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Performance of pre-hispanic irrigation systems in the Andean region of Bolivia

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ABSTRACT

In the area that is today Bolivia, the pre-Hispanic era was a period of great learning, marked by the management and use of natural resources, where farming became one of the cornerstones of production and where irrigation was an essential practice. In different areas, pre-Hispanic surface irrigation methods are still in use today, such as *kanis* irrigation and zigzag corrugated furrow irrigation. The primary aim of this paper is to compare the performance of the above irrigation systems using a potato crop at the Choquenaira Experimental Farm located at an altitude of 3877 m above sea level. During the growing cycle, there were seven irrigation events for each system.

With *kanis* irrigation, the advance times were very short due to the high flow rates and the shortness of the furrows. As a result, there were no major variations in the opportunity time. The volume of water applied per hectare during the growing cycle was 1315 m^3, while the crop-water requirement was estimated at 1854 m^3/ha. The application efficiency of irrigation varied from 18% to 100%, with deficit irrigation in three events.

In the case of zigzag corrugated furrow irrigation, the advance times were higher due to the greater length of the furrow. The total volume of water applied was 2595 m^3/ha while the calculated crop-water requirement was 2644 m^3/ha, thus quite similar. The application efficiency of irrigation varied from 18% to 91.3%, with deficit irrigation and high values of surface runoff.

The time required for irrigation, and by extension the labour required, is greater for the *kanis* irrigation system, which is consequently regarded as more suited to small areas of land. The yield of potato tubers was larger using the *kanis* method compared to the zigzag furrow irrigation method due to the more efficient use of water.

1. Introduction

Recent research has confirmed that there were humans living in the area we know today as Bolivia as far back as 8900 BC. From that time onwards, there was a gradual evolution spanning various time periods; the pre-Hispanic period is characterized by a period of learning how to efficiently manage and use natural resources, reflected in the different cultural solutions found by the different peoples, and marks the time when agriculture became one of the cornerstones of production (Medinaceli, 2015). The pre-Hispanic era saw a worsening of the climatic conditions with periods of severe drought, the worst occurring between 1250 and 1310 AD. At this time, irrigation became the most essential element for growing foodstuffs, such as potato, corn, coca, peppers, pumpkin, *quinoa* (*Chenopodium quinoa*) and *cañahua* (*Chenopodium pallidicaule*). The success and the achievements of managing the natural habitat and the climatic variables were directly linked to the development of better techniques for managing both water and land (Arze, 2015). In the same period (between 1000 and 1500 AD), irrigation was also the dominant agriculture technique in other areas of South America as the northern coast of Peru (Farrington and Park, 1978; Ertsen and van der Spek, 2009).

For example, the abrupt geography of the Andean region meant that the landscape needed to be changed, requiring the development of a system to be able to farm soils on steep slopes. Many mountain slopes, especially those on the eastern foothills of the

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mountain range, were transformed into areas of terraced farmland, held in place by retaining walls. Irrigation channels criss-crossed the fields, from one level to the next (Arze, 2015).

Following the demise of the Tiwanaku culture, the land came under feudal lordships or *Señorios* such as the *mollo* culture (1200–1480 AD), located in the temperate valleys in the north of the department of La Paz (Medinaceli, 2015). The *mollos* developed techniques to build terraces, intake structures, trapezoidal and triangular water channels and rock water-storage tanks (Chipana et al., 2011a).

Currently, in a number of different communities that were historically part of the *mollo* culture, the same pre-Hispanic surface irrigation techniques continue to be in use even today. This is true for *kanis* irrigation (*kanis* being a Quechua word that refers to the use of furrows to transport water), which is suitable for crop irrigation on small steep terraces. The system consists of laying out a series of primary distribution channels called *mama kanis.* The principal indicators for their construction are the inflow location and the slope, and channels are opened from the bottom up. The length and the number of *mama kanis* depend on the size of the plot of land to be irrigated, although generally speaking a minimum of two to three channels are used. Afterwards, on the same plot of land, *juchuy kanis* (secondary channels that generally go in the opposite direction of the *mama kanis*) are dug and irrigation begins at the outer edge of the plot and then moves backwards (Chipana et al., 2011b). From each *juchuy kanis*, small length irrigation furrows were dug. Curiously enough, this system shares certain similarities with the Arab "comb-shaped furrow" irrigation system as described by del Pino et al. (2011).

In the central and southern part of the valleys in the department of La Paz, another pre-Hispanic irrigation system called zigzag corrugated furrow irrigation is commonly used by farmers to irrigate crops on sloped land. These consist of furrows set out in the direction of the steepest slope, forming a series of bends on the surface of the land that cut back on themselves (Roldán-Cañas et al., 2010, 2015). No one knows exactly how far this type of irrigation system dates back, nevertheless Palacios and Chipana (2008) indicate that zigzag corrugated furrow irrigation systems were adapted and developed from ancient irrigation methods during the colonial period. This system also resembles the *morisco* or Moorish Arabic irrigation systems (del Pino et al., 2011).

According to information from the Ministry of the Environment and Water (2013), the total surface area under irrigation comes to 303,201 ha, located in different agro-ecological zones consisting of highlands, valleys and plains. In the first two, the growing areas are located between 1500 m and 4200 m above sea level and annual rainfall ranges from 350 mm to 600 mm (falling mainly between the months of December and March), predominantly using surface irrigation, despite the steep slopes and the rough terrain. The Andean areas of Bolivia, which comprise highlands and the Inter-Andean valleys, is where most irrigation agriculture takes place, equating to approximately 65% of the irrigated surface area. Of the total of irrigators, 70% are small farmers that irrigate less than one hectare, i.e., they are living in poverty and are highly vulnerable to climate change In said areas, the ancient irrigation techniques mentioned earlier continue to be used in family-run farms due to their flexibility and adaptability and by the lack of economic resources to implement pressurized irrigation systems, which also requires a source of energy to run the system of pumps. Moreover, the introduction of pressurized systems distorts irrigation scheduling and collective actions. Also, changes in the distribution of water often affect the rights, equity and mobilization for collective maintenance activities (Boelens and Vos, 2012; Boelens and Gelles, 2005).

In this regard, the primary aim of this paper is to compare the performance of pre-Hispanic irrigation systems, *kanis* and zigzag corrugated irrigation systems. The primary contribution of this study is to provide a comparative study and a feasibility analysis of both methods, taking irrigation performance indicators into consideration.

2. Materials and methods

This study was carried out at the Choquenaira Experimental Farm, part of the Faculty of Agronomy of the University of San Andres, located in the province of Ingavi in the department of La Paz, 38 km from the city of La Paz (Fig. 1) and located at an altitude of 3877 m above sea level. Its precise location is 16°41′35″ south and 68°17′12″ west.

The average annual temperature is 7.7 °C while the average extreme temperatures range from −15 °C to 22 °C. Rainfall is seasonal, irregular in both intensity and periodicity, falling primarily between December and March, with 72% of the average annual rainfall of 485.2 mm falling during said four-month period.

The soil at the Experimental Farm comprises fine alluvial deposits, with a loamy texture, and with an electrical conductivity measurement of 1.2 dS/m for the saturation extract.

The water source of the Choquenaira Experimental Farm is from a free aquifer with a depth below ground level of between 1 m and 10 m, depending on the time of year, which is pumped to a reservoir to be later used for irrigation. The water has a pH of 7.61 and an electrical conductivity of 0.353 dS/m.

For the research work, a native potato was used, the *Huaycha Paceña* variety (Solanum tuberosum ssp. andigena).

In order to replicate potato harvest irrigation conditions of the Inter-Andean valleys, a total area of 1707 m^2 of land was farmed, 925 m^2 of which used *kanis* irrigation while 782 m^2 used zigzag corrugated furrow irrigation. The land has between a 0.3% and a 5% slope, which is why it was divided into four sub-plots, two of which were irrigated using *kanis* irrigation and two using the zigzag corrugated furrow technique. Testing was carried out in only two of the sub-parcels (see Fig. 2).

Before preparing the soil, the water infiltration rate of the soil was determined using the ring infiltrometer method, which gave a basic infiltration rate of 10 mm/h.

The layout of the irrigation furrows for the *kanis* technique was carried out by an irrigator with a great deal of experience in this type of system, who employed ancestral know-how that had been passed down from one generation to the next. The first step was to lay out the primary channel, the so-called *mama kani*, with a 2.7% slope. From the *mama kani,* secondary irrigation channels were opened, known as *juchuy kanis*, with an average incline of 4% and a length of between 4 m and 18 m. The distance between *juchuy kanis* varied from between 1.6 m and 3.5 m. From each *juchuy kanis,* almost perpendicular furrows were dug, with an average length of 2.5 m and 0.66 m apart, resulting in an area of 1.65 m^2 (Fig. 2). The ends of the furrows were blocked off (Choque, 2015).

When laying out the zigzag corrugated furrows, the primary direction of the furrows was determined by the slope of the land, and a 2.7% incline, the same as the *mama kani,* was chosen. Later, the irrigation furrows for water derivation were laid out; they are known as *chirus* (a native Aymara word that means a separation furrow between ridges or group of corrugated furrows). From these, the openings of the furrows were made, with the average width of the ridges (average distance between two changes of direction) of 3.68 m, the average length of the ridges (average distance on the main axis) was 5.67 m, resulting in an area of 20.87 m^2, with furrows 0.56 m apart, (Fig. 2). The corrugated furrows have both a water inflow point and a water outflow point (Choque, 2015).

Sowing of the potato crop took place on 25 October 2013. The potato tubers were located at a depth of between 0.10 m and 0.15 m from the surface of the furrow, with a 0.35 m gap between plants.