 1. Van Nostrand Reinhold, New York.

Wang, C.Y. and Luh, B.S. (1991) Harvest, drying, and storage of rough rice. In: Luh, B.S. (ed.) *Rice Production*, 2nd Edn, Vol. 1. Van Nostrand Reinhold, New York, pp. 311–346.

WARDA (1993) Medium Term Plan 1994–1998 for Presentation to TAC on the 25th of March 1993. West Africa Rice Development Association, Bouaké, Côte d'Ivoire.

WARDA (1997) WARDA Medium Term Plan 1998–2000 for Presentation to the Mid-term Meeting of the Consultative Group on International Agricultural Research, Cairo, Egypt, 26–30 May 1997. West Africa Rice Development Association, Bouaké, Côte d'Ivoire.

WARDA (2001a) *Potential for Green Revolution in Rice in West and Central Africa. Report of Second Biennial WARDA/National Committee Meeting, 20–21 March 2000, M'bé, Côte d'Ivoire*. West Africa Rice Development Association, Bouaké, Côte d'Ivoire.

WARDA (2001b) *Summary of WARDA/NARS Task Forces Activities 1991–1997*. West Africa Rice Development Association, Bouaké, Côte d'Ivoire.

WARDA (2004a) *Strategic Plan 2003–2012*. West Africa Rice Development Association, Bouaké, Côte d'Ivoire.

WARDA (2004b) The Medium Term Plan 2005–2007: Charting the future of rice in Africa. West Africa Rice Development Association, Bouaké, Côte d'Ivoire.

Wooldridge, J.M. (2002) *Econometric Analysis of Cross Section and Panel Data*. MIT Press, Cambridge, Massachusetts.

World Bank (2010) World Development Indicators. Available at: http://data.worldbank.org/data-catalog/world-development-indicators (accessed 2 December 2010).

Appendix

Table 32.A.1. Stress grouping and correspondence between stress and varietal characteristics.

Major research theme	Sub-category	Varietal characteristics	Stress
Alleviate biotic stresses	Weeds	Weed competitiveness	Weeds
	Insects	Resistance	Insects (termites, African rice gall midge, stem borers)
	Birds	Resistance	Birds
	Diseases	Resistance	Diseases (bacterial leaf blight, blast, *Rice yellow mottle virus*) Nematodes
Alleviate soil-related constraints	Soil and nutrients	Resistance	Zn deficiency Salinity/Alkalinity Deficiency/low use efficiency of N, P, K Iron (Fe) toxicity Acidity
Alleviate climate-related constraints	Climate and water	Resistance	Drought Flooding Heat stress Cold stress
Alleviate postharvest-related constraints	Postharvest	Threshability, milling recovery	Postharvest losses
Raise the genetic yield potential	–	Yield potential	–

Table 32.A.2. Village variety exposure and adoption rate.

	Parameter	SE	z-statistic
Mean population potential adoption rate (ATE)	0.644	0.004	185.52***
Potential adoption rate among exposed (ATT)	0.645	0.004	203.48***
Potential adoption rate among exposed (ATU)	0.643	0.004	154.02***
JEA rate	0.399	0.002	203.48***
GAP	–0.246	0.001	–154.08***
PSB	0.001	0.001	7.3
Observed			
Exposure rate	0.467	0.002	188.98***
Observed adoption rate	0.291	0.002	129.51***
Observed adoption rate among exposed	0.624	0.005	129.51***

ATE, Average Treatment Effect; ATT, average treatment effect on the treated; ATU, average treatment effect on the untreated; JEA, joint exposure and adoption; GAP, adoption gap; PSB, population selection bias; SE, standard error.

Table 32.A.3. Varietal characteristics frontier, demand and relative demand.

Characteristics	Frontier $\max_{j=1,\ldots J}\{\theta_{jk}\}$	Demand $\frac{1}{J}\sum_{j=1}^{J}\theta_{js}\times d_j^{**}$	Relative demand $\frac{\bar{\theta}}{\hat{\theta}_s}$
Weed competitiveness	0.78	0.70	0.91
Resistance to birds	0.71	0.64	0.92
Resistance to insects	0.76	0.69	0.92
Resistance to diseases	0.78	0.71	0.92
Resistance to soil stresses	0.70	0.62	0.90
Resistance to drought	0.73	0.66	0.91
Threshability, milling recovery	0.69	0.62	0.91
High yield potential	0.66	0.58	0.90

Table 32.A.4. Varietal characteristics demand elasticities.

Varietal characteristic	Demand elasticities (adoption parameter)
Weed competitiveness	0.62
Resistance to birds	0.66
Resistance to insects	0.63
Resistance to diseases	0.60
Resistance to soil stresses	0.58
Resistance to drought	0.61
Threshability, milling recovery	0.57
High yield potential	0.60

Table 32.A.5. Yield loss and area affected by major constraints.

	Actual yield loss in 2008 (%)				
Constraint	Irrigated	Rainfed lowland	Upland	Others	Area affected in 2008 (%)
Weeds	17.6	22.5	22.6	20.7	33.4
Birds	21	17.6	18.7	13.7	26.4
Insects	19.5	21.3	22.8	16.8	29.4
Diseases	21.4	19.8	20.8	21.7	27.3
Soil and nutrient	30.2	28.7	24.9	26.3	36.5
Climate	28.2	25.6	27.6	17.7	35.9
Postharvest	28.8	23.8	13.6	34.0	26.9

Table 32.A.6. Scientist survey results grouped by major research themes and rice-growing environment.

Research theme	Environment	Yield loss reduction (t/ha)	Fixed cost ($)	Annual cost ($)	Time to delivery (years from 2010)	Probability of success (%)
Alleviate biotic stresses	Irrigated	0.53	151,981	171,708	3.95	75
	Rainfed lowland	0.38	149,715	179,391	4.12	73
	Upland	0.37	112,370	186,000	3.81	76
	Others	0.27	53,483	80,225	3.66	69
	All environments	0.39	120,889	157,313	3.88	73
Alleviate soil-related constraints	Irrigated	0.55	130,714	151,607	4.10	71
	Rainfed lowland	0.55	106,357	133,357	4.81	75
	Upland	0.40	114,077	135,857	4.09	75
	Others	0.31	37,273	55,273	4.77	72
	All environments	0.46	100,231	122,632	4.43	73
Alleviate climate-related constraints	Irrigated	0.61	157,867	203,200	4.77	73
	Rainfed lowland	0.47	113,912	120,735	4.45	73
	Upland	0.48	162,143	196,643	4.37	72
	Others	0.33	58,600	42,500	4.84	75
	All environments	0.49	127,866	147,830	4.59	73
Alleviate postharvest-related constraints	Irrigated	0.33	45,333	88,667	3.43	77
	Rainfed lowland	0.41	28,625	62,250	3.61	78
	Upland	0.39	32,875	60,000	3.55	78
	Others	0.20	25,600	41,000	2.69	84
	All environments	0.35	34,267	66,033	3.39	79
Raise the genetic yield potential	Irrigated	1.32	103,143	97,571	4.12	71
	Rainfed lowland	1.23	99,000	124,000	5.68	67
	Upland	1.02	83,333	145,000	4.67	72
	Others	0.0	0	0	0.0	0
	All environments	1.20	155,000	120,722	4.74	70
All options	Irrigated	0.60	130,080	156,123	4.11	73
	Rainfed lowland	0.51	113,328	136,769	4.4	74
	Upland	0.45	110,945	158,621	4.03	75
	Others	0.28	47,425	61,793	4.06	72
	All environments	0.48	105,556	134,063	4.15	74

Table 32.A.7. Scientist survey results grouped by major research theme and discipline.

Research to	Type	Yield loss reduction (t/ha)	Fixed cost ($)	Annual cost ($)	Time to delivery (years from 2010)	Probability of success (%)
Alleviate biotic stresses	Breeding	0.42	194,550	237,300	4.55	78
	Agronomy	0.38	65,367	97,244	2.93	63
	Postharvest	0.25	21,000	23,500	3.75	96
	Other	0.35	46,100	98,400	4.58	81
	All types	0.39	120,889	157,313	3.88	73
Alleviate soil-related constraints	Breeding	0.45	90,929	96,857	5.96	74
	Agronomy	0.51	111,083	151,500	2.89	75
	Postharvest	0.00	0	0	0.00	0
	Other	0.39	0	0	0.00	66
	All types	0.46	100,231	122,632	4.43	73
Alleviate climate-related constraints	Breeding	0.52	212,875	177,083	5.11	68
	Agronomy	0.47	82,775	173,500	4.82	74
	Postharvest	0.45	43,250	76,750	3.26	74
	Other	0.45	27,875	31,438	3.09	85
	All types	0.49	127,866	147,830	4.59	73
Alleviate postharvest-related constraints	Breeding	0.00	0	0	0.00	0
	Agronomy	0.00	0	0	0.00	0
	Postharvest	0.40	42,150	82,050	2.84	79
	Other	0.24	18,500	34,000	4.48	78
	All types	0.35	34,267	66,033	3.39	79
Raise the genetic yield potential	Breeding	1.20	95,389	120,722	4.74	70
	Agronomy	0.00	0	0	0.00	0
	Postharvest	0.00	0	0	0.00	0
	Other	0.00	0	0	0.00	0
	All types	1.20	95,389	120,722	4.74	70
All options	Breeding	0.58	155,945	169,336	5.06	74
	Agronomy	0.44	83,434	131,548	3.37	69
	Postharvest	0.38	40,692	76,731	3.03	81
	Other	0.35	31,036	56,268	4.08	78
	All types	1.20	95,389	120,722	4.74	70

Table 32.A.8. Parameters for impact models.

		Impact on income		Impact on poverty	
	Type of research	β	α	β	α
Birds	Agronomy	–4.81	0.61	0.72	0.14
	Breeding	161.16	0.74	–4.23	0.85
	Postharvest	–2.01	0.42	0.07	0.77
	Other	–4.96	0.61	0.21	0.83
Climate-related constraints	Agronomy	–3.17	0.63	0.26	0.72
	Breeding	138.54	0.74	–4.13	0.85
	Postharvest	–2.01	0.42	0.07	0.77
	Other	–4.96	0.61	0.21	0.83
Diseases	Agronomy	–4.62	0.63	0.20	0.73
	Breeding	143.63	0.73	–3.91	0.85
	Postharvest	–2.01	0.42	0.07	0.77
	Other	–4.96	0.61	0.21	0.83
Insects	Agronomy	–1.03	0.61	0.07	0.73
	Breeding	134.80	0.73	–4.49	0.85
	Postharvest	–2.01	0.42	0.07	0.77
	Other	–4.96	0.61	0.21	0.83
Postharvest-related constraints	Agronomy	–2.01	0.42	0.07	0.77
	Breeding	135.10	0.74	–4.51	0.85
	Postharvest	–2.01	0.42	0.07	0.77
	Other	–4.96	0.61	0.21	0.83
Soil-related constraints	Agronomy	–1.47	0.61	0.14	0.77
	Breeding	132.48	0.73	–4.36	0.85
	Postharvest	–2.01	0.42	0.07	0.77
	Other	–4.96	0.61	0.21	0.83
Weeds	Agronomy	–1.40	0.61	0.20	0.72
	Breeding	124.42	0.73	–4.03	0.85
	Postharvest	–2.01	0.42	0.07	0.77
	Other	–4.96	0.61	0.21	0.83
Yield potential	Agronomy	0.00	0.00	0.00	0.00
	Breeding	73.81	0.73	–4.84	0.85
	Postharvest	0.00	0.00	0.00	0.00
	Other	0.00	0.00	0.00	0.00

β, α, as per Eqn 32.4.

Table 32.A.9. Annual income benefit by actors and country ($ million).

Country	Farmers	Consumers	Processors	Traders	Total
Angola	5.3	9.6	0.0	0.0	15.0
Benin	6.1	6.2	0.3	0.1	12.8
Burkina Faso	11.8	32.4	0.6	0.3	45.0
Burundi	4.6	8.6	0.4	0.2	13.7
Cameroon	12.7	3.5	0.3	0.1	16.6
Central African Republic	6.0	3.2	0.2	0.1	9.5
Chad	25.6	6.3	0.5	0.2	32.6
Comoros	3.5	0.9	0.3	0.1	4.8
DRC	49.2	28.7	0.9	0.4	79.2
Congo, Republic	0.4	2.6	0.0	0.0	3.0
Côte d'Ivoire	68.8	5.5	2.2	1.1	77.6
Ethiopia	3.1	0.5	0.9	0.4	4.9
Gabon	0.2	0.1	0.0	0.0	0.3
The Gambia	9.1	1.7	0.1	0.0	11.0
Ghana	19.9	10.9	0.9	0.4	32.1
Guinea	80.8	1.2	4.5	2.1	88.6
Guinea-Bissau	16.8	19.2	2.3	1.1	39.4
Kenya	0.7	4.1	0.4	0.2	5.3
Liberia	42.4	4.4	0.9	0.4	48.1
Madagascar	121.6	91.7	8.5	4.0	225.8
Malawi	17.1	0.2	4.0	2.0	23.3
Mali	51.7	15.4	4.5	2.1	73.7
Mauritania	3.4	0.7	2.2	1.1	7.4
Mozambique	11.1	19.8	0.4	0.2	31.5
Niger	4.7	20.6	0.2	0.1	25.6
Nigeria	308.9	247.2	11.3	5.4	572.9
Rwanda	5.4	4.0	5.4	2.7	17.5
Senegal	8.1	16.6	1.2	0.6	26.4
Sierra Leone	75.2	0.5	3.2	1.5	80.4
Somalia	0.0	0.0	0.0	0.0	0.0
South Africa	0.2	9.6	1.2	0.6	11.7
Sudan[a]	0.7	11.3	0.1	0.0	12.1
Swaziland	0.0	0.0	0.0	0.0	0.0
Tanzania	103.5	43.8	3.7	1.7	152.7
Togo	4.6	1.7	1.8	0.9	9.0
Uganda	13.1	10.8	0.5	0.3	24.7
Zambia	2.4	4.2	0.3	0.1	7.0
Zimbabwe	0.0	3.0	0.0	0.0	3.0
All sub-Saharan Africa	**1098.5**	**650.6**	**64.2**	**30.8**	**1844.2**

[a] Including South Sudan.

Table 32.A.10. Annual income benefit for farmers by rice-growing environment ($ million).

Country	Irrigated	Upland	Rainfed lowland	Others	Total for farmers
Angola	0.7	3.9	0.6	0.1	5.3
Benin	0.1	1.7	3.9	0.4	6.1
Burkina Faso	0.1	2.1	8.8	0.7	11.8
Burundi	2.2	2.0	0.3	0.1	4.6
Cameroon	1.8	8.0	2.9	0.0	12.7
Central African Republic	0.0	5.5	0.4	0.1	6.0
Chad	0.3	22.0	3.2	0.0	25.6
Comoros	0.3	0.6	2.6	0.1	3.5
DRC	6.2	36.4	5.7	0.9	49.2
Congo, Republic	0.1	0.3	0.0	0.0	0.4
Côte d'Ivoire	1.6	45.1	21.7	0.4	68.8
Ethiopia	2.5	0.0	0.6	0.0	3.1
Gabon	0.0	0.1	0.0	0.0	0.2
The Gambia	4.1	2.1	2.4	0.4	9.1
Ghana	2.3	1.5	15.9	0.2	19.9
Guinea	2.2	48.9	27.3	2.4	80.8
Guinea-Bissau	7.4	1.8	3.6	3.9	16.8
Kenya	0.3	0.4	0.0	0.0	0.7
Liberia	0.7	28.9	11.6	1.2	42.4
Madagascar	52.1	14.5	46.1	8.8	121.6
Malawi	1.4	15.7	0.0	0.0	17.1
Mali	10.6	8.1	32.6	0.4	51.7
Mauritania	3.4	0.0	0.0	0.0	3.4
Mozambique	3.6	1.4	5.7	0.4	11.1
Niger	0.1	2.2	2.4	0.1	4.7
Nigeria	4.0	95.3	209.7	0.0	308.9
Rwanda	5.4	0.0	0.0	0.0	5.4
Senegal	7.2	0.6	0.0	0.3	8.1
Sierra Leone	0.0	58.8	12.6	3.7	75.2
Somalia	0.0	0.0	0.0	0.0	0.0
South Africa	0.0	0.2	0.0	0.0	0.2
Sudan[a]	0.5	0.1	0.1	0.0	0.7
Swaziland	0.0	0.0	0.0	0.0	0.0
Tanzania	23.7	12.1	67.6	0.1	103.5
Togo	0.3	1.8	2.5	0.0	4.6
Uganda	0.0	6.1	7.0	0.0	13.1
Zambia	0.2	2.2	0.0	0.0	2.4
Zimbabwe	0.0	0.0	0.0	0.0	0.0
All sub-Saharan Africa	**145.4**	**430.5**	**497.8**	**24.8**	**1098.5**

[a] Including South Sudan.

Table 32.A.11. Number of people lifted above the PPP $1.25 poverty in 2020 by country.

	For farmers by rice environment					
Country	Irrigated	Upland	Rainfed lowland	Others	Total	Total for consumers
Angola	2,704.1	10,936.9	1,992.3	329.5	15,962.9	101,180.2
Benin	549.9	5,006.4	13,106.8	1,430.0	20,093.0	85,623.7
Burkina Faso	952.0	9,502.9	45,249.2	3,924.6	59,628.6	391,033.2
Burundi	8,908.8	5,550.7	1,011.2	167.2	15,637.9	55,704.9
Cameroon	7,377.4	22,205.8	9,361.6	0.0	38,944.8	101,715.2
Central African Republic	85.1	9,784.7	774.9	147.5	10,792.1	24,240.7
Chad	1,299.6	61,071.0	10,311.0	23.0	72,704.5	62,648.1
Comoros	1,016.8	1,555.4	8,541.0	176.3	11,289.5	9,852.9
DRC	26,165.4	105,828.8	19,278.3	3,188.7	154,461.2	265,059.6
Congo, Republic	206.9	837.0	152.5	25.2	1,221.7	26,462.9
Côte d'Ivoire	7,756.5	155,469.9	87,342.2	1,566.9	252,135.5	216,689.9
Ethiopia	9,914.0	0.0	1,985.9	0.0	11,899.9	11,011.6
Gabon	92.1	277.1	116.8	0.0	485.9	28,681.4
The Gambia	16,573.1	5,882.6	7,787.3	1,465.0	31,708.0	37,734.1
Ghana	2,935.0	1,320.6	16,385.0	240.2	20,881.6	238,026.9
Guinea	8,743.1	135,346.7	88,421.1	7,941.0	240,452.0	20,450.5
Guinea-Bissau	29,468.1	5,077.0	11,769.6	13,081.1	59,395.8	139,768.6
Kenya	1,280.6	1,374.9	50.4	0.0	2,706.0	153,298.3
Liberia	2,791.9	80,051.1	37,465.2	3,970.2	124,278.3	22,784.6
Madagascar	259,396.9	50,044.4	185,358.8	36,518.4	531,318.4	802,251.4
Malawi	5,436.9	43,562.7	0.0	0.0	48,999.6	1,513.9
Mali	100,480.5	52,859.5	249,231.8	3,226.1	405,797.8	190,761.9
Mauritania	13,637.3	0.0	0.0	0.0	13,637.3	57,329.8
Mozambique	14,471.7	3,793.7	18,587.9	1,361.1	38,214.3	150,887.1
Niger	296.5	5,972.0	7,657.8	198.8	14,125.0	172,633.5
Nigeria	19,365.7	319,761.5	821,680.3	0.0	1,160,807.5	2,013,711.1
Rwanda	16,543.2	0.0	0.0	0.0	16,543.2	25,095.4
Senegal	35,693.5	2,038.0	0.0	1,339.0	39,070.4	353,501.4
Sierra Leone	0.0	275,379.6	68,970.6	20,818.1	365,168.3	6,078.8
Somalia	0.0	0.0	0.0	0.0	0.0	0.0
South Africa	60.3	483.1	0.0	0.0	543.4	419,157.8
Sudan[a]	1,809.3	395.4	273.8	0.0	2,478.5	120,607.1
Swaziland	0.0	0.0	0.0	0.0	0.0	0.0
Tanzania	94,945.8	33,512.1	218,582.5	276.1	347,316.5	255,127.7
Togo	1,407.0	6,126.6	10,084.2	0.0	17,617.8	33,947.1
Uganda	67.3	15,989.5	21,525.7	0.0	37,582.6	133,725.5
Zambia	747.9	5,992.6	0.0	0.0	6,740.5	29,225.3
Zimbabwe	10.8	86.3	0.0	0.0	97.0	65,623.6
All sub-Saharan Africa	**693,191.4**	**1,433,076.3**	**1,963,055.8**	**101,413.9**	**4,190,737.4**	**6,823,145.9**

[a] Including South Sudan.

Table 32.A.12. Number of people no longer undernourished in 2020 by country.

	Farmers by environment					
Country	Irrigated	Upland	Rainfed lowland	Others	Total	Total for consumers
Angola	1,356.4	5,486.1	999.4	165.3	8,007.2	173,945.0
Benin	149.3	1,359.3	3,558.6	388.2	5,455.4	32,009.5
Burkina Faso	95.5	953.6	4,540.7	393.8	5,983.6	151,401.7
Burundi	5,166.1	3,218.8	586.4	97.0	9,068.3	34,480.2
Cameroon	2,764.8	8,321.9	3,508.4	0.0	14,595.1	23,557.3
Central African Republic	72.5	8,338.1	660.3	125.7	9,196.6	18,297.8
Chad	667.5	31,369.4	5,296.3	11.8	37,345.0	50,181.1
Comoros	638.0	976.0	5,359.4	110.6	7,084.0	7,145.3
DRC	4,756.8	19,239.3	3,504.7	579.7	28,080.6	38,882.0
Congo, Republic	70.5	285.0	51.9	8.6	415.9	36,412.2
Côte d'Ivoire	1,544.3	30,952.9	17,389.2	312.0	50,198.3	28,394.4
Ethiopia	4,222.6	0.0	845.8	0.0	5,068.4	1,384.6
Gabon	56.8	170.9	72.0	0.0	299.7	2,334.4
The Gambia	4,663.8	1,655.4	2,191.4	412.3	8,922.8	3,429.3
Ghana	1,520.8	684.1	8,487.6	124.4	10,816.8	27,969.5
Guinea	2,166.5	33,537.9	21,910.1	1,967.7	59,582.2	1,768.6
Guinea-Bissau	8,693.1	1,497.7	3,472.0	3,859.0	17,521.8	62,128.4
Kenya	497.3	533.9	19.6	0.0	1,050.7	37,421.7
Liberia	1,061.6	30,437.9	14,245.4	1,509.6	47,254.5	36,021.2
Madagascar	74,257.2	14,326.1	53,062.4	10,454.1	152,099.9	429,113.7
Malawi	2,094.2	16,779.2	0.0	0.0	18,873.4	781.8
Mali	8,964.2	4,715.8	22,234.7	287.8	36,202.4	51,061.8
Mauritania	3,701.1	0.0	0.0	0.0	3,701.1	2,662.0
Mozambique	6,176.1	1,619.0	7,932.8	580.9	16,308.9	96,691.9
Niger	77.2	1,554.9	1,993.9	51.8	3,677.7	66,638.9
Nigeria	5,816.1	96,034.4	246,776.4	0.0	348,627.0	2,314,629.5
Rwanda	7,128.6	0.0	0.0	0.0	7,128.6	12,743.2
Senegal	7,939.9	453.3	0.0	297.8	8,691.1	89,394.6
Sierra Leone	0.0	67,566.8	16,922.5	5,107.9	89,597.2	2,103.8
Somalia	0.0	0.0	0.0	0.0	0.0	0.0
South Africa	9.6	77.2	0.0	0.0	86.8	28,833.5
Sudan[a]	567.1	123.9	85.8	0.0	776.9	58,256.6
Swaziland	0.0	0.0	0.0	0.0	0.0	0.0
Tanzania	44,407.9	15,674.2	102,235.1	129.1	162,446.3	354,425.6
Togo	488.9	2,129.0	3,504.2	0.0	6,122.2	6,769.0
Uganda	26.6	6,315.1	8,501.7	0.0	14,843.4	33,546.6
Zambia	410.8	3,291.3	0.0	0.0	3,702.1	55,139.1
Zimbabwe	4.3	34.5	0.0	0.0	38.8	5,739.2
All sub-Saharan Africa	**198,305.6**	**409,969.2**	**561,583.7**	**29,012.1**	**1,198,870.7**	**4,375,695.1**

[a] Including South Sudan.