La GranjA:
Revista de
Ciencias de la Vida
pISSN:1390-3799; eISSN:1390-8596
http://doi.org/10.17163/lgr.n26.2017.12

Scientific paper / Artículo científico

Agricultural Sciences

Community use of water and land for sustainable production of pasture

Uso comunitario del agua y del suelo para la producción sustentable de pasturas

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Manuscript sent on March 17, 2017. Accepted, after review, on July 22, 2017. Published on September 1, 2017.

Abstract

Milk livestock is the main system of production of the Andean communities of the Ecuador. Feeding of the animals is based with pastures, that every day is more difficult by the division of the lands "minifundios.ªnd changes in rainfall cycles. However, to maintain a constant and sustainable production, small farmers implement community systems of sprinkler irrigation, which optimize the use of soil and water. The project aimed to study the land use, efficiency of systems of irrigation, quality, and health of soil as indicators of sustainability in the production of pastures. Surveys to water users were conducted to determine the use of the soil, the irrigation efficiency were evaluated at the level of main channel, distribution and in the plot, and representative soil samples were taken throughout in the territory. It was noted that there is a stratification of the land according to the size of farms, farm-level water use efficiency is low and the quality of soils varies with altitudinal belts. It is concluded that the production of pastures for cattle feeding is done on farms between 1 to 5 ha., in the altitudinal zones of 2,850 to 3,600 m. above sea level. The implementation of sprinkler irrigation systems and management of soil quality indices contribute to sustainable pasture production.
Keywords: Sprinkler irrigation efficiency; pasture production; land use; quality of soil

Resumen

La ganadería de leche es el principal sistema de producción de las comunidades andinas del Ecuador. La alimentación de los animales se basa en el cultivo de pasturas, que cada día es más difícil por el minifundio de las tierras y cambios en los ciclos de lluvias. Sin embargo, para mantener una producción constante y sustentable, pequeños productores implementan sistemas de riego por aspersión comunitarios que optimizan el uso de los elementos suelo y agua. El objetivo del proyecto fue estudiar el uso de la tierra, eficiencia de los sistemas de riego, y la calidad y salud de suelo como indicadores de sustentabilidad en la producción de pasturas. Se realizaron encuestas a usuarios del riego de la cuenca del río Pisque, se evaluó la eficiencia del riego a nivel de conducción principal, distribución y en parcela y, se tomaron muestras de suelo representativas en todo el territorio. Se observó que hay una estratificación de la tierra según el tamaño de unidades productivas (UPA's) en donde se cultiva pasturas, la eficiencia del uso del agua a nivel de finca es baja con respecto a los otros niveles, y la calidad de los suelos varía según fajas altitudinales. En sí, la producción de pasturas para la alimentación del ganado bovino es realizada en fincas entre 1 a 5 ha y se encuentran en zonas altitudinales de 2 850 a 3 600 msnm, la implementación de sistemas de riego por aspersión y manejo de los índices de calidad de los suelos aportan a la producción sustentable de pasturas.
Palabras claves: Eficiencia riego por aspersión, uso de suelo, cultivo de pasturas, calidad del suelo.

Suggested citation: Cachipuendo, C., De Jesús, N., Gualavisí, O., Sandoval, C., Sandoval, J.. 2017. Community use of water and land for sustainable production of pasture. La Granja: Journal of Life Sciences. Vol. 26(2):142-154. pISSN:1390-3799; eISSN:1390-8596.

1 Introduction

The sustainability approach is a tool for the planning of agricultural production in a rural territory (Senisterra, Gaspari, & Delgado, 2015), and proposes a good use of water and land, among other factors. Aguirre (2010) mentions that, from the agroecological perspective, livestock can be sustainable if elements that allow the durability of the social and ecological mechanisms of reproduction of the ethno-agroecosystem are combined. Among the main ones he notes are: i) the breakdown of forms of dependence that endanger the reproductive mechanisms, be they of an ecological, socioeconomic or political nature; Ii) the use of resources that allow the existing materials and energy cycles in the agroecosystem to be as closed as possible; Iii) the use of the beneficial impacts arising from the ecological, economic, social and political environments existing in and around the production systems; And iv) non-substantive alteration of the environment when such changes through the fabric of life may imply significant transformations in the material and energy flows that allow the functioning of the agroecosystem tolerating and/or accepting adverse biophysical conditions.

Forage production as feed for dairy farms is the primary basis for Ecuador's social and economic development (Vera, 2005), but this production system requires considerable resources such as land, fertile soils and irrigation water, which in many cases are limiting factors to increase productivity (Martínez Mamian, Ruiz Erazo, & Morales Velasco, 2016), since these resources form a trilogy that determines the durability of the forage productive cycle over time (Ates et al. , 2013), which, if its equilibrium is achieved, would contribute to the non-dependence of inputs from outside the farm to ensure production throughout the productive cycles (Aguirre, 2010). For this study, the size of land tenure, the efficiency of the irrigation system and the index of soil quality and health as indicators for sustainable pasture production are considered.

The constitutional normative framework of Ecuador since 2008, proposes the paradigm of life based on Sumak Kawsay or "Buen Vivir (Good living)"where nature is a subject of rights and Ecuadorian society is oriented to live in harmony with the natural environment and not only have their basic needs met, i.e. there is a legal framework that contributes to the environmental dimension of sustainability can be incorporated into public policy. Thus, land use, water and soil management should be focused on food production and the generation of decent living conditions in the rural sector (Acosta, 2014).

In order to plan a territory, every organization must implement an information management system that is responsible for selecting, processing and distributing information on land use, soil and water management (Aja, 2002). Is the üser registry"that records: land ownership, production systems, water management, irrigation method, land use and the functioning of organized irrigation societies (Magaz, Hijano, & Martín, 2008). User patterns are geared towards agricultural purposes and depending on the approach that one wants to give to the analysis of reality, the application methodology is adjusted.

Water is managed by communities and organizations considering the principles of equity and solidarity (Sandoval Moreno & Günther, 2013); however, there are no technical parameters for water distribution and application in agricultural production units (APUs), such as: the water requirement, the net irrigation index according to crop development, local climatic conditions and soil type (Martínez Mamian et al., 2016). In this context an indicator of sustainability is the efficient use of water, determined by the relationship between the water requirements of the crop and those applied with the method known as technical efficiency that differs from economic efficiency or also known as economic valuation of water (López Geta, Rubio Campos, & Martín Machuca, 2005).

Irrigation is not only an infrastructure, but an interrelated set of physical, environmental, cultural and socio-economic elements located in a given territorial space that uses water in a timely manner, in quantity and quality to obtain maximum agricultural productivity (Guzmán C., Castro V., JÃŒngwirth M., & Palenque N., 2002). Therefore, the technical efficiency of community irrigation is closely related to the management activities that irrigation organizations implement (Van Halsema & Vincent, 2012), in an irrigation system according to the forms of organization that compose it determines the efficiency at the plot level, the irrigation community (distribution) and the main channel (Playán, 1994).

Another factor that determines the production of forage is the knowledge of the nutritional concentration of soils, the analysis of soil fertility is a key tool in sustainable agriculture, there must be a nutritional balance (inputs and outputs), being a critical factor when the çrop.ºutputs are greater than the "nutrientïnputs generating a nutritional deficit for future production, therefore, the study of the fertility indexes together with the slope Figure allows defining the potential use of the soil (García & Martínez , 2007). In the medium term, through this tool, agricultural practices are generated that consider the relationships of soil, plant, water and biota related to the rhizosphere (Vivanco, 2011).

The Decentralized Autonomous Government of the province of Pichincha GADPP in its Diagnosis of Irrigation and Drainage (2014) mentions that the agricultural activity that occupies 32.5 % of the Economically Active Population (EAP) at the rural level is the cattle raising for milk that takes on importance as a source of employment for the population of the indigenous and peasant communities of the province. In this context, this article analyzes the use and size of the land, the efficiency of irrigation systems and the index of soil quality and health, as indicators of the sustainable production of grassland in the left margin of the Pisque river basin

2 Methodology

The research was carried out with 25 irrigation organizations from the Andean communities on the left bank of the Pisque river basin located north of the province of Pichincha, 75 km from the capital of Ecuador (Figure 1). Average temperature of 13.6 ° C, an annual precipitation of 519.23 mm, and its topography is undulating with soils of volcanic origin, the territory belongs to the Kayambi people. The main productive activities with irrigation are: flower production, milk production and products for self-consumption (vegetables, cereals and tubers) (Moreno, 2015).

A participatory approach was used to collect information. The participation of irrigation system leaders for the generation of information was fundamental, and interviews, survey and direct observation were used as research tools.

In the user registry, geographic information systems, field trips and orthophotos were used to geospatially locate the APUs. The characterization index card of the productive units were applied to 5 186 irrigators in conjunction with the technicians of the UPS and leaders of the irrigation systems. The evaluation of the irrigation systems was performed in each of the components, measuring flow rates, infiltrations and evaporation in the water catchments, pipelines and reservoirs, at the application level of the water in the plot, the efficiency of the sprinklers was evaluated in 27 Productive units. Finally, to establish soil fertility indicators, 196 samples were taken at a depth of 15 cm and the following parameters were analyzed in the soil laboratory of the UPS: pH, organic matter, P, K, Ca, Mg, Na , Fe, Mn, Cu, Zn, texture, bulk density and mold and yeast counts. Expressed in colony forming units per gram of dry soil (CFU/gss).

The information was validated in meetings with the leaders of the irrigation systems, for the management of the information of the users' list, a database was elaborated in the software Access and geospatially located the UPAs using the software ARCGIS.

The water requirement for grass cultivation was determined on the basis of precipitation data provided by the National Institute of Meteorology and Hydrology (INAMHI) in the period of 10 years (2003-2013) and the Penman-Monteith equation was used, the crop coefficient (kc) recommended by the Food and Agriculture Organization of the United Nations (FAO) was taken into account (Allen, 2006).

In order to determine the efficiency of the irrigation system, the analysis at the plot, distribution and main channel level was carried out as proposed by Playán (1994). The efficiency at plot level equation 1, relates the water needs of the crop and the water applied by the sprinkler expressed in percentage.

$$EA = \frac{NHc}{Aasp} \times 100 \tag{1}$$

Donde:

EA = Efficiency of application at plot level

NHc = crop water requirements

Aasp = water applied by the sprinkler on the plot

The efficiency at the distribution level is calculated with equation 2, which expresses the relation between the water applied in the plot and the water delivered to the system.

$$ED = \frac{Aap}{Aes} \times 100 \tag{2}$$

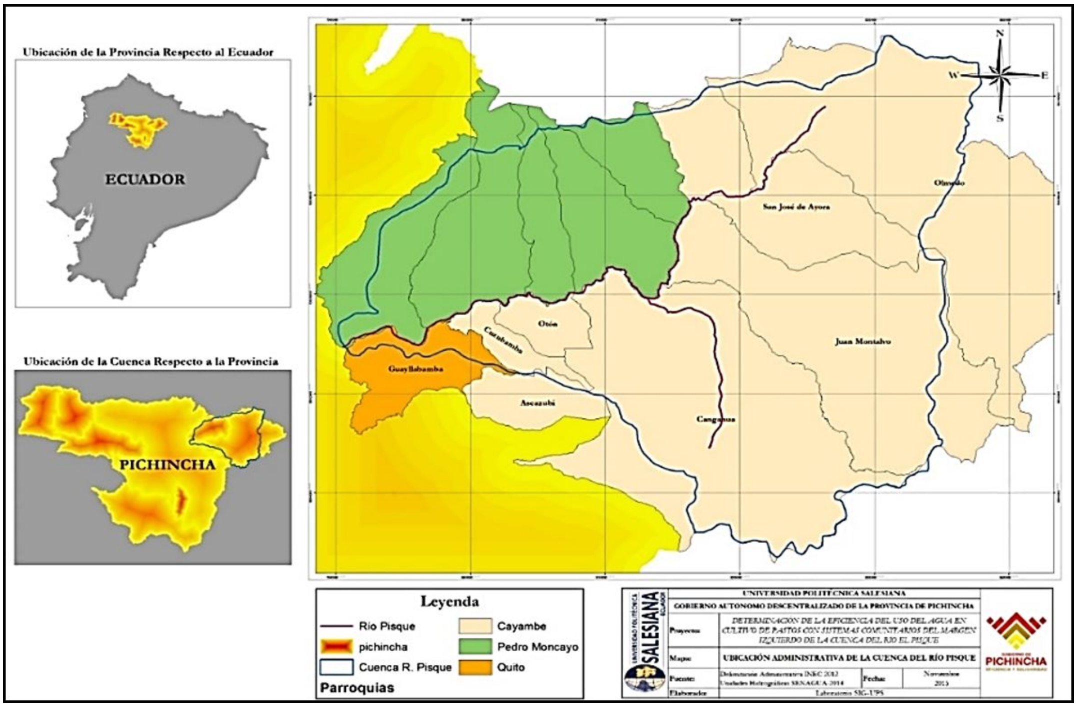

Figure 1. Administrative Location of the Pisque River Basin

Donde:

EC = Distribution efficiency

Aes = Water applied on the plot

Acp = Water delivered to the system

The efficiency at the main conduction level is the relation between the water abstracted and the one delivered to the irrigation system equation 3.

$$ED = \frac{Aes}{Acp} \times 100 \quad (3)$$

Where:

EC = Main channel efficiency

Aes = Water delivered to the system

'indent Acp = Water abstracted

To obtain system-wide efficiency, all the efficiency data described above was related to equation 4.

$$ESR = \frac{EA}{100} \times \frac{ED}{100} \times \frac{EC}{100} \times 100 \quad (4)$$

In the case of the fertility indicators, the analysis was carried out by altitudinal zones and the soil evaluation was interpolated with the physico-chemical-microbiological values of the soils using the ARCGIS software.

3 Results and discussion

3.1 Land use and land tenure for pasture production

The User Registry is a basic tool for the management of irrigation water, and it is important that the leaders of the communities, boards and/or directories of irrigation water always keep it updated, the main information is based on irrigated surface, systems Irrigation methods and number of users of the system. A total of 6 803 farms were located through the irrigation baseline and 1,037 farms (Table 1) were located with the GIS, distributed in 4 categories by farm size (971) and 66 corresponding to the area located as a community The sector. The area with the chip and the GIS totals approximately 7,840 farms located in the left bank of the Pisque river basin, 57.3% of which are less than 1 hectare, ie there is a process of minifundization of the territory in where the possibilities of capitalization of the farms are smaller and there is migration of the

Table 1. Number of farms by surface size

Category of farms by surface	No. of farms / index	No. Farms/ Ortophotos	Total No. of farms	% Farm
Farms less than 1 ha	4067	424	4491	57,3 %
Farms>1 ha hasta <5 ha	2445	309	2754	35,1 %
Farms>5 ha hasta <20 ha	275	173	448	5,7 %
Farms>20 ha	16	65	81	1,0 %
Communities/Sectors		66	66	0,8 %
TOTAL	**6803**	**1037**	**7840**	**100 %**

family members of the communities mainly seeking better opportunities of work. The minifundio also influences the design, installation and management of irrigation, this factor can cause inefficiency especially at the distribution level.

In the territory, the natural vegetation cover (highlands, herbaceous vegetation, shrub vegetation, forest) and the area of productive activities are identified, differentiating agricultural, livestock and agricultural production or mixed production (Figure 2).

Based on the information obtained through the irrigation base index, we find that 13 % of the farms are dedicated to agricultural production, 41 % of the farms have a mixed production system (agricultural-livestock), 15 % of the farms have a livestock production system, and 31 % of the farms are currently uncultivated soils.

In the agricultural subsystem, producers who allocate part of the area for the production of food for family consumption and sale of the surplus cultivate: potato, beans, corn, onion paiteña, cabbage, lettuce, carrot, radish, tomato, herbal medicine, Peas, oats, uvillas, barley, onions, cucumbers, strawberries, beans and quinoa. Others are dedicated to the cultivation of flowers and the vast majority to pasture for milk production (Table 1).

This information is relevant to the extent that it can develop processes of design, adoption and diffusion of productive systems, as well as strategies for the management of natural resources in a given territory (Torres Lima, Rodríguez Sánchez, & Sánchez Jerónimo, 2004) oriented to the higher efficiency per unit of production and not to the increase of animals per surface with parameters of low yield.

3.2 Animal load and milk production

The sustainability of productive systems goes hand in hand with the intensification of land use and land size, that is, a large number of animals fed with forage obtained in a surface unit (ha). The Andean pastures are complex, depending on the altitude and climate of the area as well as the forage species with variable availability, in Table 1 can be appreciated that farms <1 ha that have the highest percentage of improved pasture, show a higher animal load than farms>5 ha with a lower percentage of improved pastures, that is, the type of pasture determines the animal load of the farm, Requelme, (2012), reports an animal load in the area of 0.54 UBA/ha in farms of less than 5 ha in the case of extensive production systems. In terms of production, the ratio is inverse, farms>5 ha with the highest number of cows in production, have a higher production of milk 1/cow/day while farms <1 ha with less animals in production, have a lower yield (9.8 l/cow/day) but in terms of food efficiency is higher and in reducing methane emissions is less contributing thus has higher sustainability in the production of these systems of milk production.

3.3 Pasture production and water requirements

The irrigated area on the left bank of the Pisque river basin is 19 766.98 hectares, the majority of which is covered by the irrigation system of the Guanguilqui canal, which has 63 distribution ovals and an irrigated perimeter covering 4 parishes, In 43 communities and 4 famrs considering the exposed by Steel (2014). On the other hand, 11,291.36 ha of agricultural land are dedicated to the cultivation of pasture, of these 7 763.18 ha are irrigated by sprinkler

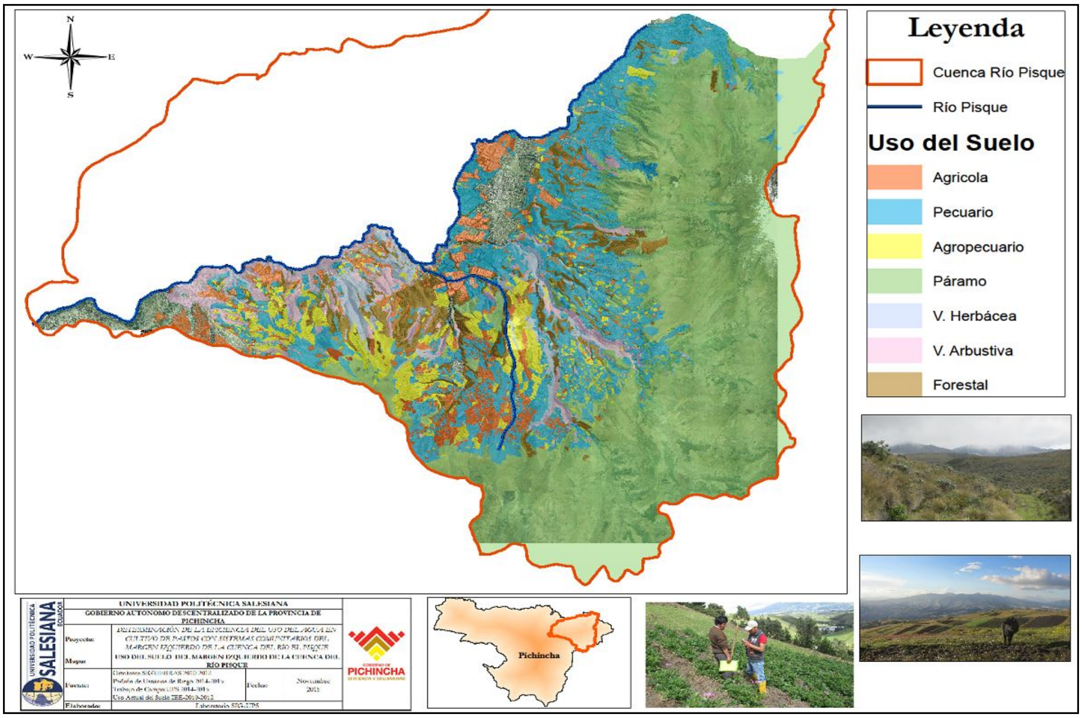

Figure 2. Identification of current land use according to natural and agricultural areas

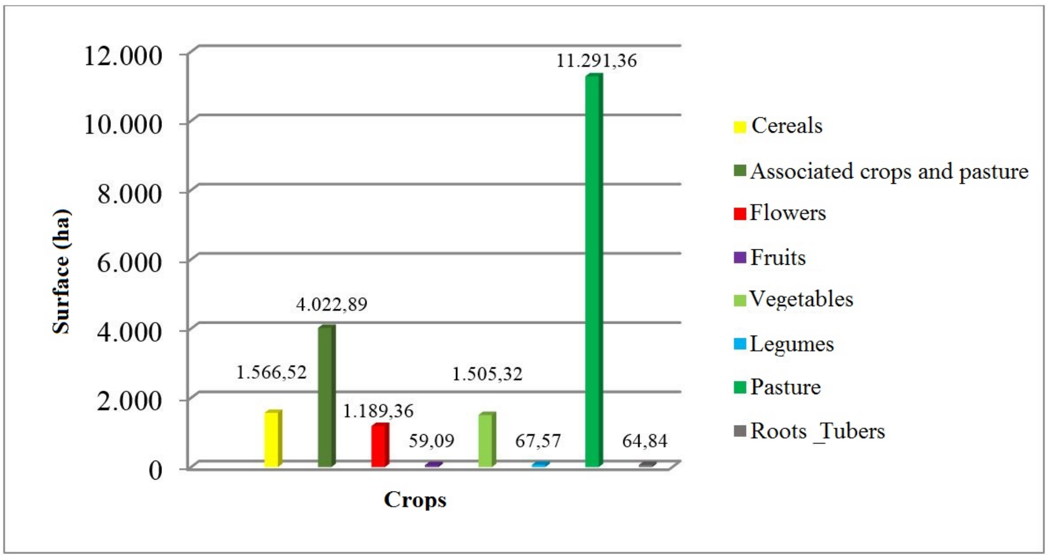

Figure 3. Area by crop type in the left margin of the Pisque river basin

Table 2. Animal load, pasture type and milk production of farms per farm stratum

Size of farm (ha)	Animal load UBAs/ha	Number of cows in production	Impoved pasture (%)	Non-impoved pasture (%)	Milk production cow/day
<1	6,28	2,21	75,85	24,15	9,82
>1 <3	4,70	3,33	77,64	22,46	9,32
>3 <5	3,76	5,22	66,31	33,69	10,47
>5	3,17	8,72	69,40	30,60	11,64
Media	**4,72**	**4,23**	**72,27**	**27,73**	**10,31**

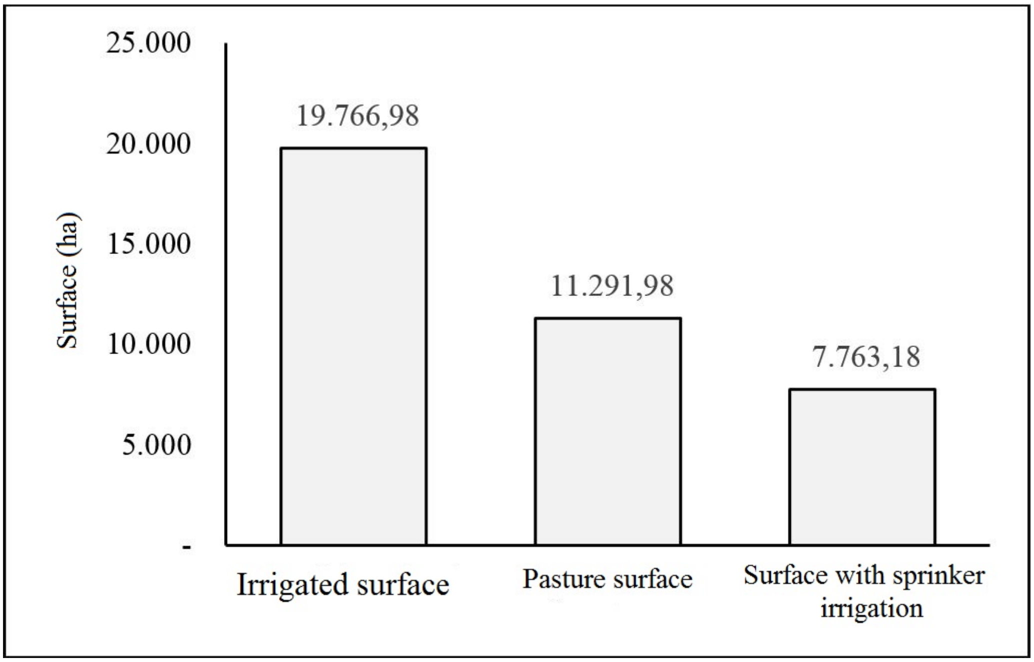

Figure 4. Irrigated area and pasture production with sprinkler irrigation

(Table 2).

The months with rainfall needed to cover crop demands were April and December with 96.02 and 78.36 mm respectively and the month with the lowest rainfall was August, this month being the one with the highest water demand (Table 3.), These months coincide with the months of high temperatures and strong winds, which increases the evapotranspiration and the water needs of the crops are higher, data that coincide with those reported by Sandoval (2014).

To supply this deficit and maintain pasture production on a constant basis throughout the year, irrigation organizations promote the pressurization of irrigation systems using the energy produced by the force of gravity, and use the method of irrigation by semifix sprinkler to apply the water in the plot. In this context, in the left margin of the Pisque river basin the surface is irrigated by three methods, about 61 % of the total surface is irrigated by spraying, 26 % water by flood and only 1 % water by drip. The remaining 12 % of the area has no irrigation at plot level. The implementation of irrigation by spraying in communitarian territories allows to optimize the use of water in agricultural production (Communal, Faysse, Bleuze, & Aceldo, 2016), allowing to increase the sustainability of the territory.

3.4 Efficiency of communitarian irrigation systems

Among the factors affecting the efficiency of the commentary sprinkler irrigation system are the size of irrigated perimeters, irrigation method and system management. With wavy topographic characteristics, inclined and the influence of the wind, the efficiency of irrigation at the plot level is 38.72 % (Table 4), being very low in comparison to those reported by other authors where irrigation by spraying oscillates between 70 % and 80 % (Cisneros, Pacheco, & Feyen, 2007). The low efficiency is attributed to wind, deteriorated fittings, hoses without their respective fittings and sprinklers in bad condition (nozzles modified) etc., another factor that greatly influences is the time of irrigation by each position of the sprinkler, that is, it applies more water than the plant requires; and, the irrigation frame is variable because the mobile equipment does not always allow a fixed distance in the overlaps.

The average efficiency at the distribution level is 74.54 % (Table 4), and it is influenced by the damages that exist in the route from the hydrants to the sprinklers where water is wasted and not is being irrigated with the whole volume of water delivered to the sector for each of the irrigation shifts or in turn the number of sprinklers that irrigate are not sufficient, i.e. the greater the irrigated perimeter the lower the efficiency. In this component, the water is pressurized and also influences the efficiency due to the loss of load that occurs in the pipelines.

The average efficiency at the main conduction level is 90 % (Table 4), mainly due to the fact that the main conduction from the uptake to the reservoir, is totally intubated in most of the evaluated systems, reason why .ªll"the flow of captured water reaches the storage site. But there are also systems that are under average and are due to the fact that the main line is open channel and on the way from the catchment to the storage place, water volumes are lost due to theft, evaporation, leaks, and vegetation that is located near the canals.

The average efficiency at the general level of evaluated irrigation systems is 30.49 % (Table 4), being a low efficiency comparing it to the results reported by Shahbaz (2006), which is around 50 %, and the 54 % reported by Uzen (2016). The optimum value is 100 %, taking into account the quantity of collected water versus the amount of water applied to the plant, but it is difficult to obtain perfection especially in Andean community irrigation systems where topographic ,climatic and mainly human factors predominate. In terms of topographic factors, strong slopes up to 45 % can be identified, the type of soil that varies from sandy, frank and clayey with their respective combinations and the type of infrastructure that in their designs only considers the hydraulic criteria leaving aside the agronomic and mainly social criteria (Playán & Mateos, 2006). The wind in the higher parts of the basin reaches up to 40 $km.h^{-1}$, which influences efficiency at the plot level and finally the most influential factor in efficiency is the social factor that depends on individual and collective human actions.

3.5 Soil quality indexes for pasture production

The evaluation of the indexes of quality and health of the soils are carried out in the area between 2 800-3 600 masl, in this altitudinal range the largest land area for pasture production was detected. In Table 5, it is observed that the soils dedicated to the produc-

Table 3. Water requirements for pasture

Month	P month mm	Water requirements en m^3		
		ha	day	month
January	47,36	25,33	286.042,27	8.867.310,31
February	62,04	19,63	221.692,93	6.429.095,09
March	72,26	16,94	191.267,69	5.929.298,43
April	96,02	8,83	99.685,60	2.990.568,02
May	48,87	25,04	282.744,26	8.765.072,17
June	29,45	28,94	326.799,33	9.803.979,94
July	16,85	31,24	352.724,43	10.581.732,79
August	10,78	35,74	403.575,06	12.510.826,88
September	23,19	36,50	412.079,89	12.362.396,82
October	72,25	19,62	221.575,56	6.868.842,23
November	69,84	19,07	215.281,75	6.458.452,62
December	78,36	26,26	296.558,80	9.193.322,66

Table 4. Average efficiency of irrigation by spray according to their levels

Efficiency by levels	Percentage
Plot	38,72
Distribution	74,54
Main channel	90,04
Average overall efficiency of evaluated irrigation systems	30,49

Table 5. Soil quality and health indexes

Average Altitudinal strips	Soil quality and health indexes	
masl	(f)	(%)
2.897	0,66	66%
3.105	0,70	70%
3.314	0,80	80%
3.480	0,81	81%
3.638	0,85	85%

tion of pastures on the 3 300 to 3600 masl, present the highest indices of quality of the soils. This indicates that the implementation of agricultural practices developed in soils over 3 300 masl, have not caused significant negative effects on physical and chemical properties. On the other hand, when reducing the altitude of the study area, the quality and health indexes of soils decrease, however, the mentioned indexes are on the values considered as suitable for the agricultural soils. Although there is a difference in relation to the quality and health index of the soils between altitudinal bands, this difference can be attributed to agricultural soil management (Communal et al., 2016).

The evaluation of the quality and health indexes of the soils obtained in the study area shows that the physical, chemical and microbiological characteristics of the analyzed soils are optimal and that the agricultural activities developed in the sector have not been able to alter the nutritional composition of the soils or to change their microbiological dynamics, on a timely basis, on the counts of colony forming units per gram of dry soil (CFU/gss) of molds and yeasts diagnosed. The latter is confirmed by Gallardo (2012), who states that the expected values of molds and yeasts in healthy high tropic soils should be between 1x106 (CFU/gss) and the microbiological values found in this research fluctuate over this value. A condition that to take care of the cultivable soils is to promote the incorporation of microorganisms to the soil that in the short term contribute in the assimilation of nutrients by the plants.

3.6 Potential pasture production

With the criteria of availability of irrigation, slope Figures and indexes of quality and health of the soils, the Figure of potential land use is elaborated for the production of pasture in the left margin of the Pisque river basin, resulting in that a surface 14 797.75 ha, would be the most advisable for this territory (Figure 5). For sustainable agricultural production the determining factor is to provide irrigation water in a timely and efficient manner (Communal et al., 2016).

4 Conclusions

Pasture production in this Andean area is mainly carried out in production units ranging from 1 to 5 ha, where the quality and health indicators of the soils are high, and farmers through innovation processes without energy costs implement systems of Sprinkler irrigation taking advantage of gravity.

The efficiency of the irrigation systems differs according to the levels, the greatest inefficiency occurs at the level of application of the water in the plot, mainly due to ignorance of the irrigator in the management of sprinklers and water indexes. At the distribution level efficiency is high because most irrigation systems have reservoirs and piped secondary and tertiary networks; and, at the main channel level, there is a high efficiency because the conduit systems from the source to the reservoirs are tubed or coated channels.

Soil quality and health indexes allow correlations of pasture production variables on soil conservation, with better indexes in the altitudinal bands close to the border or agricultural boundary (above 3 000 masl), mainly due to high contents of organic matter. The low values of pH and electrical conductivity among others, in altitudinal bands below 2 900 masl, there is a slightly neutral pH and a lower content of organic matter, so that the indicators decrease, evidenced in the erosive effect of the Soils in the sector, also these soils present a greater content of sand which allows to have soils of frank and sandy textural class. The percentage of sand on the soils decreases as the altitude increases and should be considered at the time of irrigation management. Although fertility levels range from moderate to intermediate for pasture production, it is necessary to raise awareness among producers of the importance of restoring nutrients after harvesting pastures.

The participation of research subjects generates confidence in the collection of information and, at the same time, skills and abilities are generated in the management of irrigation and soil systems, as well as the users registry allowed to know the number of users, the Irrigated surface, production systems and irrigation methods, so that decisions are based on , social, environmental, economic and technological information, so that pasture production is more sustainable in the territory. However, it remains to study the nutritional value of native fodder species in order to work fodder balances that maintain optimal levels of production and repro-

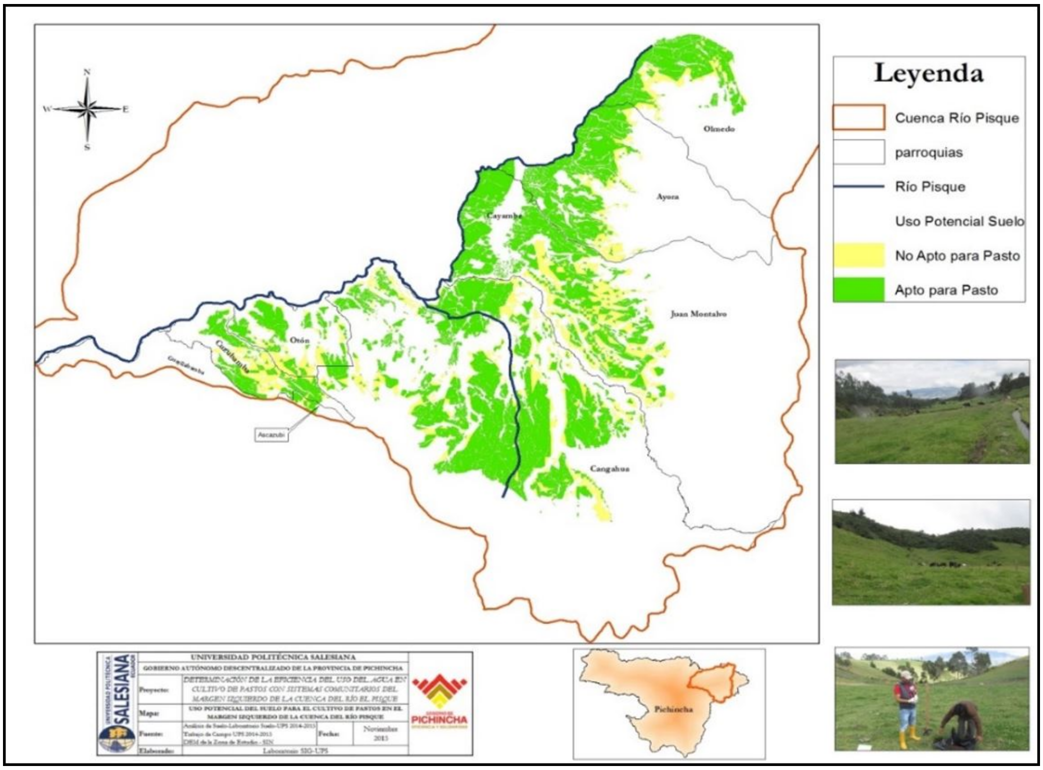

Figure 5. Potential soil use for pasture

duction and contribute to the sustainability of livestock activity.

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