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Review / Reseña bibliográfica
SUITABLE AGRICULTURE

Adoption and impact of agricultural technologies developed in Ecuador

Adopción e impacto de las tecnologías agropecuarias generadas en el Ecuador

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Resumen

El conocimiento de los efectos que tienen las tecnologías en la sociedad es el instrumento esencial para motivar el desarrollo de la investigación, ya que brinda insumos a los tomadores de decisiones y generadores de políticas que permiten proyectar el impacto de futuras inversiones. En Ecuador, el principal centro público encargado de la investigación y desarrollo de tecnologías en el sector agropecuario es el Instituto Nacional de Investigaciones Agropecuarias (INIAP), que desarrolla material genético, alternativas de manejo para incrementar y agregar valor a la producción, alternativas para el manejo del suelo y agua y la conservación de los recursos genéticos. Con el objetivo de estimar la adopción e impacto de las tecnologías agropecuarias que se generan en el país, se analizaron 37 estudios de adopción, impacto y rentabilidad económica de tecnologías generadas por el INIAP, publicados en el período 2007-2017. La tasa de adopción promedio a nivel nacional de las variedades desarrolladas por el INIAP fue del 37 %, con una tasa interna de retorno promedio del 33 %. Los impactos fueron positivos a nivel económico, ambiental y productivo para los agricultores que adoptaron las tecnologías. Estos resultados sirven de apoyo a los políticos y tomadores de decisiones en el país para el direccionamiento y planificación estratégica de la investigación, que permitan el desarrollo de una agricultura sostenible y de referencia para la región.
Palabras clave: Agricultura sustentable, economía agrícola, innovación, política agropecuaria.

Abstract

Knowing the effects that technologies have on society is the essential input to motivate the development of science, since it provides inputs to policy makers to project the impact of future investments. In Ecuador, the main public center in charge of research and development of technologies in the agricultural sector is the National Institute of Agricultural Research (INIAP), which develops genetic material (seeds) and crop management recommendations to

increase and add value to farmer's production, alternatives for the soil and water management and the conservation of genetic resources. In order to estimate the adoption and impact of agricultural technologies generated in the country, 37 studies of adoption, impact and economic profitability of technologies generated by the INIAP were analyzed. These studies were published in the period 2007-2017. The average adoption rate of the varieties developed by INIAP at the national level was 37 %, with an average internal rate of return of 33 %. The overall impacts of agricultural technologies developed in Ecuador were positive at an economic, environmental and productive level for the farmers who adopted these technologies. These results support the politicians and decision makers in the country for the direction and strategic planning of the research to invest more in science and technology, which will allow the development of a sustainable agriculture for Ecuador and the region.
Keywords: Sustainable agriculture, agricultural economy, innovation, agricultural policy.

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1 Introduction

Assessing the effects of the technologies is crucial for institutions committed to Research and Development (R+D), as it allows to demonstrate the effectiveness of the developed products and justify the investments done (Feinstein, 2012). Additionally, because technology generation, especially that which uses a proportion of public funds, has a high opportunity cost in less developed countries, i.e., government funding for science and technology is limited because it must address other social priorities (López, 2017; Rivas et al., 1992). This latter statement would explain the low investment in R+D in Ecuador, which by 2014 accounted for 0,44 % of Gross Domestic Product; and less than 0,03 % of Gross Domestic Product for the agricultural sector in particular (SENESCYT e INEC. n.d, 2014).

In Ecuador's agricultural sector, the efforts made by research organizations have focused on achieving the highest crop productivity. Therefore, much of the technological offer has been based on the provision of genetic material (seed) and recommendations of cultivation practices. The National Agricultural Research Institute (INIAP) is Ecuador's main research center, accounting for 73 % of agricultural researchers engaged in the country's full-time research, followed by education entities (universities) and private institutions or non-profit research centers, 14 % and 13 % of the country's full-time researchers, respectively (Stads et al., 2016). INIAP has developed improved plant genetic material with characteristics of yield, pest resistance and other environmental factors. It has also released technologies for crop management, such as: good practices for the use of supplies, natural resources, crop rotation and integrated pest management. From 2007 to 2013, INIAP released 38 improved varieties and around 198 technological alternatives in areas such as: beans, maize, potatoes, cocoa, rice, wheat, among others (Stads et al., 2016).

The effect or impact of several of these technologies released by INIAP have been evaluated and published in an isolated way by several research projects of different institutions (Barrera et al., 2017; Clements et al., 2016; Barrowclough and Dominguez, 2016). Consequently, it is necessary to consolidate and quantify the impact of technologies, in such a way as to serve as a tool for politicians and decision-makers for the analysis and strategic direction of the research for the country's agricultural technological development. This review aims to synthesize and analyze the results obtained in these studies, to provide more knowledge about the benefits of technologies developed in Ecuador with public resources, taking as a reference the results obtained by the country's most important research center.

Table 1. Internal Rate of Return (TIR) of the investment done in 12 items of Research and Development of INIAP

Topic	Periods (years)	Internal rate of return (%)	Reference
Rice	2000-2008	52	Mendoza2010
Cocoa	2000-2010	28	Sotomayor2011
Barley	2000-2012	0	Suquillo2014
Bean	1991-2010	35	Reyes2012
Lemon	2000-2012	13	Salgado2013
Hard maize	2009-2010	42	Racines2011
Naranjilla	2004-2021*	43	Guayasamin2015
African palm	2000-2011	46	Cordova2013
Potato	2000-2010	27	Mora2012
Piñón	2015	17	Rade2017
Soy	2000-2012	68	Alava2014
Cassava	2000-2012	21	Molina2014
Average		33	

*Analysis.

2 Materials and methods

The available information on adoption studies and impact on Google Academics was used as well as the bibliographic repository of INIAP (http://repositorio.iniap.gob.ec), which has 4660 documents to date to estimate the impact of public investment in research and technological development of the results generated by INIAP. The search focused on publications made in: scientific articles, technical publications, post-graduate thesis and pre-graduate thesis, which were published from 2007 to 2017. To facilitate the analysis, the available information was grouped according to three criteria: (i) research profitability studies (indicator: Internal rate of return - TIR); (ii) technological adoption studies, either of improved genetic material or agronomic management practices (indicator: percentage of technology adoption); and, (iii) impact studies (productive indicators, conservation of natural resources and social indicators). Once the indicators were identified, they were systematized into tables and described statistics (minimum, maximum, average and median) were used to analyze and discuss the information.

3 Results

3.1 Profitability of the R+D

The bibliographic research identified 12 studies that evaluated the profitability of the technologies generated by INIAP. Most of these studies used the economic surplus method (Mendoza et al., 2010; Racines et al., 2011) and in some cases it was combined with descriptive methods (Guayasamín, 2015; Reyes, 2012). Nine of these studies were conducted nationally on: rice (Mendoza et al., 2010), cocoa (Sotomayor, 2011), barley (Suquillo, 2014), lemon (Salgado, 2013), hard maize (Racines et al., 2011), African palm (Córdova, 2013), potato (Mora, 2012), soybeans (Álava, 2014) and cassava (Molina Loor, 2014); and the rest in specific geographical areas: beans evaluated in Sierra Norte (Reyes, 2012); Naranjilla (*Solanum quitoense*) in the provinces of Napo, Pichincha and Tungurahua (Guayasamín, 2015); and, piñón (*Jatropha curcas*) conducted in the province of Manabí (Rade et al., 2017). The average TIR for the 12 studies conducted was 33 %, while the median was 32 % (Table 1). The development of technology for soy and rice report the best return rates with 68 % and 52 %, respectively. The lowest value corresponds to the study carried out in Barley, with a TIR of 0 %, result indicated that this crop is intended basically for self-consumption; and therefore will not generate surpluses for marketing (Suquillo, 2014).

3.2 Use of technologies

Table 2 shows the adoption rates of INIAP-generated technologies obtained in 30 studies found in the analyzed databases. On average, genetic material and other management technologies or practices developed by INIAP have been adopted in 37 %. The genetic material or seed, developed by INIAP had an average adoption rate of 38 %, while culture management technologies had an adoption of 35 %. The medians were 33 % and 38 % for genetics and management practices, respectively.

Rice and potato are the crops with more adoption studies conducted (Table 2). The area with the highest adoption percentage at the national level was rice (Moreno, 2014; Monteros and Salvador, 2015) and the one with the lowest adoption was barley (Suquillo, 2014). The adoption level of technologies developed by INIAP varies a lot, from 0 % in the case of management practices for the cultivation of hard maize in the provinces of Los Ríos and Guayas (Chicaiza, 2010), up to 90 % adoption of rice seed in the province of Guayas (Mendoza et al., 2011). The reasons for this great variation were diverse. In the case of Mauceri et al. (2007), adoption rates of technological practices were in agreement with the relationship of farmers with extensionists: (i) participants in field schools: 23,3 % to 83,3 %, averaging 56,5 %; (ii) producers who had contact with participants in field schools: 3,6 % to 85,7 %, averaging 41,4 %; and, (iii) producers who had no contact with field school participants: 2 % to 52,9 %, averaging 21,9 %.

In the case of technological practices for the conservation of natural resources developed for the Upper Andean region, the adoption rate depended on the locality and the type of technology (Barrera et al., 2012). In this study, the most adopted technologies were: crop rotation (locality 1: 59,41 % and locality 2: 92,5 %), living barriers (locality 1: 24,69 % and locality 2: 63,75 %) reduction of tillage (26,36 % and 76,25 %). Carrión Yaguana et al. (2015) also found differences in the adoption of technological practices in the Andean area of Ecuador, with a range of 5.5 to 68,1 %. The most adopted technologies were: rotation of low toxicity pesticides (68,1 %), crop rotation (68,1 %) and management of plant waste in cultivation (37,1 %). The same study showed that the determining factors for the adoption of technologies were: education, health and the training method. Other authors also reported different levels of adoption depending on the type of technology under evaluation, which will depend much on the field studied (Sowell and Shively, 2012; Fernández Pérez and Mendoza Coronel, 2011; Cedeño, 2013; Bazurto, 2014).

3.3 Impact assessment

Ten impact assessment studies of technologies developed by INIAP have been published between 2007 and 2017 (Table 3). Impact assessments have been mostly ex post, using quasi-experimental econometric methods, which generally consisted of determining what would have happened to project beneficiaries if the project had not existed (Khandker et al., 2010).

The studies have been mostly conducted in naranjilla and potato. In the case of naranjilla, the impact of grafted plants was evaluated, while training programs and conservation practices were studied for potato. The

Table 2. Adoption studies of the technology developed by INIAP.

Topic	Level	Adoption technology rate	Reference
Rice	National	Genetics: 74 %	Mendoza2010
Rice	Guayas	Handling practices: 11 % a 89 % Average: 41 % Genetics: 90 %	Mendoza2011
Rice	National	Genetics: 45 %	Moreno2014
Rice	National	Genetics: 70 %	Moreno2014
Rice	National	Genetics: 50 %	Moreno2015
Rice	National	Genetics: 70 %	Monteros2015
Rice	National	Genetics: 45 %	Castro2016a
Rice	National	Genetics: 50 %	Castro2016b
Rice	National	Genetics: 23 %	Castro2016c
Cocoa	National	Genetics: 10 %	Sotomayor2011
Cocoa	Manabí	Handling practices: 1 a 100 % Average: 36 % Genetics: 6 a 7 %	Fernandez2011
Barley	National	Genetics: 1 %	Suquillo2014
Preservation of the natural resources	Bolívar	Handling practices: 7 a 68 % Average: 31 %	Barrowclough2016
Bean	Carchi Imbabura	Genetics: 50 %	Reyes2012
Cattle farming	Manabí Guayas Los Ríos	Handling practices: 36 % Genetics: 27 %	Bazurto2014
Lemon	National	Genetics: 40 %	Salgado2013
Hard maize	Los Ríos Guayas	Handling practices: 0 % Genetics: 63 %	Chicaiza2010
Hard maize	National	Genetics: 23 %	Racines2011
Hard maize duro	National	Genetics: 3 %	Lusero-Sumba2014
Naranjilla	Pichincha Napo Morona Santiago Pastaza	Handling practices: 11 a 100 % Avergae: 43 %	Sowell2012
African palm	National	Genetics: 33 %	Cordova2013
Potato	Carchi	Handling practices: 40 %	Mauceri2007
Potato	National	Genetics: 33 %	Mora2012
Potato	Carchi	Handling practices: to the 2012 year: 6 a 68 % Average: 28 %	Carrion2016
Plantain	Manabí Santo Domingo	Handling practices: 19 a 61 % Average: 39 %	Cedeno2013
Quinoa and chocho (Andean grain)	Cañar Chimborazo Cotopaxi	Genetics: 23 %	Mazon2016
Natural resources	Bolívar	Handling practices: 57 %	Barrera2012
Soya	National	Genetics: 3 %	Alava2014
Cassava	National	Genetics: 22 %	Molina2014
Cassava	Manabí	Genetics: 85 %	Nevarez2011
Average		Handling practices: 35 % Genetics: 38 %	

results of the evaluations show positive effects in economic, production (performance) and environmental variables (Table 3). In the economics, the use of integrated pest management technologies in potato cultivation increased farmers' incomes from $250 to $560 per hectare (Mauceri et al., 2007). Integrated management of natural resources in the Upper Andean region of Ecuador with INIAP technology increased farmers' net income from 65 % to 81 %. The proper handling and application of pesticides increased the benefit in potato cultivation by 50 %, while the use of grafted Naranjilla increased economic benefit by 40 % to 60 % (Sowell and Shively, 2012).

Conservation technologies evaluated by INIAP increased milk production by 122 % (Barrera et al., 2012), and in potato the production increased by 1.9 tons per hectare (Cavatassi et al., 2011). In environmental terms, the development of the INIAP quitoense naranjilla released in 2009, will prevent deforestation of 17 300 hectares in 20 years (Clements et al., 2016); this high-yielding variety allows to increase production without affecting the agriculture. In bean farming, conservation tillage technologies increased production by 10 %. The incorporation of green fodder (oats) into the soil increased 20 % of barley production and 40 % of bean (Nguema et al., 2013).

The modernization impact of technologies on the cultivation of mulberry on the market price has also been a topic of study (Barrera et al., 2017). The results indicate the importance of implementing high quality standards during the production process. A single additional modernization activity during production - such as harvesting in ready-to-market containers, the use of improved varieties, among others-increases the price by 34 %. Sophisticated marketing-organic certifications, associativity, specific knowledge of the buyer, among others- and modernization in sales- the placement of the product in appropriate markets, sale to buyers with better prices, among others- also increase the price by 19 % and 27 %, respectively.

4 Discussion

The cost-effectiveness analysis of the 12 studies presented indicates that the results of INIAP's R+D, seen in improved genetic material and new agronomic practices allow produce more with a favorable economic return. The TIR generally represents or means the interest rate or return on an investment. TIR of public investment for the generation of technologies in INIAP has an average of 33 %. The profitability distribution in the 12 studies was wide, with values from 0 % to 68 %. Although each study was conducted independently in various areas and different regions of the country, the analysis of the results showed a uniform data distribution, with average values of 33 % and a median of 32 % (Table 1).

The economic surplus method was the most used to find the TIR. This method analyzes the surpluses generated by the displacement of a curve of a calculated offer, due to the effect of the increases caused by the increment in a planted area and yields, assigning a weight attributable to R+D (Alston et al., 1998). In other words, this method is based on the use of improved technologies to produce more with the same level of input. This technological development will allow the producer and consumer to benefit to some degree. The estimate of the economic surplus generated by the technological change considers the displacement of a supply curve due to increases in yields and in the cultivated area.

The study conducted by Reyes (2012) evaluated the productivity of bean varieties developed for the replacement of ancient varieties in Central America, Honduras and northern Ecuador, using experimental productivity data. The productivity gains observed in Ecuador, particularly on speckled red varieties, are 1,68 % per year. The same author found that the economic income of researches at the regional level showed a value of $358 million and a TIR of 32 %, and in Ecuador it reached a TIR of 35 %, and a VAN of 10.9 million dollars.

The TIR obtained in 11 out of the 12 studies identified was higher than the opportunity cost of the investment offered by the active benchmark rate for the public investment (9,33 %), published by the Central Bank of Ecuador in October 2018 (Banco Central del Ecuador, 2018). These results corroborate Timmer (1992), stating that agricultural productivity can grow faster than in other sectors due to the investment in scientific and technological development.

Technological adoption in the agricultural sector is a complex process that can cover a significant period of time, since it not only requires that the technology to be transferred is good, but that the actors involved have the resources and tools and destine them to the final users (Cadena Iñiguez et al., 2018). 37 % adoption average of technologies released by INIAP is below the average (40 %) obtained from thirteen adoption studies described by Barrientos-Fuentes and Berg (2013); work that collected information from assessments carried out in several countries around the world on agricultural technologies such as: genetic material, conservation agriculture, cultivation techniques, pest and disease management, among others.

Technology transfer in Ecuador is not the exclusi-

Table 3. Impact assessment studies of technologies developed by INIAP.

Topic	Period	Level	**Economic and environmental impact indicators**	**Reference**
Potato	1998-2003	Carchi	*E: the use of Integrated Pest Management increased income by $310 per hectare.	Mauceri2007
Naranjilla	2004-2013	National	A: 17 300 ha of deforestation avoided by the adoption of INIAP Quitoense.	Clements2017
Handle and preservation of natural resources	2006-2010	Bolívar	E: increased 65 % to 81 % in net income. Proper management of pesticides in potatoes increased the profit by 50 %. P: the use of better fodder increased milk production by 122 %.	Barrera2012
Potato	2007	Tungurahua Chimborazo	P: Increased of the potato production in 1.9 t/ha.	Cavatassi2011
Potato	2009-2012	Carchi	E: Decrease in expenditure due to the pesticide use by 60 %.	Carrion2016
Banana and other musaceae	2009	Manabí Cotopaxi	A: Biodiversity, banana and musaceae in an area decreases 2.56 times the possibility of damage caused by black stinging.	Marcillo2012
Naranjilla	2010	Pichincha, Napo, Morona Santiago, Pastaza	E: The economic benefit increases from 40 % to 60 %.	Sowell2012
Handle and preservation of natural resources	2010-2011	Bolívar	A: Zero tillage in bean increases yield by 10 %. The incorporation of oats into the soil increases barley production in 20 %, and 40 % in beans.	Nguema2013
Mulberry	2015-2016	National	E: The modernization of technologies: production, and commercialization determine the price between 19 and 34 %.	Barrera2017
Handle and preservation of natural resources	2011-2014	Bolívar	P: Farmers were willing to inves 2 % more in conservation techniques to achieve a 1 % increase in yield.	Barrowclough2016

*A= Environmental; E= Economic; P= Productive

ve competence of INIAP, but is part of other actors in a national public system and non-existent technical assistance for the Ecuadorian agro. The success of the American agro-industrial sector is dueto its high technological adoption, among other factors (Vieira Filho and Fornazier, 2016).

Studies with economic, productive and conservation indicators of natural (environmental) resources were observed in the results of impact assessments (Table 3). The works have been published in indexed journals, most are expost, and explain a causal relationship by solving the counterfactual problem by using quasi-experimental econometric methods. The main challenge of an impact assessment is to identify what would have happened to the beneficiaries of a program if the project had not existed (Khandker et al., 2010).

The impact of research investment has also been assessed at the regional level, where it was estimated that the potential economic value caused by technologies developed by INIAP and other public institutes in the Andean region for late blight control in potato reached $298 million over 20 years (González, 1998). A more recent study in Brazil reported that the increase in the land productivity in recent years is mainly due to increased investment in research, especially in the National Research Agricultural Institute-Embrapa (Gasques et al., 2010). These results support the information presented in Table 3, by stating that the investment in R+D has a positive impact in the agricultural sector in the medium and long term. However, these impacts do not reach all farmers and have not solved all the needs of Ecuadorian agribusiness. Although investment in agricultural R+D recorded a growth of 9% during the period 2009–2014 (SENESCYT e INEC. n.d, 2014), Ecuador has one of the lowest investment rates in R+D activities in South America, with an expenditure of 0,18% of its Agricultural GDP - GDPA (Stads et al., 2016), a value below the recommended by the World Bank (2% of GDPA) or the Interamerican Cooperation Institute for the Agriculture (1% of GDPA) (UNCTAD, 2007; IICA, OEA, 1999).

5 Conclusions

In the period 2007-2017, 37 socioeconomic studies have been published on the impact, profitability or adoption of technologies developed by INIAP, conducted by thirteen institutions, such as: Virginia Tech, University Purdue, Escuela Politécnica del Ejército, INIAP, among others. The results show that the technologies developed by INIAP, as Ecuador's main agricultural R+D center, have generated an internal rate of return of 33% with a 37% of adoption, positive results that justify the public investment in science and technology in Ecuador's agricultural sector. However, it is clear that many more studies are required to have better statistics in a greater number of research items and topics carried out by the institute, for example in coffee, cocoa, agrobiodiversity conservation and value (agribusiness). In addition, it is necessary to increase investment in science and technology, and to consolidate a national system and technical assistance for Ecuadorian farmers to increase the adoption of the technologies generated and to contribute to the sustainable and reference agriculture of the region.

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