Agriculture and Ecosystem Services: A Case Study of Asparagus in Ica, Peru

Rosario Gómez and Francisco Flores*

Universidad del Pacífico, Lima

Abstract

Sustainable agriculture is growing around the world and is synonymous with increases in crop productivity based on the efficient use of natural resources and employing an ecosystem and intertemporal approach. This study explores the link between agriculture and ecosystem services on the basis of a case study of the asparagus crop in Ica. It emphasizes the manner in which natural capital supports the development of this crop as well as the capacity of producers to adopt soil conservation and water management practices. The results show that the probability of adopting any such practices increases with levels of education, use of extension services, capacity-building, and access to credit.

Key words: ecosystem services, production function, water management, desert

* Article received on February 27; final version approved on September 30.
Rosario Gómez is a professor in the Department of Economics and researcher at the Centro de Investigación of the Universidad del Pacífico (CIUP).
Email: gomez_zr@up.edu.pe
Francisco Flores is a final year student in the Faculty of Economics and acted as research assistant in this project.
Email: franciscoflores_10@hotmail.com

Vol. XLII, N° 77, Second Semester 2015: pages 9-55 / ISSN 0252-1865

Acronyms

ANA	National Water Authority (Autoridad Nacional del Agua)
AU	Agricultural unit
AUS	Agricultural unit size
CENAGRO	National Agricultural Census (Censo Nacional Agropecuario)
CEPAL	Economic Commission for Latin America and the Caribbean (Comisión Económica para América Latina y el Caribe)
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
MA	Millenium Ecosystem Assessment
MINAGRI	Ministry of Agriculture and Irrigation
SENASA	National Agricultural Health Service (Servicio Nacional de Sanidad Agraria)
UNEP	United Nations Environment Programme
VPD	Vapor pressure deficit

INTRODUCTION

Since 2005 and on the basis of the Millennium Ecosystem Assessment (MA 2005c), the economic importance of ecosystems and the services they provide to improve human wellbeing has been widely acknowledged. As a result, the economic analysis of ecosystems that attempts to find evidence of the relationship between ecosystem services and the operation of economic systems has gained in importance. This study explores and illustrates the link between these services and agriculture, with particular reference to the case of asparagus farming. It should be noted that this ecosystemic perspective has been reinforced by the conceptual frameworks of the economics of ecosystems (UNEP 2010) and green growth (UNEP 2011).

Peru hosts more than 80% of the planet's life zones, including 12 fragile ecosystems and megadiversity that has sustained wide-ranging ways of life and production. In the last two decades, there have been notable changes in agricultural activity, i.e. crop production in non-traditional areas, which has contributed to the diversification of agro-exports, adoption of agricultural technologies and good practices, and certification of processes. These changes are geared towards responding to the requirements of destination markets, improving the efficiency of natural resource usage, and managing the use of scarce resources such as water. Thus, ecosystem services have gradually become part of production decisions. To illustrate the articulation of these factors, we have selected the case of asparagus production in Ica, which is notable for the diversification of its derived products in terms of both form and presentation.

Asparagus production in Peru dates back to the end of the 1950s, when the only centers of production were the valleys of Chao, Virú, and Moche in the department of La Libertad. At that time, production was centered on white asparagus. Later, from the mid-1990s, planting of green asparagus was promoted in Ica. As a result, by 2005, the export value of asparagus accounted for 26% of the value of Peru's non-traditional agro-exports. Later, as the diversification of non-traditional agro-exports continued, asparagus represented 14% of the total by 2014. Its export value grew at an average annual rate of 9% between 2005 and 2014. Ica is an important region for the production of asparagus. According to the National Agricultural Census (Censo Nacional Agropecuario, CENAGRO), it accounts for 31% of the area under this crop in Peru (INEI 2012).

Asparagus is produced in areas of loose soil with flanks that ensure proper growth. Soils of this type are found along the Peruvian coastline, where desert ecosystems predominate.

As a number of studies have shown, agricultural viability depends on a host of factors that are not exclusively technological (Swinton *et al.* 2006). In addition, it is recognized that agricultural activity is not confined to the places of production but requires a broader territorial focus, given the wide-ranging economic, social, and ecological interrelations that articulate this activity. Therefore, on the basis of agriculture, conservation activities that are conducive to maintaining ecosystem services can be undertaken (Swinton *et al.* 2007). In this context, the economic agent gradually incorporates other variables into the decision-making process for selecting both technologies and markets.

This study proposes to identify the main practices undertaken by asparagus producers in Ica in their attempts to conserve soil and use water appropriately. The hypothesis is that asparagus producers stand a better chance of engaging in soil and water conservation practices insofar as their level of education and access to advice, capacity-building, and credit is improved. It is understood that the conservation of soil and water will assure producers access to ecosystem services so as to adapt to changes that could occur in the input and end-product markets, or to the effects of climate change.

The quantitative analysis was carried out on the basis of CENAGRO 2012.

1. ECONOMY, ECOSYSTEM SERVICES, AND AGRICULTURE

1.1 An economic approach to the relationship between agriculture and ecosystem services

The inclusion of ecosystem services in economic analysis is relatively recent and owes to a paradigm shift in the concept of development. In an analysis of this shift, Shah (1999) makes an analogy between the development of the natural sciences and that of economics. According to the author, there is a relationship between the reversible character of physical phenomena, as developed by Newton, and the view of economics as a circular flow in which environmental changes are ignored. For its part, the neoclassical school posited the perception of ecosystem services as freely available gifts of nature that were to be exploited to the maximum for economic growth and development. Consequently, it ignored the costs associated with environmental degradation and the deterioration of ecosystem services (Fisher 1958).

The consequences of a form of growth and economic development that overlooks these concerns became evident in those situations in which the discrepancy between the social cost and the private cost perceived by an agent resulted in decisions that were to the detriment of social wellbeing. In this regard, it was found that the tendency among economic agents to maximize economic benefit led to the deterioration or disappearance of public goods or to the overexploitation of common goods (Pigou 1951; Buchanan and Stubblebine 1962; Shah 1999).

Taking this into account, attempts have been made to find solutions to the problem of common or open-access resources and externalities using approaches centered on domain (e.g., property rights), regulation (e.g., fishing quotas), and markets (e.g., carbon credits), though the question of externalities remains unresolved (Stavins 2011). This situation has created the need to move from static to dynamic analysis and to observe intertemporal optimization processes for guidance on proposing solutions, increasing future wellbeing, and preventing the depletion of public or open-access goods over time.

However, it to be noted that intertemporal maximization is subject to the assumption of rational expectations and the availability of past observations on which probability distributions can be constructed. In the case of a number of ecosystem services, the effects of human activity are only now being considered and studied, while the availability of past data is still limited or, in many cases, "their effects are felt with a timelag, at a point when decisions based on price signals have already been made " (Shah 1999). On the basis of adequate pricing as an indicator of relative scarcity, there have been efforts to promote a search for alternative resources, the creation of technologies, and the development of substitute goods, which together serve to prevent the accelerated depletion of resources (Stavins 2011). From the above, it can be inferred that many ecosystem services are susceptible to deterioration or depletion since they are not traded on the market or, if they are, the prices are based on users' willingness to pay and do not reflect intrinsic value, given that users only perceive the direct benefits accrued from the ecosystem services.

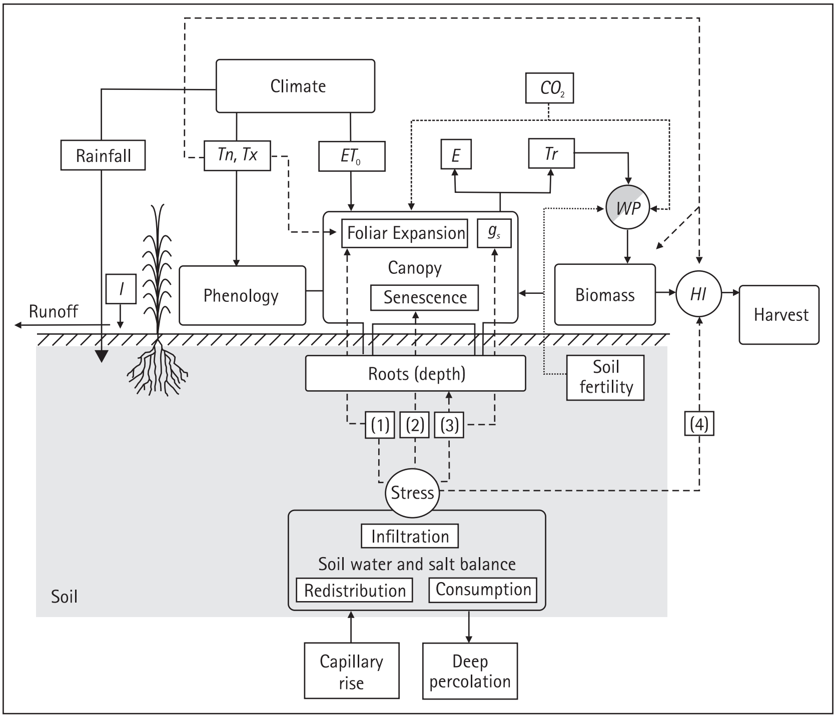
In this context, the economic decisions of agricultural agents should not be limited to the maximization of benefits in sole consideration of the production function and budget constraints, but would also have to include the costs and benefits associated with the conservation of the ecosystem services that these agents utilize. In addition, it is recognized that agricultural activity is not confined to the places of production but requires a broader territorial focus, given the wide-ranging economic, social, and ecological interrelations that articulate this activity. Therefore, although agriculture can include conservation activities that favor the maintenance of ecosystem services, some production decisions in this regard can have adverse effects that deteriorate ecosystem services and generate social costs (externalities) (Swinton *et al.* 2007). As a result, awareness and consideration of the depreciation of natural capital, in both qualitative and quantitative terms, would prompt the adoption of production techniques and decisions for its conservation over time, while minimizing adverse affects in the stream of benefits accruing from ecosystems.

1.2 The models: agricultural and economic

To explain production and its relationship with inputs, both agronomic and economic models exist. Agronomic models, according to Zhengfei *et al.*, focus "on the natural processes of crop growth in terms of the role of climatic factors, water, nutrients, and other agronomic inputs" (2006: 203). Meanwhile, economic models add socioeconomic factors (capital, labor) and are developed at an aggregate level (in regions or on an agricultural property), which creates problems in properly assessing the role of inputs and bias in the conclusions (Bachman 1952; Lave 1964; Stovall 1966; Day 1969; Paris 1981). In contrast, an integrative approach to the biological processes and their interaction with the environmental factors enables better recognition of the ecosystem services in agriculture and the effect of interventions in the ecosystem (Swinton *et al.* 2006).

An example of an agronomic model is AquaCrop, developed by FAO, whose concepts are summarized by Steduto *et al.* 2012) (Figure 1).

Figure 1
AquaCrop Model, FAO



Source: FAOSTAT.

This model is useful in explaining the production potential of a crop based on its level of water consumption. However, it would also be helpful to include other components: climate, cultivation, soil, and crop management. Climate includes the following: thermal regime (maximum temperature T_x; minimum temperature T_n), rainfall, irrigation (I), evapotranspiration (ET_o) and concentration of CO_2 (carbon dioxide). Cultivation includes aspects related to development, growth, and processes associated with final yield such as phenology, canopy (the upper part of plants), root depth, plant transpiration (T_r), soil evaporation (E), biomass production, and final usable product.

The rainfall and irrigation component allows estimation of the water and salt balance of the soil, which is considered as a set of layers whose individual characteristics condition water and salt content through inflow - infiltration (rainfall and irrigation water) and capillary rise; and outflow - runoff, percolation, and evapotranspiration, thereby determining the total availability of water in the soil. Crop management refers to irrigation practices and property administration. Irrigation systems include gravity-fed, sprinkler, and drip methods, among others, while production management activities consist of fertilization, soil mulching, and surface transformation (ridges, furrows, and embankments), among others.

Once the main components of this model are defined, the relationships between these components and the potential product must be explained, thus facilitating classification based on an ecosystem services approach. Temperature directly influences plant development (phenology) and, at extreme levels, it reduces water productivity (*WP*) and the relative level of "harvestable" product with respect to biomass (*HI*), thus decreasing potential production. Moreover, rainwater and evapotranspiration influence the soil's water balance, thus affecting plant development.

Other components and processes that aid in understanding this model are as follows: CO_2 concentration affects water productivity, canopy cover, and the plant photosynthesis and transpiration process, thus impacting plant development and end-product quality; canopy cover influences biomass level, which is related to the end product; root depth is positively related to the level of water and nutrients consumed by the plant, thus influencing its development (FAO 2003); plant transpiration is linked to photosynthesis (Allen *et al.* 1998), and also affects development; soil evaporation influences the availability of water in the soil (Allen *et al.* 1998), which also influences plant development; soil characteristics and inflows and outflows that determine total water availability in the soil also affect plant development; fertilization provides the soil with nutrients, thus promoting crop development; mulching reduces soil evaporation, preventing a reduction in total water availability in the soil; finally, soil surface treatment enables better control of runoff by retaining irrigation and rain water and aiding their infiltration, which increases the total availability of water in the soil.

Meanwhile, the Millenium Ecosystem Assessment (MA 2005a) identified the ecosystem services that are fundamental to agricultural activity. Provisioning services include water availability and genetic diversity. Water, which is necessary for the growth cycle and plant development, is also factored into the AquaCrop model in the form of rainfall, irrigation, and total availability of water in the soil. Genetic diversity is not included in this model because it is only applied to a single crop. However, this diversity is conserved in ecosystems and provides agriculturalists with a wide range of crop varieties to grow.

In the case of regulating services, MA refers to atmospheric and climatic regulation, the water cycle and the maintenance of water quality, erosion regulation and the maintenance of soil quality, and disease and pest control. With respect to atmosphere and climate regulation, both thermal regime and humidity - the components of the AquaCrop model - determine the vapor pressure deficit (VPD). This is positively related to plant transpiration, increasing water requirements, and negatively related to cloud volume. Lower cloud volume causes higher luminosity and, in consequence, an improvement in photosynthesis (Roberts *et al.* 2012).

Soil quality maintenance is achieved as a result of the interaction between soil structure and characteristics (texture, depth, and water retention) and other factors that do not appear in the AquaCrop model, such as certain chemical (level of acidity) and biological (organic matter, microfauna) properties (Jaenicke and Lengnick 1999). While pest and disease control is not mentioned among the components of this model, it is carried out by the microfauna (insects) that coexist with the crops (Swinton *et al.* 2006; MA 2005a).

Supporting services include soil formation, the nutrient cycle, and the formation of organic matter, which together form the basis for the development of any crop in that they sustain the biological processes that are fundamental for plant growth. In the AquaCrop model, the nutrient cycle is linked to canopy cover and biomass (Vandermeer 1995; MA 2005a).

In economic models, production is represented through the concept of production function, which indicates a relationship between production and the factors of production. This is normally expressed through a mathematical function that includes factors such as capital and labor and a measure relating to total factor productivity, which is usually related to efficiency gains due to technology. However, to apply this production function - formally expressed as $Qt = A\, f\,(k_t, l_t)$, where A is the productivity indicator, k capital and l labor – to explain agricultural output would be to overestimate the contribution of capital and labor in production and to disregard the role played by other factors, such as ecosystem services (Oury 1965).

One of the first ways of introducing variables such as climate was proposed by Oury (1965), who employes a Cobb-Douglas function and introduces a dummy variable to represent climate. Although this methodology appears to be of limited utility in assessing the role of ecosystem services, the author stresses the difficulty in individually selecting different climatic characteristics due to their interdependence.

Subsequent work by Mundlak and Hellinghausen (1982) uses a regression to attempt to construct a global agricultural function in which the endogenous variables are divided into an input vector (*x*) and a vector of state variables (*z*). The variables comprising the former vector include those that can be readily measured such as land, fertilizers, machinery, labor, and livestock population; while those in the latter refer to natural conditions. However, the effects of these on individual crops tend to be offset at the aggregate level, with a loss of significance in the function.

Nonetheless, the same authors consider state variables such as potential biomass production and the water deficit factor, since natural conditions do affect aggregate output through their influence on land suitability for agriculture. The formal expression is as follows: $Q_{it} = x'_{it}\beta_i + u_{it}$ and $\beta_i = \Pi z_i + w_i$, where w and u are independently distributed random variables. Although this estimation seems to consider some provisioning and supporting services through the state variables (water deficit as a reference to water availability, and potential biomass production as a representation of favorable conditions created by soil and rainfall), it overlooks the role of the remaining ecosystem services.

Fleischer *et al.* (2007) propose an alternative way of incorporating certain ecosystem services into the production process, in which the inputs subject to the decision-making criteria of farmers - capital, labor, seeds used - are taken into account in a vector of endogenous vectors (*x*); those inputs that fall outside the control of farmers - weather and soil conditions - are included in a vector of exogenous variables (*z*); finally, in the case of this model, farmers' managerial skills are included in a vector (*m*). The formal expression of this relationship is as follows: $Q_t = f\,(x_t, z_t, m_t)$. The economic use of this production function can be seen in studies such as that conducted by the Economic Commission for Latin America and the Caribbean (CEPAL 2009), which employs the function to determine production and profit losses in vital crops (beans, corn, and rice) in Central America due to the effects of climate change as reflected in alterations to the vector of exogenous variables.

In recognition of the importance of ecosystem services and the efforts made to incorporate them into the production functions, the next section analyzes a case study: the asparagus crop in Ica. The economic importance of this crop to Ica and Peru in general is discussed, followed by a description of the desert ecosystem and its services and their relationship to agriculture. In order to understand the relationship between agriculture and ecosystem services, the analysis centers on the adoption of soil conservation and water management practices as a proxy for the management of provisioning, regulating, and supporting ecosystem services.

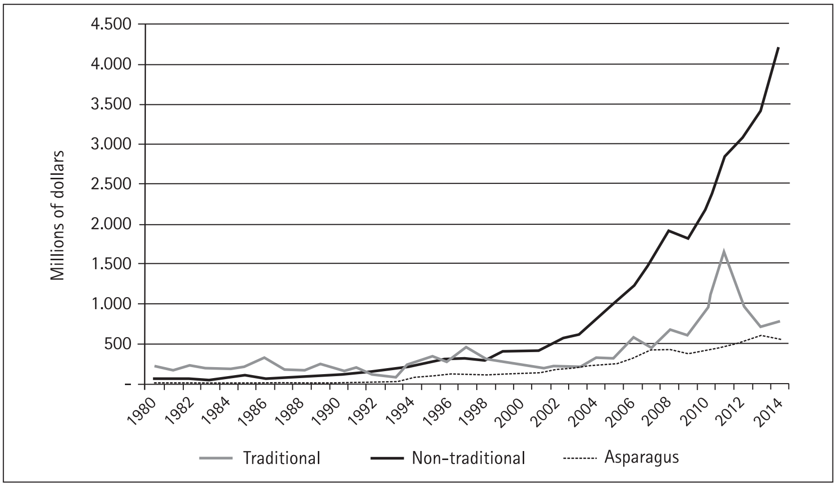
2. THE EXPANSION OF ASPARAGUS PRODUCTION IN PERU

2.1 The economic importance of asparagus

The expansion of asparagus cropping in Peru has enabled the diversification of asparagus products for export. Unlike in the 1960s, when only preserved white asparagus was exported, today both white and green asparagus are exported in preserved, fresh, and frozen form. The export value of this crop increased to the point where it comprised 26% of Peru's total non-traditional agro-export value in 2005. Then, after an intense process of diversification of non-traditional agro-export products in Peru, asparagus represented 14% of the country's total agro-exports by 2014, having grown at an average annual rate of 9% between 2005 and 2014 (Figure 2).

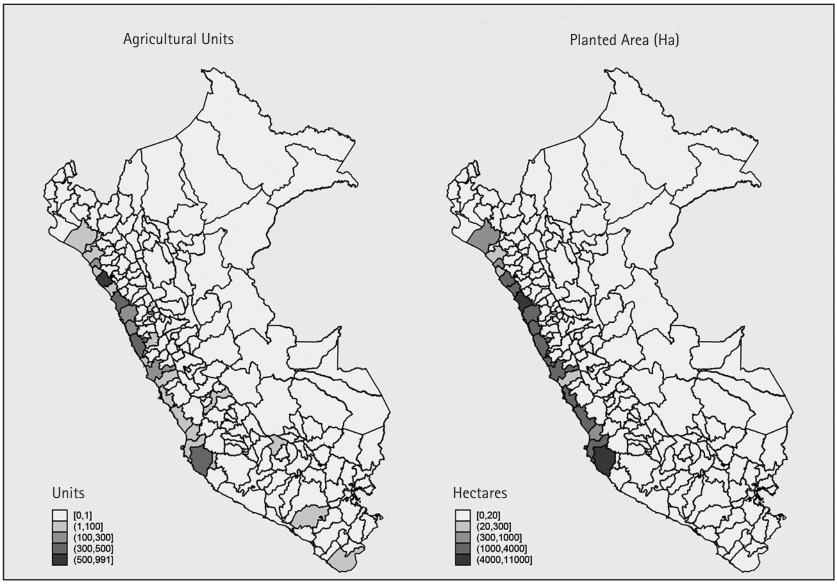
Asparagus production in Peru is concentrated on the country's Pacific coast. The departments of Ica and La Libertad are the main centers of production, with the greatest number of agricultural units (AUs) dedicated to asparagus and the largest area under this crop (Map 1). In Ica, asparagus production grew at an annual rate of 32% between 1987 and 2012, vastly outstripping the average national rate of 12%. This resulted in a spatial reconfiguration of asparagus production in Peru, in which Ica accounts for the largest share. Thus, while in 1988 La Libertad and Ica accounted for 94% and 4% of national production, respectively, by 2012 this had changed to 50% and 38%, respectively (Figure 3).

Figure 2
FOB value of traditional and non-traditional agricultural exports, and of asparagus exports, 1980-2014 (in millions of dollars)



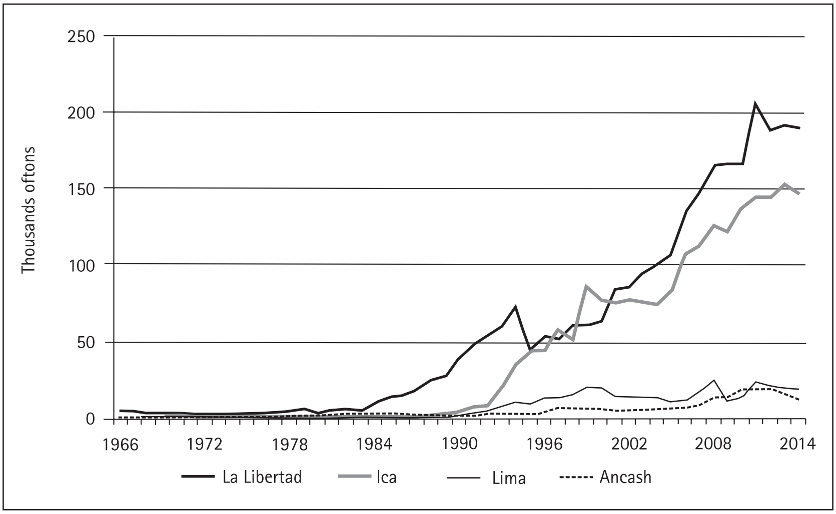
Sources: BCRP; MINAGRI; FAOSTAT; SIICEX; compiled by authors.

Map 1
Agricultural units and area under asparagus, by province, Peru, 2012



Source: INEI (2012); compiled by authors.

Figure 3
Evolution of asparagus production by main producing departments, Peru, 1966–2014 (in thousands of tons)



Source: MINAGRI; compiled by authors.

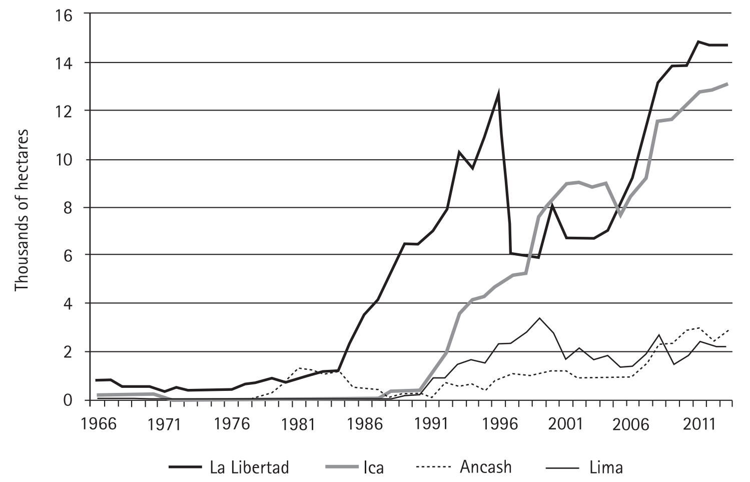
In Ica, the harvested area grew at an average annual rate of 21% between 1987 and 2012, surpassing the national average growth rate for that period of 8% (Figure 1). It is worth noting that Ica had overtaken La Libertad by 1999, with respective harvested areas of 41% and 33%. As at 2012, of the approximately 33,000 hectares used for asparagus production nationwide, 44.5% was situated in La Libertad and 38.9% in Ica (Figure 4).

Table 1
Asparagus production and planted area, average annual growth by main producing departments of Peru, 1987–2012 (in percentages)

Department	Period	Average annual rate (%)	
		Production	Area
Ancash	1987–2012	9.87	6.55
Ica	1987–2012	32.03	21.03
La Libertad	1987–2012	9.34	4.97
Lambayeque	1987–2012	11.39	8.14
Lima	1987–2012	21.03	15.01
Piura	1987–2012	- 9.99	- 9.10
Peru	1987–2012	11.87	7.70

Source: MINAGRI; compiled by authors.

Figure 4
Evolution of harvested area of asparagus, main producing departments of Peru, 1966–2011 (in thousands of hectares)



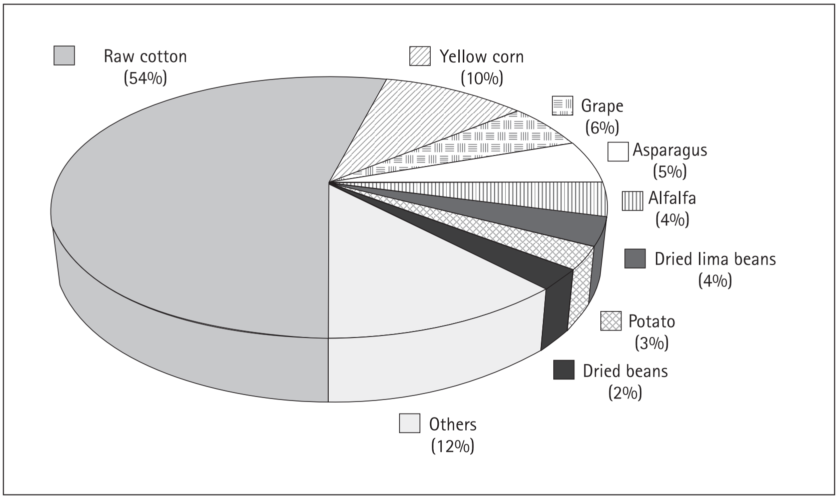
Source: MINAGRI; compiled by authors.

In Peru as a whole, the asparagus yield grew at an average annual rate of 4% between 1987 and 2012. La Libertad and Ica were at the forefront of this process, recording average annual growth of 4% and 9%, respectively. In 2012, La Libertad posted the highest yield (12,000 kg/ha), followed by Ica (11,200 kg/ha) and Piura (9,500 kg/ha).

This data shows how in a short space of time, Ica's production volume, area harvested, and yield came to rank alongside that of La Libertad - a department that, until the mid-1990s, was ahead in all aspects of asparagus production. Below, the performance of this crop in the provinces of Ica is reviewed so as to identify the main areas of production and then analyze the factors that have contributed to the leadership of the provinces identified.

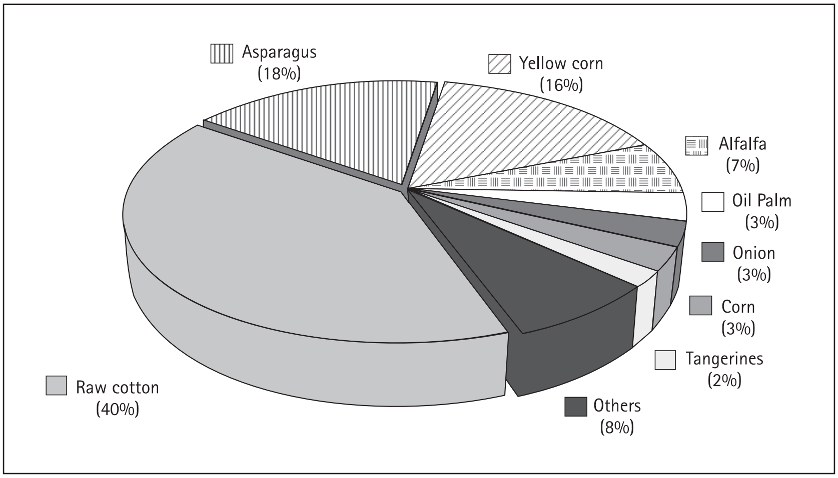
Before doing so, it is necessary to compare asparagus with other crops in Ica in order to understand its relative importance in this department. In terms of planted area, asparagus was Ica's second most prevalent crop in 2012 – moving up from fourth place in 1995 - occupying almost a fifth of the agricultural land area (figures 5 and 6).

Figure 5
Agricultural products by planted area, department of Ica, 1995 (in percentages)



Source: Dirección Regional Agraria de Ica; compiled by authors.

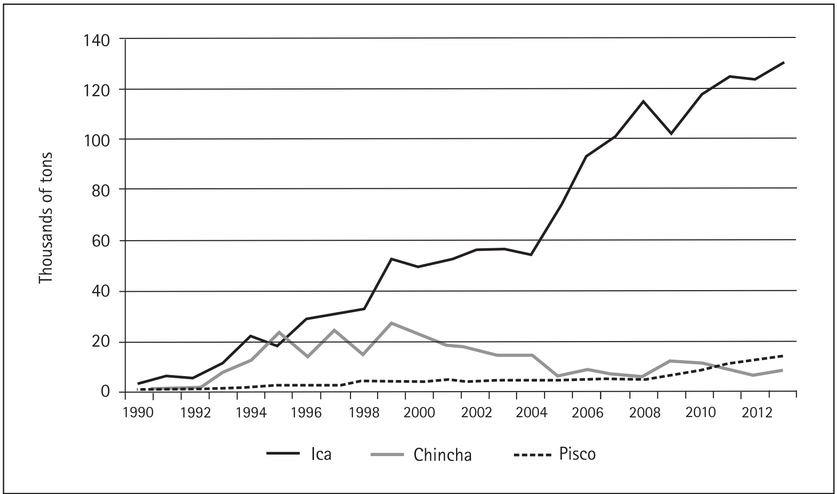
Figure 6
Agricultural products by planted area, department of Ica, 2012 (in percentages)



Source: Dirección Regional Agraria de Ica; compiled by authors.

All of the five provinces of the department Ica - Ica, Pisco, Chincha, Palpa, and Nazca - are engaged in asparagus production to some extent. In 2011, the provinces of Ica (86.1%), Pisco (7.6%), and Chincha (6%) stood out as the department's biggest producers, while Palpa and Nazca accounted for less than 1.0% between them. The province of Ica has not always been pre-eminent – it began to take the lead starting in 1999 (Figure 7).

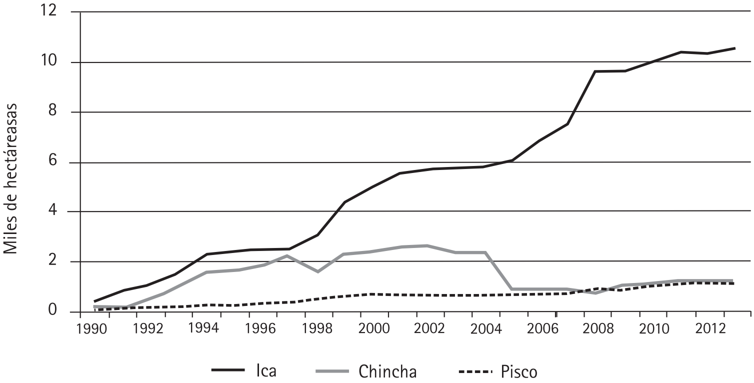
Figure 7
Evolution of asparagus production, main producing provinces, Ica, 1990-2012 (in thousands of tons)



Source: Dirección Regional Agraria de Ica; compiled by authors.

As to harvested area, in 2011 the province of Ica made up 81.2%, while Pisco and Chinca stood at 8.7% and 9.3%, respectively. The provinces of Palpa and Nazca together comprised only 0.9% of this total. Until 1999, the harvested area in Ica was only slightly higher than that of Chincha, and throughout the 1990s, Chincha had a higher annual growth rate (33.6%) than Ica (26.7%). But from 2000 onwards, the area harvested in Chincha fell by an average of 5.7% per year, while in Ica it continued to grow by 6.3%. Here, the province of Pisco again stands out, having grown by 29.4% per year during the 1990s and by 4.8% since 2000. However, despite the growth rate of Pisco having exceeded that of Chinca during the latter period, this was not true of total harvested area (Figure 8).

Figure 8
Evolution of harvested area of asparagus, main producing provinces, Ica, 1990-2012 (in thousands of hectares)



Source: Dirección Regional Agraria de Ica; compiled by authors.

There are also differences in asparagus yields across the department of Ica. In 2011, the province of Ica led with 12,000 kg/ha; followed by Pisco, with yields of 9,800 kg/ha; and then by Chincha, at 7,300 kg/ha. The province of Ica has remained at the forefront almost constantly in terms of yield and was surpassed by Chincha only in 1995 and 2009.

In summary, asparagus is economically important not only because of the value it generates, but also because it constitutes a value chain that has developed along the length of the coast. In addition, two centers of production predominate: the departments of La Libertad and Ica. For the purposes of this study, we concentrate on asparagus production in department of Ica and especially in the province of Ica, which is demonstrably an outstanding center of production. In the following section, we discuss the characteristics and ecosystem services that sustains asparagus production.

2.2. The desert and ecosystem services

An ecosystem is a community of living beings whose vital processes are interrelated and function on the basis of the characteristics of a single physical environment, acting as an interdependent functional unit. According to the United Nations Environment Programme (UNEP 2006), several criteria are used in defining a desert, but one of the most important is aridity – the lack of water as a limiting factor on biological processes. In arid and hyperarid regions, rainfall contributes less than 20% of the water necessary for plant growth. The highest levels of aridity on the planet are found in the deserts of Peru and Chile, as well as the Sahara in Africa. Almost a quarter of the Earth's surface is occupied by desert, including, of course, the Peruvian coast.

Ecosystems are important in that they provide benefits to the population that are known as ecosystem services. These include provisioning services (products that the population obtains from them), regulating services (benefits that the population obtains thanks to the ecosystem's ecological processes) cultural services (non-tangible benefits), and supporting services (those that guarantee the presence of the above-mentioned services) (MA 2005a) (Table 2).

Table 2
Desert ecosystem services

Provisioning	Regulating	Cultural	Supporting
- Fossil fuels - Water-soluble salts - Minerals - Plants with medicinal and cosmetic uses - Space for animal husbandry	- Water - Bird migration corridor - Sediment transport - Pest and disease	- Landscape - Historical and religious value - Identity and cultural diversity	- Soil formation and conservation - Nutrient cycle

Source: INEI (2006); compiled by authors.

With respect to provisioning services, deserts provide between 30% and 60% of the minerals and fossil fuels exported in the world, as well as water-soluble salts, plants with cosmetic and medicinal uses, and space for livestock activities (goats and camelids). Some deserts also contain water sources in the form of rivers that run through them, or aquifers (MA 2005b; UNEP 2006).

With regard to regulating services, some deserts that have a certain degree of plant cover provide water regulating services, determining availability for human use. In comparison with other ecosystems, deserts also act as corridors for migratory birds and constitute a source of nutrients (silicon and phosphorous) in the form of particles of sand carried by the wind. For human activities, the warm and dry climate of the desert is conducive to agriculture and horticultural energy (MA 2005c; UNEP 2006).

The cultural services furnished by the desert include scenic beauty, historical value (as the cultural cradle of the three biggest monotheistic religions), and identity and cultural diversity (nomadic cultures, linguistic diversity, among others) (UNEP 2006).

Finally, supporting services include those related to soil formation and conservation, nutrient cycles (UNEP 2006), and primary production; that is, the production of organic matter by certain species (UNEP 2006).

The Atacama-Sechura deserts extend from the province of Sechura in Piura, Peru, to central Chile. This ecoregion is situated along the western seaboard of South America between the Pacific Ocean and the Andes, and is intersected by the more than 40 low-volume rivers that make up the Pacific basin. Flora is scarce in this physical environment and fauna is restricted to certain species of insects, reptiles, small mammals, and migratory birds (Pulgar Vidal 1979).

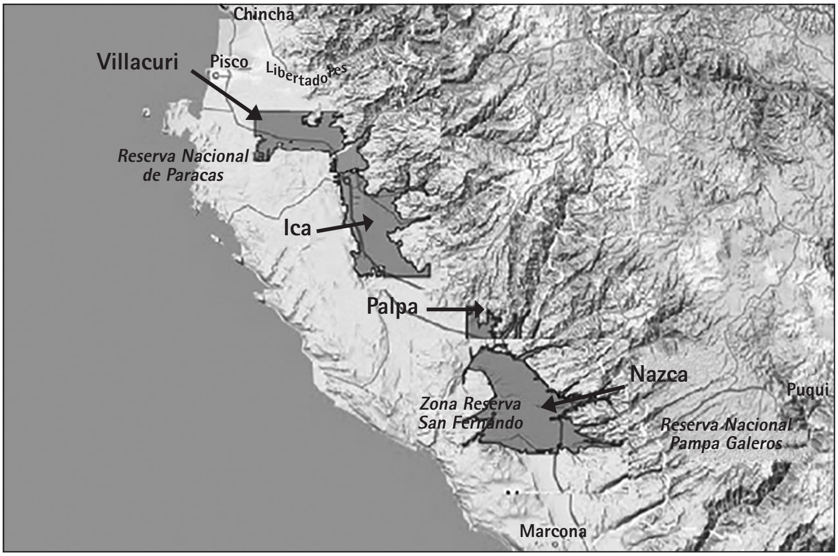
In the case of Ica, three geographical zones can be discerned: coastline, the coastal plain, and the western slopes of the Andes. The coastal plain is the largest of these zones, a 60 km expanse of desert crossed by the Pisco, Ica, Grande, and San Juan (or Chincha) rivers. These rivers originate in the province of Castrovirreyna in the department of Huancavelica. Discharges are largely restricted to the period from December to April, and the rivers usually run dry for the rest of the year (Senamhi 2008).

The coastal plain of Ica is a desert characterized by extreme aridity and limited rainfall. It has a relatively stable climate, with sunshine practically all year round. Rainfall is almost non-existent, with only negligible levels recorded during the summer (1.5 l/m2). The average, highest, and lowest summer temperatures are 27 °C, 32 °C, and 18 °C, respectively, while the equivalents for winter are 18 °C, 25 °C, and 9 °C, respectively. However, during the El Niño phenomenon, temperatures can reach up to 35 °C (Senamhi 2008).

The soil in Ica is predominantly sandy. That said, there are some mineralized areas, such as the low hills of Huamani-Molletambo where there are deposits of copper, steel, lead-silver, zinc, and other minerals, as well as deposits containing non-metallic minerals (for example, clay, limestone) that are used for construction and ornamental use (Gobierno Regional de Ica 2007).

Moreover, the Villacurí, Ica, Palpa, and Nazca aquifers are located in the department (Map 2). The Ica Aquifer is located beneath the surface of the Ica River valley, and is recharged with water from that river and from the upper part of its basin. Discharge occurs through the use of wells in addition to natural drainage, which gives rise to lakes such as Huacachina. In 2009, the depth of this aquifer fluctuated between 1.5m and 60 m (Autoridad Nacional del Agua [ANA] 2009).

Map 2
Aquifers of the department of Ica



Source: ANA; compiled by authors.

Management of the Ica Aquifer is subject to problems related to the assignment of rights, oversight of usage, and informality, which creates incentives for over-exploitation (Huamán 1997). Oré *et al.* (2011) argue that discharges through wells (543.15 million m^3) are beyond sustainable levels (252.99 million m^3), based on data from the ANA and the Regional Directorate of Agriculture for Ica (Dirección Regional de Agricultura de Ica). They also state that monitoring and control are limited and that there is a lack of will on the part of local authorities to regulate groundwater use.

Given that surface water in the area is seasonal, 75% of agriculture in the province utilizes groundwater from the aquifer, which is also the main source of water for the local population. Thus, overuse of the aquifer not only places agricultural development in Ica at risk, but could also trigger conflicts between the different users of this scarce resource.

Indeed, these is already in evidence between agro-export companies and the rural and urban populations (Oré *et al.* 2011).

2.3. Asparagus production and agricultural practices in Peru and in Ica

In Peru, slight differences can be appreciated in the distribution of land under asparagus across the different producing areas, according to agricultural unit size (AUS). While 75% of the nationwide planted area is found in AUs of more than 50 ha (Table 3), the equivalent proportions for Ica and La Libertad are 83% and 77%, respectively. Moreover, in the province of Ica, 84% of the planted area for asparagus is concentrated in AUs of more than 50 ha.

Table 3
Area under asparagus by AUS, Peru and main producing departments and provinces, 2012 (in hectares)

Location	AUS			Total
	Less than 10 ha	Between 10 and 50 ha	More than 50 ha	
Peru	5,644.81	4,306.01	29,677.86	39,628.68
Departments				
Ica	817.24	1,342.43	10,229.67	12,389.34
La Libertad	2,236.91	1,355.28	11,698.27	15,290.46
Provinces				
Ica	756.60	953.66	8,673.47	10,383.73
Pisco	46.03	262.25	1,015.67	1,323.95
Chincha	11.40	118.52	532.53	662.45

Source: INEI (2012); compiled by authors.

In the province of Ica, the asparagus crop occupies a sizable portion of each AU, with producers allocating an average of more than 65% of their AU to this crop, regardless of AUS (Table 4).

Table 4
Relative importance of area under asparagus, province of Ica, 2012 (in percentages)

AUS by planted area	Average percentage of total AU under asparagus (%)
Small: less than 10 ha	72.4
Medium: between 10 and 50 ha	64.5
Large: more than 50 ha	68.8

Source: INEI (2012); compiled by authors.

From the data in Table 3, it can be seen that asparagus is chiefly grown by large producers. This trend is nowhere as evident as in the department of Ica, where over 75% of production in the main producing provinces is concentrated in AUs of more than 50 ha.

As regards irrigation methods for asparagus production, drip and gravity-fed systems are primarily used. In 2012, drip irrigation was employed in 54.4% of productive units, compared with gravity-fed in 44%. Sprinkler irrigation accounted for only 1.5% of all cases.

In the department of Ica, 74.2% of irrigation utilizes the drip method, which is higher than the national average, while 23.6% is gravity-fed and 2.2% by sprinkler. In La Libertad, 64.4% of AUs employ drip irrigation, while the gravity-fed method accounts for 34.5%. Overall, technified irrigation systems predominate in Ica, comprising both drip and sprinkler methods.

Just as in the whole department of Ica, in the province of Ica, the use of drip irrigation in asparagus production is extensive, at 74.5%, while the gravity-fed method represents 22.8% (Table 5). Drip irrigation has enabled the optimization of the scarce resource of water. According to the San Camilo weather station in Parcona (Ica), the volume of water required for growing asparagus with a gravity-fed irrigation system is 1.7 times greater than that needed for drip irrigation. That is, gravity-fed irrigation requires 15,444 m^3/ha/year, while drip irrigation needs 9,000 m^3/ha/year, which means that the latter system allows 49,821,141 m^3/year of water to be saved in the area.

Table 5
Area under asparagus by irrigation systems used, province of Ica, 2012

Irrigation system	Planted area (ha)
Drip	7,731.4
Gravity-fed	2,367.9
Sprinkler	273.5
Exudation	9.0

Source: INEI (2012); compiled by authors.

Of equal importance as the irrigation system employed is the source of the water used. The data available (discussed below) applies to all crops, but it provides a good approximation of the case of asparagus production in the provinces of Ica, given this crop's share of agricultural production there.

Nationwide, the sources of water for irrigation are varied. The primary sources are surface and ground water, which account for 37% and 40%, respectively. Other sources with lesser shares are lakes, large and small reservoirs, and seasonally-regulated dammed water, which together make up 6% of water used for irrigation.

In Ica, groundwater is predominantly used, with a share of 43%, while 31% comes from rivers and 21% from springs. La Libertad is somewhat different, with 46% taken from rivers, 37% from springs, and just 4% from groundwater (INEI 2012)

Thus, although the use of drip irrigation is extensive for the asparagus crop, the water sources used vary from region to region. In La Libertad, the main sources are rivers and springs, while in Ica groundwater is the main source. In the foremost asparagus-producing province, Ica, wells constitute the most prevalent source, at 75%, while in other provinces surface water is of greater relative importance.

3. RESULTS OF THE CASE STUDY

3.1. Characteristics of the producers

To analyze the conditions that promote the adoption of soil conservation and water management practices in the case of asparagus in Ica, we use the results of the 4th CENAGRO, conducted in 2012.

Among the practices linked with forms of ecosystem service conservation, we selected: the use of technified irrigation (a dichotomous variable that separates the use of gravity from the use of sprinkler, drip, and exudation systems); the application of biological insecticides (natural pesticides derived from plants, minerals, bacteria, or animals [Environmental Protection Agency, EPA]); the use of biological control (pest control using beneficial species); and the possession of reservoirs or dams. As stated above, technified irrigation is an efficient means of managing water, not only as a response to scarcity in a desert ecosystem, but also to prevent runoff, mitigate erosion, and contribute to soil conservation. For their part, both biological insecticides and biological control do away with the need to use chemical pesticides, the ecological consequences of which include reduced soil fertility due to inhibition of the nitrification and oxygen fixation processes in plants, as well as the impact on soil microorganisms that contribute to the formation of nutrients and the soil itself. (FAO 1997). Finally, reservoirs provide a means of stabilizing the seasonal water supply, thereby helping to reduce irrigation in a context of possible scenarios of greater scarcity or irregular availability of water.

For this research, AUs in the province of Ica that produce asparagus on at least one plot were selected, with a total of 395 observations. These observations were then grouped into three profiles or types by AUS and legal status (natural person, corporation, etc.), which reduced the number to 318. The first profile, classified as "small farmers," corresponds to AUs of between 2 and 20 hectares that are registered to natural persons (244 observations); the second, "medium-sized farmers," includes AUs of between 20 and 100 hectares that are also registered to natural persons (35 observations); the third profile "large farmers," includes AUs of more than 100 hectares that do not correspond to natural persons (39 observations, of which 89.7% are corporations and the rest limited liability [Sociedad Comercial de Responsabilidad Limitada, SRL] or single-owner limited liability companies [Empresa Individual de Responsabilidad Limitada, EIRL]).

Using this classification, we find that 86.7% of the AUs of 100 hectares or more pertain to companies, which together comprise 71.2% of the area under the asparagus crop in Ica. On the other hand, 87.2% of AUs with more than 2 and less than 100 hectares are operated by natural persons, but only constitute 16.8% of the planted area for the crop.

Each of the three farmer profiles (small, medium-sized, and large) utilize irrigation, and more than 90% of each use seeds and/or certified seedlings. Except for these aspects in common, the profiles differ from one another across various characteristics (Table 6).

With respect to production factors, the proportion of AUs that use technified irrigation is greater among large farmers than small farmers (91.89% and 15.98%, respectively). Likewise, large farmers possess more infrastructure for access to groundwater and its storage, and use more electrical energy and biological control than other farmers (Table 6).

With respect to institutional factors, the proportion of producers who make use of the financial system is lower among large farmers (30.77%) than is the case for their small counterparts (46.31%); the former solely use full-service banking, while the latter are more reliant on municipal and rural savings banks and less on full-service banking, the Agrobanco,[1] or informal lenders (habilitadores). Extension services are widely used: more than 50% of the three types of farmers have received capacity-building or assistance of some kind. However, the proportion of those who have received technical or business advice is greater among large farmers (76.92% and 61.54%, respectively) than small farmers (40.16% and 26.64%, respectively). SENASA is the most-used provider of these services for small and medium-sized farmers, while large farmers primarily employ private companies. There are also disparities when it comes to associative practices, which small farmers engage in (81.15%) more than do large farmers (41.03%).

1. Translator's note: This is the Peruvian state-owned agricultural bank.

Table 6
General characteristics of asparagus-producing farmers by profile, province of Ica, 2012 (in percentages)

Characteristics[1]		Type of farmer		
		Small[2]	Medium-sized[3]	Large[4]
Number of AUs		244	35	39
Type of irrigation	Gravity-fed	84.02	35.29	8.11
(%)	Technified	15.98	64.71	91.89
Wells (units)		0.26	1.29	6.77
Use of own reservoirs (%)		1.23	25.71	48.72
Use of organic fertilizer (%)		95.49	91.43	79.49
Use of biological insecticides (%)		60.66	60.00	79.49
Aplication of biological control (%)		29.51	40.00	74.36
Use of certified seedlings		90.57	91.43	97.44
Access to financing (%)		46.31	51.43	30.77
Finance provider	*Habilitador*	14.16	22.22	0.00
	Agrobanco	15.93	22.22	0.00
	Full-service banking	16.81	33.33	100.00
	Municipal savings bank	27.43	27.78	0.00
	Rural savings bank	23.89	11.11	0.00
Capacity-building	Capacity-building	45.08	45.71	66.67
and advice (%)	Technical advice	40.16	40.00	76.92
	Business advice	26.64	20.00	61.54
Provider of	MINAGRI	39.84	10.00	12.12
capacity-building	SENASA	69.11	60.00	45.45
and/or advice (%)	Private company	21.14	45.00	75.76
Use of electrical	Used	27.46	54.29	94.87
energy (%)	- From the grid	22.13	37.14	92.31
	- From a generator	4.92	17.14	2.56
Participation in association, committee and/or cooperative		81.15	34.29	41.03
Destination of sale (%)	Domestic market	77.46	60.00	7.69
	Foreign market	25.00	48.57	92.31

Notes
[1] Based on multiple-choice questions.
[2] Between two and 20 ha registered to a natural person.
[3] Between 21 and 100 ha registered to a natural person.
[4] More than 101 ha, all owned by corporations, SRL, and EIRL.
Source: INEI (2012); compiled by authors.

Finally, it was found that the destination of sales is systematically different across the profiles, with large farmers primarily engaged in export sales (92.31%) and small farmers in sales to the domestic market (77.46%).

The volume of asparagus produced by large farmers in Ica has quadrupled in the space of eight years. This is consistent with the accelerated increase in export volumes during the first half of the 1990s, which coincided with a rise in production output. When it comes to irrigation, in 1994, gravity and technified irrigation systems were similarly prevalent but by 2012, use of the former had fallen to 8.11% and the latter had risen to 91.89%. Moreover, the number of wells and the use of electrical energy also increased (Table 7).

Furthermore, among this group dependence on the financial system fell, as did the level of participation in associations. With respect to conservation practices, the use of biological insecticides became widespread (increasing from 33.33% to 79.49%), and the proportion of large farmers with reservoirs fell (from 88.89% to 48.72%).

The decrease in the use of reservoirs can be explained by the increase in infrastructure for accessing water through wells, while the high percentage of AUs with access to extension services may reflect the importance of these for agricultural institutions. Thus, the empirical evidence may suggest that greater adoption of conservation practices has been accompanied by improved water-access infrastructure and a constant level of extension-service provision.

Table 7
Changes in the general characteristics of large asparagus farmers, province of Ica, 1994 and 2012

Characteristics[1]		1994	2012
Number of AUs		9	39
Type of irrigation (%)	Gravity-fed	55.56	8.11
	Technified	55.56	91.89
Wells (units)		1.33	6.77
Use of own reservoirs (%)		88.89	48.72
Use of organic fertilizer (%)		100.00	79.49
Use of biological insecticides (%)		33.33	79.49
Use of certified seedlings		100.00	97.44
Application of biological control (%)		ND	74.36
Knowledge of biological control		88.89	ND
Use of electrical energy (%)	Used	33.33	94.87
	- From the grid	66.67	92.31
	- From a generator	33.33	2.56
Capacity-building and advice (%)	Capacity-building	ND	66.67
	Technical advice	77.78	76.92
	Business advice	ND	61.54
Provider of capacity-building and/or advice (%)	MINAGRI		12.12
	SENASA		45.45
	Private company		75.76
Access to financing (%)		77.78	30.77
Finance provider (%)	*Habilitador*		0.00
	Agrobanco		0.00
	Full-service banking		100.00
	Municipal savings bank		0.00
	Rural saving bank		0.00
Participation in association, committee and/or cooperative (%)		66.67	41.03
Destination of sale	Domestic market	ND	7.69
	Foreign market	ND	92.31

Notes
ND: not determined
[1] Based on multiple-choice questions.
Source: INEI (2012); compiled by authors.

Tables 8 and 9 show that the replacement of gravity-fed irrigation with technified alternatives between 1994 and 2012 was more frequent among larger farmers than small and medium-sized farmers. The same is the case for construction of infrastructure for access to water and the use of electrical energy. Access to the financial system and to extension services were found to have fallen, while membership in associations increased slightly among small farmers. Meanwhile, conservation practices have increased, especially among small farmers, but to a lesser degree than among large farmers. Thus, a comparison of statistical data from two different moments in time corroborates that access to credit and to extension services may be related to the level of adoption of conservation practices.

In central Chile, Roco *et al.* (2014) used a two-part hurdle model to find determinants of the probability of adopting conservation practices, and proposed a first binary selection model for the probability of obtaining a positive result (application of at least one of the practices considered).

In this study, a probability model is estimated for the adoption of a conservation practice (adoption model). In contrast to Roco *et al.* (2014), here we also prepared additional models related to the adoption of each conservation practice, given the different ecosystem services linked to them (for example, water provisioning service is linked to technified irrigation, and pest regulating service is linked to biological control) and the multiple determinants of each practice identified by the literature and discussed in the theoretical framework. In addition, the data are classified by AUS and the same models are estimated for each type of AU. The following explanatory variables are factored in: characteristics of the AU operator (age, education), production characteristics (number of wells, non-agricultural activities), AU characteristics (AUS), institutional variables (access to information, advice, credit, and associative practices), the destination of asparagus sales, and its share of the entire area under crops.

Table 8
Change in the general characteristics of medium-sized asparagus farmers, province of Ica, 1994 and 2012

Characteristics[1]		1994	2012
Number of AUs		57	35
Type of irrigation (%)	Gravity-fed	96.49	35.29
	Technified	12.28	64.71
Wells (units)		1.12	1.29
Use of own reservoirs (%)		26.32	25.71
Destination of sale (%)	Domestic market	ND	60.00
	Foreign market	ND	48.57
Use of certified seedlings		94.74	91.43
Use of organic fertilizer (%)		94.74	91.43
Use of biological insecticides (%)		15.79	60.00
Application of biological control (%)		ND	40.00
Knowledge of biological control (%)		85.96	ND
Use of electrical energy (%)	Used	38.60	54.29
	- From the grid	90.91	37.14
	- From a generator	4.55	17.14
Capacity-building and advice (%)	Capacity-building	ND	45.71
	Technical advice	77.19	40.00
	Business advice	ND	20.00
Provider of capacity-building and/or advice (%)	MINAGRI		10.00
	SENASA		60.00
	Private company		27.27
Access to financing (%)		61.40	51.43
Finance provider (%)	*Habilitador*		22.22
	Agrobanco		22.22
	Full-service banking		33.33
	Municipal savings bank		27.78
	Rural savings bank		11.11
Participation in association, committee and/or cooperative (%)		80.70	34.29

Notes
ND: not determined
[1] Based on multiple-choice questions.
Source: INEI (2012); compiled by authors.

Table 9
Change in the general characteristics of small-scale asparagus producers, province of Ica, 1994 and 2012

Characteristics[1]		1994	2012
Number of AUs		55	244
Type of irrigation (%)	Gravity-fed	98.18	84.02
	Technified	1.82	15.98
Wells (units)		0.44	0.26
Use of own reservoirs (%)		3.64	1.23
Destination of sale (%)	Domestic market	ND	77.46
	Foreign market	ND	25.00
Use of certified seedlings		89.09	90.57
Use of organic fertilizer (%)		87.27	95.49
Use of biological insecticides (%)		12.73	60.66
Application of biological control (%)		ND	29.51
Knowledge of biological control (%)		81.82	ND
Use of electrical energy (%)	Used	9.09	27.46
	- From the grid	80.00	22.13
	- From a generator	20.00	4.92
Capacity-building and advice (%)	Capacitación	ND	45.08
	Asesoría técnica	58.18	40.16
	Asesoría empresarial	ND	26.64
Provider of capacity-building and/or advice (%)	MINAGRI		39.84
	SENASA		69.11
	Private company		21.14
Access to financing (%)		54.55	46.31
Finance provider (%)	*Habilitador*		14.16
	Agrobanco		15.93
	Full-service banking		16.81
	Municipal savings bank		27.43
	Rural savings bank		23.89
Participation in association, committee and/or cooperative (%)		78.18	81.15

Notes
ND: not determined
[1] Based on multiple-choice questions.
Source: INEI (2012); compiled by authors.

3.2 Estimation and results

For the analysis of the relevant CENAGRO data, a probabilistic model was used, which made it possible to estimate the probability of adopting conservation practices. Probabilistic models enable the statistical analysis of one option selected from a group of mutually exclusive and collectively exhaustive options. In the case of conservation practices, it was assumed that given situations and values related to the variables would either encourage or discourage farmers to adopt a conservation practice. Moreover, a probabilistic model permits impact and elasticity effects to be obtained. These were useful in ascertaining the behavior of the probability of adopting a given conservation practice in response to changes in the explanatory variables. It should be noted that probabilistic models require large samples to ensure the consistency of the estimators. In this research, the analysis centers on small producers given the limited number of observations for their medium-sized and large counterparts.

For the purposes of the estimation only legal persons were utilized, given that certain explanatory variables (age, sex, education) do not correspond to legal persons. Unlike the previous section which analyzes the profiles or types of farmers, in this case all natural persons were considered. On this basis, the number of observations for the estimation was 315.

Given the limited number of natural persons with reservoirs (15 farmers), it was not possible to estimate the reservoir possession model. Likewise, in the case of AUs of more than 20 hectares, it was not possible to estimate the general adoption models - which was also the case for both specific practices and combinations of practices - due to the limited number of observations (41 observations).

According to the estimators of the general adoption model for at least one agricultural water and soil conservation practice, primary education, advice and capacity-building, and the use of credit are significant and positive in the probability of adopting conservation practices, corroborating the evidence found by the literature (Abdulai *et al.* 2011; Tamini 2011). It is also observed that if asparagus represents less than 50% of the total planted area, there is a smaller probability of a conservation practice being adopted.

For each agricultural conservation practice, other variables are significantly co-related to the adoption of this type of practices. In the case of technified irrigation, on average, the group comprised of women, those who completed primary school, those who completed secondary school, and those located in the district of Salas have a higher probability of adoption. Conversely, those located in the district of Santiago have the lowest probability. As regards the use of biological insecticides, on average, those who completed primary school received advice, applied for and were granted credit, and are members of associations have a higher probability of adoption of agricultural conservation practices. Where biological control is concerned, those who have only completed primary school have the lowest probability of adopting this practice, while those with higher non-university education have a higher number of wells, and produce for sale abroad, have a higher probability of doing so. This supports the evidence in the literature regarding the significance of the characteristics of the producer and the AU (Abdulai et al. 2011) and the importance of associative practices for the case of biological practices (Boahene *et al.* 1999; Marshall 2009; Abdulai *et al.* 2011; Tesfaye and Brouwer 2012; Abebaw and Haile 2013; Roco *et al.* 2014) (Table 10).

In addition, the general adoption and agricultural conservation practice models were estimated only for natural persons with at least 20 hectares. As a result, nine significant variables were identified, in addition to those already included in the previous estimations. In the case of general adoption of at least one conservation practice, greater AUS implied a higher probability of adopting conservation practices. It is worth noting that in the largest AUs, the probability of adopting these practices grew in progressively decreasing proportion. With respect to the technified irrigation model, the number of wells increased the probability of adopting these practices. For the biological insecticide application model, AUS also implied a higher probability of adoption. When it comes to biological control, the probability of adoption increased with AUS, albeit in progressively decreasing proportion. Finally, receipt of advice and capacity-building also increased the probability of adopting the practice of biological control.

Thus far, the adoption by farmers of a single conservation practice has been analyzed. However, it is possible to extend the analysis to more than one. In this case, models are estimated for those pairs of practices for which sufficient observations exist. In general, for the joint adoption of technified irrigation and biological insecticides; technified irrigation and biological control; and biological insecticides and biological control, the number of wells acquires significance and has a positive effect on the probability of adopting conservation practices.

For the joint use of technified irrigation and biological control, the number of wells is significant and increases the probability of adopting these practices, while those farmers who completed university and live in the district of Santiago have a lower probability of adoption, on average. For the joint use of biological insecticides and biological control, the number of wells, sale abroad, and AUS have a positive effect on the probability of adoption (with a decreasing effect in the case of AUS).

Table 10
Marginal effects: private individuals (logit)

	Adoption of at least one of the conservation practices	Irrigation	Biological insecticide	Biological control
Age (years)	0.0103	– 0.00984	– 0.00701	0.0136
	(0.0653)	(0.0845)	(0.0674)	(0.0670)
Age² (age x age)	– 0.0000774	0.000112	0.0000515	– 0.000111
	(0.000564)	(0.000690)	(0.000568)	(0.000573)
Sex (0 = female;1 = male)	– 0.00837	– 0.171**	0.0349	0.0801
	(0.376)	(0.468)	(0.350)	(0.365)
Primary	0.106*	0.233**	0.163*	– 0.190***
	(0.472)	(0.557)	(0.397)	(0.434)
Secondary	0.0479	0.251***	0.0688	– 0.0979
	(0.393)	(0.481)	(0.374)	(0.384)
Higher non-university	0.0796	0.129	0.00710	0.373**
	(0.882)	(1.466)	(0.692)	(0.691)
Higher university	– 0.0218	0.160	0.0648	– 0.0803
	(0.485)	(0.658)	(0.413)	(0.417)
Access to information	0.0634	0.0473	0.0774	– 0.0547
	(0.399)	(0.576)	(0.388)	(0.379)
AUS (ha)	0.00111	0.00118	0.00375	– 0.00245
	(0.0289)	(0.0278)	(0.0183)	(0.0136)
AUS² (AUS x AUS)	0.0000125	0.0000130	– 0.0000362	0.0000148
	(0.000228)	(0.000174)	(0.000115)	(0.0000557)
Wells (units)	– 0.0109	0.0539	0.0129	0.104**
	(0.298)	(0.314)	(0.242)	(0.240)
Advice	0.152***	– 0.0133	0.338***	– 0.0903
	(0.346)	(0.394)	(0.298)	(0.300)
Use of credit	0.0797*	– 0.00176	0.174***	0.0185
	(0.306)	(0.416)	(0.272)	(0.269)
Associative practices	0.0552	– 0.0683	0.185*	0.0359
	(0.434)	(0.629)	(0.450)	(0.463)
Secondary work	0.0477	0.0617	0.0542	0.0511
	(0.400)	(0.450)	(0.327)	(0.330)
Sale abroad	– 0.0478	0.00612	– 0.140	0.210***
	(0.404)	(0.425)	(0.362)	(0.320)
< 50% of surface under asparagus	– 0.168*	– 0.0484	– 0.172	– 0.0692
	(0.494)	(0.626)	(0.453)	(0.465)
> 75% of surface under asparagus	– 0.0402	0.00900	– 0.102	– 0.0354
	(0.435)	(0.499)	(0.381)	(0.389)
District of Salas	0.0722	0.402*	– 0.0997	0.0665
	(1.265)	(1.068)	(0.882)	(0.835)
District of Santiago	– 0.137	– 0.291**	– 0.0807	0.0140
	(0.962)	(0.715)	(0.786)	(0.795)
Constant	(2.100)	(2.510)	(2.132)	(2.096)
Observations	315	315	315	315
Pseudo R^2	0.142	0.385	0.169	0.125

Notes
The marginal effects and the standard errors are in parentheses.
* $p < 0.1$
** $p < 0.05$
*** $p < 0.01$

Tables 11 and 12 show the value of the elasticities for continuous variables (AUS and wells) and the point elasticities evaluated at the mean for discrete variables (only those that are significant to at least 10%. Thus, it is possible not only to identify the significant variables, but also to establish an order of magnitude of the change between them. Analysis of all asparagus producers in the sample shows that the receipt of advice and capacity-building is the variable with the greatest impact on the probability of adopting some of the water and soil conservation practices considered. That is, if the proportion of the population that has received advice and capacity-building increases by 1%, the probability of adopting at least one of the conservation practices will increase by 0.08%. If the sample is limited to producers with less than ten hectares, the receipt of advice and capacity-building is also the variable with the greatest impact on the probability of adopting at least one of the conservation practices considered.

Table 11
Elasticities and average probabilities (A)

	All farmers				Small farmers				Combined practices among small farmers		
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Education											
Primary	0.02	0.29	0.05	- 0.11	0.04	0.40	0.06	- 0.12	0.56		
Secondary		0.47				0.48			1.00		
Higher non-university				0.04				0.06			
Higher university									0.53	- 0.13	
AUS (ha)					0.10		0.21	0.36			0.70
Wells (units)				0.15		0.18		0.17	0.21	0.26	0.23
Advice	0.08		0.26		0.08		0.24	- 0.29			
Use of credit	0.04		0.12				0.09				
Associative practices			0.22								
Sale abroad				0.23				0.20			0.20
Average forecast probability	82.11	17.13	61.25	28.17	78.78	11.47	62.36	25.11	4.73	1.83	15.60

Notes
(1) Adoption of at least one conservation practice
(2) Irrigation
(3) Biological insecticide
(4) Biological control
(5) Irrigation and biological insecticide
(6) Irrigation and biological control
(7) Biological insecticide and biological control

Table 12
Elasticities and average prior probabilities (B)

	Producers with at least 10 ha				Combined practices		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Age						- 0.89	
Education							
Primary	0.04	0.64	0,07	- 0.11	1.27		
Secondary		0.95			1.83		
Higher non-university				0.06	0.43		0.12
AUS (ha)						- 0.61	
Wells (units)		0.19					0.18
Advise	0.07		0.23	- 0.45			- 0,30
Use of credit	0.04						
Secondary work	0.03		0.06				
Sale abroad				0.30		0.75	0.41
Average prior probability	82.47	7.91	66.72	26.9	3.08	1.7	15.03

Notes
(1) Adoption of at least one conservation practice
(2) Irrigation
(3) Biological insecticide
(4) Biological control
(5) Irrigation and biological insecticide
(6) Irrigation and biological control
(7) Biological insecticide and biological control

Also worthy of note is the link between the use, whether exclusive or combined, of biological control and export sales. Taking the sample of asparagus producers as a whole, a 1% increase in the population that exports serves to increase the probability of practicing biological control by 0.23%. If the sample is restricted to producers with less than ten hectares, the percentage impact increases to 0.3%. Thus, it can be affirmed that access to foreign markets has a significant impact on the adoption of more specific conservation practices, such as biological control. The requirements for minimum quality standards, strict sanitary evaluation of the produce, and rejection of pesticides - linked to the growing preference for organic products - is likely to compel producers to adopt conservation practices. Biological control, which is a practice that does not require significant investment in physical capital, is a technique that can be reasonably applied by small farmers who seek to export.

The analysis of elasticities also shows the importance of education in the adoption of conservation practices. It should be noted that in the case of education levels, the evaluation of elasticities is carried out in comparison with an individual without any degrees whatsoever. Thus, the completion of primary education is significant for the adoption of almost all conservation practices considered, while completing a secondary education has an even greater impact on the probability of adopting certain conservation practices, though it is not significant in other models of practices. For example, in the case of the combined adoption of technified irrigation and the use of biological insecticides, if the proportion of the population that has only completed primary school increases by 1%, the probability of adopting these practices rises by 0.56%. However, if the proportion of the population that has only completed secondary school increases by 1%, the probability of adopting these practices also increases by 1%. These impacts are greater still when only producers with less than ten hectares are considered, since the percentage impact of secondary education for the same combination of practices reaches 1.83%.

It is also necessary to refer to the explanatory capacity of the model proposed. The values of the pseudo R^2 show that much of the variability in the adoption of conversation practices is not explained. This may be due to omitted variables in each model. These include perceptions about the specific attributes of the technologies, given that such perceptions contribute significantly to their adoption and intensity (Adesina 1993). As shown by Roco *et al.* (2014), experience as a farmer and past profitability are variables highlighted in the literature as significant, as demonstrated in the evaluation of the adoption of agro-ecological technology in coffee cropping in Peru (Novella and Salcedo 2006).

Other economic variables, such as the price of water, crop prices, and subsidies for irrigation technology (Ariel and Yaron 1992) may also be significant. Climate variables are also significant as determinants of the adoption of conservation practices (Di Falco *et al.* 2011), especially if the positive effect of temperature and luminosity on the speed of growth and the asparagus yield is considered (Dean 1999; Faville *et al.* 1999; Keulder and Riedel 1996). Because CENAGRO 2012 did not collect this data, these variables cannot be included in the models. However, it is suggested that they be taken into account in future research to corroborate their significance for the adoption of conservation practices among asparagus producers in the province of Ica.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

In Ica, the availability of water is a limiting factor on agricultural development. Therefore, the asparagus crop has evolved on the basis of technified irrigation systems (drip, sprinkler). This is in contrast with other asparagus-producing areas, such as La Libertad, where the use of gravity-fed systems remains significant. However, in Ica, groundwater has been extracted at such a rate that it may be appropriate to consider it as a non-renewable resource in the near future, given that its regeneration capacity is low in relation to extraction requirements.

1. Asparagus draws on a number of ecosystem services, many of which constitute public goods, while in other cases the resources are open-access and users are disinclined to pay for their conservation as a result. On the other hand, there are ecosystem services whose characteristics have been altered by decisions made by third parties decades ago (intergenerational externalities). For example, solar radiation is a component of the climate regulating service, the ongoing variability of which could affect the development of asparagus in the long term. Another important ecosystem service for this crop is water provisioning, as is the supporting service (soil nutrient cycle). On the basis of decisions about production and selection of technologies, these ecosystemic services maintain their levels of quantity and quality both for the development of the asparagus crop and to facilitate the substitution of crops that are adequate to climate conditions, resource availability, and commercial opportunities.

2. In Ica, it has been demonstrated that asparagus producers who operate as natural persons have a higher probability of adopting soil and water conservation practices the greater their level of education, the more advisement and capacity-building they receive, and the greater their access to credit. As regards the adoption practices evaluated individually, those variables that increase the probability of adoption are associative practices in the case of the use of biological insecticides, and the number of wells and export sales in the case of biological control.

3. The adoption models for conservation practices, which were evaluated only for producers with less than 20 hectares who operate as natural persons, demonstrate the relevance of AUS to increased probability of adopting such practices, though this increase is less marked the larger the AUS.

4. The adoption models for combinations of conservation practices show that better infrastructure for access to water is correlated with greater adoption of different combinations of practices.

5. The case studied illustrates that there is much to be investigated about the relationship between agriculture and ecosystem services. However, there is a need to incorporate an ecosystemic approach into the national and regional data systems, and to redefine corresponding data collection.

4.2. Recommendations

1. Design and implement internship programs and field days for farmers, enabling the exchange of information on good soil and water conservation practices, as well as promoting innovation in this area. To this end, it is necessary to coordinate efforts between organized producers, institutions providing technical advice and capacity-building services, private enterprise, and the Regional Government of Ica.

2. Conduct economic studies that analyze the cost-benefit of conservation of ecosystemic services, both for the case of asparagus and for other crops of importance to Ica. The results of such studies would be useful for technical and productive capacity-building programs for producers.

3. Given that small producers depend primarily on the Agrobanco and rural savings banks for financing, evaluate the possibility of incorporating indicators related to the adoption of soil conservation (for example, biological control) and water management (for example, reduction in water footprint) practices in credit evaluation protocols and in the monitoring system. This would enable monitoring of the impact indicators associated with adoption of the practices in question.

4. Design innovative credit programs articulated with capacity-building and advisement, in which interest rates could be linked to the results of soil conservation, water management, improved productivity, and access to markets.

5. Review the oversight and management mechanisms of groundwater wells to ensure an up-to-date inventory of those in use and their level of maintenance. This would enable better identification of the investment effort required for the aquifer, as a basis upon which to revise the tariff-based extraction system in view of the relative scarcity of groundwater.

6. In consideration of the different risks to which agriculture is subject (for example, climate change, products market, supplies market), improve the climate data and early warning systems and articulate them to national information systems based on an ecosystemic and spatial approach. This will not only promote local and regional research, but could also facilitate the design of monitoring systems for water and soil management.

7. In light of the importance of education, at the level of the Regional Government of Ica, the Regional Directorate of Education, and the Ministry of Education, incorporate an ecosystem services approach and its relationship to development and sustainable agriculture, both regionally and nationwide. The design of case studies and examples would facilitate a significant learning process concerning these relationships.

8. Articulate efforts between the private sector and academia to prepare case studies based on international experiences of incorporating ecosystem services into agricultural planning, with specific reference to desert ecosystems. The results of such research could also guide the formulation of public policies that encourage soil and water conservation practices.

9. Strengthen the integration of ecosystem services and their efficient management into agricultural policy, with a component for improving agricultural productivity and reducing rural poverty.

STUDIES CITED

Abdulai, A., Owus and, V., and Bakang, J.-E. (2011). Adoption of safer irrigation technologies and cropping patterns: Evidence from Southern Ghana. *Ecological Economics*, 1415-1423.

Adesina, A. A. (1993). Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone. Agricultural Economics, 297-311.

Allen, R., Pereira, L., Raes, D., and Smith, M. (1998). *FAO Irrigation and drainage Paper N° 56 Crop evapotranspiration - Guidelines for computing crop water requirements.* Rome: FAO.

ANA. (2009). *Diagnóstico situacional de recarga de acuíferos.* Lima.

Ariel Dinar, and Yaro and D. (1992). Adoption and abandonment of irrigation technologies. *Agricultural Economics,* 315-332.

Bachman, K. (1952). Theories and Techniques in Aggregative Analysis in Farm Management. *Journal of Farm Economics,* 787-795.

Bag, D. (2000). Pesticides and Health Risks. *Economic and Political Weekly,* 3381-3383.

Baker, J., Murray, B., McCarl, B., Feng, S., and Johaason, R. (2012). Implications of Alternative Agricultural Productivity Growth Assumptions on Land Management, Greenhouse Gas Emissions, and Mitigation Potential. *American Journal of Agricultural Economics,* 435-441.

Barbier, E. (2007). Valuing Ecosystem Services as Productive Inputs. *Economic Policy,* 177-229.

Bormann, F., and Likens, G. (1967). Nutrient Cycling. *Science*, 424-429.

Bosch, D., and Pease, J. (2000). Economic Risk and Water Quality Protection in Agriculture. *Review of Agricultural Economics,* 438-463.

Brack, A., and Mendiola, C. (2000). *Ecología del Perú.* Lima: Bruño.

Buchanan, J., and Stubblebine, W. (1962). Externality. *Economica*, 371-384.

Cannock, G., and Gonzales-Zúñiga, A. (1994). *Economía Agraria.* Lima: Universidad del Pacífico.

CEPAL. (2009). *Istmo Centroamericano: Efecto del cambio climático sobre la agricultura.* Mexico City.

Conant, R., Paustian, K., and Elliott, E. (2001). Grassland Management and Conversion into Grassland: Effects on Soil Carbon. *Ecological Applications*, 343-355.

Cooper, P., Cappiello, S., Vermeulen, S., Campbell, B., Zougmoré, R., and Kinyangi, J. (2013). *Large-scale implementation of adaptation and mitigation actions in agriculture.* Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Dasgupta, S., Meisner, C., and Wheeler, D. (2007). Is Environmentally Friendly Agriculture Less Profitable for Farmers? Evidence on Integrated Pest Management in Bangladesh. *Review of Agricultural Economics,* 103-118.

Day, R. (1969). More on the Aggregation Problem: Some Suggestions. *American Journal of Agricultural Economics,* 673-675.

De Gryze, S., Wolf, A., Kaffka, S., Mitchell, J., Rolston, D., Temple, S., . . . Six, J. (2010). Simulating Greenhouse Gas Budgets of Four California Cropping Systems under Conventional and Alternative Management. *Ecological Applications,* 1805-1819.

Dhaka, J. (2009). *Economics of Agricultural Production and Farm Management.* India: Aavishkar Publishers.

Di Falco, S., Veronesi, M., and Yesuf, M. (2011). Does Adaptation to Climate Change Provide Food Security? A Micro-Perspective from Ethiopia. *American Journal of Agricultural Economics,* 829-846.

El-Nazer, T., and McCarl, B. (1986). The Choice of Crop Rotation: A Modeling Approach and Case Study. *American Journal of Agricultural Economics,* 127-136.

EPA. (n.d.). *Environmental Protection Agency.* Retreived: 22/11/2014. http://www.epa.gov/agriculture/tbio.html

FAO. (n.d.). Retreived: 05/04/2014. ftp://ftp.fao.org/docrep/fao/010/i0142s/i0142S06.pdf

FAO. (1993a). *Soil tillage in Africa: needs and challenges.* Roma: FAO Information Division.

FAO. (1993b). *Erosión de suelos en América Latina.* Rome.

FAO. (1997). *Lucha contra la contaminación agrícola de los recursos hídricos.* Burlington: Canada Centre for Inland Waters.

FAO. (2003). *Agriculture, Food and Water.*

Fisher, E. (1958). Economic Aspects of Urban Land Use Patterns. *The Journal of Industrial Economics*, 198-208.

Fleischer, A., Lichtman, I., and Mendelsohn, R. (2007). Climate Change, Irrigation, and Israeli Agriculture: Will warming be harmful? *Ecological Economics*, 508-515.

Gabriel, S., and Baker, C. (1980). Concepts of Business and Financial Risk. *American Journal of Agricultural Economics*, 560-564.

Gobierno Regional de Ica. (2007). *Diagnóstico de la Región Ica.* Ica.

Hagan, R. (1955). Factors Affecting Soil Moisture - Plant Growth Relations. *Report of the XIVth International Horticultural Congress*, 82-102.

Holton, G. (2004). Defining Risk. *Financial Analysts Journal*, 19-25.

Huamán, M. (1997). Mercado de aguas: alcances y limitaciones en el valle de Ica. *Perú: el problema agrario en debate - SEPIA VI*, 69-92.

Instituto Nacional de Estadística. (2012). *CENAGRO.* Lima: INEI-MINAGRI.

IPCC. (2013). *Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge.

IPCC. (2014). *Summary for Policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II Contribution to the IPCC 5th Assessment Report - Changes to the Underlying Scientific/Technical Assessment.* Cambridge.

ISAT. (2005). *Condiciones de trabajo y salud de las mujeres trabajadoras de la agroindustria del espárrago, región Ica.* Lima: Instituto Salud y Trabajo.

Jaenicke, E., and Lengnick, L. (1999). A Soil-Quality Index and Its Relationship to Efficiency and Productivity Growth Measures: Two Decompositions. *American Journal of Agricultural Economics,* 881-893.

Koundouri, P., Nauges, C., and Tzouvelekas, V. (2006). Techology Adoption under Production Uncertainty: Theory and Application to Irrigation Technology. *American Journal of Agricultural Economics,* 657-670.

Lane, A., and Jarvis, A. (2007). *Changes in Climate will modify the Geography of Crop Suitability: Agricultural Biodiversity can help with Adaptation.* Rome: ICRISAT.

Lave, L. (1964). Technological Change in U.S. Agriculture: The Aggregation Problem. *Journal of Farm Economics*, 200-217.

Lifeng, H., Hongwen, L., and Xuemin, Z. (n.d.). *Using Conservation Tillage to reduce Greenhouse Gas Emission in Northern China.* Beijing: China Agricultural University.

MA

2005a *Ecosystems and Human Well-Being: A Framework for Assessment.* Washington: Island Press.

2005b. *Ecosystems and Human Well-being: Current State and Trends.* Washington: Island Press.

2005c. *Ecosystems and Human Well-being: General Synthesis.* Washington: Island Press.

Mahul, O. (2001). Optimal Insurance against Climatic Experience. *American Journal of Agricultural Economics,* 593-604.

Mankiw, N. (2012). *Principios de Economía.* Mexico City: Cengage Learning.

Mao, J. (1970). Essentials of Portfolio Diversification Strategy. *The Journal of Finance,* 1109-1121.

Marañón, B. (1994). Cambios sociales en las zonas de agroexportación en el Perú, Costa Norte. *Perú: El problema agrario en debate - SEPIA V,* 221-240.

Mba, C., Guimaraes, E., and Ghosh, K. (2012). Re-orienting Crop Improvement for the Changing Climatic Conditions of the 21st Century. *Agriculture and Food Security,* 1-17.

McConnell, K. (1983). An Economic Model of Soil Conservation. *American Journal of Agricultural Economics*, 83-89.

Menapace, L., Colson, G., and Raffaelli, R. (2012). Risk Aversion, Subjective Beliefs and Farmer Risk Management Strategies. *American Journal of Agricultural Economics,* 384-389.

Mendelsohn, R., and Dinar, A. (2003). Climate, Water and Agriculture. *Land Economics,* 328-341.

MINAGRI. (n.d.). *Ministerio de Agricultura y Riego.* Retreived: 08/03/2014. http://www.minag.gob.pe/portal/sector-agrario/agricola/cultivos-de-importancia-nacional/esp%C3%A1rragos

Moore, C. (1961). A General Analytical Framework for Estimating the Production Function for Crops Using Irrigation Water. *Journal of Farm Economics,* 876-888.

Moss, C. (2010). *Risk, Uncertainty, and the Agricultural Firm.* Singapur: World Scientific Publishing Co.

Mundlak, Y., and Hellinghausen, R. (1982). The Intercountry Agricultural Production Function: Another View. *American Journal of Agricultural Economics*, 664-672.

Novella, R., and Salcedo, R. (2006). Determinantes de la adopción de tecnologías de producción orgánica: El caso del café. *SEPIA XI,* 57-93.

Oré, M., Bayer, D., Chiong, J., and Rendón, E. (2011). Emergencia hídrica y explotación del acuífero en un valle de la costa peruana: *El caso de ica. Perú: El problema agrario en debate - SEPIA XIV*, 584-613.

Oury, B. (1965). Allowing for Weather in Crop Production Model Building. *Journal of Farm Economics,* 270-283.

Parente, S., and Prescott, E. (1994). Barriers to Technology Adoption and Development. *Journal of Political Economy,* 298-321.

Paris, Q. (1981). Perfect Aggregation and Disaggregation of Complementarity Problems: Reply. *American Journal of Agricultural Economics,* 756-757.

Pfeiffer, L., and Lin, C. (2014). Does efficient irrigation technology lead to reduced groundwater extraction? Empirical evidence. *Journal of Environmental Economics and Management,* 189-208.

Pigou, A. (1951). Some Aspects of Welfare Economics. *The American Economic Review,* 287-302.

PLADES. (2007). *El Boom del espárrago: un estudio sobre el "trabajo decente" en Ica.* Lima: PLADES - Área de Globalización y trabajo decente.

Prato, T. (1990). Economic Feasibility of Conservation Tillage with Stochastic Yields and Erosion Rates. *North Central Journal of Agricultural Economics,* 333-344.

Purvis, A., Boggess, W., Moss, C., and Holt, J. (1995). Technology Adoption Decisions under Irreversibility and Uncertainty: An "Ex Ante" Approach. *American Journal of Agricultural Economics,* 541-551.

RAE. (n.d.). *Real Academia Española.* Retreived: 27/02/2014. http://www.rae.es/

Ranjan Das, S., and Uppal, R. (2004). Systemic Risk and International Portfolio Choice. *The Journal of Finance*, 2809-2834.

Roberts, M., Schlenker, W., and Eyer, J. (2012). Agronomic Weather Measures in Econometric Models of Crop Yield with Implications for Climate Change. *American Journal of Agricultural Economics*, 236-243.

Roco, L., Engler, A., Bravo-Ureta, B., and Jara-Rojas, R. (2014). Farm Level Adaptation Decisions to Face Climatic Change and Variability: Evidence from Central Chile. *Environmental Science and Policy,* 86-96.

Rose, S., Golub, A., and Sohngen, B. (2012). Total Factor and Relative Agricultural Productivity and Deforestation. *American Journal of Agricultural Economics,* 426-434.

Rosegrant, M., Koo, J., Cenacchi, N., Ringler, C., Robertson, R., Fisher, M., . . . Sabbagh, P. (2014). *Food Security in a World of Natural Resource Scarcity - The Role of Agricultural Technologies.* Washington DC: IFPRI.

Schwartz, P., and Klassen, W. (1980). Pests. *The Antioch Review,* 493-515.

SENAMHI. (n.d.). *Guía Climática Turística.* Lima.

Shah, M. (1999). Synthesis of Ecology and Economics Towards a New Theoretical Paradigm. *Economic and Political Weekly,* 3293-3298.

Sheriff, G. (2005). Efficient Waste? Why Farmers Over-Apply Nutrients and the Implications for Policy Design . *Review of Agricultural Economics*, 542-557.

Shetty, P. (2004). Socio-Ecological Implications of Pesticide Use in India. *Economic and Political Weekly*, 5261-5267.

Stavins, R. (2011). The Problem of the Commons: Still Unsettled after 100 Years. *The American Economic Review*, 81-108.

Steduto, P., Raes, D., Hsiao, T., and Fereres, E. (2012). *FAO Irrigation and Drainage Paper N° 66 Crop Yield Response to Water.* Rome: FAO.

Stoneman, P., and Kwon, M. (1996). Technology Adoption and Firm Profitability. *The Economic Journal*, 952-962.

Stovall, J. (1966). Sources of Error in Aggregate Supply Estimates. *Journal of Farm Economics*, 477-480.

Swinton, S. F. (2007). Ecosystem Services and Agriculture: Cultivating Agricultural Ecosystems for diverse benefits. *Ecological Economics*, 245-252.

Swinton, S., Lupi, F., Robertson, G., and Landis, D. (2006). Ecosystem Services from Agriculture: Lookin beyond the Usual Suspects. *American Journal of Agricultural Economics*, 1160-1166.

Thamarajakshi, R. (1992). Some Aspects of Environmental Accounting. *Economic and Political Weekly*, 2533-2534.

Turvey, C. (2001). Weather Derivatives for Specific Event Risks in Agriculture. *Review of Agricultural Economics*, 333-351.

UNEP. (2006). *Global deserts outlook.* Nairobi: Division or Early Warning and Assessment, United Nations Environment Programme.

UNEP. (2011). *Towards a Green Economy.* Nairobi: UNEP.

UNEP. (2012). *GEO 5 Global Environment Outlook.*

University of California - Cooperative Extension. (n.d.). Retreived: 15/04/2014. http://www.igrowsonoma.org/documents/Vegetable%20Planting%20Summary-es.pdf

USAID. (2011). *Peru Climate Change Vulnerability and Adaptation Desktop Study.* Washington: International Resources Group.

USDA. (n.d.). *United States Department of Agriculture.* Retreived: 26/03/2014. Agricultural Research Service: http://www.ars.usda.gov/

Valcárcel, M. (2002). Agroexportación no tradicional, sistema esparraguero, agricultura de contrata y ONG. *Debate Agrario,* 29-44.

Valcárcel, M. (2003). *Nuevas relaciones sociales entre los productores, la industria agroexportadora y las ONG en el sector agrario peruano.* Leuven: Presses universitaires de Louvain.

Vandermeer, J. (1995). The Ecological Basis of Alternative Agriculture. *Annual Review of Ecology and Systematics*, 201-224.

Vidal, J. P. (1979). *Las ocho regiones naturales del Perú.* Lima: Universo SA.

Villacorta, G. C. (1999). El Medio Ambiente y los Recursos Naturales en las Cuentas Nacionales. *Revista de la Facultad de Ciencias Económicas*, UNMSM, 151-164.

Von Neumann, J., and Morgenstern, O. (1947). *The Theory of Games and Economic Behavior.* Princeton University Press.

Yin, P.-L., Bresnahan, T., and Yin, P.-L. (2005). Economic and Technical Drivers of Technology Choice: Browsers. *Annales d'Économie et de Statistique*, 629-670.

Zhengfei, G., Oude, A., Van Ittersum, M., and Wossink, A. (2006). Integrating Agronomic Principles into Production Function Specification: A Dichotomy of Growth Inputs and Facilitating Inputs. *American Journal of Agricultural Economics*, 203-214.

Databases

ANA
Sistema Nacional de Información de Recursos Hídricos. <http://www.ana.gob.pe/sistema-nacional-de-informacion-de-recursos-hidricos.aspx>.

FAOSTAT
<http://faostat3.fao.org/home/E>.

MINAGRI
Series históricas de producción agrícola. Compendio estadístico. <http://frenteweb.minagri.gob.pe/sisca/>.

SIICEX, SISTEMA INTEGRADO DE INFORMACIÓN DE COMERCIO EXTERIOR
PromPeru Stat. <http://www.siicex.gob.pe/promperustat/>.