

Potential returns to yam research investment in sub-Saharan Africa and beyond

Outlook on Agriculture
1–10

© The Author(s) 2020



Article reuse guidelines:

sagepub.com/journals-permissions

DOI: 10.1177/0030727020918388

journals.sagepub.com/home/oag



Djana Babatima Mignouna¹, **Adebayo Akinboye Akinola^{2,3}**,
Tahirou Abdoulaye⁴, **Arega D Alene⁵**, **Victor Manyong⁶**,
Norbert G Maroya², **Beatrice Anim Aighewi²**, **Lava P Kumar²**,
Morufat Balogun^{2,7}, **Antonio Lopez-Montes⁸**,
Deborah Rees⁹ and **Robert Asiedu²**

Abstract

Lack of good-quality planting materials has been identified as the most severe problem militating against increased agricultural productivity in sub-Saharan Africa (SSA) and beyond. However, investment of research efforts and resources in addressing this menace will only be feasible and worthwhile if attendant economic gains are considerable. As a way of investigating the economic viability of yam investment, this research has been initiated to address problems confronting yam productivity in eight countries of SSA and beyond: Nigeria, Ghana, Benin, Togo, Côte d'Ivoire, Papua New Guinea, Jamaica, and Columbia. Research options developed were to be deployed and disseminated. Key technologies include the adaptive yam miniset technique (AYMT), varieties adapted to low soil fertility and drought, nematode-resistant cultivars (NRC), and crop management and postharvest practices (CMPP). This article aims at estimating the potential economic returns, the expected number of beneficiaries, and poverty reduction consequent to the adoption of technology options. Estimates show that the new land area that will be covered by the technologies in the eight countries will range between 770,000 ha and 1,000,000 ha with the highest quota accounted for by AYMT. The net present value will range between US\$584 and US\$1392 million and was highest for the NRC. The CMPP had the lowest benefit-cost ratio of 7.74. About 1,049,000 people would be moved out of poverty by these technologies by 2037 in the region. These technologies are less responsive to changes in cost than that in adoption rate. Therefore, the realization of the potential economic gains depends on the rate and extent of adoption of these technologies. Giving the knowledge-intensive nature of some of these interventions, capacity building of potential adopters will be critical to increasing the sustainability of the yam sector, thereby enhancing food security and reducing poverty.

Keywords

Ex ante impact, staple crop, long-term benefits, public policy, poverty

Introduction

The significance of yam (*Dioscorea spp.*) in terms of volume and value of production cannot be over-emphasized in Africa and beyond. Africa accounts for 97% of the world's production far beyond the Americas (2%) and Oceania (1%) (FAO, 2019). More than five million people in yam growing countries directly depend on the yam value chain for their food security and livelihoods. Its prominence as an arable crop is intricately linked to its substantial contribution to dietary protein and wide consumption especially in West Africa (WA) and the Caribbean as an important delicacy (Asiedu and Sartie, 2010). Moreover, yam is a valued ceremonial and traditional crop playing important roles in the social ceremonies of WA region (Aighewi et al., 2002). However, arguably, availability of and access to

¹ International Institute of Tropical Agriculture (IITA), Godomey, Benin

² International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria

³ Obafemi Awolowo University, Ilé-Ife, Nigeria

⁴ International Institute of Tropical Agriculture (IITA), Bamako, Mali

⁵ International Institute of Tropical Agriculture (IITA), Lilongwe, Malawi

⁶ International Institute of Tropical Agriculture (IITA), Dar es Salaam, Tanzania

⁷ University of Ibadan (UI), Ibadan, Nigeria

⁸ International Trade Centre-Yam Development Council (ITC-YDC), Accra, Ghana

⁹ Natural Resources Institute (NRI), University of Greenwich, Greenwich, London, UK

Corresponding author:

Djana Babatima Mignouna, International Institute of Tropical Agriculture (IITA) in Benin, 08 BP 0932 Tri Postal Cotonou, Benin.

Email: d.mignouna@cgiar.org

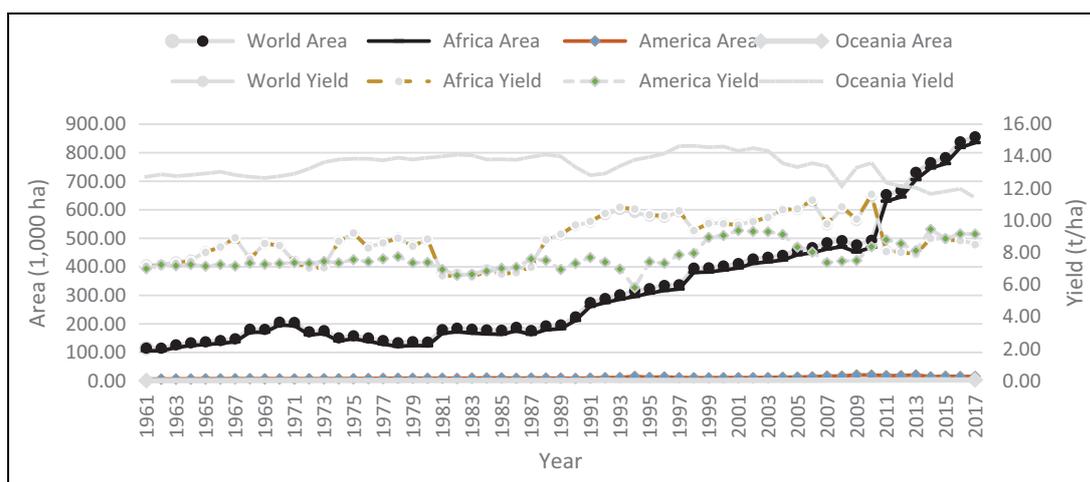


Figure 1. Trends in yam area and yields, 1961–2017. *Source:* FAOSTAT database (FAO, 2019).

good-quality planting materials is the most severe problem militating against an increase in agricultural productivity (Aighewi et al., 2015; Gildemacher et al., 2009; Poku et al., 2018). This may be reflected in the multifaceted institutional, ecological, technical, and economic seed-related problems bedeviling the yam sector (Aighewi et al., 2002). In fact, it has been posited that a considerable amount of production-related costs are usually connected with seed acquisition and use. Mignouna et al. (2015) opined that more than half of the total production costs could be allocated to yam planting materials. The associated costs could constitute a great impediment to small-holder yam farmers. The most important constraints to seed yam tuber multiplication are its low reproduction ratio in the fields and pest and disease challenges. Despite the importance of yam production in Africa, yam yield and area covered are more pronounced in Oceania though they stagnated during the 1960s but varied substantially after the 1990s (Figure 1). While the quantity of cropland under yam is growing, productivity per hectare has remained virtually unchanged. Therefore, increases in yield are often difficult to achieve globally. In addition, yam is often not prominent in the policies and resources of many governments and regional development agencies (Mignouna et al., 2015).

Inefficient traditional methods of yam production require farmers to save a minimum of a third of their harvests for the following planting season, reducing their incomes from harvests. In addition, the saved seeds are often diseased, leading to significantly lower yields. Tackling the challenges of traditional yam production could be a giant step to improving food security of resource-poor yam farming households by improving the production system especially in sub-Saharan Africa (SSA). In fact, the crop has the potential to address hunger and poverty if measures are taken to acquire and distribute technological innovations that can convey yam into a focal point in food policies across countries (Mignouna et al., 2015). These innovations along with an enabling policy environment are expected to increase the sustainability of the yam sector thereby making the crop more attractive to farmers and increasing the supply of the commodity in the subregion and beyond.

It has also become imperative to accentuate public investments in yam research consequent upon decreased funding for national and international agricultural research in recent years. Yam continues to be neglected in national food policy programs of many countries and receives little attention from African regional development agencies such as the African Development Bank (AfDB, 2016; Mignouna et al., 2015). Moreover, knowledge of economic returns to investment in yam productivity research is yet to be documented. Therefore, based on experience from the Yam Improvement for Income and Food Security in West Africa (YIIFSWA) project, this study uses the economic surplus (ES) model to assess the potential effects of research in developing and pushing out the yam technologies, thereby identifying and prioritizing technological solutions. The approach adopted involves the cost-benefit analyses of the intervention options and attempts to estimate the expected number of beneficiaries of technological options and thus poverty reduction effects. This article is developed based on the yam research priority setting exercise as part of the larger research priorities for the CGIAR Research Program on Roots, Tubers, and Bananas (CGIAR-RTB) (Abdoulaye et al., 2014). It follows Alston et al. (1995) with a special focus on SSA and the Caribbean for governing the global yam production (FAO, 2019).

Overview of the YIIFSWA project

Efforts aimed at reducing the constraints in the yam sector received a major boost through an important project on yam in SSA. The YIIFSWA project (<http://www.iita.org/web/yiifswa/home>.) is executed by the International Institute of Tropical Agriculture (IITA) and partners. The project set out to explore prospects that could double yam yields in the region and contribute to food security. It focuses on addressing the constraints of lack of sufficient quantities and the absence of quality seed yams. The YIIFSWA project has made significant progress in the realization of the set objectives through the development and deployment of technologies tailored at addressing the problems of yam productivity.

Description of intervention options

The technologies emanating from the YIIFSWA project that are considered for deployment and possible adoption in yam-growing countries to address the major constraints in yam sector for increased productivity and market potential are as follows:

Adaptive yam miniset technique. The yam miniset technique (YMT) was one of the first technique developed for seed yam production. This technology developed in late 1970 by IITA and the National Root Crops Research Institute, aimed at overcoming the problem of lack of good quality and quantity of seed yam by increasing the multiplication rate of yam (Aighewi et al., 2015). The process entails cutting mother seed tubers from a nondormant tuber into small setts (25–50 g) (Okoli and Akoroda, 1995). Its advantages over traditional methods include a reduced proportion of ware tubers used as seed, a higher multiplication ratio, faster crop emergence, the establishment of whole seed tubers produced from setts, and so on (Aighewi et al., 2014). Adoption studies revealed cases of low or reverse adoption (Morse, 2018; Nweke, 2016). Consequently, the YMT was modified by the YIIFSWA project into the adaptive YMT (AYMT) to address farmers' complaints about the size of tubers produced while incorporating the use of available chemical treatments to lessen pest and disease pressure (Aighewi et al., 2002). The project started using participatory approaches with an integrated training and visit model to disseminate the technique vigorously in yam producing countries of WA since its inception in 2012 to strengthen the yam seed system for quantity and quality assurance. This scheme consisted of grouping farmers in selected communities and assigning them to demonstration plots under the supervision and guidance of NGOs engaged by IITA. Demonstration sites were purposely selected to deal with skeptics, showing how the setts could perform, yielding good-quality seed yam tubers which would be used to produce ware yam.

Varieties adapted to low soil fertility and drought. The varieties adapted to low soil fertility and drought (VALSFD) option consisted of evaluating and disseminating adapted varieties to stress environments such as drought, low moisture, low soil fertility, and laborsaving systems to increase the yield and income from ware yam production in yam producing countries especially in WA (Maroya et al., 2014). Various stress-tolerant and virus-resistant varieties in the pipeline for release from the breeding programs of IITA and National Agricultural Research Systems, together with released/improved varieties and local popular varieties were evaluated by farmers. The evaluation was done through the conventional mother–baby trials in different localities of four prioritized production systems in those countries. The localities were selected in WA, based on YIIFSWA's value chain and baseline studies as well as yam production systems identified and characterized through a complementary project funded by the Ministry of Agriculture, Forestry and Fisheries of Japan. During the

evaluation process, farmers for each gender category ranked the top five preferred varieties relative to the existent popular landraces (Maroya et al., 2014).

Nematode-resistant cultivars. Root-knot nematode infected tubers are less marketable and deteriorate during storage faster than healthy tubers, leading to persistent decline in yam quality and production and even total loss of susceptible cultivars. Recent molecular studies on *Scutellonema bradys* populations collected throughout WA demonstrated a relatively high degree of polymorphism both within and between populations. Identification of suitable sources of resistance against *S. bradys* and the development of acceptable nematode-resistant cultivars (NRC) would improve yam yields. Therefore, through the project, a comprehensive assessment of selected yam varieties was screened for nematodes, anthracnose, and viruses.

Crop management and postharvest practices. The crop management and postharvest practices (CMPP) are expected to significantly reduce losses of tubers during on-farm storage and during transport/marketing. To achieve these goals, the project considers the potential for reducing losses through appropriate variety selection and postharvest technologies, including improved storage structures, curing, sprout control, and, in selected regions, yam preservation/processing. Optimum curing conditions were determined in controlled studies on-station, where a 50% reduction in the rate of loss was demonstrated (Rees et al., 2012). Dormancy break and sprouting are one of the most critical constraints to yam storage for long periods above 3 months after harvesting. This is due to tuber weight loss associated with sprout growth and their susceptibility to rotting. Practices of sprout removal/control aimed at reducing losses have been attempted in the project with limited success (Rees et al., 2012). Treatment with gibberellic acid was found to reduce losses due to sprouting (from 44% to 14%; or a 67% reduction) for four varieties at 8 weeks' storage. With respect to storage structures, a design for an improved yam barn constructed from local materials was tested through the project and found to reduce losses due to rotting and weight loss compared to traditional designs. As part of the YIIFSWA project, trials were undertaken to determine the impact of tuber packing and cushioning during transport on storage losses. Results obtained underlined the importance of loading the tubers by experienced packers, who can position/pack the tubers so that physical damage during transport is minimized. In addition, a particularly high level of heavy metal contamination was found, which turned out to originate from the metal drums used for soaking yam prior to drying. Improved methods for producing safer and better-quality products are being tested/validated.

Methodology

The methodology employed for this study involved the estimation of the adoption pathway, operationalizing the ES model to generate economic benefits of technological

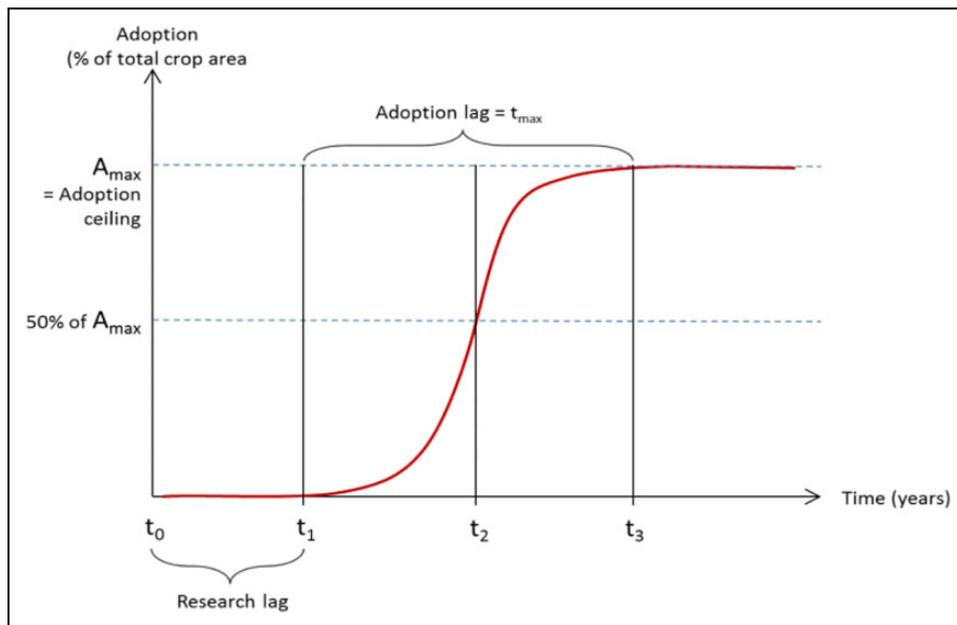


Figure 2. Hypothetical pattern of adoption of YIIFSWA technologies. YIIFSWA: Yam Improvement for Income and Food Security in West Africa.

options with sources and types of data required. The adoption pathway with its underlying assumptions were discussed first. This was followed by the concept of ES which is the model that forms the thrust of this study. Other variables and parameters relevant to analyzing the potential gains of technology options were also discussed. These include prices, research lags, productivity gains, and research and extension costs. The latter part discusses the estimation of poverty and other related outcomes.

The adoption pathway

Adoption patterns of technology options were projected using expert opinions. Adoption was assumed to begin in the year 2012 for all the technologies. Adoption started to increase slowly and is expected to reach the maximum by the end of 10–15 years. A conservative ceiling adoption rate was assumed for all the technologies (Figure 2). The adoption of NRC and VALSFD was the highest (25%). This high value was believed to be linked to the high severity of nematode disease and the high nutrient requirements of the yam crop (Amusa et al., 2003). All other technologies have their ceiling adoption rate in the neighborhood of about 17.5%. Based on the adoption ceilings, all the technologies are expected to cover at least 770,000 ha as the adopted area to reach the ceiling adoption.

The changes in total ES are calculated for the benefit period of 2012–2016 associated with the life of the YIIFSWA project as well as for the period 2012–2037 associated with the long-term consequences of investments during the life of the project as implied by the projected adoption patterns for improved yam technologies (Figure 3).

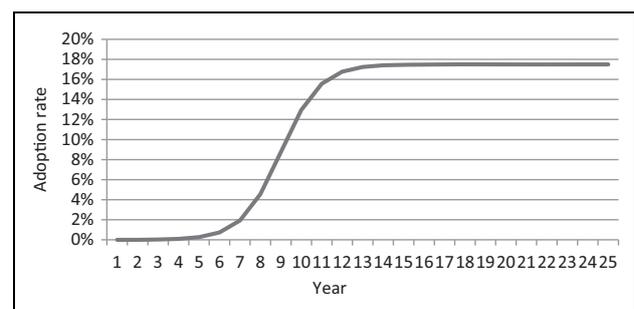


Figure 3. Projected adoption profile for YIIFSWA technologies. YIIFSWA: Yam Improvement for Income and Food Security in West Africa.

Conceptual framework

ES model and cost-benefit analysis. Many economists estimate aggregate economic benefits of agricultural interventions through a projection of farm-level gains from yield/income using the ES model by Alston et al. (1995). It hinges on the theory of cost-benefit analysis. The cost-benefit analysis allows for a consistent procedure for evaluating decisions in terms of their consequences and assists government decisions in such varied fields as tax, trade, or incomes policies; the provision of public goods; the distribution of rationed commodities; or the licensing of private investment. The model has been the most common approach for evaluating the economics of the projected costs and benefits of a new technology since the antecedent work of Griliches (1958) (Thomas et al., 2001). All agricultural research is expected to result in technological change through a change in yield, reduced losses in yield, or reduced production costs. The adoption of a technology that increases yield could lower unit production costs and increase the quantity designated for sale. This will lead to a shift of crop supply function and

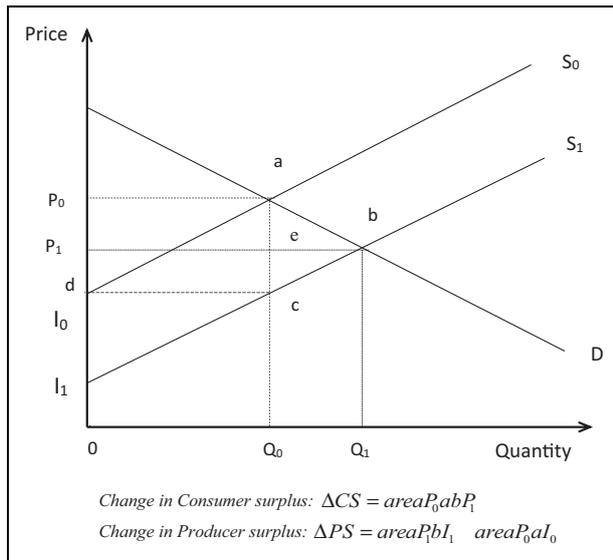


Figure 4. Surplus distribution in the model of YIIFSWA research benefits (adapted from Alston et al., 1995). YIIFSWA: Yam Improvement for Income and Food Security in West Africa.

result a higher quantity sold and a lower price for that crop. Therefore, yam producers will benefit from more quantities for sale and consumers from price reduction (Abdoulaye et al., 2014; Alene et al., 2014). An ES approach was used to estimate the potential impacts of yam research opportunities for a 25-year period from 2012 to 2037.

The benefits were measured based on a parallel downward shift in the (linear) supply curve (Abdoulaye et al., 2014). The change in ES is estimated with formulae proposed by Alston et al. (1995). An open economy is assumed as the best model that represents the market for the yam crop. As defined by Alene et al. (2014), the producer surplus (PS) is the profit realized from supplying a good at a market price higher than what he would have been willing to sell for, and the consumer surplus (CS) is the variance between the actual price consumers pay and the maximum price they are willing to pay. Also, the quantities of producer and CS are determined by means of economic modeling of demand and supply equations as depicted in Figure 4. The PS is the area above the supply curve and below a horizontal line at the actual price, while the CS is the area under the demand curve and above a horizontal line at the actual price. In an open model, following Akinola et al. (2009) based on Alston et al. (1995), the ES measures are as follows

$$\text{Economic surplus (ES)} = P_0 Q_0 K_t (1 + 0.5 Z_{t\eta}) \quad (\text{i})$$

$$\text{Consumer surplus (CS)} = P_0 Q_0 Z_t (1 + 0.5 Z_{t\eta}) \quad (\text{ii})$$

$$\text{Producer surplus (PS)} = (K_t - Z_t) P_0 Q_0 (1 + 0.5 Z_{t\eta}) \quad (\text{iii})$$

where P_0 is pre-research price (US\$/t), Q_0 represents quantity of yam in tons, K_t is the supply shift denoting the product of cost decrease per ton of output as a proportion of crop price (K) and technology adoption at time t (A_t), η for the price elasticity of demand, and Z_t means the relative reduction in

price at time t , which is calculated as $Z_t = K_t \epsilon / (\epsilon + \eta)$, where ϵ is the price elasticity of supply. Furthermore, Alston et al. (1995) demonstrate that, in a small open economy, change in ES is equal to change in PS and can be calculated as $ES = PS = P_w Q_0 K_t (1 + 0.5 K_t \epsilon)$, where P_w is the real-world price. However, the interpretation of results based on ES should bear in mind some of its shortcomings. The methodology can ignore the transaction cost, thereby overestimating the benefits. To ameliorate the likely effect of transaction costs, conservative values of the relevant parameters were employed. And to a large extent, care was taken to ensure that measurement errors that could be associated with ES were avoided.

Prices. Yam is considered a highly tradable commodity in the region as well as in other markets worldwide. Akinola et al. (2009) stated that the base model uses the open economy framework, and average international yam prices for the period specified and the figures were obtained from the FAO database. The producer price for the selected important countries varied from US\$294 to US\$681 based on 3 years average (Table 1).

Research lag. From the early research venture year in 2014 till 2017, when technologies were adopted, a research lag of 3 years was considered. Some levels of adoption were expected before then, but it would not be significant when compared with the proportion of total yam area in West African afterward (RTB, 2016). This is consequent upon the high deployment and dissemination efforts that would attend the technologies after initial research investment.

Productivity gains. Anticipated productivity gains of these technologies were obtained through expert opinions of scientists working in IITA, national research centers, and extension agents. These were the experts who had specialized in yam breeding, production, and distribution for not less than 10 years, thereby giving reliable information with respect to the subject matter. Many stakeholders working on yam were contacted through face-to-face interviews with a structured questionnaire between April and August of 2015 (there was a total of 216 respondents), and averages of values given were obtained. According to expert opinions, the expected productivity increase for AYMT is about 25%. All other technologies are expected to generate a maximum yield change of about 20%.

Total research and extension costs. The costs of research development expended at IITA on various technologies were derived from the project leadership and management and projected for other yam producing countries. Similarly, the total costs under research conducted by IITA partners for each of the technologies were also obtained from the collaborating partners and used as a platform for generating the costs for other countries. However, the dissemination and extension costs were estimated based on the adopted area and the amount required to extend. Extension costs per hectare were assumed to range between US\$80 and US\$120. The research and extension costs were subsequently calculated until the adoption ceiling is reached after about 10–12

Table 1. Socioeconomic parameters used for *ex ante* impact assessment.

Country	Price (US\$/t)	Quantity (t/year)	Area harvested (ha/year)	Household size (# persons)	Area/household (ha)
Nigeria	681	36,131,027	2,844,687	8	0.25
Ghana	378	6,298,269	389,147	6	0.33
Côte d'Ivoire	681	5,532,977	832,988	6	0.33
Benin	378	2,452,003	188,533	6	0.33
Togo	294	721,993	71,327	6	0.33
Papua New Guinea	294	413,144	20,088	5	0.11
Jamaica	294	138,821	8,314	5	0.28
Columbia	294	383,803	34,249	4	0.71

Source: FAO (2015) and RTB (2016).

years of deployment and dissemination efforts. The annual and extension costs also increased to over US\$10 million for CMPP and AYMT before the adoption ceiling is attained. However, annual research and extension costs for NRC are expected to grow over US\$20 million for the adoption ceiling to be reached.

For the cost-benefit analysis, the estimated annual flows of gross economic benefits from each yam technology for each target country were aggregated. Each year's aggregate benefits and estimated R&D costs were discounted to obtain the present value of total net benefits from the research options. The parameters considered in deriving economic benefits are expected technology adoption in terms of area under improved technologies, expected yield gains resulting from adoption, and pre-research levels of production and prices (Alene et al., 2014).

Poverty effects estimation. By extending ES results and cost-benefit analysis, the intervention options' impact on poverty was estimated following Alston et al. (1995) and Alene et al. (2009). The method considered the results from the ES model in relation to each country's relative poverty levels, the share of agriculture in total gross domestic product, and the agricultural growth elasticity of poverty. Each research technology's impact on poverty reduction was assessed by estimating the marginal impact on poverty reduction of an increase in the value of agricultural production using poverty reduction elasticities of agricultural productivity growth as described by Alene et al. (2014). So, people to be brought out of poverty was calculated by considering the estimated economic benefits as the additional increase in agricultural production value. Constant returns to scale were assumed following Thirtle et al. (2003) and Alene et al. (2014) with a 1% growth in total factor productivity, leading to a 1% growth in agricultural production. The number of poor lifted above the US\$1.5 poverty line was thus derived for each country as follows

$$\Delta N_p = \underbrace{\left(\frac{\Delta ES}{\text{Agriculture value added}} \times 100\% \right)}_{\text{Gains from RE as \% of agricultural production}} \times \underbrace{\frac{\partial \ln \left(\frac{N_p}{N} \right)}{\partial \ln(Y)}}_{\text{Poverty elasticity}} \times N_p$$

$$\underbrace{\hspace{15em}}_{\text{Poverty reduction as \% of the poor}}$$

$$\underbrace{\hspace{15em}}_{\text{Number of poor escaping poverty}} \quad (i-)$$

where ΔN_p is the number of poor lifted above the poverty line, ΔES is the change in ES, N_p is the total poor in number, N is the total population, and Y is agricultural productivity.

Number estimated of potential beneficiaries. The potential number of yam research beneficiaries follows the previous studies by the CGIAR-RTB mentioned earlier (Abdoulaye et al., 2014; Alene et al., 2014). Data for all countries were obtained from FAO databases. Questionnaires were formulated to project patterns of the adoption of various technologies in question where no previous information was available. Also, expert opinions were gathered to elicit specific information on changes in production from the current production of about 9.5 t/ha in Nigeria and cost as a result of the introduction of technology (cost attributable to the use of the technology). Data such as expected yield increase (based on the potential of the new technology to produce better than existing one), expected change in production cost (as a result of engagement of new technology), the success rate of research (probability of the technology to succeed in respective countries), when the technology will be available (including time for dissemination and deployment), and expected adoption (proportion of the population that will use the technology) and depreciation rates were collected. Thus, the main questions included research lag, expected yield or cost change, probability of success of the technology, technology adoption, and research depreciation. The quotient of the estimated area by the average area per household gives the number of adopting households; then multiplying the result with the household size generates the total number of beneficiaries (RTB, 2016).

Data and parameters. Different sources of data are used in this study in response to the scarcity of subjects on yam parameter values for such economic analysis. The consultations with stakeholders and value chain actors undertaken in 2010 identified initial research options as priorities to tackle the major constraints affecting the yam value chain sector in WA. Further consultations were made, especially with FAO statistics, and the basic parameters were consulted with experts from the yam research domain, and potential adjustments were discussed and made after their critical review. Professional meetings, visits to research organizations, universities, and institutes of experts in key

Table 2. Key assumptions and data used.

Parameters	Assumptions
Time period	25 years (starting from 2012 and running to 2037)
Elasticities	Supply elasticity: 1.0 Demand elasticity: 0.5
Productivity effects	Specific to the technology and based on expert estimation
Input cost changes	Specific to the technology and based on expert estimation Cost changes for particular inputs figured in as relative share of overall production costs
Probability of research success	Probability of research being successful and delivering an adoptable technology at the country level; max value of 0.8 for quick wins and lower values if uncertainty of research success is higher
Depreciation rate	Use 1 across all technologies
Price	Three-year averages (2010–2012) of country-specific producer price (US\$/t) from FAO Stat Assumptions/inferences where data are missing or other information if available Same price in all years of the model
Quantity	Three-year averages (2010–2012) of country-specific crop production (t) from FAO database
Adoption	Logistic adoption curve; adoption ceiling based on expert estimates; time to reach adoption ceiling (years); set adoption in the first year equal to 1% of adoption ceiling for all technologies; year of first adoption (t_0)
R&D costs and dissemination costs	Research costs: budgets available for research options and technologies Dissemination costs: fixed costs per ha of new adoption (i.e. only costs for the marginal adoption area); different dissemination costs by type of innovation: new variety: US\$50/ha, other (knowledge-intensive) technologies (e.g. crop management); US\$80/ha
Discount rate	10% discount rate
Poverty data	World Bank Development Indicators data for extreme poverty (US\$1.25/day)
Population	Most recent total population data from World Bank Development Indicators
Number of beneficiaries	Country-specific estimates based on crop area per HH for yam crop and number of persons per HH; (justify and support any deviations in estimates)

HH: household and please help.

yam-growing countries were considered in reaching out to the expert community using interviews and questionnaires. Additional data were sourced from the YIIFSWA project at its inception stage using primary data collection on household and farm information derived from the structured questionnaire and a multistage, random sampling approach applied for the baseline studies. A total selection of 1400 households from Nigeria and Ghana were randomly selected for the study using sampling frames from the surveyed communities established by community heads in collaboration with extension agents. For more details on this methodology, an interested reader is referred to Mignouna et al. (2015). Through this process, a defined set of parameters was used, and several spreadsheet templates for ES and other derived indicators computation were built.

Socioeconomic parameters. Countries' socioeconomic parameters used in the study are presented in Table 1. The production and price data were 3-year averages taken between 2010 and 2012 (FAO, 2015). Household size and yam area per household used to estimate the numbers of beneficiaries were from a data set used for the preliminary estimation of the potential number of beneficiaries of the RTB program (RTB, 2016). The data for countries in this data set originated from specific sources of published information or expert opinion.

Other key assumptions and data used are summarized in Table 2.

Research options and parameters. Many parameters related to the research and dissemination process were used in this ES model. These parameters include the research

lag, the quantity of the commodity produced in each study country, and the annual R&D costs.

An open model assumption adopted in this study implies that the use of a given technology would lead to an increase in output of yam or its products. A partial equilibrium, comparative static model, and this situation of linear demand and supply with parallel shifts had been used in country-level analysis (Akinola et al., 2009; Alene et al., 2009; Alston et al., 1995). With this model, there is an implication of at least some levels in international trade in yam and associated inputs, so that increasing supply reduces the price to producers and the cost of yam or its products to consumers. Bantilan et al. (2005) had demonstrated that in the case of a parallel shift, the functional form is mostly not relevant, and that a linear model gives a good approximation to the true functional form of demand and supply. The yield gain was presumed regarding the countries to range from 20% to 30%. The change in cost that accompanied the technology was assumed to range from 20% to 22% while the adoption ranged from 15% to 25%. For the countries, increase due to the cost of production is assumed to be around 20% and the probability of success at 60%.

The costs of dissemination per unit of area were assumed, as well as the probability of research success. The period of research phases ranges between 3 years and 10 years. With respect to the adoption lag, an assumption of most of the technologies, together with the release and diffusion of varieties, is about 5–7 years from the year of release to reach the adoption ceiling (Abdoulaye et al., 2014; Alene et al., 2014).

Table 3. Adoption ceiling and benefits (for the eight countries).

Technology	Adoption ceiling under low adoption scenario (Million)	NPV (Discount rate 10%)	IRR	BCR	Poverty reduction (Number)	Number of beneficiaries (Million)	Number of HH (Million)
AYMT	1.00	975	48.01	9.82	267,000	28.3	3.7
NRC	0.91	1392	51.90	12.48	351,000	24.3	3.3
VALSFD	0.86	1047	48.02	10.34	275,000	23.3	3.1
CMPP	0.77	584	42.79	7.74	156,000	20.8	2.8

NPV: net present value; IRR: internal rates of return; BCR: benefit-cost ratio; AYMT: adaptive yam miniset technique; NRC: nematode-resistant cultivars; VALSFD: varieties adapted to low soil fertility and drought; CMPP: crop management and postharvest practices.

Table 4. Sensitivity analysis (for the eight countries).

Technology	Parameter change	NPV (Discount rate 10%)	IRR	BCR	Poverty reduction (Number)	Number of beneficiaries (Million)	Number of HH (Million)
AYMT	Doubling adoption rate	2028	62.03	14.82	536,000	56.7	7.6
	Halving the cost	2139	65.03	20.35	529,000	28.3	3.8
NRC	Doubling adoption rate	2771	66.06	19.42	689,000	47.2	6.3
	Halving the cost	2749	66.97	23.69	666,000	24.3	3.3
VALSFD	Doubling adoption rate	2179	62.27	16.31	552,000	46.8	6.3
	Halving the cost	2133	63.03	20.02	529,000	23.4	3.2
CMPP	Doubling adoption rate	1229	55.81	11.79	312,000	41.7	5.6
	Halving the cost	1567	63.00	19.08	384,000	20.8	2.8

NPV: net present value; IRR: internal rates of return; BCR: benefit-cost ratio; AYMT: adaptive yam miniset technique; NRC: nematode-resistant cultivars; VALSFD: varieties adapted to low soil fertility and drought; CMPP: crop management and postharvest practices; HH: household.

The costs for R&D on an annual basis used are both costs incurred and estimated in the development of the intervention options in IITA and national agricultural research partners. These costs from different sources are estimated to reflect current or anticipated patterns of investment (Alene et al., 2014); the YIIFSWA budget and current CGIAR-RTB funds allocated to yam were used for IITA research cost estimation. Owing to the lack of information, we assumed that partners will also incur the same costs. An assumption was made for the costs related to dissemination as a fixed figure per adoption unit area. Different dissemination costs are assumed depending on the type of technology: knowledge-intensive technologies necessitate an investment of US\$80/ha of adopted area. The expected probability of success for the research technologies ranges from 60% to 80%.

Results

Table 3 presents the findings of the study using the ES model. The land area coverable by various technologies under the baseline adoption scenario ranges between 770,000 ha and 1 million ha in the eight countries. With 1 million ha, the AYMT is the uppermost, research option gaining great attention followed by NRC with 910,000 ha to prevent considerable damage, and then VALSFD (860,000 ha) perceived as a way out of dominant stresses. This is anticipated as many farmers are expected to easily adopt technologies that address important issues like pest and disease control and a reduction in soil fertility. This

agrees with Amusa et al. (2003) and Maroya et al. (2014) who posited soil fertility and pests and diseases as major factors affecting yam production. The lowest land area (770,000 ha) estimated was covered by CMPP. The net present values (NPVs) range from US\$584 million to US\$1392 million with the highest values for NRC paint as the best method for food security and the lowest for CMPP. The high benefits from NRC could be expected since the technology generates disease and virus-free seed. VALSFD will generate about 1047 million NPV while AYMT 975 million for the same period. Regarding the internal rates of return (IRR), they are lowest with CMPP (43%) and highest with NRC (52%). The lowest benefit-cost ratio (BCR) of 7.7 is recorded for CMPP, while the highest of 12.5 is for NRC. The results are consistent with Akinola et al. (2009) and Kostandini et al. (2009, 2011). About 1.05 million people would be moved out of poverty by these technologies in the eight countries with several people via each technology option ranging from 156,000 to 351,000 with NRC recording the highest figure. More than 96 million people would be expected to benefit from the technologies in all the yam producing countries by the year 2037.

The results are consistent with Aighewi et al. (2002) and Mignouna et al. (2015) that indicated that quality seed yam unavailability constitutes the major limitation of yam production. Moreover, the BCRs of all the research options imply that investment in research and dissemination of these technologies is worthwhile and economically viable as the benefits greatly outweigh the costs as in agreement with many similar studies on *ex ante* impact assessment

(Akinola et al., 2009; Ayanwale et al., 2013; Kostandini et al., 2009, 2011). The NPVs oscillate between US\$581 million and US\$1392 million with the highest for NRC. This could be linked to the ease connected with and speed of producing large numbers of seed yam of good quality in a short time that will engender greater availability of the technology to many farming households. About 1.05 million people would be moved out of poverty by these technologies in all the countries. This demonstrates the potency of the technologies as poverty reducing, thereby becoming strong policy thrusts in improving farmers' livelihoods and food security in the African and Caribbean sub-regions. The yam technologies in the study area are expected to reach a considerable number of households by 2037, subsequently demonstrating their far-reaching effects.

Attempts were made to determine the sensitivity of the model to ceiling adoption rate and costs of investment. This sensitivity analysis was done to gauge the returns to investments through changes with some key parameters.

The findings of the analysis are summarized in Table 4. For nearly all technologies, results indicated that doubling the adoption rate would result in about twice the value of the NPV. Moreover, the IRR would likewise increase but by less than half of the baseline value. Doubling the adoption rate resulted that the BCR will only change marginally for all the technologies. The NPV of almost all the estimates increased but not as much as when doubling the adoption rate by halving the costs. The IRR and the BCR increased by halving the cost elements.

Conclusion and recommendations

Results showed that the technologies are less reactive to change in costs than a change in adoption rate. This shows that the uptake of the technologies is better enhanced by measures that stimulate increased adoption than attempts at reducing the cost associated with research and deployment.

Therefore, the potential economic gains are extensive, but their realization is subject to the rate and extent of adoption. Since benefits are more responsive to adoption than costs, efforts at increasing the uptake of the technologies should receive greater attention than reducing costs of research and technology dissemination. Consequently, assessment of the drivers of adoption of each of the technologies becomes imperative. This estimation could help policymakers to determine factors affecting adoption, which could include extension efforts and location-specific variables, and so on. Despite potential economic gains (which are consistent with and in agreement with literature), limited resources could truncate the realization of the benefits if all the technologies are deployed simultaneously. Therefore, prioritization based on available funds and needs of the yam farming households as revealed by empirical study may be necessary. Furthermore, giving the knowledge-intensive nature of some of these interventions assessed here, capacity building of potential adopters will be critical to achieving the estimated food security and poverty reduction benefits.

Authors' note

The research was conducted at IITA through the YIIFSWA project.

Acknowledgements

The authors would like to appreciate the inputs from the YIIFSWA project team and also thank the CGIAR-RTB for its support and anonymous reviewers for their contribution. Views and opinion expressed here remain that of the authors and do not necessarily reflect those of the funding agencies, institute of research or reviewers.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the Bill and Melinda Gates Foundation.

ORCID iD

Djana Babatima Mignouna  <https://orcid.org/0000-0002-4074-2928>

References

- Abdoulaye T, Alene AD, Rusike J, et al. (2014) Strategic assessment of yam research priorities. Lima (Peru). CGIAR Research Program on Roots, Tubers and Bananas (RTB). RTB Working Paper 2014-3. Available at: www.rtb.cgiar.org/ (accessed 22 May 2017).
- African Development Bank (AfDB) (2016) *Feed Africa: Strategy for Agricultural Transformation in Africa, 2016–2025*. Abidjan: African Development Bank.
- Aighewi BA, Akoroda MO and Asiedu R (2002) *Seed Yam Production From Minisets: A Training Manual*. Ibadan: IITA, p. 40.
- Aighewi BA, Asiedu R, Maroya N, et al. (2015) Improved propagation methods to raise the productivity of yam (*Dioscorea rotundata* Poir.). *Food Security* 7: 823–834.
- Aighewi BA, Maroya NG and Asiedu R (2014) Seed yam production from presprouted minisets with varied thickness of storage parenchyma. *African Journal of Root and Tuber Crops* 5(2): 21–24.
- Akinola AA, Alene AD, Adeyemo R, et al. (2009) Economic impacts of soil fertility management research in West Africa. *African Journal of Agricultural and Resource Economics* 3(2): 159–175.
- Alene AD, Menkir A, Ajala SO, et al. (2009) The economic and poverty impacts of maize research in West and Central Africa. *Agricultural Economics* 40(5): 535–550.
- Alene AD, Oleke J, Rusike J, et al. (2014) Strategic assessment of cassava research priorities. Lima (Peru). CGIAR Research Program on Roots, Tubers and Bananas (RTB). RTB Working Paper 2014-5. Available at: www.rtb.cgiar.org/ (accessed 22 May 2017).
- Alston JM, Norton GW and Pardey PG (1995) *Science Under Scarcity: Principles and Practice for Agricultural Evaluation and Priority Setting*. New York: Cornell University Press.

- Amusa NA, Adigbite AA, Muhammed S, et al. (2003) Yam diseases and its management in Nigeria. *African Journal of Biotechnology* 2(12): 497–502.
- Asiedu R and Sartie A (2010) Crops that feed the world 1. Yams. *Food Security* 2(4): 305–315.
- Ayanwale AB, Adekunle AA, Akinola AA, et al. (2013) Economic impacts of integrated agricultural research for development (IAR4D) in the Sudan Savanna of Nigeria. *African Development Review* 25(1): 30–41.
- Bantilan MCS, Anupama KV and Joshi PK (2005) Assessing economic and environmental impacts of NRM technologies: an empirical application using the economic surplus approach. In: Shiferaw B, Freeman HA and Swinton SM (eds) *Natural Resource Management in Agriculture: Methods of Assessing Impacts*. Wallingford: CAB, pp. 245–268.
- FAO (2015) Food and agriculture organization of the United Nations. On-line and multilingual database. Available at: <http://faostat.fao.org/> (accessed 22 May 2017).
- FAO (2019) Food and agriculture organization of the United Nations. On-line and multilingual database. Available at: <http://faostat.fao.org/> (accessed 10 January 2020).
- Gildemacher PR, Demo P, Barker I, et al. (2009) A description of seed potato systems in Kenya, Uganda and Ethiopia. *American Journal of Potato Research* 86: 373–382.
- Griliches Z (1958) Research costs and social returns: hybrid corn and related innovations. *Journal of Political Economy* 66(5): 419–431.
- Kostandini G, Mills B and Mykerezi E (2011) *Ex ante* evaluation of drought-tolerant varieties in Eastern and Central Africa. *Journal of Agricultural Economics* 62(1): 172–206.
- Kostandini G, Mills BF, Omamo SW, et al. (2009) *Ex ante* analysis of the benefits of transgenic drought tolerance research on cereal crops in low-income countries. *Agricultural Economics* 40(4): 477–492.
- Maroya NG, Balogun M, Asiedu R, et al. (2014) Yam propagation using aeroponics technology. *Annual Research & Review in Biology* 4(24): 3849–3903.
- Mignouna DB, Abdoulaye T, Akinola A, et al. (2015) Factors influencing the use of selected inputs in yam production in Nigeria and Ghana. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* 116(2): 131–142.
- Morse S (2018) Analysis of yam miniset technique adoption in Nigeria. *Journal of Crop Improvement* 32(4): 511–531.
- Nweke FI (2016) *Yam in West Africa. Food, Money, and More*. East Lansing: Michigan State University Press, p. 154.
- Okoli OO and Akoroda MO (1995) Providing seed tubers for the production of food yams. *African Journal of Root and Tuber Crops* 1(1): 1–6.
- Poku AG, Birner R and Gupta S (2018) Why do maize farmers in Ghana have a limited choice of improved seed varieties? An assessment of the governance challenges in seed supply. *Food Security* 10: 27–46.
- Rees D, Westby A and Tomlins K. (2012) “Tropical root crops.” In: Rees D, Farrell G and Orchard J (eds), *Crop Post-Harvest: Science and Technology, Volume 3: Perishables*, John Wiley & Sons, pp. 392–407.
- RTB (2016) *CGIAR Research Program on Roots, Tubers and Bananas—CRP-RTB Proposal 2017-2022, Vol. I*. Lima (Peru): CRP-RTB, p. 147.
- Thirtle C, Lin L and Piesse J (2003) The impact of research-led agricultural productivity growth on poverty reduction in Africa, Asia and Latin America. *World Development* 31(12): 1959–1975.
- Thomas G, Fox G, Brinkman G, et al. (2001) An economic analysis of the returns to Canadian swine research: 1974–97. *Canadian Journal of Agricultural Economics* 49(2): 153–180.