Economic impacts of yam productivity research in West Africa: A case of YIIFSWA Project

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Abstract

A bold step to addressing myriads of constraints affecting yam productivity was achieved through *Yam for Income and Food Security in West Africa* (YIIFSWA) project. The project has embarked on a series of activities culminating in the development, deployment and disseminating intervention options/technologies in Nigeria and Ghana. This paper assesses the potential economic impacts, the number of beneficiaries and poverty reduction through these agricultural technologies/intervention options. The land area coverable by the technologies ranged 320,000–650,000 ha in the two countries. The land area under varieties for adaptation to environments with low soil fertility was the highest followed by resistance to nematode cultivars. The net present value (NPV) ranged $144 million–$616 million and was highest for YIIFSWA diagnostic tool and temporary immersion bioreactor. Crop management and postharvest practices option had the lowest benefit-cost ratios of 6.0 and 20.03 while the aeroponics option had the highest benefit cost ratio of about 36.90. Not less than 750, 000 would be brought out of poverty by these technologies. The technologies are expected to reach not less than 20 million households by 2037 in Nigeria and Ghana. The technologies are more responsive to change in adoption rate than change in costs. Overall, while the potential economic gains are considerable, realization of these gains depends on the efficiency and effectiveness of extension and input supply systems. Concerted extension efforts are needed to drive the use of these intervention options. Moreover, considerable technical advice would also be needed to explain how to apply them

1. Introduction

One major problem of increasing agricultural productivity is the availability of and access to good quality planting materials (Gildemacher et al. 2009). Limited use and gross insufficiency characterizing availabile certified seed has been grossly documented in sub-Saharan Africa (Maroya et al., 2014). Mignouna et al., (2014a) opined that less than 10 percent of the yam growing households use certified seed in yam belts of West Africa (Mignouna et al., 2014a). This might reflect with multifaceted problems rooted in institutional, ecological, technical and economic bedeviling the yam seed sector. In fact, it has been posited that a sizeable proportion of production associated costs are normally linked with seed procurement and use of seed. Mignouna et al., (2014b) opined that yam planting materials can take up to 50 percent of the total production costs. The associated costs could constitute a great discouragement to smallholder yam farmers in West Africa. A prominent technical constraint to seed yam production is its low multiplication ratio in the fields.

Ameliorating the challenges bedeviling yam production could be a giant step to improving livelihoods of resource-poor farming households in West Africa. This could be linked to importance attached to the crop in the region. About 48 million tons of yams (95 percent of global supply) are produced on 4 million hectares annually in the region, mainly in five countries, i.e. Benin, Côte d'Ivoire, Ghana, Nigeria and Togo; Nigeria alone accounts for 70 percent of global yam supply. Yam is a major source of calories in Benin, Côte d'Ivoire, and Ghana. The crop is also a good source of protein in the diet being the third after maize and rice. The crop plays important role as a ceremonies and social rites of passage (Mignouna et al., 2014). In fact, yam can be a formidable force in the war against poverty and hunger if R&D measures are implemented to develop and disseminate technologies that can bring the crop into central focus in national food policies (Mignouna et al., 2014; Maroya et al., 2014). The technological innovations are expected to enable yam to benefit from policy programs that can drive down production costs thereby making yam growing attractive to farmers and increasing the supply of the commodity in the sub-region and beyond,. Consequently, except conscious, meticulous and concerted efforts are in place producing adequate, good quality and affordable yam planting materials would be a mirage.

Efforts at relaxing the constraints of seed yam production received a major boost through the Yam Improvement for Income and Food Security in West Africa (YIIFSWA) project. The project was funded to the tune of about $13, 000,000 by the Bill and Melinda Gates Foundation and executed in Nigeria and Ghana by IITA in partnership with a consortium of national and international R and D agencies. It aims at doubling the productivity of yams that would stimulate a sustainable increase in incomes for smallholder yam producers and contribute to their food security and economic development. The project focuses on addressing constraints in seed yam production such as high cost and unavailability of disease free seed yams, on-farm post-harvest losses, Low soil fertility, unexploited potential of yam markets by smallholder farmers, unavailability of adapted varieties to stress environments of the savannah agro-ecologies, yam diseases and pests and limited opportunities for smallholder farmers mainly rural women, in yam production and marketing. YIIFSWA project has made significant progress in the realization of the set objectives through the development and deployment of many technologies tailored at addressing the problems of yam productivity. However, economic returns to investment in yam productivity research in YIIFSWA are yet to be empirically documented. Therefore, this study assesses potential research impacts of YIIFSWA project using the economic surplus model following (Alston et al. 1998). Moreover, it attempts to determine the potential number of beneficiaries and poverty reduction effects. The study aims at analyzing cost-benefit analyses the economic returns to potential investments on the development of each of technology or intervention option being deployed through the project.

2. Description of technologies/intervention options

The technologies being deployed are as follows.

2.1 Yam minisett technique

In the past 30–40 years, significant progress has been made towards improving the efficiency of the traditional technology of tuber seed yam production by developing methods that can increase the multiplication rate. One of the technologies which aim to improve on a traditional method is known as the yam minisett technique (YMT). This technology was developed by the National Root Crops Research Institute (NRCRI), Umudike, and the International Institute of Tropical Agriculture (IITA) in the early 1970s to overcome the critical problem of the unavailability of good quality seed yam by improving the rate of multiplication, especially of white yam. The process involves the cutting of “mother” seed tubers from a non-dormant tuber into small setts of 25–50 g, each part containing the periderm and some cortex parenchyma (Okoli and Akoroda 1995). With the technique, the multiplication ratio of white yam moved to 1: 10 from the traditional 1: 3. Numerous adoption studies yield discouraging results of low adoption and in some cases of reverse adoption (Nweke forthcoming). The YMT was modified (Kalu and Erhabor 1992; Ikeorgu and Igbokwe 2003, Ikeorgu et al. 2007) using minisetts weighing 25–80 g, it has reduced the production cost of seed yam (Okoli et al. 1982; Otoo et al. 1987) but its rate of adoption is still low (Kalu and Erhabor 1992).

2.2 Vine rooting technique

This research option emphasizes improving quality and access to seed yam, rapid multiplication, on-farm seed management, and decentralized multiplication with improved management practices. More recent alternatives to the tuber seed yam method that are at various stages of development by researchers in West Africa include rooting stem cuttings of the yam plant, producing and germinating true seeds of some varieties, and rooting yam sprouts generated by tubers in storage after dormancy. The rooting system of 1–3 node vines 20 cm long (Acha et al. 2004; Kikuno et al. 2007; Agele et al. 2010) produced minitubers of 50–600 g after 8 months, giving a 1: 30 propagation ratio.

2.3 Conventional tissue culture

Conventional Tissue Culture (CTC) technology involves the culture/growth of small plant parts in laboratory containers such as test tubes in a nutrient mix (medium) to regenerate the complete plant (called plantlets). The technology is ideal for crops with a long growth cycle, those with hard to- germinate seeds (dormant), those with low propagation rates or those that lose viability easily (recalcitrant). This research option has the advantages of a controlled laboratory environment, not susceptible to changing weather conditions, so that production cycles can be planned. Clean, high quality and uniform plants are produced (Yam and Arditti 2009) from otherwise infected mother plants because small uninfected plant parts are cultured. The CTC technology has found application in being capable of producing disease-free plantlets. This is because yam propagation is slow (Balogun and Gueye 2013) and vegetative (less than 1:10 compared with 1:300 in some cereals) which also encourages a build-up of diseases, especially within the existing informal seed system, causing significant yield losses. The slow rate of propagation also does not facilitate genetic improvement owing to the limited number of plants produced per year on which selection is based.

2.4 Aeroponics system

Aeroponics is defined as a system where roots are continuously or discontinuously grown in an environment saturated with fine drops (a mist or aerosol) of nutrient solution (Nugali et al. 2005). Went (1957) named the air growing process in spray culture as “aeroponics”. Simply put, aeroponics is a method of growing plants in a soilless environment with very little water (Carter 1942). Basically, it is growing without earth. Techniques for growing plants without soil were first developed in the 1920s by botanists who used primitive aeroponics to study plant root structure (Barker 1922). This absence of soil made study much easier since in aeroponics, the plants' roots dangle in midair with only the plants' stems being held in place. Hydroponics, a similar technology (growing roots in a nutrient-rich, water-based medium instead of soil), emerged later in the 1970s and overtook the development of aeroponics.

The aeroponics system has been used successfully in the production of several horticultural and ornamental crops (Biddinger et al. 1998). Aeroponics system has been applied successfully in Korea for potato seed tuber production (Kang et al. 1996; Kim et al. 1999). At the International Potato Center (CIP) in Peru, yields of over 100 tubers/plant were obtained (Otazu 2010). The technology is being tested in several African countries for the production of potato minitubers (Lung'aho et al. 2010). The initial results of both pre-rooted vines and directly planted vines were impressive as plants and vines suspended in air continued growing normally with the development of new roots and shoots. Within 10 days, more than 50% of the vines produced roots and in week 3 after planting, 85–100% of the direct vine cuttings produced roots on the aeroponics system. After 4 months of growth in aeroponics, both the pre-rooted plantlets and the vine cuttings produced viable minitubers which were harvested in June 2013.

This experiment is the first reported on successful yam propagation on the aeroponics system. Also all existing reports on aeroponics for potato or horticulture crops used only transplanted rooted plantlets but never non-rooted direct vine planting (Otazu 2010). The IITA aeroponics yam experiment is the first successful experience of the use of direct vine cuttings in an aeroponics system. Based on the results of the yam vines, new sets of improved yam genotypes (TDa 291; TDa
98/01176; TDr 89/02475; TDr 02665; TDr 95/18544; TDr 95/19177 and TDr 98/19158) were potted in the glasshouse to generate vines using minisetts of 50 g from the head, middle, and tail parts of tubers. Vines of all these genotypes grew well in aeroponics but the best was TDr 95/18544 in terms of percentage survival and growth performance. Other varieties tested in the aeroponics system are landraces (Maccakusa; Kadarko, Ogoja, Alumako, Alushi, and Obioturugu). The vines of these landraces were supplied by the virology laboratory of IITA as plants tested virus-free. There were variations among the landraces in the performance of their vine cuttings. The best variety for the survival of landraces in aeroponics is Ogoja, followed by Obioturugu and Maccakusa
For more details on the aeroponics system, an interested reader is referred to Maroya et al. (2014b).

2.5 Temporary immersion bioreactor system

Temporary Immersion Bioreactor (TIB) technology (Adelberg and Simpson 2002) is a propagation system that grows plants rapidly by immersing them intermittently in liquid nutrients in sterile laboratory containers (bioreactors). The system is propelled by air flow under pressure. In temporary immersion, the cultures are immersed in the medium for a pre-set duration at specified intervals. Their construction and operation are very simple, which has made them attractive low cost alternatives. A typical design uses two vessels (plastic or glass), one of which holds the liquid medium and the other the cultures. The TIB system is new generation tissue culture technology, and the timed immersion of plant tissues in liquid medium allows for the aeration of cultures. Each unit is a bioreactor – an enclosed sterile laboratory environment – provided with inlets and outlets for air flow under pressure. This circumvents the limitations associated with conventional tissue culture.

In most crops tested (pineapple, cocoa, potato) TIBs increased propagation rates. Another version of TIBs includes a system where a single vessel with a reservoir on one side is mechanically tilted at pre-set intervals (Adelberg and Simpson 2002). In this manner, the medium periodically bathes the cultures in the vessel and maintains the propagules in a vertical position. For a long time, bioreactors had been used in scaling up the production of plant secondary metabolites, including those that are of medicinal or health value to humans, using cell suspension cultures. These include flavonoids, phenolic acids, digitoxin and the anticancer substance Taxol, from the Pacific yew tree (Taxus sp.). Such suspension cultures were grown in stirred tank bioreactors (Srinivasan et al. 1995). Later, a diversity of bioreactors was developed to accommodate the culture of whole plants which are sensitive to shear stress. These are airlifts and bubble columns, the rocking bioreactor for the cultivation of differentiated plants in vitro systems (Steingroewer et al. 2013), including liquid-phase (stirred tank, airlift and connective flow bioreactors), gas-phase, hybrid bioreactors, and TIBs. The gaseous phase bioreactors are composed of cultures mechanically supported on a porous base and intermittently sprayed with medium (Ushiyama 1988) or exposed to a nutrient mist (Weathers et al. 1988). Excess medium is directed in the vessel and re-circulated. These bioreactors can provide excellent growth and development for most tissue and organ cultures. In the liquid layer bioreactors, only the base of cultures is exposed to the medium. The control of illumination, temperature and the gaseous environment is much the same as in standard tissue culture vessels. Stationary support systems for liquid layer bioreactors have been also developed from sealed clear plastic film with a wire frame (Takayama et al. 1991). Small, plastic films are also being used instead of vessels in commercial laboratories. Other TIBs use different designs in vessels and rotation. As the vessel turns, the culture is intermittently dipped in the medium. TIBs are simple and cost-effective to run. They are uniquely able to provide a lower level of shear stress and significantly reduce shoot hyperhydricity, culminating in increased productivity. The recipient for automated temporary immersion (RITA) (Alvard et al. 1993) is another type of TIBs in which the upper container containing the plant is linked to the lower compartment containing the medium and internal pressure regulates the movement of medium up or down in such a way that the immersion of cultures can be timed. There is also the bioreactor of immersion by bubbles (BIB) (Soccol et al. 2008) where the nutrient and air are provided to cultures by bubbling. Others are the glass jar TIB and the Box-in-Bag bioreactor which were successfully applied for the cultivation of Coffea arabica L. (Ducos et al. 2008). In all these cases, the cultures are immersed in the medium in a timed manner, in terms of frequency and duration of immersion, to allow for aeration.

As part of its objective to develop novel technologies for the high ratio propagation of high quality seed yam, the Gates-funded YIIFSWA project is developing protocols for producing seed yam using conventional tissue culture, aeroponics and TIB technologies. The use of aeroponics – growing yam in soil-free, mist nutrient – has been demonstrated (Maroya et al. 2014a, 2014b). The advantages of bioreactors include an increased culture multiplication rate, faster culture growth, a reduction in medium cost and also in energy, labor and laboratory space. The increased rate of multiplication and growth primarily reflects the effect of a liquid medium (Levin et al. 1997). The elimination of gelling agents (e.g., agar) reduces medium cost. In bioreactors, the culture density in liquid media is much higher than in the conventional vessels with semisolid media. The conventional tissue culture vessels are typically kept on shelves with a large space between the shelves. The use of bioreactors requires a much smaller space in the growth room, fewer clean work stations (laminar flow hood), and less space for media preparation, vessel storage and washing than in the CPTC. The smaller size of the laboratory and the lower number of people reduce air conditioning needs, hence energy costs. Reduced requirements for lighting and labor, the simplification of medium preparation, reduced washing of vessels and easier handling of the cultures all lead to cost reduction. For more information on TIBs, refer to Balogun et al. (2014)

2.6 Somatic embryogenesis

Somatic embryogenesis is a process where a plant or embryo is derived from a single somatic cell or group of somatic cells. Somatic embryos are formed from plant cells that are not normally involved in the development of embryos, i.e. ordinary plant tissue. No endosperm or seed coat is formed around a somatic embryo. Somatic embryos are mainly produced in vitro and for laboratory purposes, using either solid or liquid nutrient media which contain plant growth regulators (PGR's). Shoots and roots are monopolar while somatic embryos are bipolar, allowing them to form a whole plant without culturing on multiple media types. Somatic embryogenesis has served as a model to understand the physiological and biochemical events that occur plant developmental processes as well as a component to biotechnological advancement (Quiroz-Figueroa et al. 2006). The first documentation of somatic embryogenesis was by Steward et al. (1958) and Reinert (1959) with carrot cell suspension cultures.

2.7 Diagnostic tools

Sensitive and cost-effective diagnostics are central to selection of virus-free tubers, clean seed yam production through rapid micropropagation and certification of seed yams (virus indexing). Sensitive diagnostic tools for yam potyviruses are well established at NRI/IITA and are based on a combination of antibodies to trap virus particles, and the sensitive nucleic acid amplification procedure (PCR) using primers that detect the wide diversity of potyvirus sequences (detailed in Ampofo et al., 2010). Recent studies showed that yam viruses are diverse and available diagnostic tools fail to detect certain viruses. In addition, badnavirus like sequences were found to be integrated in genomes of some Dioscorea spp., particularly Dioscorea cayenensis-rotundata, widely cultivated in West Africa. Activation is considered to be triggered by the epigenetic modifications that occur during hybridization of parental genomes (possessing an asymmetric ratio of EPRV copies) as well as environmental stresses (e.g., wounding, tissue culture, drought, and heat). This poses serious problems for virus-indexing laboratories as material free from virus particles and symptoms can, when stressed, become infected. Therefore it is essential to improve existing diagnostic tools for broad-specific detection of viruses, and EPRVs, particularly in germplasm selected for wide dissemination in YIIFSWA.

This research option focuses on developing sensitive & robust virus diagnostic tools and practicable standards for seed yam quality certification. Variety of tools for yam virus detection were developed comprise of Multiplex RT-PCR, PCR and Direct binding PCR, PCR/RT-PCR with generic primers. Other methods also used were Isothermal diagnostics (LAMP and RPA) and deep sequencing for discovery of novel viruses.

2.8 Varieties for adaptation to environments with low soil fertility

Clones of D. alata and D. rotundata, in the pipeline for release from the breeding programs of IITA and NARS along with released/improved varieties and local popular varieties will be evaluated by farmers, processors and buyers using mother baby trials in three localities of two prioritized production systems of Ghana and Nigeria. The localities will be selected based on the value chain study as well as baseline studies and yam production systems identified and characterized through a complementary project funded by MAFF, Japan.
An initial diagnostic of the local yam production system, will be implemented, followed by definition of objectives, evaluation of clones and discussion of the results. Farmers will be involved using Participatory Varietal Selection combined with other methods such as: focus group (women, men and other distinct social groups) to understand key characteristics of presently grown varieties in the project area; on farm mother and baby trials with one variety per farmer, to achieve farmer evaluation of new varieties; farmers testing individual varieties on their farms; farmers evaluating varieties through farm walks; and individual semi-structured interviews with farmers conducting trials, for variety evaluations.

Using the participatory variety selection with value chain approach will allow the stakeholders to select varieties with good performance in environments with soils of low fertility and ensure the release of selected improved varieties following each country's regulations.

2.9 Resistant to nematodes cultivars

Root knot nematode infected tubers are less marketable and deteriorate during storage faster than healthy tubers. This results in the persistent decline in yam quality and production and even total loss of susceptible cultivars. Recent molecular studies on S. bradys populations collected from throughout the yam belt demonstrated a relatively high degree of polymorphism both within and between populations. Identification of suitable sources of resistance against S. bradys, and development of acceptable resistant cultivars would improve yam yields. Therefore, a comprehensive assessment of yam varieties selected in YIIFSWA will be used for their reactions to key populations would enable identify the promising varieties.

The varieties will also be screened for reactions to nematodes, anthracnose, and viruses.

2.10 Crop management and postharvest practices

Interventions on crop management and postharvest practices would have a significant impact on home consumption and provide more options for marketing. This research option focusses on improving quality and safety of processed products and increase income from these products by 20%. To achieve these goals the project considers the potential for reducing losses through appropriate variety selection and post-harvest technologies, including improved storage structures, packaging, curing and yam preservation/processing.

Harvest damage of tubers increases deterioration through water loss and rots. Under appropriate conditions tubers can heal surface wounds (Rees et al. 2010). Despite clear advantages, the curing of yams (maintaining under conditions to promote healing) is not widely practiced in West Africa. This may be partly because as optimum curing conditions vary by variety/species and maturity, it has been difficult to define the conditions to be used in each situation (Rees et al. 2010). Optimum curing conditions will be determined in controlled studies on-station, and this information used to transfer the technology on-farm.

Dormancy break and sprouting is one of the most important constraints to yam storage, due to tuber weight loss associated with sprout growth, and because the tubers become more susceptible to rotting.
Practices of sprout removal can reduce losses, but although other methods of sprout control have been attempted, so far there has been limited success (Rees et al. 2010). Location of storage structures relative to production area, houses and transport links is important. Common storage facilities across several households could be advantageous in certain situations.

Although not accurately quantified, damage during road transport to urban markets is considered to be significant more especially in Nigeria. Mechanical damage from vibration and impact lead to fungal and bacterial infections. With an increasing volume of tubers being transported to the urban centers, the levels of losses as a result of transport damage are increasing. Understanding the levels of loss is important to target interventions.

Improvement in our understanding of the post-harvest characteristics of varieties would both help farmers select varieties best suited to their needs, and feed back into breeding objectives to help them produce varieties with appropriate post-harvest behaviour. Development of tools to facilitate breeding for extended dormancy would be a valuable longer-term strategy. Curing is accepted as a valuable practice to promote wound-healing and extend shelf-life, but information on how varieties may differ in the efficiency of wound-healing is scarce. Damage during transport is highly related to tuber shape, but there is little information on how varieties may differ in the strength of the tuber surface.

Yam is a relatively perishable crop, subject to high levels of quantitative and qualitative losses throughout the marketing chain. To counteract these losses some farmers and processors are processing yam into chips, flakes, and ultimately flour. Such processing is common in Southwest Nigeria. Studies in Nigeria have indicated that there is a significant problem of aflatoxin contamination as a result of poor drying and storage (Adeleke, 2009). Informed by the market potentials for these products from the value chain analyses, this activity will focus on the improvement of technologies for yam drying and dried product storage to ensure safety and good quality. Activities will concentrate on small-scale farm and enterprise level for home consumption and local marketing within selected project target areas of Nigeria.

3.0 Economic surplus model and cost-benefit analysis

Many economists are estimated aggregate economic benefits of agricultural interventions through projection of farm-level yield or income gains using partial equilibrium simulation models such as the economic surplus model (Alston et al., 1998). The most common used approach for evaluating economics of the expected benefits and costs of a new technology is economic surplus model. Every agricultural research is expected to result in technological change through change in yield, reduced yield losses, or reduced cost of production. If the new technology is yield increasing, adoption could result in lower per-unit costs of production as well as a higher quantity of goods sold on the markets. This will shift the supply function of the commodity and lead to an increase in the quantity sold and a fall in the price for that good. As a result, consumers benefit from a price reduction and producers benefit from selling larger quantities of the product. A closed economy economic surplus model was used to derive summary measures of the potential impacts of yam research options for a period of 25 years (2012-2037). The benefits were measured based on a parallel downward shift in the (linear) supply curve We estimated the change in economic surplus (defined as the combined benefit consumers and producers receive when a good or service is exchanged) using formulas presented in the standard book written by Alston et al. 1998. We assumed that a closed economy model best represents the market for the yam crop. The consumer surplus is the difference between the maximum price consumers are willing to pay and the actual price they do pay. The producer surplus is the benefit a producer receives from providing a good/service at a market price higher than what he would have been willing to sell for. Through economic modeling of supply and demand equations, the related quantities of consumer and producer surplus are determined. The consumer surplus (individual or aggregated) is the area under the (individual or aggregated) demand curve and above a horizontal line at the actual price (in the aggregated case: the equilibrium price). The producer surplus (individual or aggregated) is the area above the (individual or aggregated) supply curve and below a horizontal line at the actual price (in the aggregated case: the equilibrium price). 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 derive the present value (in 2014) of total net benefits from the research interventions. The key parameters that determine the magnitude of the economic benefits are the following: The expected technology adoption in terms of area under improved technologies, Expected yield gains (or avoided losses) following adoption, and pre-research levels of production and prices.

3.1 Estimation of poverty effects

By extending the results of the economic surplus and cost-benefit analysis, the impact of each of the intervention options on rural poverty reduction was estimated following Alene et al. (2009). The method employs the economic surplus results according to the poverty levels in each of respective countries, the share of agriculture in total GDP, and the agricultural growth elasticity of poverty. The impact of each research option on rural poverty reduction was estimated by first estimating the marginal impact on poverty reduction of an increase in the value of agricultural production using poverty reduction elasticities of agricultural productivity growth. Total number of people brought out of poverty was calculated by considering the estimated economic benefits as the additional increase in agricultural production value. Following Thirtle et al. (2003) we assume a constant returns to scale. A 1% growth in total factor productivity leads to a 1% growth in agricultural production. For each country, the number of poor lifted above the \$1-a-day poverty line was thus derived as follows:

$$\Delta N_p = \underbrace{\underbrace{\underbrace{\left(\frac{\Delta \mathrm{ES}}{\text{Agriculture value added}} \times 100\%\right)}_{\text{Gains from R\&E as \% of agricultural production}} \times \underbrace{\frac{\partial \ln\left(\frac{N_p}{N}\right)}{\partial \ln(Y)}}_{\text{Poverty elasticity}}}_{\text{Poverty reduction as \% of the poor}} \times N_p}_{\text{Number of poor escaping poverty}}$$

Where ΔN_p is the number of poor lifted above the poverty line, N_p is the total number of poor, N is the total population, Y is agricultural productivity, and ΔES is the change in economic surplus. The poverty elasticity is interpreted as the marginal impact of a 1% increase in agricultural productivity in terms of the number of poor reduced as a percentage of the total poor (N_p), and not of the total population.

3.2 Estimation of the number of potential beneficiaries

We used data on average crop area per household and average household size to estimate the numbers of beneficiaries, following a procedure and dataset developed to estimate total number of beneficiaries (CGIAR 2011). Data for individual countries were obtained mostly from FAO database, published sources of information, or expert opinion when needed. Estimated area was divided by the average area per household to estimate the number of adopting households, and then multiplied by household size to estimate total number of beneficiaries.

4.0 Parameter estimates and sources of information

Information and underlying parameter values for economic surplus estimation used in this study were generated from YIIFSWA baseline surveys, from individual scientists working in YIIFSWA upon which further consultations were made, especially with FAO statistics. Through this process we defined the set of parameters used for generating the results presented in this report.

4.1 Socioeconomic parameters

The socioeconomic parameters for the both countries used in the analysis are presented in Table 1. The three-year averages (2010–2012) for production and prices were taken from FAO (2013).

Table 1: Socioeconomic parameters used for ex-ante impact assessment

Country	Price (\$/t)	Quantity (t/year)	Area Harvested (ha/year)	HH Size [# persons]	Area/HH (ha)
Nigeria	681	36,131,02	2,844,687	8	0.25

		7			
Ghana	378	6,298,269	389,147	6	0.33

The data on yam area per household and household size that were used to estimate the numbers of beneficiaries were taken from a dataset used for the preliminary estimation of the potential number of beneficiaries of the productivity program (CGIAR 2011). Data for individual countries in this dataset were based on specific sources of published information or expert opinion. Other key assumptions and data used are summarized in Table 3.

Table 3: Key assumptions and data used

Parameter	**Assumption**
Time period	25 years (starting in 2014 and running to 2039)
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 (or implementation uncertain
Depreciation rate	Use 1 across all technologies/crops
Price	Three-year averages (2010-2012) of country specific producer price ($/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 Stat;
Adoption	Logistic adoption curve; adoption ceiling based on expert estimates; time to reach adoption ceiling (years); set adoption in 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: $50/ha, other (knowledge intensive) technologies (e.g., crop management); $80/ha
Discount rate	10% discount rate

Poverty data	World Bank Development Indicators data for extreme poverty ($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)

4.2 Research options parameters

The economic surplus model used for this analysis represents a closed economy model with no demand shift. A closed model assumption adopted in this study implies that the use of a given technology would lead to increase in output of yam or its products. A partial equilibrium, comparative static model of a closed economy and the simple case of linear supply and demand with parallel shifts had been used in country level analysis (Aston et al., 2008; Okike, 2002; Akinola et al., 2009). With a closed model, there is an implication of little or no international trade in yam and associated inputs so that the increase in supply reduces both the cost of yam or its products to consumers and the price to producers. Previous studies had had demonstrated that when a parallel shift is used, the functional form is largely irrelevant, and that a linear model provides a good approximation to the true (unknown) functional form of supply and demand (Bantilan et al., 2005). Accordingly, the technology effects that are directly captured by the model and for which explicit parameter values have been estimated are changes in yields and costs of production. For some of the technologies these two parameters may not represent all sources of benefits. In these cases, the appropriate changes in the current economic surplus model or the use of alternative modeling approaches will be identified and discussed below..

With respect to the two countries, the yiedd gain was assumed to range from 20% to 30%. The change in cost that accompanied the technology changed was assumed to range from 20 to 22% while the adoption ranged from 10% to 20%. For all the countries, increase due to cost of production is assumed to be around 20% and probability of success at 75%.

5.3 Parameters related to research and disseminated process

Moreover, the economic surplus model uses a number of parameters that relate to the research and dissemination process. These parameters comprise the duration of research phase (i.e., the research lag), the quantity of the commodity produced in each country, the annual R&D costs, an assumption on the costs of dissemination per ha of area on which the technology is adopted, and the probability of research success. The duration of research phases (i.e., the time until the resulting technology will be released) ranges 3–10 years. With respect to the years to maximum adoption (the adoption lag), we assume that most of the technologies, together with the release and diffusion of germplasm (varieties), will take about 5 to 7 years from the year of release to reach the adoption ceiling.

The annual costs for R&D included in **Error! Reference source not found.**are an estimation of both costs incurred in the development of the intervention options in IITA and the national agricultural research systems. These costs are made to reflect current or anticipated patterns of investment and are based on different sources of information: YIISFWA budget and current RTB budget allocated to yam were used to estimate IITA research cost. Owing to lack of information, we assumed that partners will also incur about the same costs. For the dissemination cost, a fixed figure per ha of adoption is assumed. This cost was assumed to be incurred only once—that is, only for the marginal area of adoption. Depending on the type of technology, different dissemination costs are assumed: variety technologies require an investment of $50/ha of adopted area, while more knowledge-intensive technologies (e.g., aeroponics and Temporary Immersion Bioreactors technologies) require an investment of $80/ha of adoption.

The probability of success expected for the different research options ranges 60–80%. The latter probability was given YIIFSWA diagnostic tools management options. Some of the options considered (e,g. yam minissets technology) already existed, but they need more packaging to fit current farmers' conditions.

5. Results of the ex-ante assessment using economic surplus model

The results of the ex-ante assessment using economic surplus model is presented in Tables 4 and 5. Under the low adoption scenario, the land area coverable by different technologies ranged 320,000–630,000 ha in Nigeria and Ghana. The land area under the varieties for adaptation to environments with low soil fertility option was the greatest (650,000 ha), followed by resistant to nematode options (630,000) and YIIFSWA diagnostic tool (580,000 ha). This is expected as many farmers are expected to adopt technologies that address soil fertility depletion and pest and disease control easily. Aeroponics technologies covered the lowest land area (320,000 ha). This might be connected with indirect contact of aeroponics technology with the end users. The immediate beneficiaries of the aeroponics technology would be private seed company operators. The net present value (NPV) ranged $144 million–$660 million. The values were highest for YIIFSWA diagnostic tools and lowest for conventional tissue culture. The net present values for Temporary Immersion Bioreactor were $616 million and 387 million, respectively. Resistance to nematode had about 400 million net present values for the same period. The internal rates of return were lowest in varieties for adaptation to environments with low soil fertility option and highest in Temporary Immersion Bioreactors option. Crop management and postharvest practices option had the lowest benefit-cost ratios of 6.0 and 20.03 while the aeroponics option had the highest benefit cost ratio of about 36.90. The number of people that would be brought out of poverty ranged from 32, 000 to 158, 000. Temporary Immersion had the highest figure while crop management and postharvest practices had the lowest figure. Through aeroponics technology and YIIFSWA diagnostic tools about 98,000 and 77,000 people would be brought out of poverty respectively. The number of households expected to benefit from the technologies ranged from 9.8 million to 9.6 million. Varieties for adaptation to environments with low soil fertility options were expected to have the highest number of beneficiaries. Total beneficiaries, adoption were to be exclusive, would not be less than 20 million in the two countries by the year 2037.

Attempts were made to determine the sensitivity of the model to ceiling adoption rate and costs of investment. The results indicated that for nearly all the technologies, doubling the adoption rate would result in about twice the value of the net present value. Moreover,, the internal rate of return would also increase but less than half of the baseline value. The result of doubling the adoption rate also showed that the benefit cost ratio will only change marginally for all the technologies. However, about twice of the baseline figures would be brought out of poverty when the adoption rate doubles for all the technologies or intervention options.By halving the costs, the net present value of all the estimates reduced less than half of the NPV estimates. Internal rate of returns also reduced but less than half of initial baseline figures. The benefit ratios and the number of people brought out of poverty reduced marginally.

Table 4: Summary of adoption ceiling & benefits

Technology	Adoption	All Benefits	Poverty reduct	Beneficiaries	Beneficiaries

	Ceiling under Low Adoption Scenario				ion		
		Net present value & Inter. Rate of Return		Benefit cost ratio			
	(million ha)	NPV (million $)	IRR (%)	B.C ratio	No ('000)	No of households (million)	Number of beneficiaries (million)
Aeroponics	0.32	387	132	35.9	98	9.8	1.25
Temporary immersion bioreactor	0.57	616	185	33.10	158	17.1	2.19
Conventional tissue culture	0.48	144	107	9.0	35	14.7	1.88
YIIFSWA diagnostic tool	0.58	660	142	16.0	77	17.6	2.60
YIIFSWA minissett	0.49	273	138	16.1	65	14.7	1.88

Table 4: Summary of adoption ceiling & benefits (cont'd)

	Adoption Ceiling under Low Adoption Scenario	**All Benefits**			**Poverty reduction**	**Beneficiaries**	**Beneficiaries**
		Net present value & Inter. Rate of Return		**Benefit cost ratio**			
Technology	(million ha)	NPV (million $)	IRR (%)	B.C ratio	No ('000)	Number of beneficiaries (million)	No of households (million

Resistance to nematode cultivars	0.63	400	153	18.2	91	19.3	2.50
Somatic embryogenesis	0.47	269	135	17.6	68	14.0	1.3
Varieties for adaptation to environments with low soil fertility	0.65	297	104	14.5	76	19.6	2.51
Crop management and postharvest practices	0.56	194	151	6.0	32	17	2.0
Vine rooting technique	0.49	372	146	21.2	52	14.7	1.88

6. Conclusions and outlook

YIIIFSWA project was initiated to address miryiads of problems confronting yam productivity in West Africa, especially Nigeria and Ghana. In its efforts of addressing the targets objectives, the project has developed and tested many intervention options or technologies. These technologies are now being deployed and disseminated in West Africa. This study documents empirically the returns to productivity research in YIIFSWA. The land area coverable by different technologies ranged 320,000–650,000 ha in the two countries. The land area under Varieties for adaptation to environments with low soil fertility was the highest followed by resistance to nematode cultivars. The net present value (NPV) ranged $144 million–$616 million and was highest for YIIFSWA diagnostic tool and temporary immersion bioreactor. Not less than 750, 000 would be brought out of poverty by these technologies. The technologies are expected to reach not less than 20 million households by 2037 in Nigeria and Ghana. The technologies are more responsive to change in adoption rate than change in costs. Overall, while the potential economic gains are considerable, realization of these gains depends on the efficiency and effectiveness of extension and input supply systems. Concerted extension efforts are needed to stimulate uptake of these intervention options. Moreover, since the technologies are knowledge-intensive, considerable technical advice would also be needed to explain how to apply them

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