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Quinoa Expansion in Peru and Its Implications for Land Use Management

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Abstract: Quinoa (*Chenopodium quinoa* Willd.) has gained prominence worldwide over recent years and suddenly Peru has emerged as a major player in the global quinoa market. This study aims to analyze the expansion of quinoa farming in Peru in the period 1995–2014 and to discuss the changes in land-use the country has experienced as a result of the boom in the global demand for quinoa. Two statistical approaches, principal component analysis (PCA) and exponential smoothing, were applied in the data analysis to explore the evolution of the quinoa boom in Peru by periods and to forecast what the acreage expansion rate would have been if the boom had not occurred. The results show that the quinoa boom was responsible for an increase of 43% in the number of hectares planted with quinoa in 2014, in relation to the number predicted if there had been no boom. This provoked an acceleration of production in traditional quinoa farming areas and the extension of this activity to new regions. The consequences are already apparent in the land-use changes seen in Peru, namely the: (i) displacement; (ii) rebound; and (iii) cascade effects.

Keywords: Andean crops; land use; agricultural sustainability; food production; displacement effect; rebound effect; cascade effect

1. Introduction

One of the various approaches adopted in investigating the globalization of agriculture is concerned with when and how the production of internationally marketed foods is increased in response to changes in dietary patterns among populations [1]. An example of this is the explosion in global demand for quinoa (*Chenopodium quinoa* Willd.), or the quinoa boom, which is the process by which this pseudocereal, which was previously considered a NUS (Neglected and Underutilized Species), has become one of the most promising food products in the world in the 21st century [2], due to its exceptional nutritional value [3–5].

The implications of the boom regarding the international demand for quinoa for land use in the major producing countries, Peru and Bolivia, have been poorly documented [6]. To a large extent, the current knowledge is related to the studies carried out in Bolivia where the intensification of quinoa production raises concerns, on both soil degradation and the compromise of the socio-ecological bases of the agrosystem, in order to face the multiple challenges for resilience to climate change and food security [7–10]. For these reasons, it is possible to place the Peruvian case within this problematic considering the country has become the world's largest producer and exporter of quinoa since 2014, accounting for about 60% of the total production [11]. Furthermore, land-use issues have become a central concern in the country. According to the Peruvian Ministry of Environment, approximately one third of the country's surface is in some state of desertification, being either "desertified" or in the process of "desertification", mainly due to salinization and soil erosion [12]. Added to this is the fact most of the Peruvian territory is categorized as either "very highly vulnerable" or "extremely vulnerable" to climate change, disaster and food insecurity [13].

The relationship between international trade and the globalization of agriculture has received increasing attention from researchers and public policy makers because of the challenge it represents to the proper use of finite natural resources, such as land, especially in developing countries [14–18]. This issue is even more current and relevant given that land-use change is a fundamental driver of global environmental change and sustainability [19,20] and a central element in the effort to ensure global food security [21,22].

In this context, the present study presents and discusses issues raised as a result of the quinoa boom regarding trends in land-use change in Peru. Therefore, the starting point of this study was to describe and analyze how the Peruvian and international markets for quinoa have evolved over time, in terms of production, trade and land-use. After which, the hypothetical case of the non-occurrence of the quinoa boom was considered by asking the following question: If the quinoa boom had not occurred, what would have been the pattern of land-use in Peru? Based on the typology proposed by Lambin and Meyfroidt [15], regarding the effects of globalization on land-use change, three concepts that have guided the conduct of this research—the displacement, rebound and cascade effects—are identified and discussed.

2. Material and Methods

2.1. Data Collection

Data referring to the production and acreage of quinoa crop were obtained from The Office of Economic and Statistical Studies of the Peruvian Ministry of Agriculture and Irrigation [23]. Data related to trade flows were obtained from the Integrated Information System on Foreign Trade [24].

The analysis covers the period from 1995 to 2014; 1995 was adopted as the base year due to the availability of data on the SIICEX records and because, of the four agricultural censuses conducted in Peru to the present, the third census was published in 1994 [25]. The data were collected separately for the 18 regions producing quinoa in 2014. Among them are the traditional producer-regions (in which quinoa was produced before the boom: Puno, Arequipa, Junin, Ayacucho, La Libertad, Ancash, Cusco, Apurimac, Huanuco, Huancavelica, Ayacucho) and the 7 new producer-regions (that have emerged since the quinoa boom: Lambayeque, Tacna, Lima, Ica, Piura, Moquegua, and Amazonas).

2.2. Data Analysis

Two statistical approaches, principal component analysis (PCA) and exponential smoothing, were applied in the data analysis.

In the first analysis, the data were divided into groups to explore the evolution of the quinoa boom in Peru by periods. The variables acreage and quantity of exported quinoa were used.

Exponential smoothing was used to analyze the data on the annual expansion rate of the acreage of quinoa, by region (traditional producing regions). For this, the following methodology was used: first, an exponential smoothing model was applied to data from 1995 to 2008. The idea was that the model would capture the expansion pattern of the acreage of quinoa before the quinoa boom in Peru, which began in 2009. Based on that model, the expansion rate of the acreage of quinoa for the period from 2009 until 2014 was predicted. That prediction represents an estimate of what the expansion rate of the acreage of quinoa would have been if the quinoa boom had not occurred, while assuming other variables such as climate and yield, etc. remained constant. The predicted expansion rate is referred to as the "natural expansion" of the acreage of quinoa. The predictions were compared with the observed values in order to determine the difference between the predicted expansion rate (PER) and the observed expansion rate (OER) of the acreage of quinoa.

The study cut-off point was 2008, and the PERs were compared with the OERs for the 2009–2014 period. One exception was the data series for the Junin region, which showed a structural decrease in period from 1995 to 2000. This structural decrease is represented by a sudden change in the pattern of the series before and after 2001, which prevents any minimally faithful adjustment from being made in the pattern of the series in the whole period. Thus, the model was adjusted considering only the period 2001–2008, giving an effective sample size of 8 observations. Due to these aspects, the results for Junin should be analyzed separately. In all cases, Holt's adjustment was used (for more details about Exponential Smoothing approach, see [26,27]).

3. Results and Discussion

3.1. A Temporal Analysis of the Quinoa Production in Peru in Response to Global Demand

The principal component analysis (PCA), presented in Figure 1, shows the division of the data in groups: the acreage and exported quantity of quinoa in Peru.

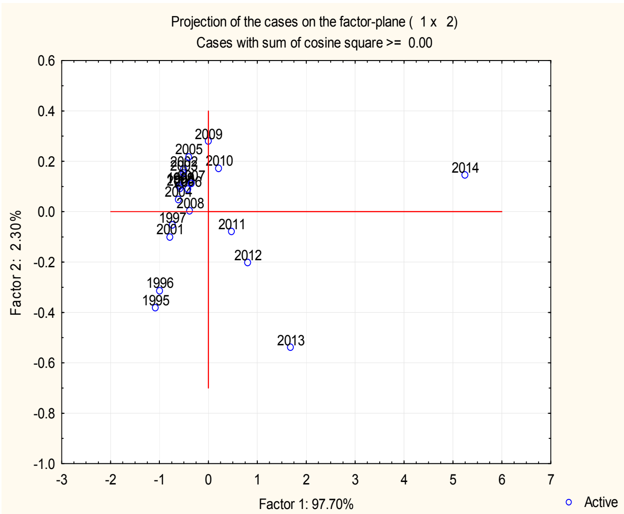


Figure 1. Principal component analysis (PCA) applied to the acreage and exported quantity of quinoa in Peru by year. The figure shows the difference in the behavior of variables over the years, notably for the year 2014. This can be seen in the relative position of the year in relation to the factor 1 axis. The vertical line shows where the pattern of the series began to change. Four groups are considered: 1995–2001, 2002–2008, 2009–2013 and 2014.

In Figure 1, a difference in the pattern of the variables can be seen to start in 2009. The differentiation intensifies over the years, with the behavior in 2014 being particularly noteworthy. This event is associated with the beginning of the quinoa boom in Peru, which was a response to the convergence between increased domestic production and international demand in 2009.

At the domestic level, the consumption of quinoa passed through a transition phase, from being a little-valued crop for decades to achieving prominence in the 21st century. Among the explanations for the prolonged marginalization of quinoa, even among the Peruvian population in general, one can mention the lack of knowledge regarding its nutritional value, the preference for wheat-derived products and discrimination arising from the association of its consumption with the poorest segments of society [28]. Nevertheless, while lacking notoriety, quinoa was thought to have great potential for human agriculture and food [28,29], because its importance in ensuring the food security of the pre-Inca and Inca societies was not unknown [30]. The increase in the yield and acreage of quinoa in the 1990s can be credited primarily to the Peruvian government, which, within the framework of policies designed to reduce poverty, fomented food assistance programs.

The increase in production in the period is also contributed to the increased value attributed quinoa as food among the population.

In 1994, the direct purchase of Andean agricultural products from small farmers was authorized for the first time (Regulation DS No. 029-94-PCM and RM No. 114-94-PRES, of the National Food Support Program—PRONAA), with quinoa being one of those products. Hence, in the following years, the Peruvian government became a major buyer of quinoa, thus enabling and promoting the expansion of the acreage. Analysis of the historical series of agricultural production shows the area planted with quinoa was 47% smaller in the 1980s than that in the following decade [23]. However, the food assistance programs further favored quinoa farming as from 2008, when Law No. 27060 was passed, which specifically encouraged the social inclusion of local small quinoa farmers (Regulation DS No. 005-2008-MIMDES). Thus, in 2008, the expansion in the acreage was 1.7 times greater than in that in 1995, with an expansion rate of 5%, while the production doubled with a growth rate of 8%. Since then, although changes have taken place at the institutional level, with the restructuring of food aid programs in 2012, the state still strongly promotes quinoa production in different regions of the country for this purpose (e.g., National Program School Food *Qali Warma* (DS No. 008-2012-MIDIS), Social Development Cooperation Fund *Fondo de Cooperación para el Desarrollo Social*—FONCODES, *Cuna más* National Program).

The importance of the period beginning 2009 can also be seen in the export volumes of Peruvian quinoa (Figure 1). The amount of quinoa produced increased in proportion to the quantity marketed internationally. Between 2008 and 2014, the export volume increased approximately 18 times, while the price increased approximately twofold. In this context, the United States was the main importer of Peruvian quinoa, and between 1995 and 2014 concentrated, on average, 60% of the total quantity exported (see the historical series [24]). This growth in the international demand for quinoa may be related to the health concerns of consumers in developed countries, since they are increasingly seeking functional, nutritious and highly beneficial foods [31–34].

Looking at Figures 1 and 2, it can be seen that 2014 represents the start of a period of unprecedented growth in production and exports, with a variation of approximately 120% and 97%, respectively, compared to 2013. There was also an increase in the price paid to farmers and the export price, of approximately 21% and 26%, respectively. Certainly this was influenced by the events of 2013, which was declared the "International Year of Quinoa (IYQ)" [2].

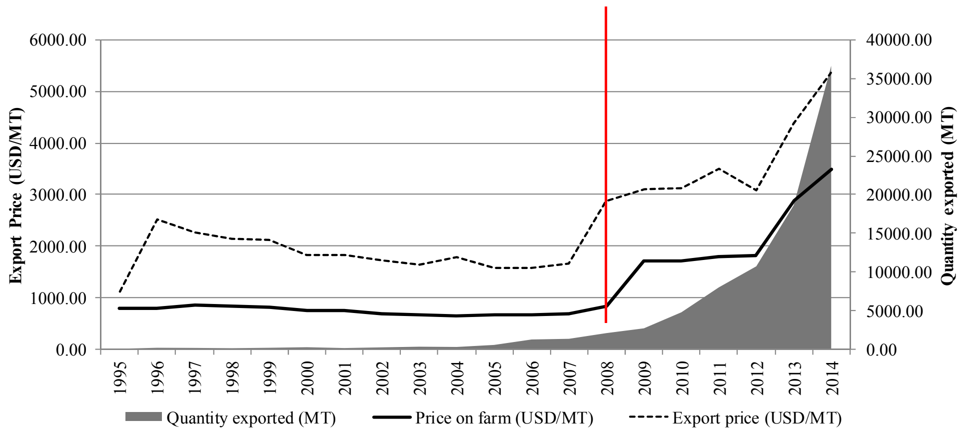


Figure 2. Export volumes and prices of Peruvian quinoa and the price paid to the farmer (1995–2014). Source: Based on Based on [23,24]. The prices were deflated for December 2014.

In Appendix 1 of the document published by the Peruvian Ministry of Agriculture [35], there is a detailed list of the activities carried out by Peruvian government institutions to promote Peruvian quinoa at the domestic level in following the IYQ (e.g., boosting research and launching new varieties of quinoa, drafting laws on food and nutritional security, promoting food fairs and partnerships with renowned chefs, etc.) and at the international level (e.g., promoting seminars, festivals, conferences, trade fairs, business encounters, etc.). The result of these actions was made apparent in the increasing per capita consumption of quinoa among the Peruvian population, which, according to [36], increased 129% in the period from 2000 to 2014, from 1.10 kg/person to 2.54 kg/person.

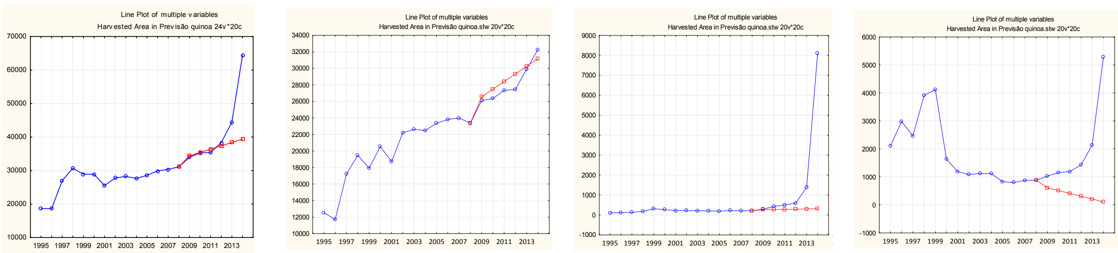
Therefore, the incentives provided by the Peruvian government to increase the production of quinoa, especially from 2008, were successful, as they brought about a change in the pattern of production, which also made it possible to meet the international demand. Internally, while Peru has strongly encouraged the export of fresh food in recent years, no other foodstuff has demonstrated rates of growth in production as radical as those of quinoa, which at the same time, is an example of the recovery of a neglected and underutilized species (NUS). Thus, it seems both timely and necessary to describe and analyze the changes in land-use that have accompanied the expansion of quinoa farming. Below, there is an examination of the impact of the quinoa boom in relation to the trends in the use of agricultural land in Peru and their implications.

3.2. Quinoa Expansion in Peru and Its Implications in Land-Use

The increasing global demand for quinoa has led to the restructuring the use of productive land in Peru, as presented in Figure 3, which shows the pattern of expansion of the acreage under quinoa in the 11 traditional producing regions in the period 1995–2014 considering two variables: the observed expansion rate (OER) and the predicted expansion rate (PER). The PER reflects the predicted expansion rate of the acreage of quinoa in Peru considering the pattern seen in the pre-boom period of 1995–2008. Note the difference in the patterns of expansion that followed both variables. As from 2009, the average values of OER and PER were 16.23% and 2.76%, respectively. This shows that the expansion of the acreage with quinoa in these regions would have been lower than the observed behavior, if there had been no boom in the demand for quinoa.

The expansion rate varied among the geographic regions due to the new land-use trends in Peru, which are being shaped according to the market demand for quinoa. Since the quinoa boom is a relatively recent phenomenon, it is important to analyze the implications for land-use arising from the expansion of the acreage. This is especially relevant because Peru is the largest producer of quinoa and has its agriculture based on small-scale production, since approximately 82% of the existing agricultural units in the country cover fewer than five hectares [37].

TPR (aggregate)	**Puno** [a]	**Arequipa** [a]	**Junin** [b]
OER = 14.7%;	OER = 4.4%;	OER = 140.5%;	OER = 46.4%;
PER = 2.8%	PER = 3.3%	PER = 3.4%	PER = −28.6%



Ayacucho [b]	**La Libertad** [c]	**Ancash** [c]	**Cuzco** [c]
OER = 38.7%;	OER = 58.6%;	OER = 108.0%;	OER = 5.6%;
PER = 4.3%	PER = 2.5%	PER = −5.2%	PER = 3.0%

Figure 3. *Cont.*

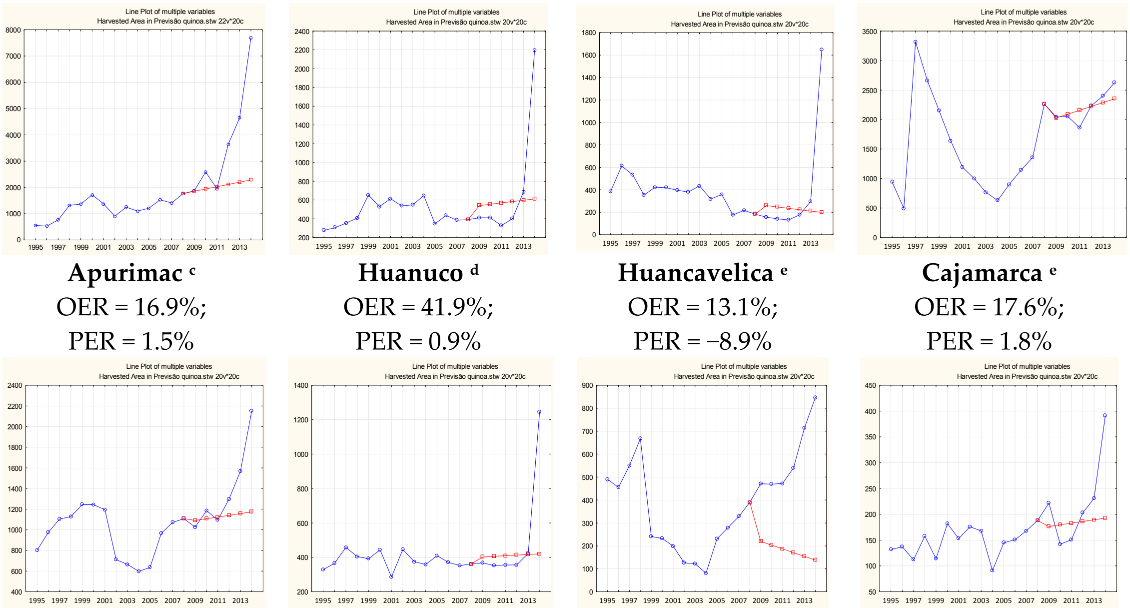


Figure 3. The observed expansion of the acreage of quinoa vs. the predicted expansion in the traditional producing regions (TPRs) of Peru (1995–2014). The blue lines represent the observed expansion rate (OER) and the red lines represent the predicted expansion rate (PER) of the acreage of quinoa. The PER represents an estimate of what the expansion in the acreage of quinoa would have been as from 2008–2009, if there had been no quinoa boom. The regions considered concentrate the largest part of the area occupied by quinoa in the country. Production volume [a] > from 30000 MT; [b] 10000–30000 MT; [c] 3000–10000 MT; [d] 1000–3000 MT; [e] < from 1000 MT.

Given that land-change science is an interdisciplinary field [38], the analysis is based on contributions from Lambin and Meyfroidt [15], who, in addressing the influence of globalization on land-use change, explore three phenomena, namely: the displacement, rebound and the cascade effects. Displacement is related to the migration of activities from one place to another in a manner that brings about land-use changes in new locations. The second phenomenon, rebound, relates land-use changes with the measures taken to increase the efficiency of production, whether by the use of technology or an increase in the number of companies. Finally, the third phenomenon, the cascade effect, is a chain of events caused by a disturbance that affects the land system as a result of the substitution of areas for the production of other crops in specific agro-ecological conditions or land conversion, thus leading to additional environmental effects that are not immediately measurable.

The first phenomenon, displacement, may be associated with the quinoa boom given the speed of the increase in production in Peru to meet global demand, resulting in the expansion of the acreage in traditional producing regions as well as in the expansion in the Peruvian coastal regions, where quinoa has been introduced thanks to its adaptability and tolerance of extreme environments, such as saline soils and temperatures of up to 38 °C [39].

As can be seen in Figure 3 and Table 1, in view of the quinoa boom, the Arequipa region stands out because it largely meets demand, with an average expansion rate of 123% in the acreage between 2008 and 2014, but the magnitude of its importance is even greater if we consider this means an increase of 7773% in the acreage, compared to the year 1995. This extraordinary expansion meant that while in 2008 it accounted for approximately 1%, of national production, by 2014 that figure was 30%.

Table 1. Change in the expansion rate of the acreage, yield and market share, by period, in traditional quinoa farming regions in Peru.

Production Volume in 2014 (MT)	Region	Variation in Acreage (%)			Yield Kg/ha Variation %			Share of National Production (%)		
		2002–2008	2009–2013	2013–2014	2002–2008	2009–2013	2013–2014	2002–2008	2009–2013	2013–2014
	Peru (Total)	**1.91**	**7.33**	**51.85**	**1041.00** **1.51**	**1158.40** **0.09**	**1681.00** **44.66**	**100**	**100**	**100**
>de 30,000	Puno	0.89	3.50	7.95	1064.71 1.78	1137.20 −4.66	1121.00 14.25	81.2	72.2	31.6
	Arequipa	−0.71	55.31	481.29	1317.00 4.37	2379.60 24.57	4086.00 7.03	0.9	3.9	28.9
10,000–30,000	Junin	−2.69	21.27	146.89	1291.86 −0.25	1424.00 7.70	1998.00 10.94	4.1	4.5	9.2
	Ayacucho	13.39	32.03	65.40	873.00 1.96	962.00 6.23	1341.00 26.78	3.8	6.5	9.0
3000–10,000	La Libertad	−1.76	18.36	219.65	732.86 13.97	1214.80 13.97	1892.00 13.28	1.1	1.3	3.6
	Ancash	−7.00	21.33	454.55	1046.43 0.06	1063.60 4.06	1968.00 68.18	1.0	0.4	2.8
	Cuzco	19.01	4.60	9.45	917.14 3.33	1009.00 4.67	1149.00 −2.04	3.4	4.9	2.6
1000–3000	Apurimac	9.33	11.80	37.20	885.00 1.25	1202.00 10.38	1339.00 4.33	2.4	3.4	2.5
	Huanuco	−2.95	3.97	193.87	807.86 0.68	847.80 2.81	929.00 1.17	1.0	1.0	0.7
<de 1000	Huancavelica	34.16	11.71	18.63	567.71 6.68	883.20 2.46	950.00 1.10	0.4	1.1	0.7
	Cajamarca	6.04	4.63	69.26	842.43 7.56	954.80 −1.88	1022.00 8.05	0.4	0.4	0.3

Source: Elaborated by the authors based on data from the [23].

To achieve the record quinoa harvest, between 2013 and 2014, the rate of expansion of the acreage accelerated in all the traditional producing regions (Figure 3), ranging between 8% in Puno and 481% in Arequipa. Thus, there was also a redistribution of production between regions, which is highlighted by the reduction in Puno's share of the total national production from 81% in the period 2002–2008 to 32% in 2014.

Given the situation outlined above, it is clear that the quinoa boom has caused two phenomena. On the one hand, it encouraged the acceleration of the expansion of agricultural areas in the traditional quinoa farming regions, leading to competition for greater market share. On the other hand, it led to the extension of quinoa farming to new regions. Hence, given that, worldwide, the ability to produce food is affected by the intensification of competition for land [40], the future requirements for farmland to produce quinoa in Peru need to be considered by decision makers and the formulators of public policy. This is particularly important if one considers that to meet the Peruvian Ministry of Agriculture's projected production of 212 thousand tons for the year 2020, a total of approximately 114,000 hectares of land [36] would be required, which is 167% more than the amount used in 2014.

The second phenomenon, the rebound effect, is related to changes in land-use in Peru, with increasingly efficient production through the use of technology and the increased number of companies related to the processing of quinoa. To highlight the first case, Table 1 shows the variation in yield per region and shows that, during the 2009–2013 period, the rate varied between −5% in Puno and 25% in Arequipa. In absolute values, this means a yield equal to 1137 kg/ha, in the case of Puno and 2380 kg/ha, in the case of Arequipa. With the increase in production between 2013 and 2014, the yield in the Puno region remained close to 1121 kg/ha, while the Arequipa region achieved a yield of 4086 kg/ha. In general, a large part of these differences can be attributed to the heterogeneity of the edaphoclimatic factors (soil and climate), at the different ecological levels where quinoa is farmed.

For example, in Puno—the main quinoa producing region—the crop occupies areas located between 3800 and 3950 m above sea level, and resists dry and cold weather [39]. In that region, crop rotation (potatoes, cereals, legumes, tubers, forage) is the basis of quinoa farming, with the soil left fallow to recover fertility [40]. Given the characteristics of the production system, if there is an increase in yield in this region, there may be greater demand to expand the planted area, substitute crops or abandon traditional agricultural practices to meet market demand. In turn, in the case of the Arequipa region—the second largest quinoa producing region in the country since 2013—yields are highly favorable since the weather conditions are less severe than in the Puno region and also because it includes part of the Peruvian coast. In this case, the highly efficient quinoa production also leads to an expansion rather than a reduction in the acreage, since the high yields obtained in the region make it more attractive and conducive to the expansion of activity.

To highlight another rebound effect, the case of the new quinoa producing regions along the Peruvian coast, which have higher yields than the traditional producing regions, is explored. While the yield in the Peruvian coastal regions was around 2465 kg/ha in 2014, that of the traditional producing regions was approximately 1618 kg/ha, in the same year. Thus, it seems that the rebound effect was caused by technological improvements that raised the efficiency of quinoa production to meet the demand of new industrial companies that settled in the area to boost the integration of this product, with some added value, in global value chains. For example, in 2015, export-oriented processing plants producing ready-to eat products made from quinoa were opened in the La Libertad region, (e.g., Danper S.A.C Trujillo, Sociedad Agrícola Virú S.A.).

Land-use change through the rebound effect is especially important considering that the market for quinoa is expanding. Thus, given the expansion of the quinoa market and due to the rebound effect, and also considering that the expansion in acreage cannot continue indefinitely, there will certainly be pressure on land-use. Thus, it is crucial that decision-makers and/or public policy makers in Peru stimulate the use of good farming practices in the production of quinoa, especially in the traditional quinoa producing regions.

The third phenomenon, the cascade effects, may be one of the consequences of the quinoa boom, since, if the growing demand for the product persists together with the need to intensify or expand production, there may be environmental impacts on the soil leading to further degradation and even desertification in certain regions [12]. It is known that the soil ecosystem, through soil retention and soil formation functions, helps preserve land arable, prevent erosion, ensure productivity and protect naturally productive soils, among others [41], thus, directly impacting the food production capacity [42].

Erosion is the main cause of land degradation in the Peruvian Sierra, affecting about 50–60% of the agricultural area under cultivation [12], within which lie the traditional quinoa producing regions. It has already been pointed out that the future of global agricultural productivity is linked to soil erosion, and soil quality is affected by agricultural practices [43]. Thus, it is opportune to review the subject of soil conservation in the traditional quinoa producing regions (e.g., proper soil management, farming practices, etc.). For example, in the Puno region, there are signs traditional agricultural practices are being abandoned to increase the volume of quinoa produced [44]. The region has the greatest genetic diversity of quinoa [6,39,40] and is the home of other Andean food products of great importance (such as cañigua, mashua, oca, tarhui, etc.). This could trigger the loss of genetic diversity in the local agriculture, if other crops are no longer grown or fewer varieties are grown due to commercial pressures. Another possible consequence might be the emergence of difficult-to-control pests due to the reduced genetic diversity and climate change in the producing regions [45–47], reducing the number of natural enemies of pests [48], and certainly impacting on nutritional security in those regions [49].

The conservation of agricultural biodiversity encompasses multiple dimensions: ecosystem services [50], sustainable production, food security, product diversification, reduced dependence on external inputs and improvement of livelihoods for small farmers [51–53]. In the case of the Andean region, the biodiversity is also the basis of food sovereignty because there are human communities that maintain and support the agrobiodiversity as part of their social and natural heritage [54,55].

Salinization is the main cause of land degradation along the Peruvian coast, which includes the new quinoa producing regions, and affects 40% of the occupied agricultural area with a significant part in the Piura and Lambayeque regions [12]. Unlike the traditional producing regions, the farming practices used in the cultivation of quinoa in the new regions along the Peruvian coast are still experimental, since quinoa was introduced to reconvert areas of other crops, mainly rice.

Since 2014, the Peruvian Ministry of Agriculture has encouraged the conversion of rice farmland to quinoa in the regions of La Libertad, Lambayeque and Piura to reduce the water consumption required for rice cultivation, which has accentuated the process of salinization. While rice requires, on average, 15,000 m^3/ha of water, quinoa needs only 6000 m^3/ha. However, while the crop conversion measures in these areas may be convenient, phytosanitary problems affecting quinoa production could be a source of concern for local agriculture. The study by [56] shows there are a variety of known diseases which appear especially when quinoa is grown in areas outside the traditional growing regions, although Downy Mildew (caused by the fungus *Peronospora farinosa*) is the most common disease in quinoa. In view of this, the "Import Refusal Report" from the United States Food and Drug Administration (FDA) shows that, in 2014, quinoa from Peru was refused entry due to excessive levels of pesticide residues [57]. As it is basically dealing with quinoa from the Peruvian coast, it can be deduced that, due to biological pressure from pests such as "Ticona" (*Feltia experta*) and/or "Kcona Kcona" (*Eurysacca quinoae Povolny*) [39], producers adopt harmful control measures, such as the excessive use of pesticides. Furthermore, pesticides can contaminate the soil and affect its fertility, because the heavy application of pesticides can cause the decline of beneficial microorganisms in the soil [45,58].

As shown above, through the cascade effects, the land-use changes accompanying the boom quinoa are associated with the disturbance of the soil ecosystem. Thus, the variability of expansion rate of the acreage of quinoa at the regional level requires urgent attention, mainly because soil properties are so variable over space and time [43]. There is a need to determine whether expanding the acreage of quinoa jeopardizes agricultural productivity, the production of other crops, and/or accelerates soil fertility loss, either by transformations to traditional agricultural practices or the excess use of pesticides [45,59].

4. Concluding Remarks

This study addressed the changes in land-use that Peru has experienced as a result of the boom in the global demand for quinoa and the Peruvian exports, from 61.0 tons in 1995 to 36,000 tons in 2014. That means an increase of 600 times the export volume, 10 times the export price and 4 times the price paid to farmers. Across the data set, it was possible to identify that the quinoa boom in Peru began in 2009, but the year 2014 marked the beginning of an unprecedented period in the history of the production of this crop. Because of the quinoa boom, the average rate of expansion of the acreage of quinoa was 16.23%, whereas, if that boom had not occurred, the expansion rate would have been 2.76%, and in 2014, there would have been 43% fewer hectares planted with quinoa. At the same time, the export volume increased approximately 18 times, while the price increased approximately twofold. There was also an increase in the price paid to farmers of approximately twofold.

The growth of the international quinoa market from 2008 has started to show its impacts on the land-use change in Peru through displacement, rebound and cascade effects. On the one hand, displacement was associated with the quinoa boom given the speed of the increase in production in Peru to meet global demand, resulting in the expansion of the acreage in traditional producing region as well as in the expansion in the Peruvian coastal regions. Without the quinoa boom, the expansion of the acreage of quinoa, in traditional quinoa producing locations, would have been 2.8%. However, this phenomenon has encouraged an accelerated expansion that can be observed with an expansion rate of 14.7%. Furthermore, the expansion in the acreage of quinoa in traditional regions such as Junin, Ancash and Huancavelica would have been decreased. The quinoa boom led to the extension of quinoa farming in such a way that has brought land-use changes in new locations. On a particular note, the Arequipa region, where the cultivation increased approximately 30 times, has seen, between 2013 and 2014, a variation in acreage of 481.29%.

On the other hand, rebound and cascade effects were identified as a result of changes in land-use by increasing efficient production through the use of technology and the increased number of companies operating in the sector. The variation in yield in the two main quinoa producing regions showed that the yield in the Puno and Arequipa region, in the period 2002–2008, were 1064.71 kg/ha and 1317.00 kg/ha, respectively. With the increase in production between 2013 and 2014, the yield in the Puno region remained close to 1121 kg/ha, while the Arequipa region achieved a yield of 4086 kg/ha. Thus, changes in the expansion rate of the acreage and market share were observed. The Peruvian coast has higher yields than the traditional producing regions. In general, a large part of these differences can be attributed to the farming practices, being that quinoa farming has traditionally involved the use of crop rotation. Thus, the cascade effects are associated with the disturbance of the soil ecosystem related to substitution of areas destined for the production of other crops, the transformation of traditional farming practices, the land degradation, the excess use of pesticides, phytosanitary problems, among others.

Because Peru is home to an extraordinary wealth of genetic resources of great importance to agriculture and food production [60,61], future research directions may address, for example: the future requirements for farmland to produce quinoa and other native crops in Peru, the pressure on land-use given the expansion of the quinoa market and the transformation of agricultural practices especially in the traditional quinoa producing regions.

By providing a perspective on the link between the intensification of the international quinoa trade and the expansion of the acreage of quinoa in Peru, this study contributes to the literature in construction regarding the consequences of land-use changes on the sustainability of agrobiological systems. Understanding the processes of direct or indirect land-use change resulting from trade is essential so that decision-makers in Peru can better manage natural systems, in order to ensure the long-term sustainability of agricultural production in the country.

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