Is quinoa cultivation on the coastal desert of Peru sustainable? A case study from Majes, Arequipa

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Saca tu largavista, tus mejores anteojos. Mira, si puedes…

Las cien flores de la quinua que sembré en las cumbres hierven al sol en colores; en flor se han convertido la negra ala del condor y de las aves pequeñas…

En esta fría tierra siembro quinua de cien colores, de cien clases, de semillas poderosas. Los cien colores son también mi alma, mis infatigables ojos.

(José María Arguedas. Llamado a algunos doctores.
Publicado en diario *El Comercio*, 03/07/1966)

"Take out your binoculars, your best eyeglasses. See, if you can...

The hundred quinoa flowers I sowed on the summits boil in colours under the sun; in flower, they have become the black wings of the condor and of smaller birds...

In this cold land, I sow quinoa of one hundred colours, of one hundred types, of powerful seeds. These one hundred colours are also my soul, my inexhaustible eyes"

(José María Arguedas. *'Call to some professors'.* Published in the newspaper *El Comercio*, 03/07/1966 [own translation])

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I would like to acknowledge several people who helped me throughout this process of doing my master thesis.

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Abstract

Quinoa is a staple crop in the Andes region. Due to an increasing demand of its grain, it is recently being cultivated in coastal desert areas of Peru. In the Andes, traditional agriculture is practiced, whereas intensive conventional agriculture is practiced in the coastal areas. This thesis is a case study of intensive quinoa production in Majes, in the desert area.

Farming practices, yield and N components were registered in Majes and in Camacani, in the Andes, for comparison. Data were collected through surveys and small-plant-cut samples. A total of 27 farms and 35 fields were accomplished.

In Majes, up to 287 kg N/ha, 14 pesticides, and 600 mm of water were used for quinoa production. Downy mildew and chinch bugs are of concern. In Camacani quinoa cultivation is rain fed. Inadequate use of pesticides to control larvae of *Eurysacca* might affect its sustainable quinoa production. The N utilization in Majes covered the N demand of quinoa. Yield was between 1963-6010 kg/ha. The average NUE of 43 % did not decrease with 194 kg N/ha or higher doses applied.

Camacani has 4-years crop rotation, N-manure is applied the 1st-year. In 2nd-year, unfertilized quinoa utilizes soil-N. Yields ranged from 542-4466 kg/ha. The NUE was left out for comparison due to assumptions in N utilization.

The improvement of nutrient and pesticide application, incorporation of organic matter, and improvement of water use on quinoa production seems to be possible without affecting yield and revenues for farmers in Majes. This is needed to make a more sustainable quinoa production, especially in the desert area.

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1. INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd.) is a staple crop that has been cultivated for thousands of years in the Andes of South America. In recent years, there has been an increasing interest and demand of quinoa around the world (Krivonos 2013, Bazile et al. 2015). The recent awareness of quinoa lies, among others, in its protein content higher than cereals like rice, barley and maize (Martínez 2015), and good balance of essential amino acids, like lysine (Repo-Carrasco et al. 2003, Wu 2015). Quinoa possesses a great adaptability to different agro-climatic conditions, and it is able to tolerate drought, frost, heat, salinity, poor soils among others (Jacobsen 2003, Jacobsen et al. 2003, Mujica et al. 2004, Geerts et al. 2008, Martínez et al. 2009). Due to this adaptability to different conditions, the cultivation of quinoa has been tested in different latitudes and altitudes (Mujica et al. 2001), and recently in different arid countries (Bazile et al. 2016).

Quinoa has mainly been cultivated under traditional sustainable agriculture in the Peruvian and Bolivian Andean region (N.R.C. 1989, Garcia et al. 2015). The traditional agriculture of quinoa in the Andes is characterized by abatement of mineral fertilizers and pesticides, cultural control of weeds, crop rotation, intercropping, and multiple cropping among others (Camino et al. 1982, Camino and Johns 1988, Halloy et al. 2005, Jacobsen 2011). In other words, quinoa has been produced in a sustainable way. The sustainable production basically means an efficient use of resources to provide food and maintain the balance of natural resources such as biodiversity, water and soil (Gliessman 2007, N.R.C. 2010, Altieri and Toledo 2011). Due to the increasing demand, the leading suppliers of quinoa Bolivia and Peru have done attempts to increase their production of quinoa (Krivonos 2013). This has meant that cultivation of quinoa has been expanded from its original Andes region to new agroecological areas.

The expansion of quinoa to new areas, i.e. desert coast, has been done to increase the production. This involves a shift in the production system, from a traditional sustainable production of quinoa in Andean regions to intensive conventional agriculture in desert areas. For example, in the desert areas of Majes, in Peru, quinoa is being produced through intensive agriculture with adoption of irrigation technologies, and high use of external inputs like fertilizers and pesticides (Gómez-Pando et al. 2015). The effect of this high use of inputs has caused that yields can reach four to six ton/ha or even more, in contrast to 0.9-3 ton/ha in the Andean region. Although this current intensive production of quinoa in new coastal areas might have an impact on production of quinoa, little scientific literature is available about its cultivation, and there is a need for recording data of farming practices, yield, nitrogen (N) efficiency, fertilizer and pesticide applications, irrigation and so on. This information is needed to describe the challenges and agro-environmental concerns, and to evaluate whether the production of quinoa in coastal desert areas is sustainable or there is necessary to improve the efficient use of resources to become more sustainable.

In the Andes, the sustainable agriculture is traditionally practiced by small-scale farmers. Production is mainly for home consumption or home use and only the remainder is sold. It is cultivated with traditional practices, and most of the practices are manual with low inputs (Orellano and Tillmann 1984, Jacobsen 2011). In traditional agriculture, farmers practice crop rotation, intercropping, and multiple cropping to reduce the loss caused by climatic risks and pests. The Andes is characterized by harsh climate with severe droughts, frost, hail, wind and poor drained soils (N.R.C. 1989, Jacobsen et al. 2003, FAO 2011, Garcia et al. 2015). Moreover, the traditional practices reduce the yield losses caused by pests and diseases. Quinoa might be affected by different pests like insects and birds (Rasmussen et al. 2003), by different diseases like downy mildew caused by *Peronospora variabilis*, nematodes; and other pests like additional vertebrates and weeds (Mujica 1997, Mujica et al. 2001, Danielsen and Ames 2004).

While quinoa in the Andes is being produced with traditional practices the story in the coastal desert is another. As it was mentioned, the production of quinoa has recently been expanded to arid zones in Peru (Nolte 2014). For instance, the area of Majes in the southwestern Arequipa region, which is characterized by desert soils. The desert sandy soil conditions with low content of organic matter, high salinity, low water retention are not limiting factors for quinoa, due to its adaptability to such limiting conditions (Mujica 1997, Jacobsen 2003, Jacobsen et al. 2003). Quinoa is being cultivated with intensive methods and with high use of fertilizers compared to traditional practices (Cherfas 2016), and water in the area is available due to the Majes Irrigation Project (MIP). Application of mineral fertilizers, via the irrigation system, can reach levels of 300 kg/ha of nitrogen, 120 kg/ha of phosphorus, 300 kg/ha of potassium, 40 kg/ha calcium, 20 kg/ha magnesium and 1.5 kg/ha zinc (Gómez-Pando et al. 2015, MINAGRI 2015). Cultivation of quinoa in the desert coastal areas of Peru involves new challenges like pests and diseases, and methods to control them. Some of the pests affecting the production of quinoa in Majes seems to be similar to those in the Andes such as caterpillars of lepidopteran species, and other pests are recently being reported and researched, like chinch bugs (Callohuari et al. 2014, Nolte 2014, Cruces et al. 2016). These pests are controlled chemically as same as diseases, being downy mildew the main disease affecting quinoa (Danielsen and Munk 2004). However, the interaction of pests, spray of pesticides and its environmental impacts need to be studied in more detail. Regardless of this, these inputs have made that yields can now reach up to 6 ton/ha or even more (RedAgrícola 2014).

The application of high doses of fertilizers and pesticides lead to environmental, as well as economic, issues. For example, in 2014 Peruvian newspapers informed that the US Food and Drug Administration (FDA) had rejected shipments of quinoa due to presence of pesticides (Bárcena Carpio 2014). It can be discussed by farmers of both regions whether all the quinoa came from the Andean areas or from the coast of Arequipa as it is claimed by the newspaper, but nonetheless, the presence of pesticides reveals the problem of farmers dealing with pests and diseases. On the other hand, the amounts of mineral fertilizers utilized in the coastal area are almost threefold higher than in Andes, where 60 kg/ha to 80 kg/ha of nitrogen, 40 kg/ha of phosphorus and 0 kg/ha of potassium are applied, and most of it is supplied through animal manure (Mujica 1997, Mujica et al. 2004).

Although the conventional cultivation of quinoa in coastal areas seems to be recent, the cultivation of it has been practiced since a long time ago. There are coastal varieties of quinoa, i.e. from Chile, Southern America (Jacobsen 2003, Martínez et al. 2009, FAO 2011). However, most of the former quinoa in the coastal desert Peru has been cultivated as experiments to evaluate the adaptation of quinoa to the soil and climate conditions of the coastal desert. It has been found that some varieties cope well with the salinity, sandy soils, temperature and that high yields might be possible (Mujica 1997, Mujica et al. 2001, MINAG 2012, Gómez-Pando et al. 2015). Nonetheless, many of these experiments covered a short period, or only took place in experimental plots.

In despite of the impacts of the intensive production of quinoa and agro-environmental concerns in the desert coastal areas of Peru, its scientific documentation is scarce and it is little known about the detailed use of inputs and crop management. However, in this geographical area of Peru, during the last years quinoa is mainly produced at a commercial scale for export (MINAGRI 2015), and the use of a high amount of inputs make a large scale production possible, and is justified by the increasing demand for quinoa. The production is further intensified with the increasing prices on the international market.

This thesis is a case study of the new quinoa production in the desert area of Majes. It compares its production with the area of Camacani in the Andean Altiplano, where quinoa is still cultivated traditionally. Further, the thesis evaluates and discusses the sustainability of the production of quinoa produced in Majes. More specifically it seeks:

a) to describe the quinoa production in areas with intensive production, with regards to farming practices and inputs, like fertilizers, pesticides and water in Majes, compared to traditional Andean production,
b) to analyze the intensive conventional quinoa production in relation to the yield components, nutrient accounts, and nitrogen utilization,
c) to suggest improvements in the management of quinoa in the desert coastal area.

Expansion of quinoa production in Peru

To understand the expansion of quinoa to the desert coastal areas, it is necessary to describe the variation of quinoa in Peru on acreage, production, yield and prices throughout the last years both at national level and at the level of the studied area.

As reported by the Ministry of Agriculture of Peru (MINAGRI, 2015; Appendix A), the total national production of quinoa in Peru was stable during the period 2000-2008. After this, there was a slight increase until 2013. The remarkable change occurred in 2014. Compared to the previous year, there was an increase of 119%; from 52132 tons in 2013 to 114343 tons in 2014. The increasing production occurred with a 52 % increase in the acreage in the same period (Figure 1). Moreover, the production of 2014 is five times more than the referential production of 28191 tons in 2000. In addition, not only the acreage and production increased but also yields increased from 976 kg/ha to 1681 kg/ha, since 2000 to 2014 (Appendix A).

Since 2008, both the acreage and the production have increased more steadily than years before (Fig. 1). This is due to the increasing demand of quinoa. One reason for this could be the recent international interest in and awareness of the nutritious value, high quality food and good balance of amino acids, specially the presence of essential Lysine, compared to cereals (Jacobsen 2003, FAO 2011, Martínez 2015, Wu 2015). Another reason could be that attention to the crop has furthermore been drawn by the United Nations' General assembly with the declaration of “The International Year of Quinoa” in 2013 (Bazile et al. 2015, MINAGRI 2015), which seems it has had an additional impact on the international demand of quinoa.

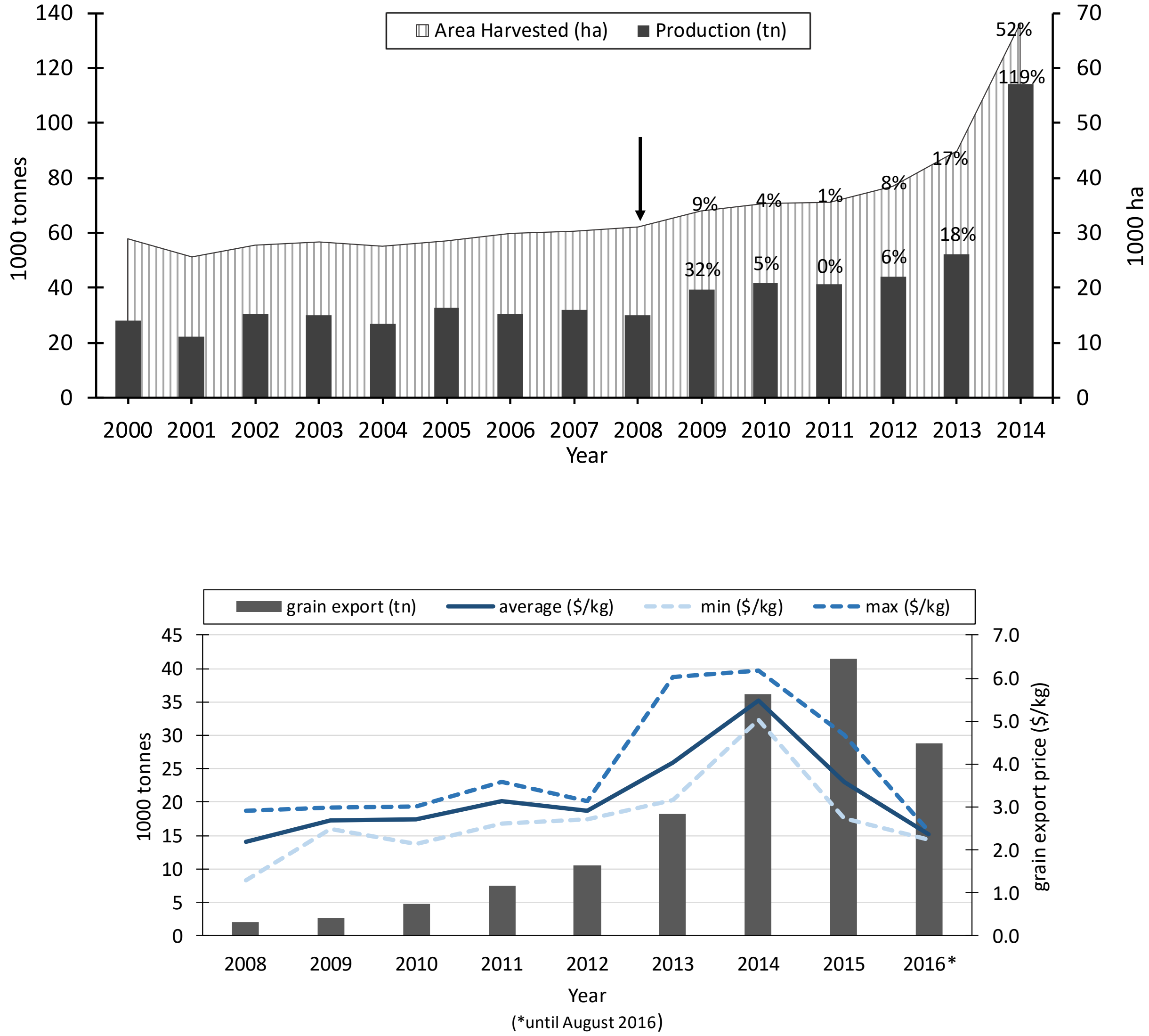

Figure 1. National production and export of quinoa in Peru. Top, total production and acreage of quinoa in Peru until 2014; percentage compared to previous year (MINAGRI 2015). Bottom, grain exported, and minimum, average, and maximum export prices in USD/kg (elaborated from MINAGRI 2016)

Thus, Peru has increased its export to supply the global demand since 2008 (Fig. 1, bottom). An increasing production allows Peru to steadily export quinoa to different countries, with more than 40000 tons in 2015 as reported by the statistics of the Ministry of Agriculture's website (MINAGRI 2016), being the United States one of the important importers of quinoa (Nolte 2014, MINAGRI 2015). In parallel, the export prices rose from US$ 1.30 per kg in 2008 to a record of US$ 6.17 in 2014 (MINAGRI 2016, Appendix B), which has affected farm prices as will be discussed further below. Export market and production mean that quinoa exports have increased from US$ 13 million in 2010 to US$ 143 million in 2015 (Appendix B). Nonetheless, in the last year the export prices have started to drop to similar prices to those eight years ago (minimum of US$ 2.23 in august 2016; see Appendix B), having an impact on the production and producer price (or prices received by farmers for their produces) of quinoa at regional and local scale.

The drop in the export prices in 2016 had a negative impact on the export and production of quinoa, which is seen in Majes. First, the acreage, production and farm prices of quinoa have been reduced over the last two years, according to the website of the Regional Agriculture Office of Arequipa (AgroArequipa 2016). Figure 2 shows the reduction of around 87% of harvested areas in the last season (2015-2016) compared to the season 2013-2014. Therefore, the production has been reduced abruptly by 90% at local levels of Majes in the last year. From profitable farm price of US$ 4.00 per kg in 2013, with a cost of production of US$ 1.33-1.67 per kg (RedAgrícola 2014), farm prices have dropped to current values such as US$ 1.05 to 1.24 per kg (see details in Appendix C), which causes economic losses for farmers. This is a characteristic when farm incomes depends on commodity prices (Calviño and Monzon 2009).

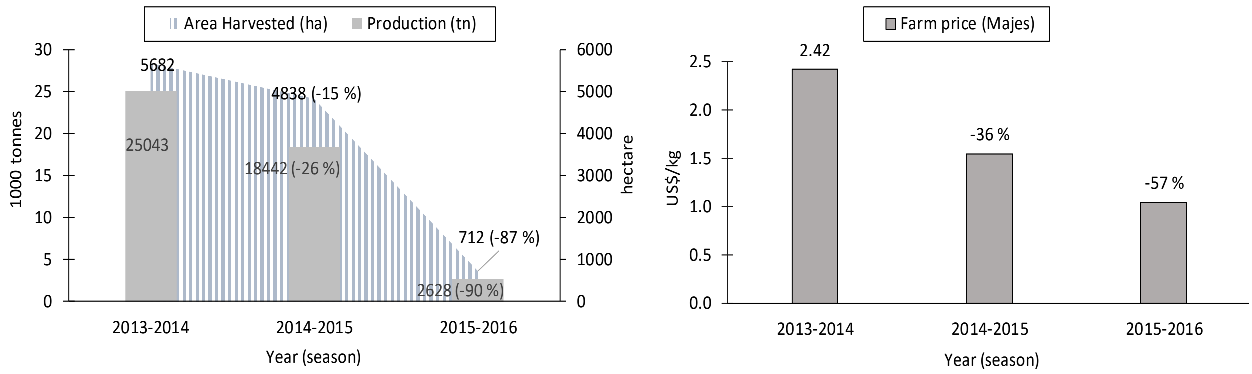

Figure 2. The Production of quinoa and farm prices for period 2013-2016 in Majes. In parenthesis change in percentage compared to season 2013-2014 (Elaborated from AgroArequipa, 2016)

It is complicated to explain the reasons for the drop in international prices, since there are many aspects to consider (S.E. Jacobsen, pers. comm.). In Peru, beside the expected price fall of international market because of increased supply (The Economist 2016), at national level it is claimed by the media that the price drop is also due to farmers who made excessive use of pesticides, which led to a rejection of quinoa shipments by the Federal Drug Administration FDA, because many of the compounds detected in conventional quinoa were not allowed. It is worth to remark that most of the commercialization to the USA is for certified organic quinoa (Núñez de Arco 2015), and for conventional quinoa there was no regulation agreement between Peru and USA in relation to the pesticides permitted for quinoa production, as it already exists in the Europe

Union, where some pesticides are regulated and allowed for conventional quinoa (EC 2017). However, an agreement of Peru with the United States is recently being implemented by both governments, in order to have a list of maximum residue levels (SENASA 2016).

2. METHODS

2.1 Study Area

The study area encompasses Southwestern coast and Southeastern Andes of Peru. It focuses mainly on Majes as a new area of intensive conventional quinoa production in the coastal desert, which is compared to the zone of Camacani, in Puno, as a place of traditional Andean agriculture (Figure 3).

Majes is a plateau located in the coastal desert strip in the western part of Arequipa region (Fig. 3). The climate of Majes is classified as tropical arid desert (Osborne 2012). The altitude ranges between 1080 and 1590 m a.s.l. (AUTODEMA 2014). The average annual precipitation is 8 mm, and the average annual temperature varies between 18-22 °C. The maximum temperature is registered in February and March (25.9 °C), which are part of the Austral summer months (December to March), whereas the minimum temperature (9.3 °C) occurs in June and July (Figure 4). It is a very dry region with scarce or no rainfall at all. The presence of the Pacific Ocean at a distance of approx. 50 km provides the arid climate of Majes with sporadic fog (SENAMHI 2016).

The water for agriculture is provided by the Majes Irrigation Project (MIP) through a large-scale water transfer (Vera Delgado and Linden 2013; Appendix D). The area irrigated encompasses 14805 ha, under possession of 2685 farmers or owners. The size of each farm is 5.5 ha (AUTODEMA 2014), from which 5 ha have been designated as arable farm and the rest for different infrastructures, e.g. farmer's house, stable for the herd, manure storage, among others. Majes encompasses sandy and sandy loam soils. The organic matter (OM) content varies from 0 to 2 %, the latter in soils with more than 20 years of cultivation, and pH is higher than 7 (Dazzi 2006, Medina Hoyos 2008).

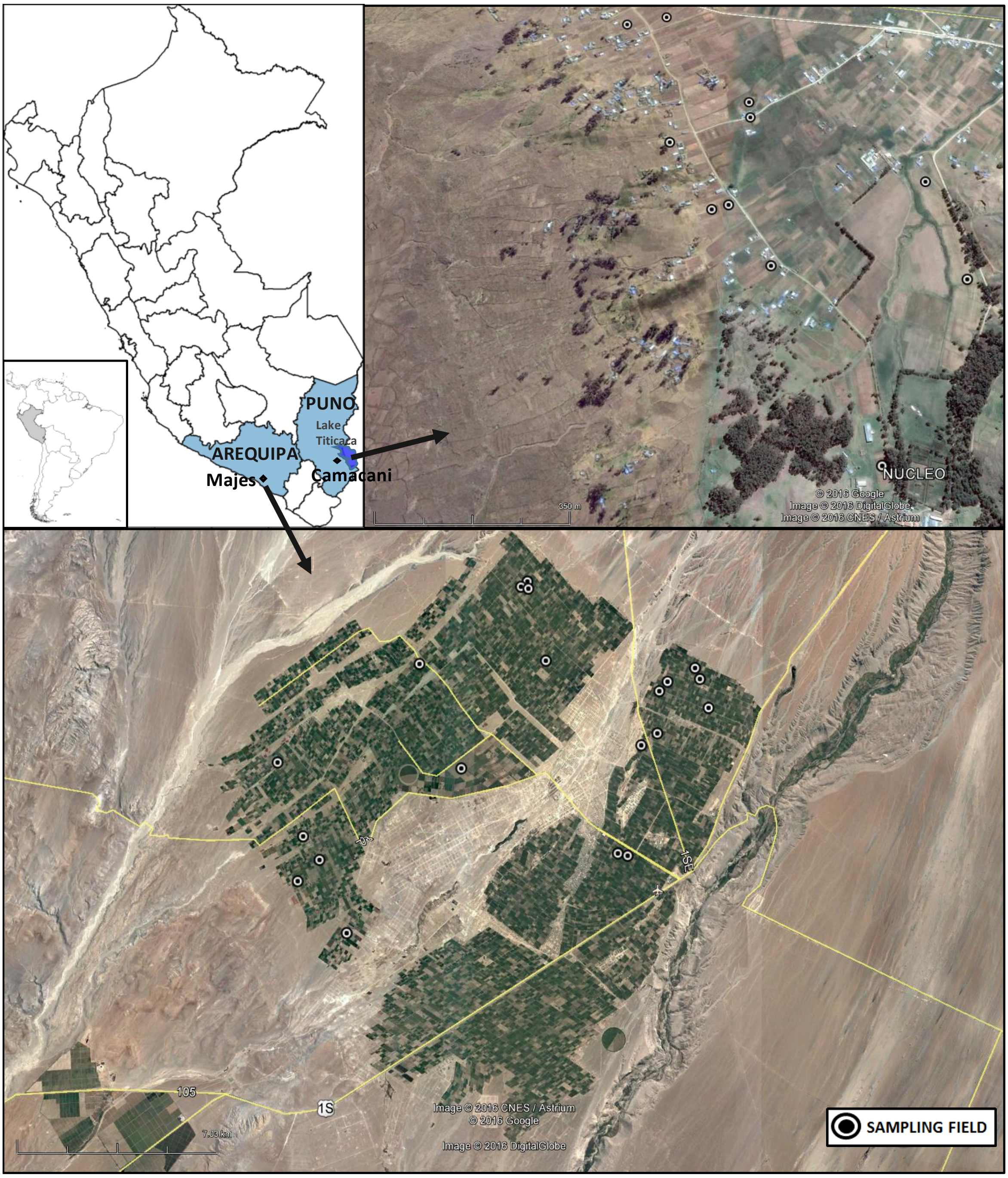

Figure 3. The study area of Majes, in Arequipa region, and Camacani, in Puno region; Southern Peru (Images from Google Earth, Oct. 10, 2016).

Camacani is located in the region of Puno, near Lake Titicaca. The altitude varies from 3830 m to 3900 m a.s.l. According to the records of climate data from Puno weather station, Camacani shows an average temperature of 8.9 °C and average annual precipitation of 733 mm (Figure 4). A maximum temperature of 16.6 °C is registered between November and December, whereas a minimum of -1.2 °C is registered in June and July. Rainfalls occur during the summer months, from December to April. Precipitation above 100 mm are concentrated in the months of December to March. The climate is classified as cold temperate and semi-dry, with rainy summer and cold dry winter (SENAMHI 2016). The area encompasses loamy, silt clay loam, sandy loam and silty loam soils; the OM content varies from 2.5 – 7 %; the pH ranged from 4 to below seven (Cervantes Zavala 2012).

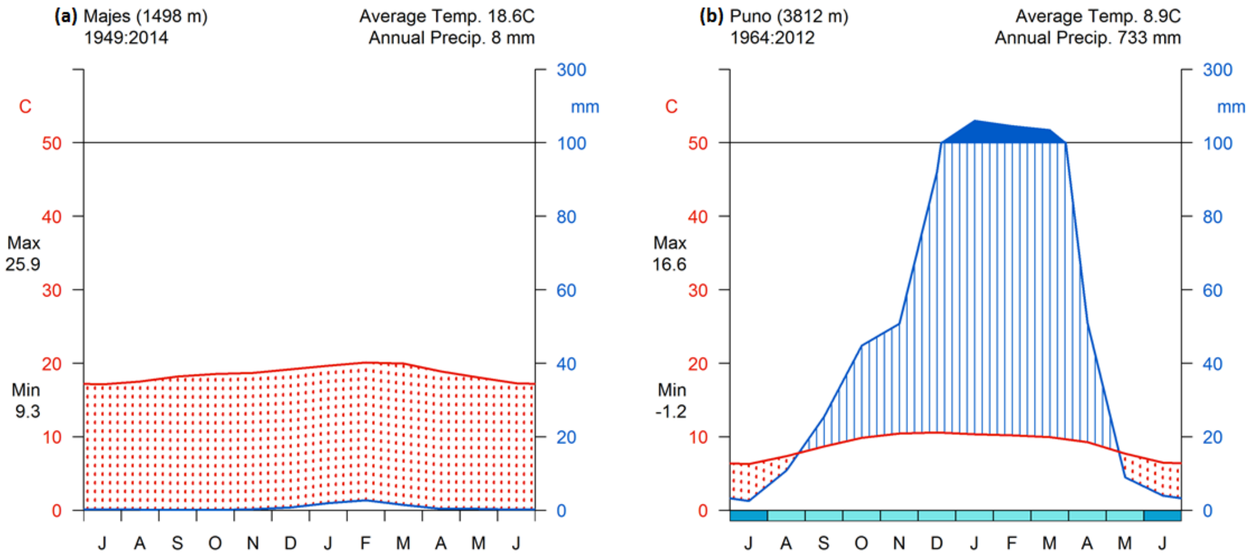

Figure 4. Precipitation and mean annual temperature of (a) Majes and (b) Camacani (elaborated from SENAMHI 2016)

2.2 Data collection

The research was carried out on 27 farms in the study areas, where a total of 35 field were selected, and respective samples were obtained. The farms were taken into consideration after conversation with owners that gave the permission to take field samples of small plant cuttings. Along with the field work, surveys were applied from farmers willing to participate. The number of farms are acceptable for representation and detailed information about the individual farm, as is suggested by Kristensen and Hermansen (Kristensen and Hermansen 2000).

2.2.1 Farm surveys

Field surveys were developed to collect data needed to describe the farming or agronomic management in both traditional and new areas, the use of fertilizers and other inputs as water and agrochemicals in general (pesticides, fungicides, hormones, and so on), costs of production, details about crop rotation, and cultural practices. A total of 14 surveys were collected in Camacani, which include two from technicians of the experimental center of the UNA. In Majes, 20 surveys were collected from farmers throughout the area in addition to seven applied to advisors, which shared their management plans for fertilization and biocides applications.

The surveys where developed in Spanish to farmers and advisors in both Majes and Camacani. They were draw up based on dialogs and conversations using a survey step-by-step template. It started with collecting the activities done at different stages, for instance, before sowing (Pre-sowing), the day of sowing, post-sowing, harvest and post-harvest. Among others the data recorded includes use of machinery, number of persons for labor, cultural practices, type and amount of fertilizer utilized, acquisition of seed, pest and weed control, dates of cultural practices; storage, commercialization and uses of quinoa and residues, etc. As an example, one survey from Majes was translated to English and it is presented in Appendix I.

A limitation to the surveys is that some farmers did not give answer to all aspects included. Some farmers were too busy to answer, since it took around 40 minutes to complete. Sometimes it took more than 40 minutes because farmers started to provide information not related with the objectives of this study, such as role of stakeholders, scarcity of water, climate variation, perception about the market. Most of surveys were done during field visits, and it took time to move around the study areas. Although some surveys were not fully completed, the overall surveys provided substantial information and experiences of farmers to get an overview of the farming practices.

2.2.2 Farm trials

The field work with collection of the samples encompassed the following sequence of activities: Samples of plant cuttings by hand (1 cm above soil) => plants were air dried (7 to 10 days) => threshed => grain sifted => weighted (fresh) => oven dried => weighted (dry matter) => winnowed the grain to separate chaff (residues) => grain weighted => send to lab for N analysis.

More in detail. In Majes, 19 farms and 20 fields were accomplished. In Camacani, eight farms and 15 fields were selected, including five from experimental trial of the Research Center of National University of Puno (CIP UNA; Angel Mujica’s project). The trial consisted of one field cultivated with ten varieties (Figure 5) to conserve the germplasm of pure lines. The five varieties selected were the commercial and broadly cultivated ones in the area: Salcedo, Blanca de Juli, Kancolla, Negra Collana and Roja Pasankalla.

Figure 5. Experimental trial with pure line plants of ten varieties in the Research Center of UNA in Camacani

The number of samples encompass a total of 89 and 75 for Majes and Camacani, respectively. In each field, quinoa plants were collected by samples of small plant-hand-cuts (or small-cuts) with 3 to 5 representative samples. The small-cuts consisted of two lines of quinoa plants by one-meter length. Plants were cut 1 cm above the soil surface. The plants were cut over plastic bags to reduce the biomass losses, i.e. of seeds and leaves. Due to different furrows' widths (Fig. 6), the samples were adjusted and standardized in square-area units (1 m x furrow width) for each study area and field. In Camacani, furrows varied from 0.55 m – 0.70 m width, with one line per furrow. Then the sampling square unit varied from 1 m^2 to 1.7 m^2. In Majes levelling furrows or beds encompassed 0.75 m; 0.80 m and 0.90 m width or spacing, and two lines per bed. The sampling units varied from 0.75 m^2 to 0.90 m^2. In both cases, representative samples where used to extrapolate comparable data to hectares. The samples were used for further calculations of grain dry matter (DM), harvest index (HI), yield and nitrogen (N) content.

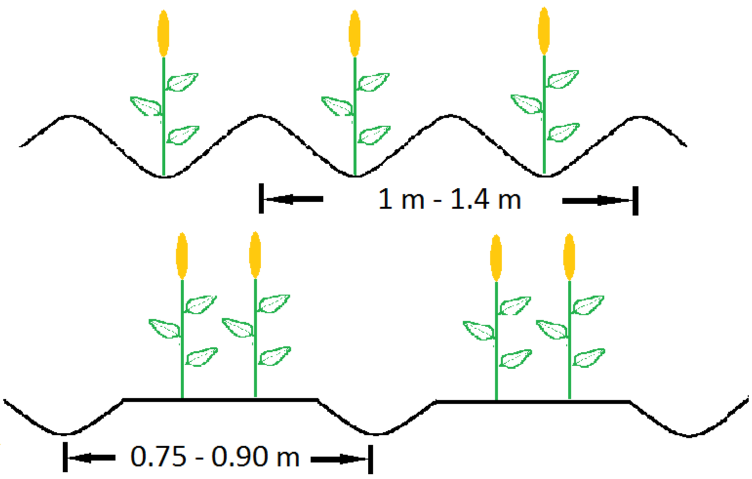

Figure 6. Representation for furrows in Camacani (top) and levelling furrows or beds in Majes (bottom)

2.2.3 Yield, Dry Matter (DM) and N content

The small-cut samples were weighted after 7-10 days of air-natural drying. Each small plant-cut sample was threshed, split into grain plus residues of husk and leaves1, and small pieces of stalk plus leaves. Grains were lightly sifted, weighed individually in bags, one for the grain plus chaff, the other one with the stalk.

To obtain the dry matter (DM), plants were dried in an oven at 80 °C for 20 hours, following the procedure suggested by the laboratory of Foulumgård (Dyrberg et al. October 2014). Afterwards, dry samples were weighed and winnowed to separate the grain from chaff, which was done by a self-designed procedure (Appendix E). Finally, the grain separated from chaff, and stalk dry samples were weighed and values obtained were extrapolated and standardized in kilogram per hectare (kg/ha) for further calculations of the dry matter.

For each field the grain DM samples were mixed and send for N analysis. The percentage of N content (N %) in the grain was determined by the Kjeldahl method. The analysis was performed in the laboratory of the Faculty of Chemistry, National University of Arequipa (UNSA).

2.3 Analysis

Data is presented through descriptive statistics, average and coefficient of variation (CV, expressed in percentage). Further calculations were mainly based on weights of grain dry matter (DM) and total DM for the research purposes, which were obtained with the following equations:

a. Grain DM (kg/ha) : $\frac{Grain\ DM \times 10000\ m^2}{sampling\ square\ m^2\ x\ 1\ ha}$ (1)

b. Grain N uptake (kg N/ha) : $\frac{Grain\ DM \times \%N}{100}$ (2)

c. Harvest Index (%) : $\frac{grain\ DM}{total\ plant\ DM}$ (3)

d. Crude protein DM (%) : $\%N \times 6.25$ (4)

e. Total N in manure (kg N/ha) : $\%N\ standard\ value^{\dagger} x\ kg\ Manure$ (5)

†%N values according to (Tapia and Fries 2007)

f. Mineral fertilizer (kg/ha) : $\Sigma(kg\ fertilizer\ x\ \%fertilizer\ content^{**})$ (6)

** % values obtained from www.yara.com.pe

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1 In the Andes, these residues are specifically named as “jip’i”, further this is categorized as chaff.

g. Nitrogen Use Efficiency NUE (%): $$\frac{Eq.(1)\ \mathrm{kg\ N}}{Total\ kg\ N\ fertilizer\ [eq.(5)+eq.(6)]kgN} \quad (7)$$

All the weight data were standardized in units of kg/ha to make comparable data from both areas. The whole data of weights and N component are shown for Puno (Appendix J) and Majes (Appendix K).

In this study NUE (%) is used following definition of Halberg et al. (1995), using kg N in grain going out of farm divided by fertilizer kg N going into the farm. This is different to the traditional concept of agronomic nutrient efficiency (agroNUE) defined as unit of product produced per unit of nutrient supplied (kg grain DM/ kg N). The reason is that NUE (%) will better illustrate when there is need to balance the production (Halberg et al. 1995).

3. RESULTS

This chapter summarizes the findings of surveys and following calculations based on data from small-cuts. First section describes the farming practices in quinoa cultivation from a general comparison between Majes and Camacani to a detailed description of different phases. Then follows calculations based on data from small-cuts (or field samples). These encompass grain and total dry matter (DM) weights, harvest index (HI), nitrogen use efficiency (NUE), crude protein content in grain and amount of fertilizers applied.

3.1 Farming practices

The farming practices carried out in the farms are summarized in Table 1, which is based on the surveys. In Majes, the production of quinoa is characterized as an intensive conventional agriculture. Many of the activities are mainly mechanized, but some are made by labouring (or manual). The Majes Irrigation Project (MIP) provides the water, which is available on fields through drip-irrigation. Fertilization is done by use of mineral fertilizers applied through the irrigation system (hence forward named fertigation). Pest control is done mainly by use of agrochemicals for insects and diseases. Quinoa was cultivated among February to May, or even later.

In contrast, in Camacani the production is named traditional agriculture characterized by four-year crop rotation, manual activities and non-use of mineral fertilizers for the quinoa crop. The agriculture occurred once a year because it is constrained by the rainy season (Fig. 4b). Quinoa is sown in the second year after potato. Many of the activities were more time demanding or consuming, as explained below. Mechanical activities only accounted for secondary tillage or harrowing. For insects and diseases cultural control was mainly performed, which embraced cultivation of different quinoa varieties, crop rotation and multiple cropping. The chemical control of pests was considered as a last option to save the grain production. Quinoa cultivation in general took place in October, or first week of November at the latest.

However, despite the differences in both sites some activities are done in similar ways. For example, the seeding is manually performed as well as weeding after sowing, and cutting of plants during harvesting process. This latter is still performed by using sickles. More substantial details of the different farming practices are explained below.

Table 1. Main farming practices in the study sites (based on surveys)

Activities	Majes (Desert)	Camacani (Andes)
1. Pre-sowing		
- Primary tillage	Disc plough	no
- Secondary tillage	Disc harrow + rigid tiller	Disc harrow
- Furrowing or ridging	Ridge + roll	animal-drawn ridge
- Irrigation system or water supply	drip irrigation	rain fed
- Weed control	herbicide spraying	tillage
- Seed acquisition	traded	own or interchange
2. Sowing		
- Seed disinfection	agrochemicals	none
- Sowing	manual	manual
3. Post-sowing		
- Emergence evaluation	yes	no
- Re-sowing	yes	no
- Fertilization	mineral	manure (year-crop before)
- Thinning out	yes	no
4. Pest control		
- Pest and disease control	chemical control	cultural control‡
- Weeding	manual	manual
5. Harvest		
- Harvest with sickle	yes	yes
- Drying of plants	plants lying on soil	Stacking of plants
6. Post-harvest		
- Threshing	mechanical	manual
- Crop residuals	incorporated	burnt
- Storage	no	yes
- Trade of grain	Market	Mainly home consumption
		‡ chemical at last alternative

3.1.1 Crop rotation

In both regions crop rotation and multiple cropping were performed, but the objectives were different. In Majes the crop rotation was related to or constrained by the market. When one crop was profitable some farmers did not practice crop rotation at all, as it happened with production of quinoa in 2013 and 2014. The farmers of Camacani practiced crop rotation and multiple cropping as an alternative to recycle nutrients into the soil. This was because farmers cannot afford manure fertilizer continuously and it is how they are used to practice it. In addition, multiple cropping on the same or in different fields of the farm was a common practice in Camacani, as well as Majes. In Camacani, this practice is also useful to cope with adverse climate.

Table 2. Examples of crop rotation practiced in Majes and Camacani. Rotation encompasses the crops two years (or seasons) before quinoa and intended crop after quinoa (based on surveys)

Site	Year or season			
	1st year (2014)	2nd year[b] (2015)	3rd year (2016)[a]	4th year (2017)
Camacani	potato	quinoa	wheat oat barley (potato) £	faba bean Lupinus bean lucerne‡ (cereal) £
	Winter 2015	Summer 2016	Winter 2016[b]	Summer 2017
Majes	quinoa Salcedo quinoa black quinoa red fodder maize grain (purple) maize potato onion	potato pumpkin onion fodder maize paprika grain (purple) maize artichoke (quinoa)	quinoa Salcedo quinoa black quinoa red	tomato fodder maize grain (purple) maize paprika potato lucerne‡

[a] in Camacani, if cereal was for consumption, it was sown in September
[b] Period when study was carried out (harvest in 2016)
£Cultivated when farmer can afford the manure
‡ two years of growth

In Majes climate conditions and access to irrigation allow two seasons of cultivation per year, meanwhile in Camacani there was one season of cultivation per year because it is rain fed. Table 2 summarizes the examples of crop rotation found in both areas. In Camacani the crops followed always the same order of four years and multiple cropping were practiced. If lucerne was sown it grows two years, then it was five-year crop rotation. Meanwhile in Majes multiple cropping or monoculture were practiced on farms. There were different crops that varied before or after quinoa. Table 2 can be used as reference of possible crop combination sequences.

3.1.2 Pre-sowing

In Majes, soil preparation started around 20 days before sowing (DBS). It began with primary tillage to invert the soil and bury crop residues. Five to seven days later it was followed with secondary tillage to shatter clods for seed bed preparation. Tillage encompassed the use of machinery with disc plough, disc harrow and rigid tiller. Soil preparation finished with the furrowing and levelling of beds by ridge joint to a levelling roll (Fig. 6a). Seed beds were ready at the latest seven DBS (Fig. 6a). Then it is followed by installing the drip irrigation by hand (Fig. 6b). Right before sowing, the field is irrigated between seven to 10 days or more. This is done to promote the germination and emergence of weeds. Afterwards, the chemical control of weeds is done one or two times by spraying Paraquat (Fig. 6c). In general, the herbicide was sprayed one or two days before sowing.

Figure 7. Farming practices in Majes. (a) Furrowing and levelling 10 DBS, (b) installation of drip irrigation 7 DBS, (c) chemical control of weeds 2 DBS, and (d) sowing with a hook.

In Camacani, the soil is prepared by secondary tillage, only one of the farmers achieved primary tillage and one farmer sowed with no tillage out of a total of 14 farmers. Tillage is the main activity to remove and control weeds. Chemical control for weeds before sowing was not performed. The tillage started along the months of July, as earliest, to September; one to two months before the sowing date, taking advantage of early rain.

The seed acquisition differs in the study sites. In Majes, the quinoa seeds were provided by advisors or farm chemicals business or stores. No certified seed were recorded. Whereas in Camacani some farmers selected their own seeds from former quinoa cultivated and other farmers exchanged grain seeds with farmers from the same area or away.

3.1.3 Sowing

It was observed that quinoa fields were sown between February and May in Majes. Since Majes is an irrigated area, the cultivation of different crops is performed any time of the year. Camacani depends on rain fed, therefore many of the fields were sown after middle October, or at the latest the first week of November.

A remarkable difference is the furrows for sowing. In Majes, sowing took place two days after chemical control of weeds. Quinoa is sown in furrows levelled or beds (Fig. 6 and 7a), with two lines per bed, each line eight to ten centimeters from drip-hose. Beds had a width of 0.75, 0.80 or 0.90 m. In contrast, sowing in Camacani is into the furrows or ridges, with 0.55 m to 0.70 m of distance between furrows (Fig. 5 and 7b). In both places the sowing of quinoa is done by hand. Some differences were that in Majes required to hire more labouring, around five persons per hectare, whereas in Camacani seeding is performed by two persons. This due to the different size of the fields.

The sowing technics were also different. In Majes, people dug small holes approximately every 20 cm with a hook (‘gancho’) and put a little amount of seeds, which were immediately covered (Fig. 7d). The amount of seed utilized was 10 kg/ha. In Camacani, the furrows were done the same day of sowing by an animal-drawn ridge, and the seeds were spread into the furrows. These practices were similar to other Andes areas (Figure 8). Afterwards, the furrows with the seeds were soil-covered with a bunch of tree-branches. Other alternative was to let the sheep into the field to step over the furrows. The average amount of seed utilized was around 30 kg/ha.

Figure 8. Sowing practices in Andes: (a) furrowing by animal-drawn ridge, and (b) spreading of seeds (pictures from Cusco, August 2016).

3.1.4 Post-sowing

The main activities in this period encompassed re-sowing, thin out, weeding, irrigation, and fertilization and pesticide applications. In Majes, the re-sowing of quinoa took place in the first 10 days after sowing (DAS), if there was a fail in germination or emergence. Thinning out was done after 14 DAS, in order to have a quinoa plant density of 30 to 40 plants/m^2. This is also done by labour. The weeding was also performed manually one to three times between the second and eighth weeks (56 DAS) after sowing. Around six persons per hectare were hired to perform the activity, which depends on the rate of weed attack or the size of the field. After 14 DAS, or true leaves stage, farmers started the fertilization plan, quantified in the next section. Pesticides were applied from seven DAS (BBCH scale 1) until 50 DAS (BBCH scale 6) or later. Both fertilization and pesticide applications are described in detail in the following chapters.

There was no re-sowing of quinoa in Camacani, and no thinning out was performed. This is due to the technique in which seeds were sown on the field. The farmers explained that there was no need for re-sowing due to the way and amount of seeds were spread in the furrows, and they rely on their experience. The weeding is done by the owner with collaboration of some relative. Weeds were used to feed animals. Nevertheless, the weeding is highly time consuming because it is performed many times during the quinoa's growth season.

3.1.5 Fertilization

In Majes, mineral fertilizers were the main source applied to quinoa production, whereas farmers of Camacani did not apply any mineral fertilizer and not any manure either in the year of quinoa cultivation. In Camacani the main manure fertilizer is sheep manure, which was applied the year before in the cultivation of potato. Amount of manure N ranged from 74 to 279 kg N/ha. Additionally, during fallow on dry season (April to September), the farm animals, cow and sheep, foraged on the fields. Application of complementary manure fertilizer in cultivation of quinoa takes only place if the farmer can afford the manure.

Table 3. Fertilizers doses recommended for quinoa in Majes, including total minutes of irrigation (Elaborated from 6 local advisors)

	Fertilizer amount‡ in kg/ha										
	N		P[a]		K[b]		Ca[c]		Mg[d]		Irrigation (minutes)
Advisor 1	280	(3)	120	(3)	300	(3)	40	(1)	20	(1)	
Advisor 2	120	(2)	100	(2)	120	(2)	25	(1)	20	(1)	1620
Advisor 3	300	(3)	120	(3)	250	(3)	40	(1)	20	(1)	1170
Advisor 4	300	(3)	120	(3)	300	(3)	40	(1)	20	(1)	1170
Advisor 5	250		120		180						
Advisor 6	250		150		250						

‡ Frequency of split-doses application per week in parenthesis. [a]Amount of phosphorus is expressed in P_2O_5 (phosphorus pentoxide), [b]amount of Potassium is expressed in K_2O (potassium oxide), [c]amount of Ca is expressed in CaO (Calcium oxide) and [d]amount of magnesium is expressed in MgO (Magnesium oxide)

Farmers in Majes applied the fertilizers via the irrigation system (fertigation) in different split doses for fertilizer per week (Table 3). Six different doses of fertilizer suggested by local advisors were registered. These fertilizer formulas were roughly followed by farmers, but they often adapted the fertilizer formula (Appendix G), as it is showed in chapter 3.2. Both the total amount of fertilizer and type of mineral fertilizers are detailed in Table 3. Around 300 kg/ha of nitrogen (N) and potassium (K) fertilizers were recommended to apply as the highest amount, followed by phosphorus (P). In Denmark, only 80-120 kg N/ha is recommended. Lower doses of Ca and Mg were utilized or were not recommended at all by some advisors (Table 3).

The equivalent of fertilizers for N was 33% of ammonium nitrate or 46% of urea, for P was 61% of monoammonium phosphate (some farmers utilized 46% of di-ammonium phosphate), for K was 60% of potassium chloride or 52% of potassium sulfate, for Ca was 26% of calcium nitrate, and for Mg was 16% of magnesium sulfate. The fertilizers were applied via the irrigation system. The suggested amount of fertilizer varied among the different advisors' schemes. The amounts of mineral fertilizers applied by farmers on fields are described in chapter 3.2.

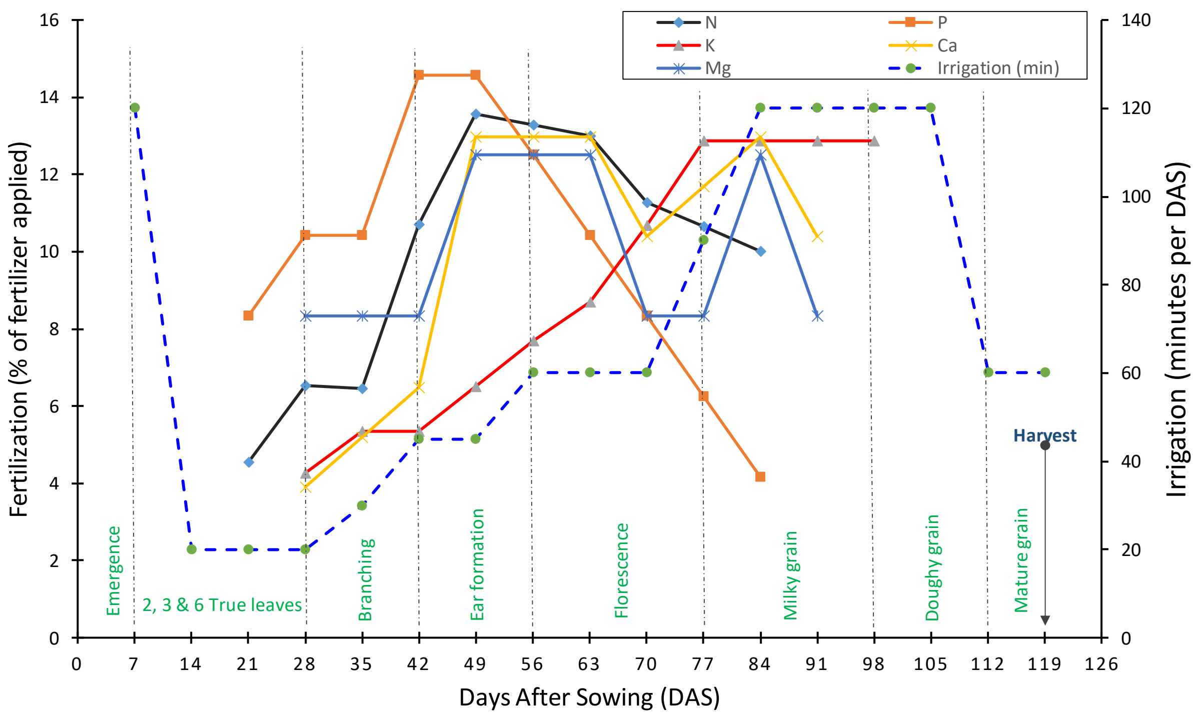

Figure 9. Fertilization and irrigation in relation to phenology stage of quinoa in Majes (Elaborated from local advisor Alfredo Aza)

The fertilizers were applied in doses corresponding to the phenology of quinoa. The scheme of doses that the farmers followed are showed in Figure 9, which represents both the percentage rates of fertilization and the timing for irrigation of the field in relation to the phenology stage of the crop and days after sowing (detailed doses in kg/ha, in Appendix F). The fertilization started right after 14 DAS when plants were at two true leaf stage (BBCH 12). The fertilization plan represents the inputs for a phenological growth up to 98 DAS (BBCH < 8). More percentage of N, P, Ca and Mg fertilizers were applied between the ear formation and florescence stages. On the other hand, more percentage of K is applied during the grain formation (milky grain stage, BBCH 7) until doughy grain (BBCH 8). Figure 10 represents other recommended fertilization plans. One had a slightly change of the fertilizer doses and the percentage applied weekly, on another farm the formula of doses were low (Table 3, Advisor 2) and the application of some mineral fertilizers were not continuous.

3.1.6 Irrigation

The water supply in Majes was controlled by time of irrigation. Irrigation time recommended by advisors encompassed a total of 1170 minutes (Fig. 9) to 1630 minutes (Fig. 10) in 17 weeks of growth or 120 DAS (Table 3), which can be extended. Irrigation was higher in the beginning to be reduced drastically in the 14 DAS, but after 35 DAS (BBCH>3) the time of irrigation increased steadily. The irrigation was reduced after 105 DAS (BBCH>8), when the grain started to mature. After 120 DAS, the grain is mature and might be harvested, so no irrigation was needed, but it could be still applied if harvesting was delayed. In compliance with the total minutes of irrigation between 500 mm to 600 mm of water per hectare were supplied along the growth of quinoa. This was calculated with a water flow of 6 L/s, which is supplied to each farm by the MIP (Alfredo Aza and Esteban Falconi, local advisors, pers. comm.).

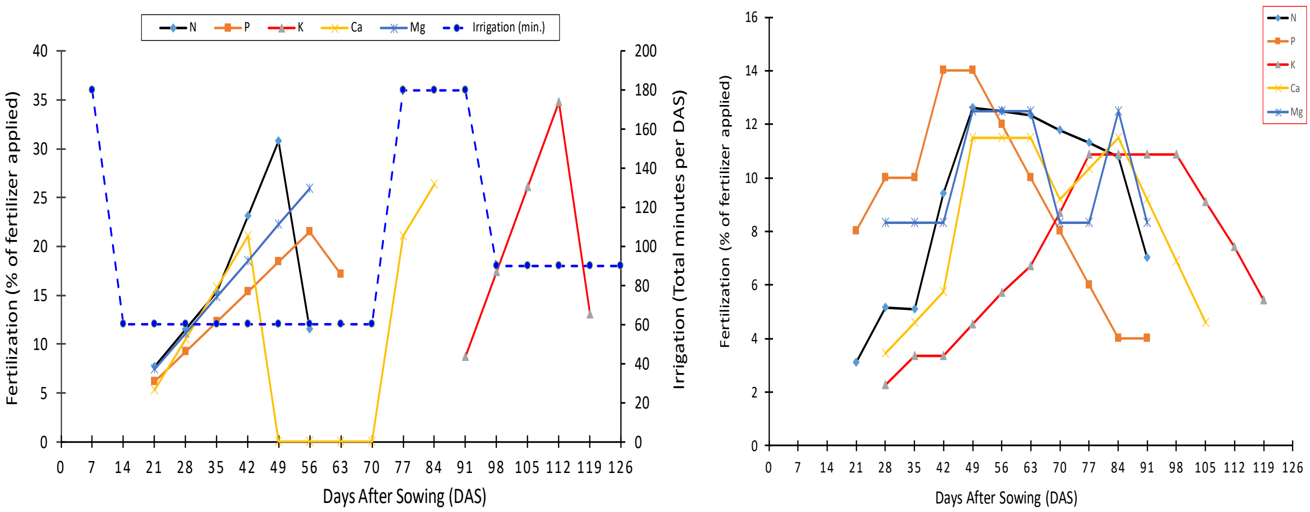

Figure 10. Different fertilization schemes in Majes (Elaborated from local advisors; left: Alfredo Ccasa, right: Alex C.)

3.1.7 Pests in general

Insects

The farmers in Majes were most concerned about the hemipteran ‘chinch bugs’ (*Nysius* sp, Lygaeidae; *Dagbertus* spp, Miridae; and *Liorhyssus hyalinus*, Rhopalidae; Figure 11). These were known because they caused severe damage to the crop in year 2013-2015. Farmers were almost ‘scared’ talking about the presence of chinch bugs. This is because last months of 2013, all 2014 and first semester of 2015, this pest caused severe damages to quinoa crops. In fact, some of farmers admitted the overuse of pesticides in those years to control this pest, even with applications few weeks before harvest. Other pests that were mentioned by farmers were cutworms ‘cogolleros’, leaf-miners ‘minadores’ and leaf-eaters ‘cortadores’. This might correspond to larvae of *Delia platura* and caterpillars of different Lepidopteran species (not registered on field in this study). In Camacani the main concern about pest was related to “qona-qona”, a caterpillar of the genus *Eurysacca* (Lepidoptera: Gelechiidae), which feeds on the grain. In fact, “qona-qona” destroyed the production in one field (pers. obs.) because the harvest of it was much delayed.

Birds

In both areas, birds were mentioned as a constant problem. They often affected the quinoa crops in two ways. First, by eating the grain and dropping additional grains from the panicle. Another way was plant breaks and lodges when a high number of birds perched on quinoa panicles. In Majes the variety of quinoa that was sown is Salcedo, which has a big and sweet grain, with low content of saponins. Therefore, probably more bird-loss of quinoa is associated to this variety as was observed in experimental trials (Fig. 11). In Camacani there were different varieties which include some bitter quinoas.

The small size of fields in Camacani, allows control for birds more easily. It is done by scaring them with sounds, or throwing stones or hanging cassette tapes with plastic bags around the field. In Majes the control of birds seems to be more sophisticated with use of ‘air cannons’ or with similar methods to those in Camacani. However, the size of the field made it difficult to control birds’ attack. The losses associated to birds were difficult to quantify.

Weed

Some of the plants that affect the cultivation of quinoa are listed. In Majes, the presence of yellow sweet clover (*Melilotus officinalis*, Fig. 12a) and *Malva sp* (Mallow family) were more prone invading the fields. Other weeds such as purslane (*Portulaca oleracea*), shepherd’s purse (*Capsella bursapastoris*), field mustard (*Brassicum campestris*), Species of the Compositae family and species of potato family, were lightly recorded in Majes. After sowing, manual control of weeds was necessary.

In Camacani the main weed problem was burr marigold or tickseeds (*Bidens* spp) of the compositae family, (local name: 'amor seco' or 'chiriro', Fig. 12b), which competes with quinoa plants. Beside this its seeds sticks to the clothes, annoying the farmers. The presence/control of weeds is critical during the emergence of quinoa. Other plants affecting the quinoa plants were crops from the previous year, as barley, or from neighbor fields that invaded quinoa fields.

Figure 11. Some pests of quinoa, (a) *Liorhyssus hyalinus*, (b) nymphs of chinch bugs, (c) birds on quinoa, and (d) field with plants laying down after bird presence (a, b and c from Majes; d from Camacani)

Diseases

The downy mildew of quinoa (*Peronospora variabilis*) and *Fusarium* were mentioned as the main diseases that attack quinoa plants. *Fusarium* was referred to attack the plant in the first stages of plant development, affecting seriously the roots. Downy mildew attack quinoa in different stages. When the attack of *Peronospora variabilis* occurred in early stages the risk of loss of production was high. The attack on quinoa was more frequent when there was the presence of fog, or 'camanchaca' as it is locally named.

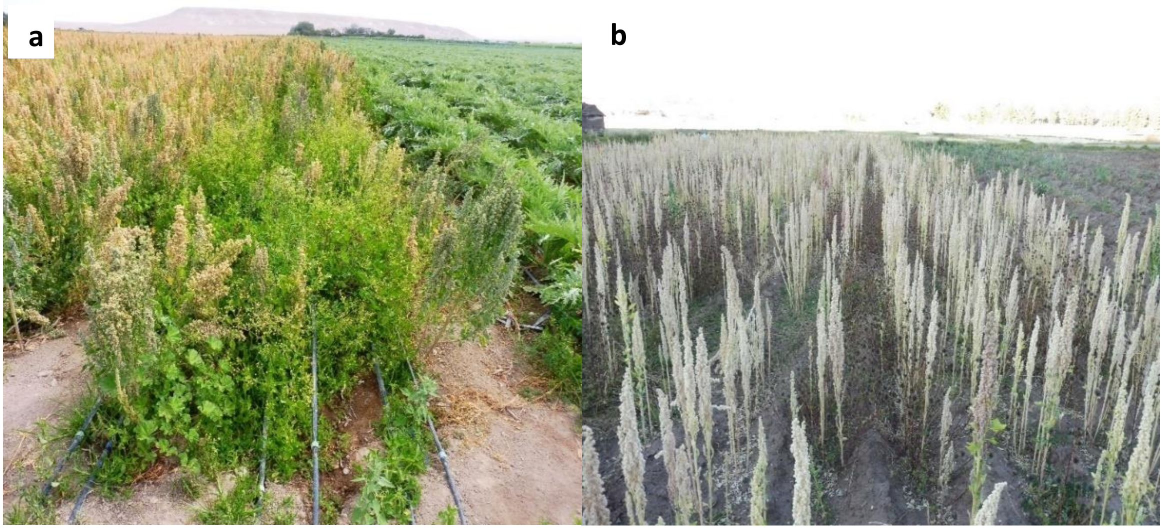

Figure 12. Presence of weed on field: (a) sweet clover in Majes, and (b) tickseeds in Camacani

Farmers in Camacani did not notice the attack of downy mildew during this year of production. They remarked that 2016 was a dry year, therefore the presence of quinoa downy mildew affecting the crop was negligible. To spread and become infectious, this pathogen requires both mild and humid conditions (Danielsen and Ames 2004). At the same time, farmers insisted that the way they practice agriculture, i.e. crop rotation and change of quinoa varieties or seeds, enhance the resistance to attacks from downy mildew.

3.1.8 Pesticides

In Majes, chemical control was performed to control the different pests and diseases in the production of quinoa. In the beginning, a couple of days before sowing to control weeds, and up to 45-50 DAS (BBCH<6) being the last day for application to control insects and diseases (detailed schedule in Appendix H). At the same time, there were farmers that applied chemicals after 50 DAS. Twenty-one different compounds were listed from a phytosanitary scheme of quinoa (Table 4), from these 14 were related to control of insects (7), diseases (6), and weeds (1). The other one were used as adjuvants and surfactants. The doses of application were mixed in a barrel (or container) of 200 L of water. For one hectare, two barrels were needed (Fig. 13).

The control of weeds by chemical control is performed before sowing of quinoa, but not after sowing since there is no selective herbicide of quinoa. The herbicide utilized by farmers against weeds was Paraquat. To control diseases, products with Mancozeb as active ingredient were most recommended. Pesticides are applied by fumigation or direct contact (Fig. 13), as well as via irrigation system. The first application after sowing was during first days (BBCH 0) via irrigation as a preventive measure to prevent attack of *Fusarium*.

Figure 13. Methods to prepare the recommended pesticide doses (left) and how field is fumigated by a sprayer equipment (right)

The control of insects was performed at three times. First to prevent the attack to the seedlings from cutworms that attack the germinating quinoa seeds, the main concern is with seedcorn maggot or bean seed fly (*Delia platura*, Diptera). The other control is after the emergence of the plant, when it is susceptible to cutworms, leaf-miners (larvae of *Liriomyza* spp, Diptera), and leaf-eaters (larvae and caterpillars of different Lepidoptera species). Finally, control against nymphs and adults of chinch bugs (*Nysius* sp, *Dagbertus* spp and *Liorhyssus hyalinus*) took place especially during the reproductive stage of quinoa (BBCH>6). However, in some fields the presence of chinch bugs was much lower or no attack at all than previous years. The most ingredient active recommended contained Cypermethrin.

In Camacani, chemical control is performed as a last alternative to save the grain against larvae or caterpillars of *Eurysacca* spp ('qona-qona'). Farmers that made chemical control utilized pesticides with Cypermethrin, Methamidophos and Lambda-cyhalothrin as active ingredient. The pesticides were applied mainly in the stage of doughy grain (BBCH 8). The pesticide doses were measure in spoons (8 ml – 10 ml) dissolved in 10 L to 15 L and it was applied using a sprayer equipment as it was performed for farmers in Majes (Fig. 13).

Table 4. Different chemical compounds for quinoa production (Majes)

Active ingredient	Target	Unit	Doses/200 L	Total amount/ha
Phosphoric acid	Adjuvant (pH regulation)	L	0.32	0.70
Organo-silicon surfactant	Surfactant	L	0.62	1.36
Deltamethrin	Chinch bug	L	0.25	0.63
Matrine	Chinch bug	L	0.75	1.88
Spinetoram	Chinch bug	L	0.80	2.00
Alphacypermethrin	cutworms, leaf-miner & leaf-eaters	L	0.43	0.86
Emamectin benzoate	cutworms, leaf-miner & leaf-eaters	kg	0.20	0.40
Methomyl	cutworms, leaf-miner & leaf-eaters	kg	0.20	0.40
Thiodicarb	Delia platura	L	0.13	0.13
Copper sulphate	Downy mildew	L	1.00	2.50
Cymoxanil+Mancozeb	Downy mildew	kg	1.00	2.00
Cymoxanil+Propineb	Downy mildew	kg	1.00	2.50
Dimethomorph+Mancozeb	Downy mildew	kg	1.00	2.00
Metalaxyl+Mancozeb	Downy mildew	kg	1.00	2.00
Liquid fertilizer (foli-zyme)	Foliar fertilizer	L	1.00	2.00
Benomyl	Fusarium	kg	0.40	0.40
amino acids	growth regulator	L	0.50	1.00
Auxin, cytokinin, gibberellin	growth regulator	L	0.40	0.80
Potassium phosphite	growth regulator	L	1.50	3.25
Cytokinin, auxin, gibberellin	improve grain filling	L	0.13	0.31
Paraquat	weed	L	1.50	3.00
	Total	kg	4.80	9.70
		L	9.32	20.41

3.1.9 Harvest

In Majes, optimum time for harvesting quinoa was around 120 DAS, BBCH stage 89. It could be extended for other reasons than agronomical, like no people available for labor, lack of money to pay the labor or harvest of other crops. In Camacani the development of the crop took around 150-160 DAS and the harvest was done between the months of March and May. In both areas, harvesting quinoa with a sickle was the only way registered in this study. Plants were cut 10 to 20 cm above the soil. The differences between the two areas were that in Camacani the cutting was performed more than one time because not all the plants were grain mature at the same time; whereas in Majes all the plants were cut at once (Fig. 14).

Another difference was observed on fields (Fig. 14); harvest in Camacani was performed when drought season started, so the plants initiated the senescence stage and loss the leaves. Whereas in the irrigated and fertilized fields of Majes, the plants were still ‘green’ and did not loss much of its leaves.

Figure 14. Harvesting quinoa by cutting plants with a sickle in (a) Camacani and (b) Majes

3.1.10 Post-harvest

The activities to obtain the grain included drying of plants, threshing, storage and trade, which differ between the two study sites.

Drying

Drying was performed in the same way in the study sites, cut plants were left on the field, with some variants. In Majes plants were arranged in bunches lying completely on the soil after cutting (Fig. 14b). The time of drying ranged from seven to 10 days. In Camacani, the plants were arranged in stacks immediately after cutting. This consisted of different methods with panicles leaning upward. For example, one method was to stack the plants forming an arc, in other places stacks were grouped together, and others had stacks slightly inclined leaning against a table (Fig 15). Time of drying could be up to 20 days. Stacks were not in direct contact with the soil, in that way avoid humidity of soil or damage by unexpected rain. These ways of drying implied losses of grain, affecting the final yield.

Threshing

The threshing methods were mechanical and manual for Majes and Camacani, respectively (Fig. 16). In Majes, the machinery consisted of a rice thresher with a container capacity of around 850 kg. The thresher left the grain clean, ready to be packed and traded to intermediaries. Whereas in Camacani, threshing consisted of beating the panicles with a stick (Fig. 16). After that the grain had to be sifted and winnowed traditionally many times. The farmer separated the grain from the chaff in presence of moderate winds before storing the grain. This activity was performed for many days, mainly in the afternoon, after other farm daily activities were accomplished.

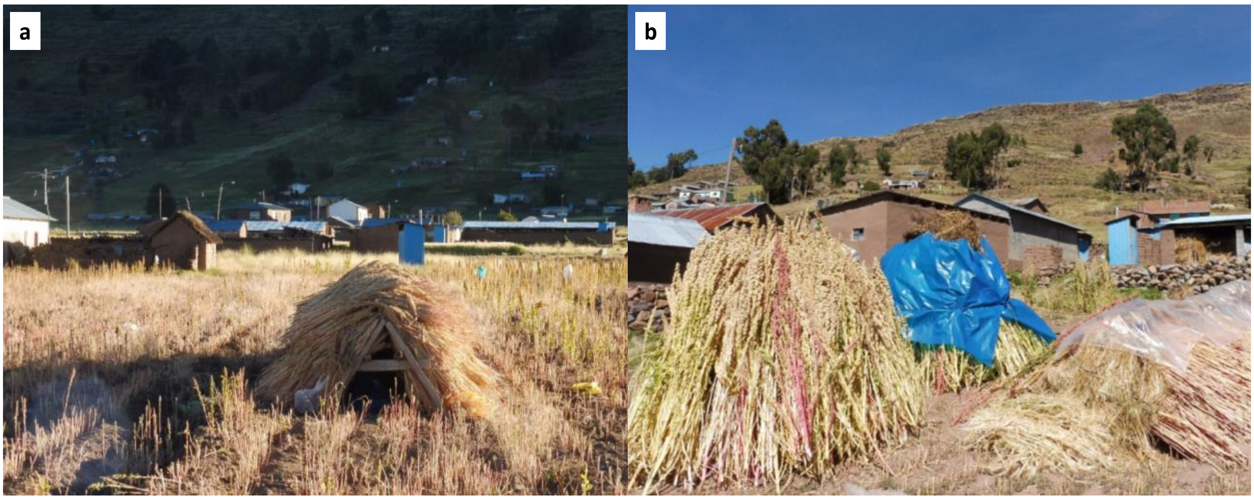

Figure 15. Different dry methods of quinoa in Camacani by stalking the cut plants

Figure 16. Mechanical and manual threshing in Majes (left) and Camacani (right)

Storage and trade

In Camacani, the grain was stored up to one year and low quantities were sold to intermediaries because the grain was used mainly for home consumption. Another reason for not trading or selling the grain was the current lower prices of quinoa. Farmers informed that the producer price were around 0.57 – 0.87 USD $/kg (equivalent to S/. 20 – S/. 30 PEN/arroba or 11.5 kg). Most of the grain that was sold was commercialized in local markets.

In Majes, all the production of quinoa was for commercialization. It was sold by farmers the same day after threshing or one to two days later to intermediaries. The intermediaries sell the collected grain production to quinoa export companies. The producers sold the quinoa in prices that ranged from 1.09 to 1.23 USD $/kg, and the intermediaries received around 1.5 USD $/kg from companies.

3.1.11 Residuals

Plant residuals were used in different ways in the two sites. Not all the plant residuals were incorporated into the soil. In Camacani the straw is mainly burned on the field or used as fuel. Some farmers used the chaff (or "*jip'i*") as livestock feed, which was mixed with barley silage. In Majes, many of the farmers incorporated all the residues on the field to prepare the soil for the next crop. Other farmers burned the straw. Reasons to burn or not the straw depended on the next crop to be cultivated, for example it was not burned when the next crop was lucerne.

3.1.12 Description of Cost Production

Table 5 shows the cost analysis for quinoa production in Majes. Gross profit or revenue per ha was USD 3783 with a grain farm price of US$1.1/kg, assuming average values of yield 3317 kg/ha, 194 kg N/ha, 69 kg P/ha, 143 kg K/ha, 18 kg P/ha and 11 kg Mg/ha (Table 5). A management of two sprays of herbicide, three sprays against pest, three sprays against diseases were considered into calculations. 42 persons of labor for drip installation, seeding, thin out, and two weeding were considered, including farmer's own labor for application of fertilizers and pesticides.

The contribution margin per hectare is profitable (USD 2598). The gross margin after paid machinery and labor reduce the revenue. A cost that affects the profit is the land rent. So, the gross margin will be relevant for those farmers that possess own machinery and cultivate their own land. Therefore, as a means to increase the yield and get high profit the farmers applied high doses of N to cover its expenses and get more revenues. A detailed look at into the different items in Appendix I (Cost of production), showed that the cost of labor represents around 20 % and fertilizer 23 % of gross margin after machinery. The machinery represented around 10 %. Together labor, fertilizers and pesticides amounted more than 50% of the cost of production.

Therefore, the farm management in the amount of fertilizers and pesticides applied, number and times of labor performed and land tenure, beside the farm price of the grain, had an impact in the revenues for the farmer. This is the first report of conventional quinoa production at commercial level for Peru, it is delivered just for information and it is not further discussed.

Table 5. Cost analysis of quinoa production for average yield and fertilizers in Majes

Profit	amount/ha	Unit	price unit USD	
Grain sold	3317	kg	1.1	3783
Straw, Chaff, or Saponin	332	kg	0.0	0
Gross output				**3783**
Unit costs				
Seed	10	kg	9.4	94
N	194	kg	1.1	212
P	69	kg	2.2	148
K	143	kg	1.0	146
Ca	18	kg	0.5	10
Mg	11	kg	2.3	26
weeds				88
disease				147
pests				64
growth regulation				227
adjuvant				24
Total unit cost	-1			**-1185**
contribution margin per ha				**2598**
machinery & labor costs				
Ploughing		mach		109
harrowing+tiller		mach		88
furrowing		mach		35
irrigation installation		labor		39
seeding		labor		88
weeding		labor		256
thinning out		labor		116
spraying		labor		60
harvesting		labor		141
thresher		mach		125
drip-hose		pckg		656
transport agrochemicals				19
water				39
Total machinery & labor	-1			**-1770**
Gross margin after machine and labor costs				829
Land rent	-1			**-781**
Gross margin after land rent				47

3.2 Yield components, fertilizers and Nitrogen utilization

3.2.1 Yield

Higher yield average components were recorded in Majes compared to Camacani. From hand-cuts the gross yield is measured to 3317 kg grain-DM/ha in Majes (Table 6) and 1848 kg DM/ha in Camacani (Table 7) or even less (1764 kg DM/ha, without data of experimental trials). The sold yield by farmers will be expected to be lower due to losses in field, storage and cleaning. Total dry matter was also higher in Majes than Camacani. The harvest index (HI) were 43 % in Majes and 36 % in Camacani. Further comparisons are related to the average data of Camacani without including data from the variety field trials. This was done because experimental conditions were different to data from farmers in two aspects. High amount of manure fertilizer was utilized in experimental trials, and there has not been crop rotation at all. With extreme high fertilizer input in the trials, there is a risk of a bias influence on the average calculations of Camacani.

The lowest field yields registered were 542 kg DM/ha and 1963 kg DM/ha for Camacani and Majes, respectively. The correspondent highest amounts were 4466 kg/ha and 6010 kg/ha (Table 6, 7). High application of N fertilizer (349 kg N/ha) was registered on the experimental trials of Camacani, though the yield was lower than both the second farm with high rate of N fertilizer (278 kg N/ha) and the higher average yield (Table 7).

In general, there were differences between the two sites of study, but variation of data within samples were also relevant. More variation within data samples was registered in Camacani than Majes. For example, Field01 in Camacani had the highest CV of 116 %, whereas Field07 in Majes had a variation of 52%. The average variation of yield and N components were lower in Majes compared to Camacani (Table 6 and 7). It means that variation among farms were lower in Majes than variation among farms in Camacani.

3.2.2 Fertilizers

Mineral fertilizers are the main source of nutrients in Majes. Table 6 shows the average amount of N fertilizer applied by farmers in Majes was 194 kg N/ha. The highest amount of N fertilizer applied was 287 kg N/ha, the lowest amount was 103 kg N/ha. Not all the farmers in Majes applied manure fertilizer. There was registered only two farmers out of 20 where manure was applied. On Field11 the Guinean pig manure, with a N content of 0.06 % (Tapia and Fries 2007), provided and amount of 1.1 kg manure N/ha. Field20 applied a total of 260 kg N/ha, 160 kg N/ha were obtained from 8 ton/ha of cattle manure with a 2 % of N content (data provided by Esteban Falconi, research advisor).

Potassium was the second mineral fertilizer utilized, with 143 kg K/ha. One field did not apply K at all. The farmer manifested that was due to lack of funds, he could not afford it. The highest amount of K fertilizer was register in Field10, even higher than N fertilizer. Phosphorus was the other mineral fertilizer most applied with 69 kg P/ha. Calcium and Mg fertilizers were not applied by all the farmers. The amount of Calcium was in average 31 kg Ca/ha and Magnesium was 8 kg Mg/ha. At the same time, the amounts applied by farmers were different from the amounts recommended by local advisors. Information on amount of fertilizer applied, was provided by farmers through the surveys.

The values of nitrogen utilized by quinoa are lower than Majes. These are assumed values since no manure was applied in quinoa. N values were calculated through a theoretical value of 1.95 % of N content in sheep manure (Tapia and Fries 2007). Moreover, amounts of N-manure applied were estimated values because farmers did not measure the weight of sheep manure applied. They used reference values of number of sacks, equivalent to quintal, which is a pound-based unit of weight equivalent to 46 kg[2]. So, this values corresponds to observed values from the year before rather than measured values on year of growth of quinoa.

3.2.3 Nitrogen and Crude protein

In Majes, the grain N-uptake was 77 kg N/ha, with a minimum of 44 kg N/ha and a maximum of 144 kg N/ha. The grain NUE showed an average efficiency of 43 % with a rate of 194 kg N/ha, and the agronomical-NUE showed that in average 19 kg of grain was produce for unit of kg N fertilizer. The crude protein in grain ranged from 12 % to 17 %, with an average of 14 % (Table 6).

In Camacani the values of crude protein ranged from 11 % to 16 %, with an average of 13.5 % (Table 7). The grain N-uptake was 39 kg N/ha, with a minimum of 11 kg N-uptake/ha and a maximum of 111 kg N-uptake. The values of NUE in Camacani, showed in Table 7, where calculated considering many assumptions because quinoa fields were unfertilized. It has been assumed that the former crop, potato, had a N leftover of 40 kg N/ha. The nitrogen accounted for

[2] Another unit weight used in the area is arroba, 11.5 kg, equivalent to ¼ of a quintal.

quinoa is assumed to be the soil-N, equivalent to N fertilizer applied in potato minus N uptake. The N-uptake was calculated under the assumption of a yield of 12.5 kg fresh matter/ha, 9.2 % of crude protein; and 22 % of dry matter. This is a simplest calculation assuming that no leaching occurred, since fallow occurred during dry season. Therefore, with too many assumptions, comparison of N components was left out. This will be discussed further below.

Table 6. Summary statistics of average and coefficient of variation (CV) on total dry matter (DM), grain yield (grain DM), N-uptake, nitrogen use efficiency (NUE) and agronomical NUE (agroNUE), harvest index (HI %) and crude protein in grain DM (%); and amounts of fertilizers, farm area and furrow width; quinoa var. Salcedo; in Majes.

Field	Area (ha)	Furrow width (m)	Grain DM		TOTAL DM		Grain N-uptake		NUE		agroNUE		HI		Crude protein of G DM (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)
			kg/ha	CV%	kg/ha	CV%	kg/ha	CV%	%	CV%	kg/kg N	CV%	%	CV%						
Field01	1.08	0.90	3374	32	7749	35	73	32	26	32	12	32	44	8	14	278	84	192	30	7
Field02	2.00	0.90	2700	10	6123	12	60	10	22	10	10	10	44	6	14	272	122	180		
Field03	0.83	0.75	2607	31	6385	32	67	31	NA	NA	NA	NA	41	3	17	NA	NA	NA	NA	NA
Field04	5.00	0.75	3505	32	7918	25	90	32	48	32	19	32	44	13	16	188	76	94	13	8
Field05	1.33	0.80	3102	17	7553	27	80	17	35	17	14	17	42	11	16	226	69	273	24	9
Field06	1.67	0.75	2108	28	4829	28	54	28	37	28	14	28	44	9	16	148	94	187	16	10
Field07	0.75	0.90	2427	52	5385	46	52	52	42	52	20	52	41	25	14	124	102	121	26	21
Field08	0.83	0.75	3831	25	10110	22	104	25	39	25	14	25	38	6	17	266	73	187	23	10
Field09	1.33	0.90	1963	35	4076	37	44	35	38	35	17	35	49	6	14	116	23		5	
Field10	5.00	0.75	6010	12	14292	13	144	12	50	12	21	12	42	6	15	287	58	296	36	24
Field11	5.00	0.80	4632	18	10674	16	108	18	94	18	40	18	43	5	15	115[a]	46	104		
Field12	1.00	0.80	3485	17	7790	11	76	17	NA	NA	NA	NA	45	9	14	NA	NA	NA	NA	NA
Field13	5.00	0.75	4292	22	10224	25	120	22	58	22	21	22	42	9	17	208	49	125		
Field14	1.17	0.80	3231	43	7862	43	61	43	60	43	32	43	41	3	12	103	39	178	17	10
Field15	1.50	0.80	2288	49	5695	42	49	49	46	49	22	49	40	15	13	106	51	87	13	8
Field16	5.00	0.90	4354	13	9808	14	92	13	37	13	18	13	45	8	12	248	46	52	13	6
Field17	2.14	0.80	3681	40	8947	44	78	40	44	40	21	40	42	16	13	176	54	61	9	9
Field18	1.00	0.80	3300	24	7255	25	71	24	NA	NA	NA	NA	46	4	14	NA	NA	NA	NA	NA
Field19	1.67	0.75	2477	36	5079	35	54	36	31	36	14	36	49	1	14	173	69	39	12	5
Field20	0.49	0.80	2983	17	9559	27	67	17	26	17	11	17	32	12	15	260[b]	120	249		
Average			3317	28	7866	28	77	28	43	28	19	28	43	9	14	194	69	152	18	11

[a]Field11 includes 1.1 kg N/ha from Guinean pig manure. [b]Field20 includes 160 kg N/ha from cattle manure

NA = not available information from farmers

Table 7. Summary statistic of average and coefficient of variation (CV in %) for fields and trials, on total dry matter (DM), grain yield (grain DM), grain N-uptake, nitrogen use efficiency (NUE, values of 2nd year crop), harvest index (HI%) and crude protein in grain DM. Values of farm area harvested, furrow distance; and amounts of N fertilizer for first (potato) and second (quinoa) year crop in Camacani.

Field	**Variety**	**Area (ha)**	**Furrow distance (m)**	**Grain DM**		**TOTAL DM**		**Grain N-uptake**		**Grain NUE**		**agroNUE**		**HI**		**crude protein of DM (%)**	**N 1st year crop (potato)**	**Soil-N[a] 2nd year crop (quinoa)**
				kg/ha	**CV**	**kg/ha**	**CV**	**kg/ha**	**CV**	**%**	**CV**	**kg/kg**	**CV**	**%**	**CV**		**N[b] (kg/ha)**	**N[b] (kg/ha)**
Field01	Blanca Juli	0.04	0.60	1807	116	6878	74	34	116	40	116	22	116	20	57	12	124	83
Field02	Blanca Juli	0.06	0.60	1507	38	3519	41	29	38	40	38	21	38	43	7	12	113	73
Field03	Blanca Juli	0.05	0.60	4466	21	11057	18	111	21	46	21	19	21	40	3	16	279	239
Field04	Blanca Juli	0.07	0.55	1848	35	5113	28	42	35	121	35	54	35	36	8	14	74	34
Field05	Blanca Juli	0.05	0.55	542	43	1931	43	11	43	31	43	15	43	28	17	13	76	36
Field06	Blanca Juli	0.07	0.55	2233	27	6047	17	49	27	98	27	45	27	36	12	14	90	50
Field07	Blanca Juli	0.04	0.50	2130	46	7311	23	48	46	39	46	17	46	28	31	14	165	125
Field08	Blanca Juli	0.24	0.55	905	44	4198	31	19	44	37	44	18	44	21	25	13	92	52
Field09	Salcedo	1.15	0.70	1041	25	2286	23	24	25	15	25	6	25	46	10	15	206	166
Field10	Blanca Juli	0.60	0.70	1164	59	2464	46	23	59	14	59	7	59	43	36	12	206	166
	Average			1764	45	5080	34	39	45	48	45	22	45	34	21	13	142	102
		Area (ha)	**Furrow distance (m)**	**Grain DM**		**TOTAL DM**		**Grain N-uptake**		**Grain NUE**		**agroNUE**		**HI**		**crude protein of DM (%)**	**N 1st year crop (quinoa)**	**N 2nd year crop (quinoa)**
				kg/ha	**CV**	**kg/ha**	**CV**	**kg/ha**	**CV**	**%**	**CV**	**kg/kg**	**CV**	**%**	**CV**		**N[b] (kg/ha)**	**N[b] (kg/ha)**
Trial01	Blanca Juli	0.02	0.60	2611	26	5960	24	53	26	15	26	7	26	44	7	13	350	350
Trial02	Kancolla	0.02	0.60	2138	5	4984	8	50	5	14	5	6	5	43	6	15	350	350
Trial03	Salcedo	0.02	0.60	1797	33	4933	23	42	33	12	33	5	33	36	12	15	350	350
Trial04	Roja Pasankalla	0.02	0.60	1844	14	5130	18	33	14	9	14	5	14	36	13	11	350	350
Trial05	Negra Collana	0.02	0.60	1682	30	3958	26	41	30	12	30	5	30	42	15	15	350	350
	Average			2015	22	4993	20	44	22	12	22	6	22	40	11	14	350	350
	Total Average			1848	37	5051	30	41	37	36	37	17	37	36	17	13	212	185

[a]N leftover in soil with assumption of 40 kg N uptake by potato, explanation in the text. [b]Calculated with theoretical value of 1.95% N content for sheep manure (Tapia and Fries 2007).

4. DISCUSSION

This chapter will discuss the farming practices and yield component in relation to fertilizer applications and use of pesticides from the point of view of implications in sustainable production. It will focus mainly in Majes, since it is a sort of a new problem and little published literature is available about this area. On the other hand, production of quinoa in the Andes, as it is practiced in Camacani, has been described often over time (Orellano and Tillmann 1984, Halloy et al. 2005, Tapia and Fries 2007, FAO 2011, Garcia et al. 2015) as its implications and its sustainability has been discussed (Halloy et al. 2005, Jacobsen 2011, Jacobsen 2012, Winkel et al. 2012, Murphy and Matanguihan 2015).

The data obtained from surveys has the limitation that it was obtained in specific moments of the quinoa cultivation. The field study from March to May encompassed the harvest season for Camacani and sowing season of quinoa in Majes. The period from August to September encompassed the harvest season in Majes, with a short-days visit to Camacani for sowing season. It implied that some detailed characteristics of production were not registered, as for example amount of fertilizers applied and irrigation management per week in Majes. However, the information provided by different farmers allowed to get a picture of the quinoa production in the area. A continuous visit throughout the whole growth season with biweekly interviews would have been optimum as recommended by research in farm systems (Halberg et al. 1995, Kristensen and Hermansen 2000).

4.1 Farming practices

The differences in some farming practices in both areas, Majes and Camacani, are not surprising. On the one hand, the production of quinoa in Majes can be characterized as conventional agriculture, because of its large-scale production, intensive use of mineral fertilizers and pesticides, and other farm inputs like high use of energy (Curtis and Riley 1990). On the other hand, the traditional cultivation of quinoa in Camacani lies in the concept of sustainable agriculture, with no use of mineral fertilizers, no use or low application of pesticides, cultivation at small-scale, reduced use of energy, conservation of natural resources like soil through less tillage, incorporation of organic matter, fallow, among others (Gliessman 2007, Altieri and Toledo 2011).

Labor

Although the production of quinoa in Majes is conventional, some cultural practices are still performed in a similar way to those in the Andes. It will be necessary to improve the management to maintain relevant yields. In both areas, same activities are carried out by manual labor, such as sowing, weeding, thinning out, and cutting of plants.

The sowing method most often used is the manual method. In Majes, there is no specialized machinery to sow the seeds, although there have been attempts to use semi-mechanical sower in Majes (Fig. 17). Equipment was develop by entrepreneurs, but according to the experience of some farmers it did not perform well on spreading the seeds or it did not work well for fields with soils where the presence of gravel or pebbles were predominant (Medina Hoyos 2008). There is an opportunity to develop or improve sowing machinery. Thus, the seeding by hand is still required. Sowing the appropriate number of seeds will depend on the skills of the persons hired. Therefore, the thinning out is necessary to have an appropriate number of 30 to 40 plants per meter. However, there was a farmer that did not care about the thinning out, because in his experience it did not affect the grain yield. This can be supported by studies in Brazil where it has been demonstrated that the number of quinoa plants per hectare has no relation to the yield (Spehar and Santos 2005, Spehar and da Silva Rocha 2009). The same relationship has been observed in this study. This is explained by the agronomic performance of quinoa, which is to develop more branches, therefore more ear formations, when plant densities are low.

Figure 17. Semi-mechanical sowing equipment for quinoa (image from https://www.youtube.com/watch?v=eOzhqN3DJ8I)

The weed control after sowing is manual because there is no selective herbicide for quinoa. In both areas, farmers rely on manual weed control with no other alternatives. In Majes, weed control is one of the main costs of production. The number of control often depends on the skills of workers and this signifies an expense for the farmer. A good control will only need to be done once, on the contrary two to three times will be required. Additionally, an extra weed control has budgetary implications for the farmer, who may not be able to afford it. The farmers do not use mechanical control to avoid damage on the drip irrigation system, which might be a limitation to consider if machinery needs to be designed. However, there are mechanical methods to control weeds by harrowing and hoeing in other areas where quinoa has been introduced with promising results (Jacobsen and Christiansen 2016). Under all circumstances, this dependency on labor means an expense in the conventional production of quinoa in Majes.

On the contrary, in Camacani and other Andean areas, the weed control does not necessarily mean an expense for the farmer. Weeds are used to feed farm animals, therefore the control, though time consuming, is a continuous activity, that is done by the farmer. Otherwise, weeds can affect negatively the yield. But weed control depends on the availability of people to perform the activity. Anyway, manual control of weeds is a characteristic of such small-scale agroecosystems where weeds can be utilized into the farm system (Gliessman 2007).

The harvesting performed by cutting plants with a sickle is also a constraint to the production of quinoa. The reason for this is the traditional practice to allow the drying of the panicle and ripening of grains before threshing to get a good grain quality. In this way, it will be easy to thresh the grain. Nevertheless, such method requires that it is cut at the right time, because when plants exceed maturity grains drop from the panicle. In Majes, a way to reduce this issue is irrigating the crop until one day before cutting, but it implies on the other hand a waste of water. In Camacani, the way how farmers solved the asynchrony on ripening of grain is by performing cutting of plants two to three times. This method avoids the harvest of unripe seeds.

The use of labor in these areas then is justified because there is not machinery adapted to perform such activities, at least for a crop under drip irrigation in the arid area of Majes. Claims to initiatives to improve the cultural practices and technologies for cultivation of the crop are not new, but they have to deal with the fact that more efforts are focused in the breeding of new varieties (Galluzzi et al. 2015). Other constraint would be that Andean communities maintain their traditional agricultural practices, because it is a challenge to combine their practices with a conventional agricultural model, due to adverse factors such as farm size, climate, economy and so on. Anyway, the agro-ecological practices of Andean farmers results in being more appropriate in an environment subject to major abiotic constraints like water and harsh climate (Chevarría Lazo et al. 2015).

Summarizing, the systems of production are different in the regions of Majes and Camacani, one conventional and the other traditional. The traditional cultivation of Camacani uses intensive manual labor from sowing to harvest, which is similar to and a characteristic of the Altiplano and Inter-Andean valleys of Peru (Gómez-Pando et al. 2015). What is surprising is that the cultivation system in Majes is also characterized by the intensive use of manual labor. Agricultural activities like sowing, thinning out, weeding after sowing, harvesting are carried out manually in both areas. This is because of the lack of machinery adapted to carry out these activities in the conventional system of Majes, and because Andean farmers rely on their traditional agricultural practices that are more appropriate to such agroecosystems. However, the use of labor remains as an agricultural and economical constraint that affects the production of quinoa.

Pests

Neither *Nysius spp, Dagbertus spp* nor *Liorhyssus hyalinus* were mentioned in recent FAO reports of quinoa (Gandarillas et al. 2015, Gómez-Pando et al. 2015), which is not a surprise since much information is focused on the Andean region, although the presence of the pests in quinoa has been recorded in different coastal regions of Peru (Callohuari et al. 2014). Nevertheless, the presence of chinch bugs has also been reported in other areas at low latitudes. The insect pest has been found on quinoa and other crops in Argentina (Dughetti 2015) and in soybean crops in the warm areas of Brazil (Dalazen 2014). Even these polyphagous pests were reported attacking other crops in different regions, it was remarkably the overwhelming amount of individuals feeding on quinoa (Dughetti 2015). An understanding of the pest biology might help to assess alternative pest controls or an integrated pest management rather than chemical control.

Downy mildew (*Peronospora variabilis*) is still the main disease that affect quinoa production in Majes. It remains as a problem due to the following reasons observed during field work and mentioned by farmers. There was a commercialization of non-certified seeds, which could explain the presence of the pathogen in the area of Majes and along the fields as it was observed in other regions where quinoa has been introduced and *P. variabilis* has been reported (Testen et al. 2012, Choi et al. 2014). Although Majes has an arid climate, the irrigation would provide the humidity to enhance the epidemic of *P. variabilis* together with the mild climate. In a study carried out in both the coastal and Andean areas of Peru, it was mentioned that warm and high humidity conditions of the coast might enhance the epidemic of downy mildew (Danielsen and Munk 2004).

Use of pesticides

The current phytosanitary management reported in Majes is less intensive compared to the quinoa production between 2013 and 2015, as it was reported by the farmers. Intensive application of pesticide in the area was also observed before but with little information about type and doses applied (Gómez-Pando et al. 2015). In former years, products were used that left high amounts of residues into quinoa grain because they were used intensively or were highly toxic (Aza 2016). In previous years, applications of pesticides were up to 105 days after sowing with several intensive applications, following the phytosanitary management of local advisors (data not shown). Many of them were mainly to control downy mildew and chinch bugs attack. For example, use of fungicides encompassed up to 5 applications against downy mildew in the first to two months and up to 7 applications against insect pests. Currently, the use of pesticides was recommended just until 45 DAS, and the number of applications has been reduced. Around three applications against downy mildew were found, although there were some fields that suffered more infection due to presence of 'camanchaca' (fog). If chemical control of downy mildew or chinch bugs were necessary after 45 DAS, the use of copper sulfate and sulfur was recommended. These are products characterized by their high solubility and low toxicity with little risk to human health. They are allowed to use in the USA and EU as fungicide and insecticide (EC 2017, EPA 2017).

Another aspect that requires to be further investigated is the doses formerly and currently used and their environmental hazards. For example, the herbicide product often used before sowing of quinoa is Paraquat, an active ingredient that is not allowed anymore in Denmark (SEGES 2017) nor in the EU. The doses recommended by the manufactures were 3.75-4.25 L/ha, but in Majes it was suggested to apply up to 6L/ha during the 2013-2015 years. It means a high dose. On the contrary, nowadays a dose of 3L/ha is applied, which is a lower dose than recommended by the producer. Other example of a wrong use of pesticides is the product Alphacypermethrin. It is recommended to apply 0.25-0.4L/ha, but in current phytosanitary plans the application of 0.66L/ha is suggested via irrigation system two days before sowing as preventive measure. After sowing the suggested doses is 0.20 L/ha, which represents an extreme range from higher to lower doses.

In the traditional agriculture of Camacani, the Cypermethrin and Lambda-Cyhalothrin products used to control pest attack are the same that are used in conventional quinoa farming in Bolivia (Gandarillas et al. 2015). An exception is the use of methamidophos, an organo-phosphate insecticide, the use of which is restricted in Peru (SENASA 2017). Although there is not an overuse of pesticides in Camacani, the application needs to be addressed correctly as to the use of some active ingredient, doses and time of spraying. For example, it was observed that some farmers used methamidophos, which is not approved in the EU (EC 2017). In the USA methamidophos is a restricted-use insecticide, which means that it can be used only under supervision (EPA 2017), cypermethrin products could be used instead following the doses recommended by the producer.

Fertilization

In Camacani, the non-application of fertilizer in the quinoa fields is similar to traditional cultivation of quinoa on the Peruvian Altiplano. It is common in crop rotation that quinoa is grown after potato. In this way, quinoa finds and takes the nutrients from the soil, which might fulfill the nutrient requirements of quinoa. It has been observed that nutritional conditions and organic matter content were favorable for subsequent quinoa cultivation after a potato crop (Aguilar and Jacobsen 2003, Mujica et al. 2004). This might be due to a slow decomposition of manure, coupled with immobilization of nutrients from the potato crop residues (Garcia et al. 2015). Additionally, the organic matter left by potato enhanced the N turnover, N mineralization and further N availability for following crops in the crop rotation systems of high Andes (Coûteaux et al. 2008).

In Majes, the amount of mineral fertilizers applied is high compared to order areas where quinoa is also cultivated at commercial scale. Regarding the application of N, the recommended dose of 300 kg N/ha is higher to the 120-200 kg N/ha recommendations in other areas like USA and Europe (Jacobsen 2015, Peterson and Murphy 2015, Piva et al. 2015). The reason that might explain high application of N fertilizer is the look for high yields. This is justified by the fact that the type of production of Majes depends primarily on market prices and production costs. To sustain and increase the farm income depends in increasing the productivity. This is a phenomenon that has been observed on production of other grains in other regions where farm income depends on commodity prices. In Majes, the prices were the major driver to increase the yields, which are obtained with high doses of N fertilizer. This dependency in increase the productivity puts at risk the sustainable production of different grains (Calviño and Monzon 2009).

From the perspective of farmers and advisors in Majes, greater nutrient inputs amount lead to high yields. This has an impact in the sustainable nutrient management. It is known that high amount of fertilizers applied have economic and environmental consequences. It implies an increase in the expenses to the farmer, and leaching of fertilizer, putting at risk, for example, surrounding water bodies. Recommendations of 120-200 kg N/ha might maintain the seed quality of quinoa, so no high doses are needed. But, it would not be worthwhile to focus merely in grain quality parameters such as protein content when worldwide most farmers are paid for grain yields. At the same time in the sand soils of Majes, N mineral not used by quinoa might be leached because the high amount of water applied on the field. This is discussed below.

4.2 Yield

The grain yield of quinoa in Majes was higher than Camacani. This was expected because of the levels of fertilizers applied, and because the climate conditions and the availability of water were more favorable in Majes.

First, the levels of fertilizers applied in the production of quinoa in Majes are higher than levels utilized in the Andes. Regarding N application, the levels are even higher than other countries where quinoa has started to be produced at commercial scale. It has been tested that quinoa yield responds strongly to increasing levels of N application (Schulte auf'm Erley et al. 2005). For example recommended amounts are 170-200 kg N/ha in USA (Peterson and Murphy 2015), 80-120 kg N/ha in Denmark (Jacobsen 2015, Jacobsen and Christiansen 2016), or 170-230 kg N/ha in France (Piva et al. 2015). In these countries, the yields under field conditions range from 1000 to 3000 kg/ha; alike the yields in Camacani. However, this is less than yields in Majes as reported in this study, with an average of 3317 kg/ha (Table 7) and a maximum of 6010 kg/ha (Appendix K).

Second, the difference in yields among areas might be enhanced by environmental conditions. The mild weather of Majes during the winter season might provide suitable conditions to growing quinoa. Similar conditions have been observed in the savannah of Brazil, where the quinoa variety enhanced its grain yield compared to the same genotype under the Altiplano conditions. Additionally, the biological cycle was reduced from 180 days to 120 days (Spehar and Santos 2005, Spehar and da Silva Rocha 2009). Same yield performances occurred in the former experimental test of quinoa varieties in different regions. Different quinoa varieties, including the

Salcedo-INIA variety, which is the most common in Majes, showed higher yields in warm areas compared to yields achieved in temperate or high altitudes areas under similar fertilization formulas (Mujica et al. 2001). Here it is worth mentioning that high temperatures have a negative effect on Andean quinoa ecotypes causing abortion of flowers thus reducing grain formation. This has occurred in Majes, and other areas, where quinoa seeds have been brought from Andean regions of Peru. Low grain yields could have happened when quinoa was grown during the summer season, as it is claimed by farmers. Unfortunately, there is no data registered in the area, although flowers abortion has been reported in desert and hot areas (Jacobsen et al. 2003). Therefore, it could be suggested that the mild weather of winter in Majes conferred suitable conditions to enhanced growth of quinoa and grain yield, taking into mind the levels of fertilization.

Finally, limited access to water constrains the development of the crop and yield. In Camacani, the cultivation of quinoa relies on water coming from rainfall. However, the occurrence of drought or delay of rain often happens. It has negative effect on yields, if there is less than 200 mm available, especially during the emergence or reproductive stages of the plant development (Geerts et al. 2008). However, this is not the case in Majes, where water is available due to the Majes Irrigation Project, which transfers water from the Peruvian Atlantic basin to the coastal Pacific (Vera Delgado and Linden 2013). It has been difficult to obtain precise numbers from farmers about the amount of water utilized in the quinoa cultivation. The way that farmers calculated the water needed is based on the time span of irrigation, which approximately followed the irrigation time suggested by local advisors. Thus, with a flow of 6 L/s and a range of 1170 to 1630 minutes of total irrigation, the estimated amount of water range between 500 to 600 mm of water supplied (Aza, pers. comm.). Experimental trials with quinoa conducted by Esteban Falconi (data unpublished) in the area has reported an average of 6000 m^3/ha of water. This amount fits into the estimated volume of water (10000 to 13500 m^3/ha/year) provided by the MIP, according to the Peruvian National Authority of Water (ANA 2016). This represents an overuse of water if it is taken into account that significant yields were obtained around 300 mm under deficit irrigation strategies in the Bolivian Altiplano (Geerts et al. 2008), and, more recently, in dry conditions of the Mediterranean region (Lavini et al. 2014).

Yield variation within study areas by N management

Regarding the differences or variation of yield within the farms in each study area, Majes showed low variation in yield and N utilization components compared to Camacani. The variation may be related to the management of agricultural practices on how the N fertilizer and water was handled and how adverse factors as the presence of weed and pest were controlled. A couple of possible explanations can be mentioned.

First, the plant growth and yield on field was enhanced by N application. In Camacani N fertilizer comes from sheep manure applied by hand on the field, therefore the spread could have been less homogeneous. Additionally, fields situated far from the place where the manure was stored would receive low manure application, as it also happened to fields that were located far from the farm infrastructure. This was also observed by Agüero García (2014) on localities of Puno. Manure had to be carried by the farmer into the field, thus fields placed close to the farm received more manure, whereas less manure was carried to fields further of the farm. A specific situation was observed in Camacani (Field01, Appendix J), which also showed the highest variation (116%). Manure for cultivation of potato had been gathered close to the quinoa field. Plants of quinoa growing in the surrounding area showed a high plant growth and high grain yield compared to plants growing further, 5292 kg/ha and 580 kg/ha respectively; as it was registered by the extrapolated data from the same field (Field01, Appendix J).

In Majes, the variation within fields are also related to fertilization plus water. All the fertilizers are dissolved and applied via the irrigation system. It seems that the water volume carrying the nutrients was not uniform on the field because of changes on pressure. There was more pressure at the beginning of drip hoses, therefore more volume with nutrients, and less pressure at the end of drip-hoses. This abiotic factor might explain the variation of yield on field samples.

Yield variation by biotic factors

Another reason that had an influence on yield variation within field samples on both areas were the biotic factors such as the presence of weeds and birds. Weeds were manually controlled. A bad control of weed meant that its presence could reduce the development of quinoa plants, affecting negatively the number and development of plants and consequently the yield because it would compete for resources like nutrients and light (Norris et al. 2003, Kakabouki et al. 2015).

Birds were another factor for reducing the yield and exerted and influence on samples variation. They stepped on quinoa plants, breaking panicles or making seeds fall off. Birds can destroy as much as 60% yield (Rasmussen et al. 2003). The combination of weed and bird presence together caused yield losses. A specific example was observed on samples of Field07 in Majes, where one sample was registered with a yield loss of around 90% compared to the average, due to combined attack of birds and a considerable presence of weeds. This is of course only one example and should not be generalized, but it indicates that birds are an issue of concern in yield losses in Majes.

In Appendix J and K with data for both places is mentioned the reason for harvest loss on some samples. Quantitative data of weeds has not been taken, which is a weakness for this study. A measurement of the volume or biomass of weeds per square meter would have allow to stablish relationships between yield loss and weed as it was done by Kakabouki et al. (2015).

In summary, the yield variation between areas is influenced by the application of fertilizers, water available and climate conditions. At the same time yield variation within fields in the same area is related to the different agronomic practices performed by the farmers, which together with biotic and abiotic factors might enhance yield loss and variation within the grain production in the field.

4.3 Nitrogen efficiency

The N utilization in Majes seems to over provide the N demand of quinoa; furthermore, it seems that the averaged NUE of 43 % for the sandy soils of Majes will not decrease with a rate of 194 kg N/ha or higher doses applied. This is assumed when the NUE of Majes is compared with the NUE from two experimental trials of other regions with different conditions, since no literature has been found for the area. One trial is from Germany, where NUE has been calculated for rates of 80 kg N/ha and 120 kg/ha (Schulte 2005). It represents 85 % and 68 % NUE, respectively. The other one is from Denmark with a rate of 120 kg N/ha under sandy, sandy loam and sandy clay loam soils and two water treatments, full (FI) and deficit irrigation (DI). Calculated NUE values for the sand soil were 45 % and 40 % under FI and DI, respectively. For sandy loam soil NUE was 59 % for both water treatments. In sandy clay loam soil NUE were 69% and 62 % for FI and DI, respectively (Razzaghi 2012). This studies also shows an effect of the soil in the N utilization by quinoa.

The remarkable difference is the N levels applied on those experimental trials compared to the average 194 kg N/ha in Majes. It means that the high rate of N in Majes made no increase in the NUE of quinoa. Moreover, the NUE (%) of Majes (43 %) was lower than the 68 % with 120 kg N/ha registered in Germany and was within the range reported for the sand soil in Denmark (40 % - 45 %) with the same N rate. These differences of NUE indicate a possible interpretation of the values found in Majes taking into account the benchmarks of typical NUE levels for cereal crops with recommended management practices (Fixen et al. 2014). The NUE of Majes is lower than recommended values which range from 70 % - 90 % (Fixen et al. 2014). The lower level suggests that changes are needed in the nutrient management to improve the efficiency in the N utilization, and there would not be a reduction in the yield of quinoa. This interpretation should be seen as preliminary rather than conclusive statements, therefore, it is necessary to carry out more trials on new areas of quinoa production, like Majes, in order to estimate levels of N fertilization (efficient management practices), and therefore sustainable nutrient practices.

There were many assumptions related with the N utilization in Camacani, and a discussion of NUE is left out, due to the following reasons. First, sheep manure is applied in the potato the year before of quinoa or first year of the crop rotation; therefore, the reaming N in the soil will be used by the quinoa (second year of crop rotation). Second, it is assumed that the N-uptake by potato corresponds to an amount of 40 kg N/ha[3]. After harvest the field is left in fallow during the dry season. Third, it is assumed that no leaching occurs. The N leftover for quinoa might correspond to remaining soil-N, which might be represented by the simplistic calculation of the amount of kg N applied subtracted by potato N uptake. In addition, the data from variety trials in Camacani (Table 7, bottom) represents the N application on a field with a quinoa-quinoa rotation, but the trials had no replicates and it would be difficult to compare with. Finally, the simple assumption is the N values showed in Table 7 corresponds to 1.95 % of the sheep manure. But there are many factors that have not been taken into consideration like the N mineralization and the N immobilization rates, the soil-N at time of harvest of previous crop, the N coming out and in from plant residues and so on.

No study about soil N dynamics was found for similar areas. Just one study on carbon and nitrogen dynamics conducted in the Bolivian Altiplano was found (Coûteaux et al. 2008). The study describes the dynamic for a two-year rotation of potato-barley and potato-potato followed by fallow, which differs from the four-year rotation of Camacani. The study found that N supply from sheep manure (1.4 % N content) and the crop residues of a 2-year rotation of potato-barley, and potato-potato enhanced the availability of soil organic matter; and N from litter, besides the soil-N covered the demand for the following crop (Coûteaux et al. 2008). The study reports a maximum

[3] It was calculated with a yield of 12500 kg (fresh matter), Crude protein of 9.2 % and dry matter of 22 %; as it was explained previously.

demand of 20 kg N/ha for the potato, which is half of the value assumed in Camacani. When the N demand was not covered for rotation with barley (deficit of 4 to 8.5 kg N/ha), it was expected that it was provided by the soil-N. The study estimated a native N stock of 180 t/ha in the upper 20 cm layer with a rate of 0.004 % of N mineralization (7 kg N/ha). In rotation of potato-potato the N balance was positive with 19 kg N/ha. For the N balance of two-year rotation, the study accounted the N from manure, the N from residues, N mineralization from 1st and 2nd year, organic N and so on. However, the study of Coûteaux et al. indicates the numbers that are necessary to make a balance of N, which lacks in the case of Camacani. Nevertheless, looking for an improvement in the productivity of Peruvian Andean farming system should start by accounting good estimated numbers about the N turnover in such agroecosystems.

4.4 Where to improve?

It cannot be denied that over the last decades the intensive agriculture has been criticized because of the inputs and management required to maintain such system of production (Curtis and Riley 1990, Gliessman 2007). So, whether to define the current production of quinoa in Majes as sustainable or unsustainable is not necessarily the pursuit of this chapter. As the National Research Council (N.R.C. 2010) stated, the pursuit of sustainability "rather is about assessing whether choices of farming practices and systems would lead to more or less sustainable system" (N.R.C. 2010, page 5). It is undeniable that current production of quinoa in Majes needs to use the resources more efficiently. This is one of the characteristics that a farming system needs to achieve to become sustainable (N.R.C. 2010).

Briefly, the cultivation of quinoa in Majes was characterized by high inputs of both fertilizers and pesticides, which are applied through the irrigation system of the farm (Gómez-Pando et al. 2015). The amount of fertilizer, regarding N, is higher compared to other areas where quinoa is cultivated at commercial scale. This study shows that pesticide doses needs to be managed both more efficiently and more appropriately. Irrigation is a complex subject, but based on the experience in other areas, the current volume of water in Majes could be reduced without affecting the yield. The farming practice with more concern here is to the weed control post-sowing, due to the high requirement of labor. All these subjects are discussed further to be improved and to achieve the sustainable production.

In Camacani cultivation seems sustainable, but this type of agriculture is facing many other challenges such as socio-economic issues that affect the agricultural aspects of quinoa, like commercialization (Agüero García 2014, Mercado and Gamboa 2014, Frankel 2015), which are outside the scope of this research. I am aware of the limitations of this study since such a small area not represent all the complexity and different aspects that production of quinoa encompasses.

Nitrogen

The application of low amounts of N without compromising the grain yield might be possible. The levels of N fertilizer applied in Majes exceeds the amounts applied compared to other areas. Different experiments performing high levels of N showed a positive effect on quinoa seed yield with some implications. In Colorado, USA, the recommendation was 170-200 kg N/ha with adverse effects like lodging and delayed maturity (Peterson and Murphy 2015). In Denmark the recommendation was levels lower than 160 kg N/ha (Jacobsen and Christiansen 2016), but the increase in yield response was minimal compared to 120 kg N/ha. In Germany, quinoa had a strong response to increased nitrogen fertilization. A level of 120 kg N/ha produced a yield up to 3500 kg/ha, which was the double compared to yields with no fertilization (Schulte auf'm Erley et al. 2005). Nevertheless, the experiments show lower yields compared to those registered at the commercial scale of quinoa's production in Majes. The reason for such differences might be not only the high levels of N fertilizer. The favorable warm climate conditions in Majes might enhance the production of grain as it was observed in the introduction of quinoa into the warm climate of Brazilian savannah (Spehar and Santos 2005, Spehar and da Silva Rocha 2009).

Surprisingly, the research of Martinez et al. (2009) in the arid areas of Chile showed yields up to 7.7 t/ha with a level of 150 kg N/ha under irrigation conditions, even with a lower amount of water (150 mm/period) compared to Majes (500-600 mm/period). This might provide interesting insights. The authors pointed out that the incorporation of worm humus (*Eisenia phoetida*), rich in organic matter (18% content), enhance the quinoa yields, even under conditions of low irrigation (Martínez et al. 2009).

Organic matter (OM)

The animal manure as source of organic matter is plenty available in the region of Majes, but it is randomly used by farmers in quinoa cultivation. In fact, the application of organic matter has been recommended to improve plant growth under semiarid and Mediterranean conditions (Biazin et al.

2012, Lavini et al. 2014). On the one hand, the application of organic matter might increase the soil fertility and water-holding capacity (N.R.C. 2010). For example, incorporation of organic matter in combination with water management and inputs of mineral fertilizer had increased grain yield, as it was demonstrated in a 3-year experiment with maize in semi-arid areas of Tanzania (Biazin et al. 2012). Therefore, crop yields are improved by fertilizer application in the presence of soil moisture, which is enhanced by incorporation of organic matter.

On the other hand, incorporation of organic matter has shown contradictory results in relation to yield and water management in other areas. The experiment in Chile by Martinez et al. (2009) showed low yield (4,9 t/ha) under irrigation of 250 mm/period, in contrast to the 7.7 t/ha with an irrigation of 150 mm/period. Soil salinity might explain the low yield by having an interaction in the water use efficiency (Martínez et al. 2009). Another contrasting result comes from experiments with quinoa carried out in the Mediterranean regions of Italy, Morocco and Syria by Lavini et al. (2014). It was stated that OM improves grain yields under drought conditions in one region, but no relation was found between deficit irrigation (DI) with amendment of OM on seed yield of quinoa in the other regions of study (Lavini et al. 2014). This should be because the different varieties, and phenological stages in which drought or water deficit were performed. There will not be an effect of the organic matter as soil amendment when the deficit of water is most severe during early stages of emergence, whereas deficit during flowering has less negative impact.

Water - Irrigation

Another reason for the high quinoa seed yields in Majes is the availability and amount of water applied on the crop, which should, however be managed more efficiently. A water utilization of more than 500 mm/period by quinoa’s cultivation in Majes is larger than levels suggested in dry climates. Around 100 to 200 mm of water controlled by deficit irrigation maintained relevant quinoa grain yields in dry conditions in the Bolivian Altiplano, and caused a better water use efficiency (Geerts et al. 2008). The same has been tested by Lavini et al. (2014), with levels around 300 mm of water supplied by irrigation, and with a deficit of 50%. Nevertheless, it is necessary to take into account that several studies showed that quinoa yield has been affected negatively by water deficit (Lavini et al. 2014). Anyway, it is necessary to reduce or improve the consumption of fresh water.

Some alternatives to reduce and improve water utilization in Majes might be inducing deficit irrigation (DI) on the quinoa crop or including different levels of fertilization under drought conditions. Effects of DI in quinoa and quinoa responses to drought with different levels of N were tested by Geerts et al. (Geerts et al. 2008) in the Bolivian Altiplano and by Alandia et al. (2016), respectively. The results indicated that cultivation of quinoa might be improved by N management practices and can ameliorate the negative effect of water deficit. Nitrogen has an effect on the physiology of the crop enhancing the tolerance to drought events (Alandia et al. 2016). Moreover, it is important to avoid deficit of water in early vegetative stages of plant development and reproductive phases. Adequate water supply during germination phase and reproductive phases improves the water use efficiency, even though the crop was under drought stress in the vegetative phase (Geerts et al. 2008). The challenge is to test these experiences at commercial scale, though the water management scheduling of Majes' local advisors more or less fits with what has been done experimentally (Fig. 9; Fig. 10), but the volumes of 500-600 mm/period utilized are still higher.

Other alternative might be water distribution through efficient drip irrigation design as it was observed. The design of irrigated systems was different among farmers in drip-hoses length and furrows' width. First, drip irrigation is the technique utilized. It consisted of a plastic tube as main connection where drip-hoses of 120 m length were connected. This was the most common drip irrigation design among farmers. But one farmer reduced the drip-hoses connected to the main connection to 90 m length. This would have made possible to get the same water pressure at the beginning and at the end of drip hoses. In that way, the fertilizer application was also more efficient. The design mentioned was applied by farmer on the Field10, which had the highest yield, it has high N application tough. Second, measures to manage the water were linked to the width of furrows. To have more water available for the crop, some farmers made more spacing furrows (0.90 m) instead of the standard of 0.75 meter. On that way, more volume of water might be available for the crop with low number of total plants per hectare.

However, the availability of water is not a constraint in Majes due to the Irrigation Project, but there might become less water in the future. Less occurrence of rain in the Andes had reduced the storage of water in the MIP's dam to more or less half of its capacity in 2016 (AgroArequipa 2016). It meant a reduction in the water flow from 8 L/s to 6L/s (Aza 2016), which had an influence on the water management of the farmers. They still prefer to grow quinoa because it requires less water than other crops and it also diversify the crop production.

Weed control (post-sowing).

Previously it has been mentioned that a mechanization of the control of weeds might be more effective as it might be an alternative in organic production of quinoa (Jacobsen and Christiansen 2016). Regarding the high levels of fertilization on the quinoa production in Majes, it would influence the proliferation of weeds. Kakabouki et al. (2015) found that the density and biomass of weed were influenced by different N fertilization levels (100 kg N/ha and 200 kg N/ha). This would indicate that fields with high application of N fertilizer might have more problems with weeds. Additionally, the presence of weed was also controlled by tillage and it had an influence on yield (Kakabouki et al. 2015). In fact, during the fieldwork, it was observed that the growth and subsequent grain yield in some samples were affected by the presence of weeds, though unfortunately this was not measured quantitatively. At the same time, tillage seems an alternative to control weeds. In addition, a mechanization and a good management of machinery would have an impact reducing seed weeds carried by people from field to field. This is of course an assumption that needs to be evaluated. Mechanical control of weeds depends on designs that do not damage hoses for drip irrigation lying on the levelling furrows or beds, which is an importance issue in Majes.

Pesticides

In Majes, the current use of pesticides in the quinoa production is efficient and it seems more sustainable than former years. During 2013 to 2015 there was an overuse of pesticides, as the phytosanitary managements indicate. Thus, the over application and application of pesticides, that left high residues, were intensive compared to applications reported in this study. The explanation for this was not necessarily the awareness of environmental implications.

First, the production of quinoa was intensive during 2013 to half 2015. As many of farmers mentioned, there was no field where quinoa was not growing, which is supported by the quinoa acreage of ca. 5700 ha, around 40 % of total irrigated area, in the season 2013-2014 (AgroArequipa 2016). Thus, this could have led to an exponential presence of insect pests. It is claimed by some farmers that the presence of chinch bugs could be noticed as they could form clouds over quinoa fields (Farmer Percy H. pers. comm.). Thus, the use of pesticides was intensive to the level of spraying chemicals even few days before to harvest and hence to save the investment or production. If a product was reliable for controlling the pest, it was overused.

Second, the drop of quinoa prices and the news about the rejection of quinoa from Peru by the USA, made farmers to abandon the cultivation of quinoa -unfortunately or not-, in the second semester of 2015. It meant a reduction in area harvested and production (Fig. 2). This also implied a change on farming decisions, as they had to look for other crops, and thus crop rotation and multiple cropping were retaken. Without the resource or grain, the presence of chinch bugs was diminished. This is explained in the following section.

The main pest problem in Majes is still *Peronospora variabilis*, which is more or less well controlled when fungicides, containing Mancozeb as active ingredient, are sprayed on early stages of plant development as it was observed on other areas (Danielsen and Ames 2004, Danielsen and Munk 2004). The application of fungicides might reduce the infection of downy mildew, but it can increase the cost of production and it involves environmental issues. Nevertheless, the use of organophosphorus pesticides in Majes is intensive on other crops and also affects human health (WHO 2000, Yucra et al. 2006). More research is required in the area to regulate or reduce amounts of pesticides to prevent undesirable and long-term harmful effects.

Farmers and local advisors have learned by experience. Now they use little and different products for chemical control. This decision is also influenced by the fact that quinoa production in Majes is for export, thus they must comply with the international regulations about the maximum level of residues allowed.

Looking at the production of quinoa in Camacani, the farming practice that might more affect its sustainability is the use of pesticides. The appropriate pesticides and doses of spraying it to control the *qona-qona* pest (*Eurysacca spp*) needs to be evaluated. Farmers are using pesticides that are known to leave high level of chemical residues and highly toxic, as methamidophos, especially when they are sprayed in the last month of growth or weeks before to harvest. This represents a serious health risk for them because quinoa is mainly for home consumption. Group of organophosphorus pesticides are known as chemicals that implies hazards for humans, life in water bodies, and the environment (WHO 2000). Therefore, early spraying of pesticides with low or moderate toxicity will reduce the level of attack in the stage of maturity grain; i.e. when the larvae of qona-qona is observed during the flowering stage of quinoa.

To control pests in a sustainable way in Camacani, farmers have to respect the recommended by-product doses. For example, producer of lambda-cyhalothrin recommends a dose of 100-250 ml/200 L, which depends of the pest target, instead farmers use some general doses of 15-20 ml/15 L (equivalent to 195-260/200 L) or lower. Moreover, this pesticide does not include *Eurysacca spp* into their targets. Inappropriate use of pesticides doses, also in Majes, could create pest resistance or accumulated pesticide application could cause adverse harms on the environment (Norris et al. 2003, IRAC Website). Finally, the applications of pesticides must be timed correctly, as it is recommended by the Insecticide Resistance Action Committee (IRAC Website). Farmers in Camacani might spray at last in the flowering stage, which might exert a control of the *Eurysacca* (qona-qona) population. It would target the insect pest in a vulnerable life stage, so that further attacks to the quinoa grain by larvae will be less.

In conclusion, as IRAC stated "the use of spray rates and application intervals recommended by the manufacturer and in compliance with local agricultural extension regulations is essential" (IRAC Website).

Pest control

Preventive actions are of primordial importance against pest, diseases and birds, which cause significant losses on quinoa (Danielsen et al. 2003, Rasmussen et al. 2003). Among the insects that attack quinoa, two pest groups are of special concern. In coastal production, the polyphagous chinch bugs, *Nysius sp, Dagbertus spp* and *Liorhyssus hyalinus*, which had caused serious damage in former production of quinoa among 2013 to 2015. The grain is attacked at milky stage by the nymphs and adults, which suck the grain. In Camacani and Andean production *qona-qona*, a lepidopteran pest (*Eurysacca spp*) caused yield losses. In larval stage, it feeds from the grain and it is very destructive. It was observed that one field was completely damaged by qona-qona because the farmer delayed the harvest of the crop (pers. obs.).

Crop rotation seems an effective measure as cultural control to reduce the attacks of pests in quinoa, which is practiced in the traditional agriculture of Camacani. This cultural control is at present performed in Majes, but for the wrong reasons. After the drop on market prices of quinoa, there was a reduction on acreage of quinoa cultivation as described before (Fig. 2) and farmers looked for alternative cash crops. This meant less resource for the pest which affected its reproductive cycle, causing a reduction in its population and of incidence of further attack (Norris et al. 2003).

After the ‘catastrophe’ with quinoa in the last years, farmers changed their practices. For instance, now they cultivate quinoa just one season per year and they cultivate other crops together with quinoa, but based on market decisions, as it was explained above. However, the crop rotation is one of the cultural methods to reduce pest attacks (Norris et al. 2003). These practices are recommended by the literature to reduce pest attacks and, indeed, to reduce application of pesticides and reduce the resistance to it (Norris et al. 2003, IRAC Website). In fact, it was often mentioned by farmers that the presence of chinch bugs was low. Some of them indeed commented that they did not spray against the insects at all. This shows a clear example of influence of crop rotation, but it is needed to perform complementary studies to know if population fluctuations of chinch bugs are also enhanced by temperature as it happens in Brazil (Dalazen 2014). Currently, quinoa is cultivated during winter season but in previous years is was also cultivated in summer season when it seems the attack were severe as it was mentioned by farmers.

At the same time, there are still farmers that practice monoculture of quinoa, but at least they started to shift to other varieties and alternate its cultivation. Many others have introduced the rotation to other crops like paprika or maize for at least one season. Other farmers sow different crops as an alternative to cope with uncertainty on market prices. This dependency in market is still a main driver in the sustainable management of farms (Calviño and Monzon 2009). These practices might indirectly influence the control of pests.

Two measures are recommended to prevent and reduce the source and rate of infection of *P. variabilis*. The first one is crop rotation, which shows positive effect reducing the availability of tissues where the pathogen could grow and reproduce (Danielsen and Ames 2004). It might reduce the rate or spread of infection. The second one is cultivation of resistance varieties. It is an option to protect the crop and reduce the rate of infection of the disease. Quinoa has the advantage that the plant possesses a wide range of varieties with resistance against *P. variabilis* (Danielsen and Ames 2004, Zurita-Silva et al. 2014). Some farmers sow different varieties of quinoa on the same field, based on the bitterness and the time of maturity. Anyway, in Majes this measure has to cope with the fact that varieties selected have to fit with the requirements of big size grain, low saponins content which confer less bitterness, and short time of maturity. The cultivar is preferred because of its grain size (2 mm), low bitterness, and it mature in 120 days or even less. The variety Salcedo-

INIA is widely cultivated in Majes but it is susceptible to downy mildew, although in Andean areas the same variety is moderately resistant. It seems that the resistance of varieties is enhanced by environmental conditions.

The literature about these topics are abundant in other regions. In fact, multiple cropping, and crop rotation, are measures recommended in the sound Integrated Pest Management (Norris et al. 2003). Unfortunately, there is a lack in conducting this type of research in the new area of Majes, and moreover, to apply this knowledge at farm scale. But the traditional cultural control like growth of different quinoa varieties, multiple cropping, and crop rotation remain as effective measures to control pest attacks, not only in Camacani, has by observation shown its positive effects, but has not been measured in Majes. However, these are two areas geographically and culturally different; rather than a barrier this must be seen as a challenge to combine the experience of farmers from both areas.

5. CONCLUSION

In Majes quinoa is produced through conventional intensive agriculture, whereas in Camacani it is produced by traditional agriculture through a four-year crop rotation, being quinoa cultivated in the second year. Although they are two different systems of production, the requirement of labor is for performing the same activities like sowing, weeding, thinning out and harvesting of the crop. If a mechanization instead of labor is needed, machinery design has to cope with the drip-irrigation system.

Water is a main driver for agricultural practices in the Andes and Coastal areas of Peru. In Camacani, agriculture is rain fed, cultivation of crops occurs between October to March, followed by five to six months of fallow. In Majes agriculture is practiced the whole year due to availability of water through the irrigation project, although the resource will become less available in the future, due to decrease in the occurrence of rainfalls. Better design in drip-irrigation system will enhance water utilization.

Mineral fertilizers are the main source of nutrients for quinoa crop in Majes. In Camacani, sheep manure is mainly used, which is applied in potato the 1^{st}-year for the crop rotation. Quinoa is unfertilized; thus, remaining soil-N is available for quinoa the 2^{nd}-year of rotation. Regarding N application in Majes, the average of 194 kg N/ha, with maximum of 287 kg/ha, are higher than recommended levels of 120-200 kg N/ha in other regions. The yield dry matter averaged 3317 kg/ha, with a max. 6010 kg/ha, higher than 1848 kg DM/ha registered in Camacani.

The implication of the N level applied in Majes is reflected in the NUE of 43 %. It indicates that the higher rate of N in Majes will not make an increase in the NUE of quinoa. Higher NUE values with lower N rates have been register in other areas. It means that the nutrient management by farmers in Majes needs to be improved to achieve better N utilization. To become sustainable in the nutrient management, a reduction on the N levels might be possible without affecting the yield. More research is needed to find the economical N-optimum, it means the amount of N that keep economic yields, for the quinoa production in Majes.

New pests, like chinch bugs of genus Nysius, Dagbertus and Liorhyssus have been recently reported in quinoa and have caused severe crop losses between 2013-2015 in Majes. Currently, the pest attack is low or negligible, but is still the concern among farmers. Downy mildew, *Peronospora variabilis*, is the main disease that might cause losses if it is not controlled on time. Different pesticides and doses are applied to control the different pest and diseases. The quinoa production in Majes is for export, thus the current phytosanitary management seems to cope well with international regulation respect to level of residues allowed in the grain. However, the dependency in the Market is always a risk for the farmer and for sustainable production. In the traditional agriculture of Camacani, organo-phosphorus pesticides like methamidophos to control larvae of 'qona-qona' (Eurysacca spp) are of concern. An effective timing and dating in the spraying of pesticides is possible. However, application of pesticides is seen as the latest alternative.

Conventional intensive agriculture is criticized due to its high use of inputs. Reduction in fertilizers, pesticides and water without affecting the yield is possible. Amendment of organic matter will improve soil structure and increase the soil water retention, which cause a better utilization of N. Reduction in use of water might not affect the yield when it is scheduled correctly, around 200-300 mm/period maintain relevant yields, in Majes 600 mm/period of water is utilized. Water must be available during emergence and initial reproductive phases; otherwise, negative effect might be severe. Better control in doses and timing in application of pesticides might be more effective to control different pests. Cultural practices as crop rotation, multiple cropping and sowing of different varieties remains as effective measures to prevent pest attacks

6. PERSPECTIVES

Quinoa is becoming more and more attractive, due to its nutritious properties, but also due to its adaptability to different agro-ecosystems, especially those where water is scarce. It is also valuable in terms of food security. This said, the trend is that quinoa has become cultivated in different regions at experimental and commercial scale.

The information provided in this research might serve merely as a benchmark in what should and should not be done. First of all more information from the farmer is needed, at the end they are the ones who deal with different aspect in the production of quinoa. At the same time the information that exist, need to be shared with them, as it is done in many developed countries.

Second, for similar regions, it will be necessary to establish the recommended standard values of Nitrogen Use Efficiency for quinoa. Moreover, it is necessary to examine what the recommended rates of Nitrogen to obtain optimum economic yield are. This should be done under site-specific conditions. Thus, the next step would be to conduct trials in Majes to know, what the recommendable amount of fertilizer required to obtain economic yields are and what the NUE will be at different Nitrogen rates.

A third question is, whether it will be possible to increase the NUE of the quinoa crop in the region. Again, this requires further research.

Studies in NUE in the Andes and new areas such as Majes will provide valuable information to figure out the amount needed to produce with low economic and environmental impacts. These have to be accompanied by better understanding of Nitrogen flow in such areas considering their agricultural practices.

As all this indicates, there is still a need for a lot of research to be done in Majes, and in other areas where quinoa is starting to being cultivated on a commercial scale. This also involves research in water utilization, a resource that will become scarce in the future. The future scenario seems to be the production of more food, which implies further pressure on the agroecosystems.

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Pictures front page: top left, traditional farmers harvesting quinoa in Camacani (14/04/2016), Puno; top right, quinoa field in the desert of Majes (24/05/2016); bottom, abandoned field of quinoa after attack of chinch bugs in Majes (22/03/2016).

APPENDIX

Appendix A. Quinoa National Production of Peru

Year*	Area Sown (ha)	Area Harvested (ha)	Production (TN)	Yield (kg/ha)
2000	28982	28889	28191	976
2001	28327	25600	22267	870
2002	28156	27852	30374	1091
2003	28931	28326	30085	1062
2004	28763	27659	26997	976
2005	28738	28632	32590	1138
2006	30382	29949	30428	1016
2007	31288	30381	31824	1047
2008	33120	31163	29867	958
2009	34068	34026	39397	1158
2010	36193	35299	41537	1177
2011	38083	35494	41446	1168
2012	42077	38502	44046	1144
2013	47543	44870	52132	1162
2014	68099	68037	114343	1681

*Production campaign: from August - July (next year)
Source: Elaborated from MINAGRI 2015

Appendix B. Statistics for export of quinoa, FOB prices and grain

Year	FOB (thousands of US$)	Grain weight (tons)	Price Export US$/kg**	
			average	min-max
2008	5077.35	2095.60	2.18	1.30 - 2.90
2009	7307.11	2712.61	2.69	2.48 - 2.98
2010	13138.25	4762.60	2.71	2.14 - 3.01
2011	23913.67	7524.19	3.13	2.61 - 3.57
2012	30713.48	10567.18	2.90	2.72 - 3.14
2013	77826.03	18250.28	4.04	3.17 - 6.03
2014	196379.46	36224.14	5.47	5.04 - 6.17
2015	143333.83	41404.33	3.59	2.73 - 4.69
2016*	67811.47	28750.33	2.36	2.23 - 2.44

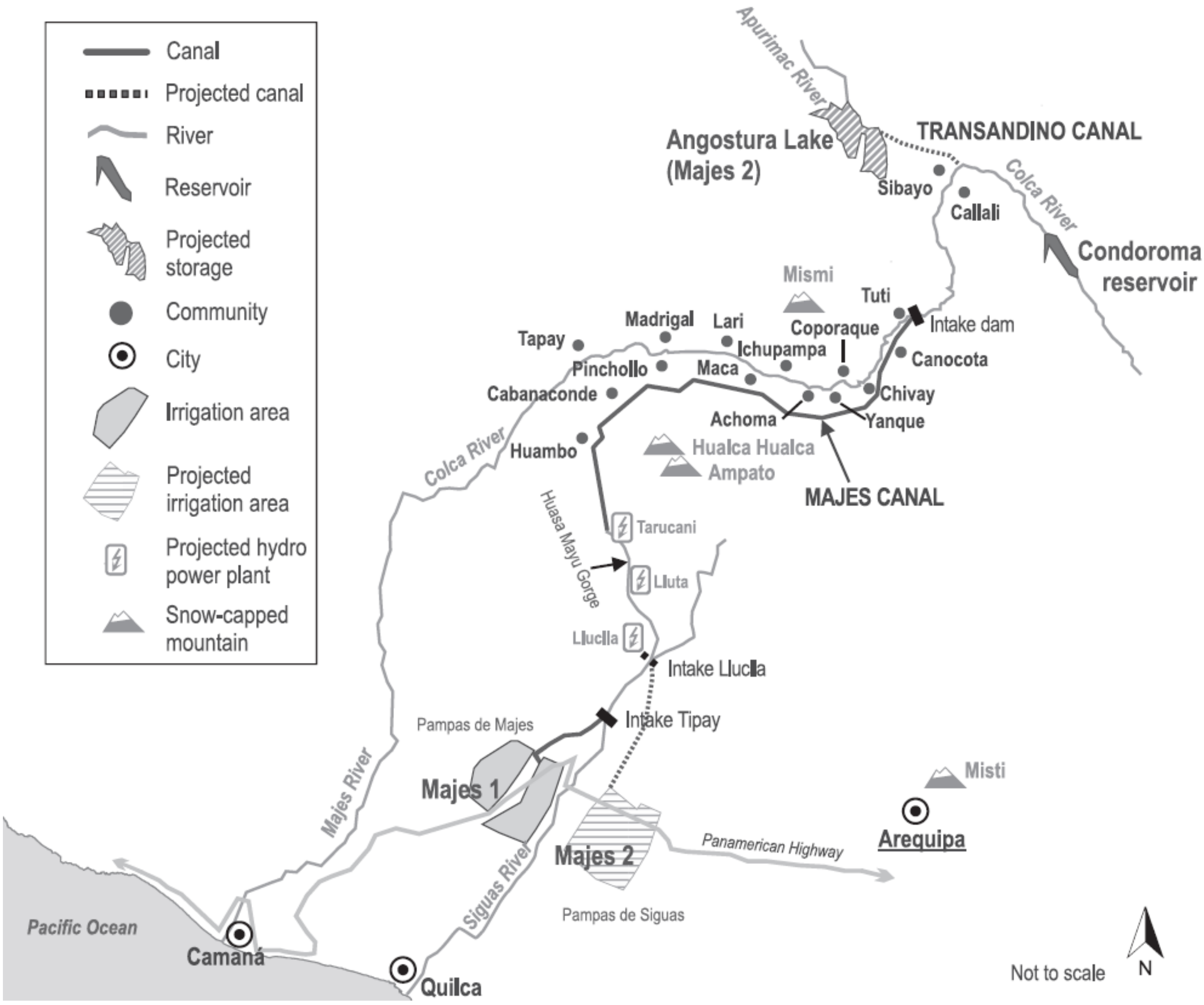
*data available until August **exchange rate 1US$ = S/. 3.00 NS
Source: Elaborated from (MINAGRI 2016)

Appendix C. Acreage and production of quinoa in Majes

Region	Season*	Area Sown (ha)	Area Harvested (ha)	Production (TN)	Yield (kg/ha)	Price Farm US$/kg**
Majes	2013-2014	5052	5682.00	25043.35	4407.49	2.42
Majes	2014-2015	5423	4838.00	18442.22	3811.95	1.55
Majes	2015-2016	1156	712.00	2628.06	3691.10	1.05

*season from August to July next year
**exchange rate 1US$ = S/. 3.00 NS
Source: Elaborated from (AgroArequipa 2016)

Appendix D. The water transfer of the Majes Irrigation Project (Vera Delgado and Linden 2013)



Appendix E. Processing of field samples. Plant cuts, threshing, sifting, oven drying, winnowing and weighting of samples

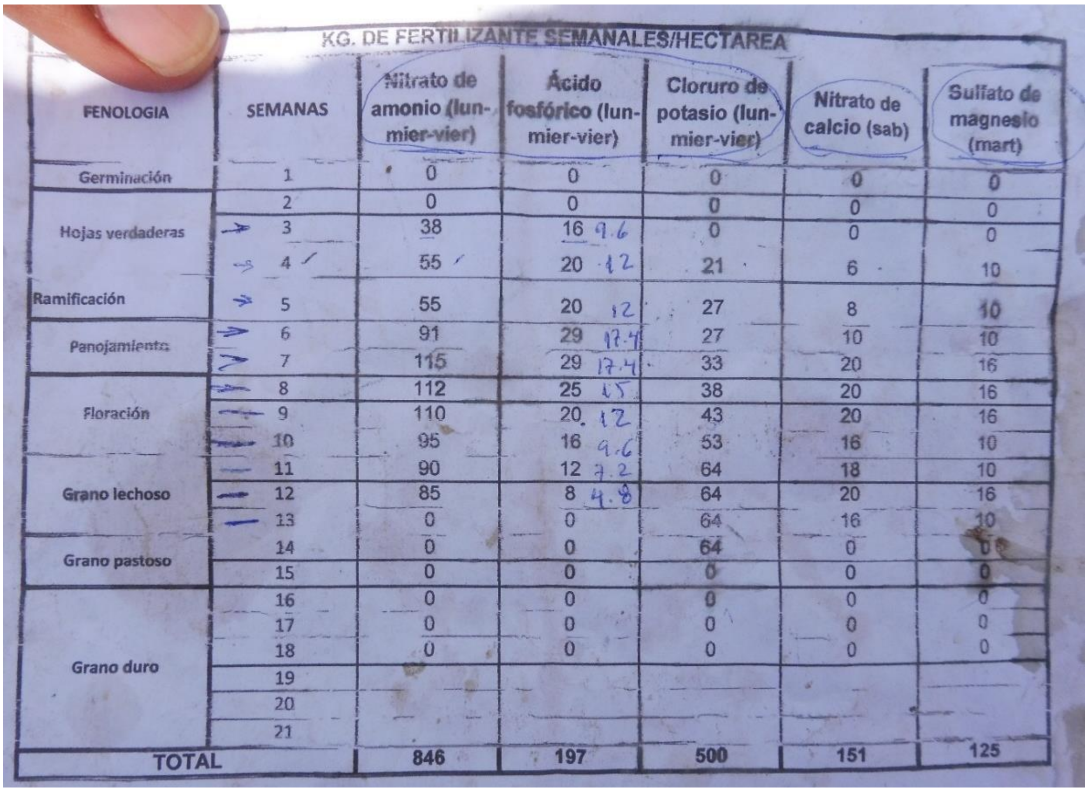
Appendix F. Fertilization management from three local advisors in Majes

Advisor 1. Mineral fertilizer application (kg/ha)								
Phenology	DAS	Week	N	P	K	Ca	Mg	Irrigation (min)
Emergence (+cotyledon)	7	1						120
True leaves (2, 4 & 6)	14	2						20
	21	3	14	10				20
	28	4	20	13	11	2	2	20
Branching	35	5	19	13	13	2	2	30
	42	6	32	18	13	3	2	45
Ear formation	49	7	41	18	16	5	3	45
	56	8	40	15	19	5	3	60
Florescence	63	9	39	13	22	5	3	60
	70	10	34	10	27	4	2	60
	77	11	32	8	32	5	2	90
Milky grain	84	12	30	5	32	5	3	120
	91	13			32	4	2	120
	98	14			32			120
Doughy grain	105	15						120
	112	16						60
Mature grain	119	17						60
	126	18						
Total (kg/ha)			300	120	250	40	20	1170

Advisor 2. Mineral fertilizer application per week (kg/ha)						
Phenology	Week	N	P	K	Ca	Mg
Emergence (+cotyledon)	1					
True leaves (2, 4 & 6)	2					
	3	9	10			
	4	14	12	7	1	2
Branching	5	14	12	10	2	2
Ear formation	6	26	17	10	2	2
	7	35	17	14	5	3
Florescence	8	35	14	17	5	3
	9	35	12	20	5	3
	10	33	10	26	4	2
Milky grain	11	32	7	33	4	2
	12	30	5	33	5	3
	13	20	5	33	4	2
Doughy grain	14			33	3	
	15			27	2	
Mature grain	16			22		
	17			16		
	18					
Total (kg/ha)		280	120	300	40	20

Advisor 3. Mineral fertilizer application per week (kg/ha)							
Phenology	Week	N	P	K	Ca	Mg	Irrigation (min.)
Emergence (+cotyledon)	1						180
True leaves (2, 4 & 6)	2						60
	3	9	6		1	2	60
	4	14	9		3	2	60
Branching	5	18	12		4	3	60
Ear formation	6	28	15		5	4	60
	7	37	18		0	5	60
Florescence	8	14	21		0	5	60
	9		17		0		60
	10				0		60
Milky grain	11				5		180
	12				7		180
	13			10			180
Doughy grain	14			21			90
	15			31			90
	16			42			90
Mature grain	17			16			90
	18						90
	19						
Total (kg/ha)		120	100	120	25	20	1620

Appendix G. Fertilizer scheme from advisor; modified by farmer in P application



KG. DE FERTILIZANTE SEMANALES/HECTAREA						
FENOLOGIA	SEMANAS	Nitrato de amonio (lun-mier-vier)	Ácido fosfórico (lun-mier-vier)	Cloruro de potasio (lun-mier-vier)	Nitrato de calcio (sab)	Sulfato de magnesio (mart)
Germinación	1	0	0	0	0	0
Hojas verdaderas	2	0	0	0	0	0
	3	38	16 9.6	0	0	0
	4	55	20 12	21	6	10
Ramificación	5	55	20 12	27	8	10
Panojamiento	6	91	29 17.4	27	10	10
	7	115	29 17.4	33	20	16
Floración	8	112	25 15	38	20	16
	9	110	20 12	43	20	16
	10	95	16 9.6	53	16	10
Grano lechoso	11	90	12 7.2	64	18	10
	12	85	8 4.8	64	20	16
	13	0	0	64	16	10
Grano pastoso	14	0	0	64	0	0
	15	0	0	0	0	0
Grano duro	16	0	0	0	0	0
	17	0	0	0	0	0
	18	0	0	0	0	0
	19					
	20					
	21					
TOTAL		846	197	500	151	125

Appendix H. List of agrochemicals and time of application (DAS: Days after sowing)

DAS	Target	Type or function	Active ingredient	Unit	Dose/ha
-2	Adjuvant (pH)	Adjuvant	Phosphoric acid	Lt	0.08
-2	weed	Herbicide	Paraquat	Lt	3.00
-2	cutworm	Insecticide	Alphacypermethrin	Lt	0.66
-2	Surfactant	Surfactant	Organo-silicon surfactant	Lt	0.16
0	Fusarium	Fungicide	Benomyl	kg	0.40
0	Delia platura	Insecticide	Thiodicarb	Lt	0.13
5	Adjuvant (pH)	Adjuvant	Phosphoric acid	Lt	0.08
5	cutworms & leaf-eaters	Insecticide	Alphacypermethrin	Lt	0.20
5	cutworms & leaf-eaters	Insecticide	Methomyl	kg	0.40
5	Surfactant	Surfactant	Organo-silicon surfactant	Lt	0.12
16	Adjuvant (pH)	Adjuvant	Phosphoric acid	Lt	0.08
16	growth regulator	Phytoalexins' inductor	Potassium phosphite	Lt	1.00
16	cutworms & leaf-eaters	Insecticide	Emamectin benzoate	kg	0.20
16	Downy mildew	Fungicide	Metalaxyl+Mancozeb	kg	2.00
16	Surfactant	Surfactant	Organo-silicon surfactant	Lt	0.16
25	Adjuvant (pH)	Adjuvant	Phosphoric acid	Lt	0.08
25	Downy mildew	Fungicide	Dimethomorph+Mancozeb	kg	2.00
25	growth regulator	Plant bio-stimulator	amino acids	Lt	1.00
25	growth regulator	Phytoalexins' inductor	Potassium phosphite	Lt	1.00
25	Surfactant	Surfactant	Organo-silicon surfactant	Lt	0.16
34	Adjuvant (pH)	Adjuvant	Phosphoric acid	Lt	0.08
34	Downy mildew	Fungicide	Cymoxanil+Mancozeb	kg	2.00
34	Foliar fertilizer	Foliar fertilizer	Liquid fertilizer (foli-zyme)	Lt	2.00
34	growth regulator	Plant bio-stimulator	Auxin, cytokinin, gibberellin	Lt	0.80
34	leaf-eaters	Insecticide	Emamectin benzoate	kg	0.20
34	Surfactant	Surfactant	Organo-silicon surfactant	Lt	0.16
42	Adjuvant (pH)	Adjuvant	Phosphoric acid	Lt	0.10
42	Downy mildew	Fungicide	Cymoxanil+Propineb	kg	2.50
42	growth regulator	Phytoalexins' inductor	Potassium phosphite	Lt	1.25
42	improve grain filling	Grow regulation	Cytokinin, auxin, gibberellin	Lt	0.31
42	Chinch bug	Insecticide	Spinetoram	Lt	2.00
42	Surfactant	Surfactant	Organo-silicon surfactant	Lt	0.20
*51	Adjuvant (pH)	Adjuvant	Phosphoric acid	Lt	0.10
51	Downy mildew	Fungicide	Copper sulphate	Lt	1.25
51	Chinch bug	Insecticide	Deltamethrin	Lt	0.63
51	Surfactant	Surfactant	Organo-silicon surfactant	Lt	0.20
60	Adjuvant (pH)	Adjuvant	Phosphoric acid	Lt	0.10
60	Downy mildew	Fungicide	Copper sulphate	Lt	1.25
60	Chinch bug	Insecticide biological	Matrine	Lt	1.88
60	Surfactant	Surfactant	Organo-silicon surfactant	Lt	0.20

* Optional pesticide application after 45 DAS when pest and disease attack are severe

Appendix I. Survey filled with activities at different plant development stages, and cost of production. From a farm of 5 ha size, amounts were standardized to 1 ha

Farm code	E1-52	Farm price	1.1	$/kg
Area (ha)	1	yield kg/ha	5868	kg

Date	DAS	Category	Activity	unit	amount/ha	cost unit $/ha	total $/ha	owner $/ha
		1. Pre-sowing	***soil preparation***					
16-Apr-16	-25	plough	disc plough to incorporate plant residuals and invert soil	h/mach	2.2	37.5	83	
21-Apr-16	-20	plough	disc harrow to crush soil	h/mach	1.2	21.9	26	
29-Apr-16	-12	weed	herbicide (Paraquat)	L	3.0	14.7	44	
29-Apr-16	-12	pest	insecticide (Alphacypermethrin)	L	0.6	18.8	11	
29-Apr-16	-12	spraying	fumigation	labour	1.0	18.8	19	18.8
30-Apr-16	-11	harrow	harrow to shatter clods	h/mach	3.0	21.9	66	
30-Apr-16	-11	harrow	rigid tiller to loosen the soil and prepare seed bed	h/mach	1.0	21.9	22	
1-May-16	-10	furrow	ridge furrow to furrow and level beds	h/mach	1.6	21.9	35	
		1. Pre-sowing	***installing drip irrigation system***					
1-May-16	-10	irrigation	tube installation	labour	1.0	18.8	19	
1-May-16	-10	irrigation	tube installation	labour	1.0	18.8	19	18.8
1-May-16	-10	drip	drip-hose	pack	3.0	218.8	656	
2-May-16	-9	irrigation	drip installation	labour	2.0	17.2	34	
		1. Pre-sowing	***Pest control after 10 days irrigation***					
10-May-16	-1	pest	insecticide (Alphacypermethrin)	L	0.6	18.8	11	
10-May-16	-1	weed	herbicide (Paraquat)	L	3.0	14.7	44	
10-May-16	-1	spraying	Fumigation	labour	1.0	18.8	19	18.8
		2. Sowing						
10-May-16	-1	Seed	Seed acquisition from advisor	kg	10.0	9.4	94	
11-May-16	0	seeding	Sowing	labour	5.0	15.6	78	
11-May-16	0	disease	fungicide (Benomyl) for seed disinfection	kg	0.4	12.5	5	
		3. post-sowing	***emergence (BBCH 0)***					

20-May-16	9	pest	insecticide (Emamectin benzoate) to control cutworms	kg	0.2	17.2	3	
20-May-16	9	pest	insecticide (Cypermethrin) to control leafeaters	L	0.7	20.3	14	
20-May-16	9	adjuvant	surfactant	L	0.1	40.6	5	
20-May-16	9	spraying	fumigation	labour	1.0	18.8	19	18.8
		3. post-sowing	***vegetative stage (BBCH 1)***					
28-May-16	17	thinning out	thin out	labour	6.0	15.6	94	
28-May-16	17	thinning out	thin out	labour	1.0	15.6	16	15.6
31-May-16	20	adjuvant	pH control (Phosphoric acid)	L	0.0	3.8	0	
31-May-16	20	disease	fungicide (Metalaxyl+Mancozeb) to control downy mildew	kg	2.0	21.9	44	
31-May-16	20	growth regulator	bio stimulator (Potassium phosphide)	L	1.0	15.6	16	
31-May-16	20	growth regulator	hormones (cytokinin, auxins, gibberellins)	L	0.6	37.5	23	
31-May-16	20	adjuvant	surfactant	L	0.1	40.6	2	
31-May-16	20	spraying	Fumigation	labour	1.0	18.8	19	18.8
		3. post-sowing	***branching stage (BBCH 4)***					
5-Jun-16	25	weeding	weeding	labour	7.0	15.6	109	
5-Jun-16	25	weeding	weeding	labour	1.0	15.6	16	15.6
		3. post-sowing	***ear formation (BBCH 5)***					
17-Jun-16	37	adjuvant	pH control (Phosphoric acid)	L	0.0	3.8	0	
17-Jun-16	37	disease	fungicide (Dimethomorph+Mancozeb)	kg	2.0	21.9	44	
17-Jun-16	37	growth regulator	bio stimulator	L	2.0	15.6	31	
17-Jun-16	37	growth regulator	hormones	kg	0.5	21.9	11	
17-Jun-16	37	growth regulator	agrochemical*	L	0.4	15.6	6	
17-Jun-16	37	adjuvant	surfactant	L	0.1	40.6	3	
17-Jun-16	37	spraying	Fumigation	labour	1.0	18.8	19	18.8
29-Jun-16	49	weeding	weeding	labour	8.0	15.6	125	
29-Jun-16	49	weeding	weeding	labour	1.0	15.6	16	15.6
		3. post-sowing	***florescence (BBCH 6)***					
30-Jun-16	50	adjuvant	pH control (Phosphoric acid)	L	0.1	3.8	0	
30-Jun-16	50	disease	fungicide (Cymoxanil+Mancozeb)	kg	2.5	21.9	55	
30-Jun-16	50	growth regulator	Cytokinin, auxin, gibberellin	L	0.3	112.5	35	
30-Jun-16	50	growth regulator	boro+calcium to stimulate filling of grain	L	1.3	15.6	20	

30-Jun-16	50	pest	insecticide (Alphacypermethrin) against chinch bug	L	0.6	18.8	12	
30-Jun-16	50	adjuvant	surfactant	L	0.2	40.6	8	
30-Jun-16	50	spraying	Fumigation	labour	1.0	18.8	19	18.8
		3. post-sowing	***florescence ending (BBCH 69)***					
13-Jul-16	63	adjuvant	pH control (Phosphoric acid)	L	0.1	3.8	0	
13-Jul-16	63	growth regulator	bio stimulator (Potassium phosphide)	L	2.5	15.6	39	
13-Jul-16	63	growth regulator	boro+calcium to stimulate filling of grain	L	1.3	15.6	20	
13-Jul-16	63	growth regulator	hormones (cytokinin, auxins, gibberellins)	L	1.3	21.9	27	
13-Jul-16	63	pest	insecticide (Alphacypermethrin) against chinch bug	L	0.6	18.8	12	
13-Jul-16	63	adjuvant	surfactant	L	0.1	40.6	5	
13-Jul-16	63	spraying	Fumigation	labour	1.0	18.8	19	18.8
		4. harvest	***Mature grain (BBCH 89)***					
8-Sep-16	120	harvesting	harvest	labour	6.0	18.8	113	
8-Sep-16	120	harvesting	harvest	labour	1.0	18.8	19	18.8
		5. post-harvest	***threshing***					
19-Sep-16	131	harvesting	threshing	labour	2.0	15.6	31	
19-Sep-16	131	thresh	Thresher	mach/ha	2.0	125.0	250	
		6. fertilizers	**type of fertilizer**					
		N	ammonium nitrate	kg	287.0	1.1	313	
		P	monoammonium phosphate	kg	58.0	2.2	125	
		K	Potassium sulphate	kg	296.0	1.0	302	
		Ca	Calcium nitrate	kg	36.0	0.5	19	
		Mg	Magnesium sulphate	kg	24.0	2.3	56	
		7. others						
		transport	transport agrochemicals	unit	2.0	9.4	19	
		water	water tax	month	5.0	7.8	39	
		land rent	land/field rent	month	1.0	781.3	781	
			Total expenses				4255	216
			Grain sold				6693	
			gross margin (income)				**2439**	

Appendix J. Puno data

field	variety	grain DM (kg/ha)	total DM (kg/ha)	grain N-uptake (kg)	grain NUE (%)	HI	crude protein	N fertilizer (kg/ha)	harvest loss
Field01	blanca_de_juli	580	3420	11	9	17	12	124	Weed&manure
Field01	blanca_de_juli	144	2903	3	2	5	12	124	Weed&manure
Field01	blanca_de_juli	805	5024	15	12	16	12	124	
Field01	blanca_de_juli	2214	7694	41	34	29	12	124	lodging
Field01	blanca_de_juli	5292	15349	99	80	34	12	124	
Field02	blanca_de_juli	864	1923	17	15	45	12	113	Weed&birds
Field02	blanca_de_juli	1158	2427	23	20	48	12	113	
Field02	blanca_de_juli	1923	4560	38	33	42	12	113	
Field02	blanca_de_juli	1330	3349	26	23	40	12	113	
Field02	blanca_de_juli	2260	5336	44	39	42	12	113	
Field03	blanca_de_juli	5649	13557	140	50	42	16	279	
Field03	blanca_de_juli	4884	12085	121	43	40	16	279	
Field03	blanca_de_juli	3892	9893	97	35	39	16	279	
Field03	blanca_de_juli	4664	11487	116	42	41	16	279	
Field03	blanca_de_juli	3239	8265	80	29	39	16	279	lodging
Core01	blanca_de_juli	1953	4683	40	11	42	13	350	birds
Trial01	blanca_de_juli	1803	4333	37	10	42	13	350	birds+qona_qona
Trial01	blanca_de_juli	2942	6077	60	17	48	13	350	
Trial01	blanca_de_juli	3050	7398	62	18	41	13	350	
Trial01	blanca_de_juli	3309	7308	67	19	45	13	350	
Trial02	kcancolla	2069	4334	48	14	48	15	350	
Trial02	kcancolla	2298	5418	54	15	42	15	350	
Trial02	kcancolla	2177	5088	51	15	43	15	350	
Trial02	kcancolla	2068	5007	48	14	41	15	350	
Trial02	kcancolla	2079	5071	49	14	41	15	350	
Trial03	Salcedo	1828	4730	43	12	39	15	350	Qona-qona
Trial03	Salcedo	2642	6366	62	18	41	15	350	
Trial03	Salcedo	2027	5833	47	14	35	15	350	
Trial03	Salcedo	1237	3793	29	8	33	15	350	weed+qonaqona
Trial03	Salcedo	1250	3945	29	8	32	15	350	weed+qonaqona
Trial04	pasancalla	1541	4270	28	8	36	11	350	
Trial04	pasancalla	2265	5986	41	12	38	11	350	
Trial04	pasancalla	1858	6238	33	10	30	11	350	
Trial04	pasancalla	1726	4866	31	9	35	11	350	
Trial04	pasancalla	1831	4291	33	9	43	11	350	
Trial05	negra_collana	942	2669	23	6	35	15	350	weed+birds
Trial05	negra_collana	2338	4816	56	16	49	15	350	
Trial05	negra_collana	1758	3773	42	12	47	15	350	
Trial05	negra_collana	1549	3372	37	11	46	15	350	weed
Trial05	negra_collana	1826	5161	44	13	35	15	350	
Field04	blanca_de_juli	2809	7313	63	85	38	14	74	weed+manure
Field04	blanca_de_juli	1594	4510	36	48	35	14	74	weed+manure
Field04	blanca_de_juli	1611	4534	36	49	36	14	74	
Field04	blanca_de_juli	2123	5665	48	64	37	14	74	

Field04	blanca_de_juli	1105	3543	25	34	31	14	74	weed+manure
Field05	blanca_de_juli	719	3059	15	19	24	13	76	weed+manure
Field05	blanca_de_juli	441	1316	9	12	34	13	76	weed+manure
Field05	blanca_de_juli	356	1467	7	10	24	13	76	weed+manure
Field05	blanca_de_juli	860	2584	17	23	33	13	76	weed+manure
Field05	blanca_de_juli	333	1228	7	9	27	13	76	weed+manure
Field06	blanca_de_juli	2007	5870	44	49	34	14	90	
Field06	blanca_de_juli	2369	6479	52	58	37	14	90	
Field06	blanca_de_juli	2388	6484	52	58	37	14	90	
Field06	blanca_de_juli	1383	4406	30	34	31	14	90	weed
Field06	blanca_de_juli	3017	6995	66	73	43	14	90	
Field07	blanca_de_juli	1521	6234	35	21	24	14	165	
Field07	blanca_de_juli	756	4907	17	10	15	14	165	weed+qonaqona
Field07	blanca_de_juli	2622	8875	60	36	30	14	165	
Field07	blanca_de_juli	2599	8435	59	36	31	14	165	
Field07	blanca_de_juli	3154	8104	72	43	39	14	165	
Field08	blanca_de_juli	466	2063	10	11	23	13	92	qonaqona
Field08	blanca_de_juli	1190	4740	25	27	25	13	92	
Field08	blanca_de_juli	1056	5358	22	24	20	13	92	
Field08	blanca_de_juli	494	3858	10	11	13	13	92	qonaqona
Field08	blanca_de_juli	1316	4971	28	30	26	13	92	
Field09	Salcedo	1118	2750	26	13	41	15	206	
Field09	Salcedo	1319	2444	31	15	54	15	206	
Field09	Salcedo	1341	3024	31	15	44	15	206	
Field09	Salcedo	737	1714	17	8	43	15	206	weed
Field09	Salcedo	878	1956	21	10	45	15	206	weed+birds
Field09	Salcedo	851	1829	20	10	47	15	206	weed+birds
Field10	blanca_de_juli	2004	3875	39	19	52	12	206	
Field10	blanca_de_juli	1002	2028	20	9	49	12	206	
Field10	blanca_de_juli	1421	2649	28	13	54	12	206	
Field10	blanca_de_juli	1260	2952	25	12	43	12	206	
Field10	blanca_de_juli	131	815	3	1	16	12	206	weed+birds

Appendix K. Majes data

field	variety	grain DM (kg/ha)	total DM (kg/ha)	grain N-uptake (kg)	NUE (%)	HI	crude protein	N fertilizer (kg/ha)	harvest loss
Field01	Salcedo	4313	10283	94	34	42	14	278	
Field01	Salcedo	3311	8231	72	26	40	14	278	
Field01	Salcedo	4401	9778	95	34	45	14	278	
Field01	Salcedo	1728	3486	37	13	50	14	278	water
Field01	Salcedo	3118	6969	68	24	45	14	278	
Field02	Salcedo	2614	6466	58	21	40	14	272	
Field02	Salcedo	3004	6833	66	24	44	14	272	
Field02	Salcedo	2353	5184	52	19	45	14	272	
Field02	Salcedo	2827	6009	62	23	47	14	272	
Field03	blanca_de_juli	3416	8483	88	NA	40	17	NA	
Field03	blanca_de_juli	2855	6821	74	NA	42	17	NA	
Field03	blanca_de_juli	2655	6689	69	NA	40	17	NA	
Field03	blanca_de_juli	1503	3545	39	NA	42	17	NA	weed
Field04	Salcedo	2993	7007	77	41	43	16	188	
Field04	Salcedo	3375	6811	87	46	50	16	188	
Field04	Salcedo	4877	9963	126	67	49	16	188	
Field04	Salcedo	4252	10039	109	58	42	16	188	
Field04	Salcedo	2028	5773	52	28	35	16	188	weed
Field05	Salcedo	3600	9800	93	41	37	16	226	
Field05	Salcedo	2543	5706	65	29	45	16	226	
Field05	Salcedo	3164	7154	81	36	44	16	226	
Field06	Salcedo	2495	5613	64	43	44	16	148	
Field06	Salcedo	2273	5337	58	39	43	16	148	
Field06	Salcedo	2780	6359	71	48	44	16	148	
Field06	Salcedo	1593	3207	41	28	50	16	148	weed
Field06	Salcedo	1397	3631	36	24	38	16	148	weed
Field07	Salcedo	3492	7533	74	60	46	14	124	
Field07	Salcedo	2921	6263	62	50	47	14	124	
Field07	Salcedo	3012	6327	64	52	48	14	124	
Field07	Salcedo	2452	5703	52	42	43	14	124	
Field07	Salcedo	257	1099	5	4	23	14	124	birds+weed
Field08	Salcedo	4499	11599	122	46	39	17	266	
Field08	Salcedo	4304	10472	117	44	41	17	266	
Field08	Salcedo	4568	12497	124	47	37	17	266	
Field08	Salcedo	2337	6668	63	24	35	17	266	water
Field08	Salcedo	3448	9313	93	35	37	17	266	weed
Field09	Salcedo	2319	5313	52	45	44	14	116	
Field09	Salcedo	2952	5941	67	57	50	14	116	
Field09	Salcedo	1784	3546	40	35	50	14	116	weed
Field09	Salcedo	1539	3218	35	30	48	14	116	water+weed
Field09	Salcedo	1220	2363	28	24	52	14	116	water
Field10	Salcedo	5928	15049	142	50	39	15	287	
Field10	Salcedo	6793	15669	163	57	43	15	287	

Field10	Salcedo	5309	12156	128	44	44	15	287	
Field11	Salcedo	3465	8456	81	70	41	15	115	weed
Field11	Salcedo	4669	10285	109	95	45	15	115	
Field11	Salcedo	5514	11926	129	112	46	15	115	
Field11	Salcedo	4154	9911	97	84	42	15	115	
Field11	Salcedo	5356	12789	125	108	42	15	115	
Field12	Salcedo	4178	8448	91	NA	49	14	NA	
Field12	Salcedo	3099	7498	67	NA	41	14	NA	
Field12	Salcedo	3089	7740	67	NA	40	14	NA	
Field12	Salcedo	4084	8748	89	NA	47	14	NA	
Field12	Salcedo	2975	6519	65	NA	46	14	NA	water
Field13	Salcedo	4112	8716	115	55	47	17	208	
Field13	Salcedo	3816	8859	107	51	43	17	208	
Field13	Salcedo	3948	10824	111	53	36	17	208	
Field13	Salcedo	3604	8289	101	49	43	17	208	
Field13	Salcedo	5979	14433	167	81	41	17	208	
Field14	Salcedo	1568	3741	30	29	42	12	103	water+weed
Field14	Salcedo	2040	5021	39	38	41	12	103	weed
Field14	Salcedo	4673	10979	89	86	43	12	103	
Field14	Salcedo	4436	10953	84	82	41	12	103	
Field14	Salcedo	3438	8615	65	64	40	12	103	
Field15	Salcedo	1855	3910	39	37	47	13	106	weed
Field15	Salcedo	1976	5165	42	40	38	13	106	weed
Field15	Salcedo	1469	3824	31	29	38	13	106	weed
Field15	Salcedo	1888	5909	40	38	32	13	106	
Field15	Salcedo	4251	9666	90	85	44	13	106	
Field16	Salcedo	3816	8852	81	33	43	12	248	weed
Field16	Salcedo	4449	9389	94	38	47	12	248	
Field16	Salcedo	4716	11821	100	40	40	12	248	
Field16	Salcedo	5082	10510	108	43	48	12	248	
Field16	Salcedo	3710	8467	79	32	44	12	248	
Field17	Salcedo	3756	7595	80	45	49	13	176	
Field17	Salcedo	5103	13379	109	62	38	13	176	
Field17	Salcedo	2184	5866	47	26	37	13	176	water
Field18	Salcedo	2643	5963	57	NA	44	14	NA	water
Field18	Salcedo	4184	9320	91	NA	45	14	NA	
Field18	Salcedo	3074	6484	67	NA	47	14	NA	
Field19	Salcedo	3075	6357	67	39	48	14	173	P management
Field19	Salcedo	2191	4475	47	28	49	14	173	P management
Field19	Salcedo	3284	6645	71	41	49	14	173	P management
Field19	Salcedo	1360	2839	29	17	48	14	173	weed+P
Field20	Salcedo	3330	10833	75	29	31	15	260	
Field20	Salcedo	3448	11265	78	30	31	15	260	
Field20	Salcedo	3288	12140	74	29	27	15	260	
Field20	Salcedo	2374	6844	54	21	35	15	260	
Field20	Salcedo	2478	6711	56	22	37	15	260	

Appendix L. Scheme of survey for farmers in the study area

Cultivo de quinua	Nombre: *Propietario: ☐ **Arrendatario: ☐	Ficha nr.: Parcela nr: Area quinua (ha/topo): Area total parcela(ha):	
Variedad	*Con camayo: Sueldo:	** Costo Alquiler:	
Cadena productiva: ☐	Independiente: ☐		

Cultivo previo	Duración	Fertiliz. NO3	Rendimiento
2 campaña ant.			
1 campaña ant			
campaña despu.			

Semilla (kg/ha)	Calculado:
	Usado:

Distancia de surco (cm):

Rendimiento (kg)

Etapa / Estadío	DDS	Semana	Labor Cultural / Plan de Acción	Cantidad	Unidad	Costo S/.	Nota / Observación
Antes de la siembra (mes______)	-20	-3	1 rompe de terreno				
			2 incorpora Estiércol o Gallinacea				incluye transporte?
			3 volteado con polidisco				
			4 rastrado/desmenuzar/retirar basura				
			5 Surcado y nivelado				
			6 Tendido de cintas				
	-2		7 herbicida fumiga o por sistema				
			8 Adquisición semilla, quién provee				
			9				
Siembra (D0)	0	0	10 Desinfecta la semilla?				
(fecha:___/___/___)	0	0	11 maquina o jornal (golpe, gancho)				
Emergencia			12 Evaluación resiembra				
			13 quién hace la resiembra?				
(DAS 7-10)			14 presencia de plagas o culebrilla?				
Despues de Emergimiento total			15 ha raleado (jalado) o desahijado?				
			16 presencia de plagas? control				
			17 presencia de mildew? control				
(DAS 15-30)			18				
Estadío IV			19 deshierbe o qoreado				
(Ramificación)			20 Evaluación o aplica adyuvantes o reguladores?, i.e Ca, Mg, K				
(DAS 35-45)			21				
Estadío V			22 Evaluación o aplica adyuvantes o reguladores?, i.e Ca, Mg, K				
(Panojamiento)			23				
(DAS 45-55)			24				
Estadío VI			25 Evaluación o aplica adyuvantes o reguladores?, i.e Ca, Mg, K				
(Floración)			26 Presencia de plagas? Control				
(DAS 55-75)			27 Presencia mildiu¨?				
			28				

Estadío VI			25 Evaluación o aplica adyuvantes o reguladores?, i.e Ca, Mg, K				
(Floración)			26 Presencia de plagas? Control				
(DAS 55-75)			27 Presencia mildiu¨?				
			28				
Estadío VII			29 Evaluación o aplica adyuvantes o reguladores?, i.e Ca, Mg, K				
(Grano lechoso)			30 Presencia de plagas? control				
(DAS 75-95)			31 presencia de mildiu? Control				
			32				
Estadío VIII			33 Presencia de plagas? Control				
(Grano pastoso)			34 Evaluación o aplica adyuvantes o reguladores?, i.e Ca, Mg, K				
(DAS 95-105)			35 Aves control?				
			36				
Grano Maduro			37 Evaluación color panoja, grano?				
(DAS 105-120)			38 Aves control?				
Antes de Cosecha			39 Evalua posible rendimiento?				
Cosecha			40 corte o siega peones, cuadrilla?				
			41 Disposición y tiempo secado quinua				
(fecha:___/___/___)			42				
Despues de cosecha			43 trillado con máquina estacionaria o móvil				
			44 Peones para trillado				
			45 almacena grano o vende de inmediato?				
			46				
			47 Que hace con residuos?				