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Small-Scale Irrigation in the Highlands of Western Cameroon: A Diagnostic Study of the Southern Slope of the Bamboutos Mountains

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Abstract

Irrigated agriculture in Cameroon is practiced on a large scale by large private firms and parastatals, and on a small scale by individual producers in different production areas of the country. Although small-scale irrigation can supply local and sub-regional markets with food in the off-season, it has received little research and its challenges are therefore rarely addressed. In order to contribute to the knowledge of these small-scale irrigation systems, with a view to improving their structure and the management of irrigation water and energy, an assessment of small-scale irrigation in the southern slopes of the Bamboutos Mountains has been done. After direct observations, field measurements, surveys of 100 irrigators with questionnaires and interviews with administrative managers, analyses were carried out using Xlstat software. It was found out that about 226 small-scale irrigation systems designed and managed by producers have been installed on this slope between the end of December 2022 and mid-March 2023. Intended for market garden crops, 84.96% of these irrigation systems use sprinklers and 15.04% surface irrigation (furrow irrigation). Surface or underground water is mobilized using gravity (50%), fossil fuels (34.51%), electricity (14.6%) or solar energy (0.9%). Sprinkler irrigation is mainly carried out using locally manufactured hydraulic turnstiles. There is a lack of formal associations of irrigators in an environment marked by conflicts between water users, when there is not allocation for water withdrawal. Apart from the high cost of pumping energy ($1.32 per liter of fuel), the main constraint identified, which has become more acute over the years, is the lack of irrigation water during the water shortage period (from mid-January to mid-March). These constraints have led to a transition from surface irrigation to sprinkler irrigation, and the adoption of new energy supply and water mobilization technologies. The construction of collective surface and groundwater catchment structures with solar-powered pumping systems, the setting up of formal irrigators' associations and an irrigation support service, could improve the availability of water throughout the irrigation season, thereby helping to improve the income generated by irrigated market-garden farming on the southern slopes of the Bamboutos Mountains.

Keywords

Market Gardening, Water, Energy, Small-Scale Irrigation, Southern Slope of the Bamboutos Mountains

1. Introduction

According to [1], the world average population growth rate is only 1.2%, whereas it is estimated at over 3% in Africa. With the current challenge of meeting the food needs of this ever-growing population, it is becoming difficult for African agriculture to increase production solely by extending cultivated land; hence the adoption of irrigation to produce more on land already under cultivation. In Cameroon, irrigated agriculture is practiced on a large scale by large firms and on a small scale by individual producers in various production basins. The country has 7,750,000 ha of arable land with an irrigation potential of 290,000 ha, of which only 22,450 ha are actually irrigated [2]. There are parastatal hydro-agricultural schemes such as the Maga-Vrick-Logone system, the Lagdo dam and reservoir, set up by the state for rice production, and irrigation systems installed by large agricultural firms such as *Société Sucrière du Cameroun* (irrigation of sugarcane), *Plantation du Haut Pendja* (irrigation of bananas), Cameroon Development Coorporation (irrigation of bananas) and others. Individual farmers use gravity or pump irrigation, which in most cases is informal. Irrigation, considered formal, is officially known, subject to the regulations put in place by the State and is conducted in accordance with the principles taught in educational structures. Informal irrigation, on the other hand, is family, private or collective irrigation, which uses local resources and technologies with know-how acquired outside educational structures and whose scale of operations is generally small [3]. This informal irrigation is generally not included in official statistics (and probably not, or only partially, in AQUASTAT statistics either, as is the case for most countries) due to the difficulty of obtaining data [1]. It is generally carried out on a small scale, but represents a significant added value in terms of income for each farmer. In other countries, on the other hand, there are agencies in charge of irrigation that, in collaboration with research institutes, are working to develop solutions that enable them to meet the challenges of their contexts. From these works, numerous scientific publications on irrigation in different contexts, like the one of

[4] in the region of Mississipi have been produced.

It is estimated that small-scale farmers who rely on rain-fed agriculture provide around 90% of agricultural production in Sub-Saharan Africa [5]. The same is true of small-scale agriculture in Cameroon, which supplies local and sub-regional markets with foodstuffs all year round, thanks to small-scale irrigation. In several of the country's production basins (the Noun plain, the slopes of the Bamboutos Mountains, etc.), small-scale farmers are developing irrigation systems to supply markets in major cities (Douala, Yaoundé, Bafoussam, etc.) and neighboring countries (Gabon, Equatorial Guinea, Central African Republic, etc.) in the off-season. To date, little is known about these irrigation systems, and their difficulties are rarely taken into account in the agricultural policies developed. Irrigation initiated by state structures is currently the best regulated (Prime Ministerial Decree 2024/00176 of February 26, 2024). Given the importance of small-scale irrigation for Cameroon and the countries of the sub-region, the present study focuses on the situation of small-scale irrigation in the western highlands, specifically on the southern slopes of the Bamboutos Mountains, one of the region's major rain-fed and irrigated market-garden production basins. This slope of the Bamboutos Mountains is characterized by high agricultural intensity and the common practice of small-scale sprinkler irrigation, which leads to a shortage of water resources [6]. After studying the typology and efficiency of irrigation systems on this slope, it was reported that these irrigation systems presented a very low level of performance [7]. Competition for access to and control over water in the Bamboutos Mountains has been very tense and sometimes violent for several decades [8]. Given that this dynamic around water resources is likely to influence the practice of irrigation, it is appropriate to assess the irrigation situation in this production basin. The hypothesis is that water and energy constraints are leading to changes in irrigation practices and technologies. The aim of this work is therefore to contribute to the understanding of irrigation systems on the southern slopes of the Bamboutos Mountains, with a view to improving their structure and the management of the resources (water and energy) mobilized. Specifically, the aim is to characterize them in terms of the typology and technologies of irrigation systems, irrigated crops, water and energy sources, and water management at farm and basin level; to highlight the strengths, weaknesses, opportunities and threats of irrigation in this production basin, and to define avenues of improvement.

2. Methodology

2.1. Study Area

The southern slope of the Bamboutos Mountains extends over the locality of *Bafou* North (latitude 5˚06' to 5˚10' N, longitude 10˚26' to 10˚43' E), in Nkong-Ni sub-division (Nkong-Zem council), Menoua division, West Cameroon region. That locality has a temperate Sudano-Guinean climate, also known as a high-altitude Cameroonian climate. This climate is characterized by a long rainy season of 8 months from mid-March to mid-November, and a short dry season of 4 months from mid-November to mid-March, with average annual precipitation of 2388.93 mm. The average wind speed of 1.19 m/s is not an obstacle to sprinkler irrigation, as the recommended wind speed limit for sprinkler irrigation is 4 m/s [9]. With an annual average monthly irradiance of 5.08 kWh/m^2/day, July is the least sunny month with 4.14 kWh/m^2/day, and February the sunniest with 5.96 kWh/m^2/day. Under these climatic conditions, farmers on the southern slope of the Bamboutos Mountains produce three cycles of vegetables per year: first cycle (March-June); second cycle (July-October) and third cycle (November-February) with irrigation. The climatic variability observed in recent years, forces farmers to start irrigation some years in October and extend it until March. The production basin lies between 1600-2740 m altitude; the soils are of volcanic origin and among the most fertile in the country. Over the last 2 decades, there has been an accelerated degradation of the vegetation cover around the Bamboutos Mountains due to the intensity of human action [10]. The southern slope of the Bamboutos Mountains has more or less seasonal streams and springs, which dry up in the dry season. One of the most significant reasons for the drying up of watercourses is the informal but widespread cultivation of market garden crops on the banks of watercourses, which leads people to divert the watercourses to water their farms [11].

2.2. Identification and Characterization of Irrigation Systems

Direct observations, field measurement and survey with questionnaire consisting of open and closed questions, were used to collect data characterizing the irrigation systems installed on the slope.

The size of the sample of irrigators to be surveyed was determined by the formula expressed in Equation 1. The number of producers engaged in irrigation during the data collection period (between the end of December 2022 and mid-March 2023) was about 170.

$$n=\frac{(N)(p)(1-p)}{(N-1)\left(\frac{B}{C}\right)^2+(p)(1-p)} \tag{1}$$

Where: n = sample size;

N = population size;

p = degree of variability (p = 0.8);

B = precision level (B = 5%);

C = associated Z statistic at the 95% confidence level (C = 1.96).

The questionnaire was administered to 100 irrigators randomly selected. Interviews with irrigators took place in the field, so that direct observations and measurements could also be done. Among the irrigators surveyed were producers designated as the pioneers and benchmark for irrigation on the slope, and whose irrigation practices are copied by several irrigators.

Documents from Nkong-Zem council departments (communal development plans and data consolidation documents) were also consulted, and interviews were held with agricultural officials for the Nkong-Ni sub-division (Sub-divisional delegate of the Ministry of Agriculture and Rural Development and the Head of agricultural post of Djuttitsa), and with staff from the local water boardof Nkong-Zem counsil. These interviews covered the local water and energy resources (typology of sources, facilities, works and installations in place), the management of these resources (resource allocation systems and the role of the State in managing resources and conflicts) and irrigation-related projects or actions completed or underway in the basin.

Following data collection, the qualitative data obtained were analyzed using a systematic diagnostic approach; and the quantitative data were tabulated, coded and analyzed using Xlstat software.

The questionnaire used covered the typology of irrigation systems installed, sources of water and energy used, irrigated crops, and water management at farm and basin level.

2.2.1. Typology of Irrigation Systems and Irrigated Crops Identification

Visits to irrigated farms in the basin enabled us to identify the different types of irrigation system (surface, gravity or pump sprinkler irrigation), using direct observations and a questionnaire. The geographical coordinates of all the irrigation systems identified were taken at the level of the irrigated plots using a Garmin GPS with 3 m accuracy. The QGis software was then used to map these irrigation systems using the coordinates taken on the field. Tracking the irrigation systems from the point of water withdrawal to the irrigated farm enabled us to identify and characterize the components of the irrigation systems. With the help of irrigators, the characteristics of irrigation system components (water intake, pump, main, secondary and lateral pipes and sprinklers) were obtained. A Fisher's exact test was performed on the data in **Table 1** ($\alpha = 5\%$), in order to assess the relationship between change of irrigation system type and water availability.

Irrigated crops were also identified during farm visits. For the irrigators surveyed, the areas occupied by these crops were measured using GPS. Irrespective of the varieties grown, yields were estimated with the contribution of irrigators, by dividing harvested quantities by irrigated areas.

Table 1. Change of irrigation system type versus water availability.

Change of irrigation system type	Water availability per irrigator at the catchment point	
	Water in sufficient quantity	Insufficient water quantity
Changed system	6	36
Unchanged system	28	30

2.2.2. Irrigation Water Characterization

For installed irrigation systems, the nature (surface water or groundwater) of the water source used was identified. Irrigators gave precisions on the availability of water throughout the irrigation season, the reasons for choosing the water source to use and the difficulties associated with irrigation water. The low-water flows of two rivers were measured, and also the dimensions of groundwater catchment structures. Surface water flows were calculated using the median section method. To this end, water velocity was measured using a Qualimetrics micro-spinner with an accuracy of 0.01, considering the orientations given by [12]. Discharge was obtained by multiplying water velocity by stream cross-section (product of average stream width and depth, measured with a decameter).

Since salinity is usually the most serious problem resulting from the use of poor water quality for irrigation, a water quality meter was used to measure the electrical conductivity of the identified water sources.

During the survey, irrigators provided information on water availability throughout the irrigation season, motivations for choosing water sources to use, and difficulties related to irrigation water.

2.2.3. Irrigation Energy Characterization

While the geographical coordinates of the irrigation systems were being taken, the energy source used by each irrigation system was also recorded. This data was used to draw up a map showing the typology of irrigation energy sources. During the interviews, each irrigator indicated the source of energy used, giving details of availability, access and cost. In addition to the information provided by the irrigators on fossil fuels, discussions on fuel prices and availability were also held with fuel sellers of the local markets (*Ndoh* and *Djuittitsa*), and the main fuel supply points for irrigators, in villages *Meloung* and *Lingang*.

2.2.4. Irrigation Management at Farm and Basin Level Characterization

To understand irrigation management at farm level, irrigators were asked about their irrigation management (watering duration, irrigation interval, quantity of water applied), and the criteria they use to make irrigation decisions. A Kruskal-Wallis test was used to determine whether the differences in watering duration and irrigation intervals by type of energy source used were significant. Multiple comparisons were made using Dun's test.

On a basin-wide scale, irrigators shared their views on possible associations of irrigators, established allocation systems and the involvement of the State or other bodies in irrigation.

2.3. Identifying the Strengths, Weaknesses, Opportunities and Threats of Irrigation in the Southern Slopes of the Bamboutos Mountains

The matrix of strengths, weaknesses, opportunities and threats of an activity is a tool whose aim is to guide possible actions, projects or interventions aimed at improving this activity, by acting on one or more points highlighted by this matrix. The analysis and interpretation of data collected through surveys, observations and field measurements served as the basis for drawing up this matrix for irrigation practices on the southern slope of the Bamboutos Mountains. The technical, social, economic and environmental aspects of the situation were identified:

- Strengths: advantages, assets, factors favorable to irrigation that are linked to irrigators;
- Weaknesses: shortcomings, limitations, inadequacies related to irrigators, who are a brake on irrigation;
- Opportunities: factors favorable to irrigation that do not depend on irrigators;
- Threats: factors unfavorable to irrigation that do not depend on irrigators and on which they cannot directly act.

This analysis enabled us to identify the causes of the main existing problems in irrigated systems and to propose possible solutions.

3. Results and Discussion

3.1. Results

3.1.1. Irrigation Characteristics in the Southern Slope of the Bamboutos Mountains

A total of 226 irrigation systems were identified in 09 hillside villages (*Tallé*, *Femock*, *Meloung*, *Loung*, *Lingang*, *Ngui*, *Pastoral*, *Aghong* 1 *and Aghong* 2).

(a) Typology of irrigation systems

Bafou North farmers use surface irrigation (furrow irrigation) at 15.04% and sprinkler irrigation at 84.96%; water transport in both cases may be by gravity or motorized. The following types of irrigation are used:

- Gravity-fed furrow irrigation (2.65%): water is collected and transported in earthen canals under the effect of gravity, and spread in the furrows of the plot to be irrigated;
- Pumped furrow irrigation (12.39%): water is pumped and transported through pipes to the plot to be irrigated, where it is spread in the furrows;
- Gravity sprinkler irrigation (51.77%): water is collected and gravity-fed to the plot to be irrigated, where it is spread over the crops in the form of rain by hydraulic turnstiles;
- Pumped sprinkler irrigation (33.19%): water is pumped and conveyed to the plot to be irrigated, where it is spread over the crops in the form of rain by hydraulic turnstiles.

Figure 1 shows the distribution of these different types of irrigation system in the basin. It should be noted that some irrigators (3.98%) simultaneously use sprinkler irrigation on parts of their farms, and furrow irrigation on other parts.

The choice between sprinkler and furrow irrigation depends on water availability and the crop being irrigated. Indeed, when water is plentiful, some irrigators prefer to apply water in the furrows, particularly for crops such as green peppers, which are highly susceptible to disease and insects when the leaves are constantly wet.

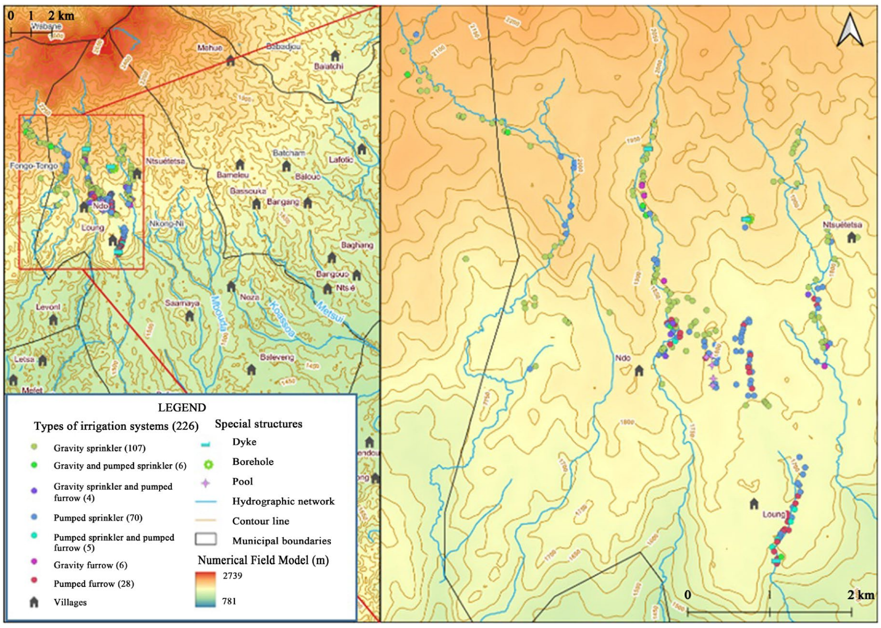

Figure 1. Distribution of irrigation systems on the southern slope of Mont Bamboutos.

More than four decades ago, furrow irrigation was the most common method of irrigation on the slope, but over time, sprinkler irrigation has become more widespread: 45% of irrigators surveyed said they had switched from furrow irrigation to sprinkler irrigation. Irrigators justify the move from surface irrigation to sprinkler irrigation (installed on 84.96% of farms) by the increase in the number of irrigators, which has led to a reduction in the quantity of water available per irrigator, and by the advantages of sprinkler irrigation (less arduous, more water-efficient and less favourable to aphids and whiteflies). The probability of Fisher's exact test (p = 0.001) leads us to accept the hypothesis that the change in the type of irrigation system is linked to the availability of irrigation water.

(b) Irrigation systems structure

Irrigation systems in *Bafou* North consist of a water intake, a pumping system (if necessary), a water transport system, a plot distribution system and a sprinkler system shown on **Figure 2**.


(a) Gravity water collection (b) Electric pump in a stream (c) Motor-driven pump (d) Water Transportation in pipes


(e) 6-output divider (f) Hydraulic turnstile (g) Watering without turnstiles

Figure 2. Elements of the irrigation systems.

- **The water intake** (Figure 2(a)): for gravity-fed systems, a PVC or Panaflex pipe with a diameter of 40, 32 or 25 mm, to the end of which is attached a half plastic bottle covered with a screen (mosquito netting or permeable fabric), is introduced into the bed of the watercourse. For pumped systems, the submersible pump or motor pump suction pipe (fitted with a strainer) is introduced into the watercourse or pond.
- **The pumping system** (Figure 2(b)(c)): motor-driven pumps of various makes (King max; Honda, etc.) are used, with heads ranging from 23 to 32 m, flow rates from 34 to 66 m^3/h and power ratings from 2.6 to 4.1 KW. The electric pumps are all INTERDAB submersible pumps with a power rating of 0.55 KW, a flow rate range of 0.9 - 2.7 - 4.5 m^3/h, and a delivery head range of 70 - 56 - 27 m.
- **The water transport system** (Figure 2(d)): After collection, the water is transported by gravity (due to the difference in altitude between the water source and the plot to be irrigated) to the plots to be irrigated, using PVC or panaflex pipes. Pipe diameters are reduced along the transport lines, in order to increase pressure at the farm entrance. In most cases, water arrives at plot level in a 25 mm diameter pipe. Electric pumps deliver the water through 32 mm panaflex pipes to the plot to be irrigated. Depending on the output diameter of the motor-driven pump, water is delivered to the farm via PVC pipes with diameters ranging from 50 to 80 mm. In some cases, the diameter may be reduced if the transport distance is long (more than 100 m).
- **The water distribution system** (Figure 2(e)): At farm level, the water passes through a divider, which distributes it through polyethylene pipes with a diameter of 9, 10 or 11 mm. Made locally by a welder, a divider distributes the water into pipes ranging in number from 2 to 20 or more.
- **The watering system** (Figure 2(f)(g)): Polyethylene pipes of varying lengths (from 25 to a hundred metres, depending on the surface area of the plot to be irrigated) are connected to hydraulic turnstiles (local sprinklers) which distribute the water over the plot in the form of rain. These turnstiles, varying in length from 19 to 25 cm and fitted with 2 nozzles of 3 mm diameter, are attached by fronds to stakes of varying heights (0.9 to 2 m) planted in the ground. When flow rates at the source become low, irrigators plug one of the sprinkler nozzles to keep them running at considerable pressure. The pressures of sprinklers operating with one nozzle varied between 0.2 and 0.8 bar, with a watering radius ranging from 3 to 5 m. Another watering technique involves manually moving a hose connected to a motor-driven pump over the plot, spraying the crops. This labor-intensive technique is not suitable for young plants, which can be destroyed by the water pressure. This is why it is rarely used.

(c) Irrigated crops

Irrigation on the southern slopes of the Bamboutos Mountains is mainly used to grow market garden crops, the main crops being potatoes, leeks, cabbage, carrots and peppers. Most irrigators divide their irrigated plots into "squares", on which they grow two or three pure crops. Table 2 shows the distribution of irrigated crops on the southern slopes of the Bamboutos Mountains.

Table 2. Main irrigated crops on the southern slopes of the Bamboutos Mountains.

Crop	Percentage of irrigators growing crops (%)	Average plot size (ha)	Estimated yield (t/ha)
Leek	44	0.21	10.4
Irish potato	40	0.18	18
Carrot	38	0.31	18
Cabbage	18	0.47	24
Green Pepper	16	0.1	12

The suitability of de farm's soil for a crop, the crop's market (price and easiness to sell), crop profitability and length of crop cycle are the main criteria for choosing which crops to irrigate. Farmers cultivate market garden crops because the slope's soil is favorable to these crops, particularly potatoes, which are widely grown. According to the irrigators, the advantage of leeks, which are the most widely produced crop under irrigation, is their high resistance to water stress and the fact that, once mature, harvesting can be postponed if the market price is too low for the farmer.

In terms of the origin of irrigated land, 36% is family heirloom, 32% leased and 32% purchased by irrigators. Small-scale irrigated plots (less than 1500 m^2) are, in most cases, family heirlooms resulting from shares between brothers, while relatively large areas are rented or purchased.

(d) Irrigation water

Irrigation on the southern slope of the Bamboutos Mountains is carried out using surface water (rivers and streams) and groundwater (ponds, springs and boreholes). Of the irrigators surveyed, 64% use exclusively surface water, 34% use groundwater and 2% use both sources of water (when surface water is still abundant, they capture it by gravity, and resort to groundwater when stream flows drop and competition for surface water begins).

As far as surface water is concerned, three main rivers (*Femock*, *Meloung* and *Lingang*) along which water is collected by gravity or pumping have been identified in the basin, as well as creeks. The flow of the *Femock* stream measured in January was 0.004 m^3/s; that of the *Meloung* stream was 0.005 m^3/s in January and 0.002 m^3/s in February 2023. At the catchment point located downstream of the flow measurement point on the *Meloung* stream, 15 pipes were installed, making only 0.33 l/s and 0.13 l/s available per irrigator in January and February respectively. On these rivers and creeks, dykes (Figure 3) are sometimes built by hand and without prior study, to increase the water level in the reservoir created and thus facilitate water withdrawal.

These watercourses experience a gradual decline in flow with the dry season, while most creeks dry up. At the beginning of the irrigation season (usually in

November and some years, in October), water is abundant and most irrigate by gravity. As the dry season drags on (from mid-January onwards), flows drop considerably and some streams dry up (**Figure 4(a)**), creating competition for water. Those who have no other alternative for obtaining water are forced to abandon their crops for lack of water to irrigate (**Figure 4(b)**), while others resort to water sources that can only be mobilized by pumping.

Figure 3. Dikes built for water catchment on Meloung stream.

This competition is reflected in the presence of several pipes at a catchment point, whereas there are several along each watercourse. At the end of the dry season, the number of irrigators per catchment point varies between 10 and 25, with an average of 15 irrigators per point. This number is higher at the beginning of the irrigation season.

(a) *Femock* riverbed in January

(b) Plot abandoned due to lack of irrigation water

Figure 4. Effects observed with lower flows in rivers used for irrigation.

Groundwater is collected by boreholes (two identified at the *pastoral* site, one of which is 56 m deep) and by ponds created by farmers whose plots are close to marshy areas. These ponds vary in cross-section (1 to 10 m^2) and are generally 2 to 4 m deep. It should be noted that groundwater catchment structures are for personal use or are operated by a maximum of three neighboring irrigators who have built the structure together. The irrigators who use the groundwater report that the flow rate or quantity is stable throughout the year. Based on this observation, the widespread use of groundwater catchment structures could help alleviate the shortage of irrigation water during low-water periods.

Groundwater is located at distances of between 0 and 300 m from the irrigated plots, for an average of 82 m, while surface water is collected at distances of between 1 and 5000 m, for an average of 823 m. Among the irrigators surveyed, 41.86% find that water is not sufficient for their plants, particularly those who use surface water. While some irrigators use a water source because the position of their plot gives them no other alternative, others prefer water that will be collected by gravity because it is cheaper, and others opt for water that is close to the plot and does not dry up. In 50% of cases, the water sources are used exclusively for irrigation, and in the remaining cases, the water taken for irrigation is also used for laundry, domestic chores and drinkable water. These other uses of water are detrimental to irrigation, as the abundance of soap in the water causes damage to plants, and local residents disconnect pipes to obtain water for domestic use.

The electrical conductivities of water used for irrigation are between 0.028 and 0.153 dS/m. They therefore have no restrictions on their use for irrigation. Indeed, the degree of restriction on the use of water for irrigation is zero for electrical conductivities below 0.7 dS/m; mild to moderate when the electrical conductivity is between 0.7 and 3 dS/m and severe when it is greater than 3 dS/m.

(e) Irrigation energy

Irrigation water mobilization on the southern slopes of the Bamboutos Mountains is 50% gravity-fed, 45% motorized and 5% mixed (gravity-fed and motorized), as shown on **Figure 5**.

The choice of irrigation energy source depends on the topographical position of the plot to be irrigated in relation to the water withdrawal point: when it is favourable to pressurizing the water by gravity, gravity irrigation is used, and when it is not, pump irrigation is adopted. Because it's free, gravity is the preferred method for mobilizing water, despite the amount of money required to purchase pipes when the water has to be transported over several kilometers. However, because of the water shortage at the height of the low-water period, some people prefer to pump (electrically or using fossil fuels) from permanent water sources. Pumping is very common in low-lying areas such as *Loung,* as these are swampy areas where stream flows are stable during the irrigation season, and where ponds are created.

Motorized withdrawal uses three energy sources, namely fossil fuels (motor-driven pumps) at 69.03%, electric power (submersible electric pumps) at 29.20% and solar power (solar-powered pumps) at 1.77%. It should be pointed out that the use of electric power for irrigation in the basin is recent and booming, as all irrigators using electric pumps installed them less than 4 years ago. Motor-driven pumps are gradually being replaced by electric pumps, due to their relatively high operating costs.

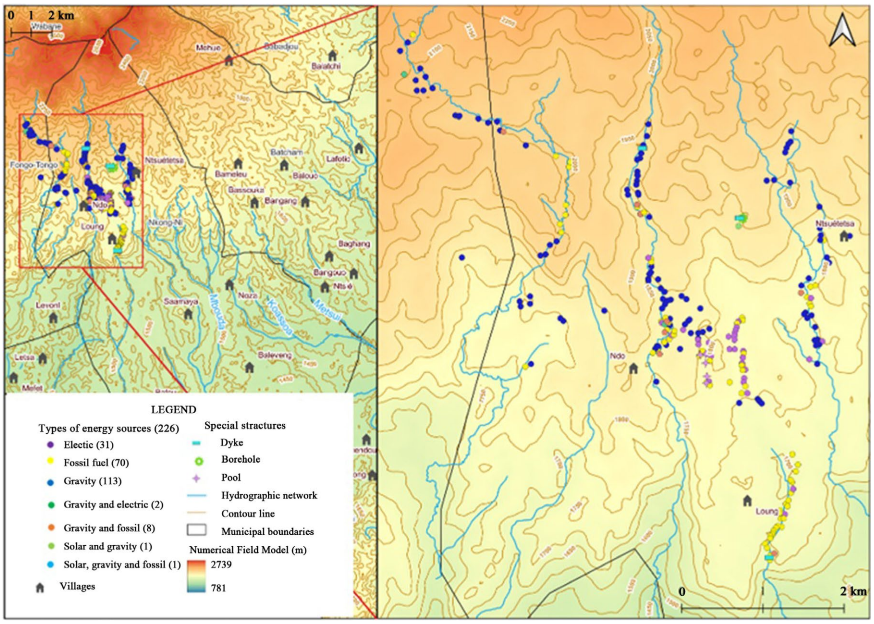

Figure 5. Distribution of the irrigation energy sources on the southern slopes of the Bamboutos Mountains.

Regardless of the energy source used, irrigators find it accessible, but expensive. Petrol is available in the various villages, but at an average cost of $1.41 per liter, while monthly electricity bills average at least $41.39 for those using electric pumps. Solar energy, on the other hand, requires a substantial initial investment, which most irrigators cannot afford. For a 4 ha farm, the installation of a solar field consisting of 48 panels, with a theoretical power of 18.89 kW, and the construction of a 56 m deep borehole, required around $1,903.97. Given that 85.33% of farms in *Bafou* Noth are less than 1 ha in size [13], similar installations could be set up for community use. This could help solve the problems of water scarcity and the high cost of irrigation energy. It should be pointed out that the proximity of the farm to be irrigated to the *Energy of Cameroon* (Enéo) network is the main condition to be met by irrigators wishing to switch from fossil fuels to hydroelectric power. This condition is a limiting factor for hydroelectric pumping, as many irrigators are forced to continue using motor-driven pumps because their farms are so far from the power grid. This explains why the cost of renting plots meeting this condition is relatively higher in the basin.

The main difficulties linked to irrigation energy that were highlighted by irrigators are the high cost of petrol for fossil energy; voltage drops and power cuts for electrical energy.

(f) Irrigation management at farm and basin level

- **Irrigation management at farm level**

On the southern slopes of the Bamboutos Mountains, 82.5% of sprinkler irrigation systems are mobile. For these mobile sprinkler systems, the turnstile stake is moved from one sprinkler station to another. The decision to move sprinklers around the farm is justified on the one hand by the impossibility for an irrigator to have a water flow capable of supplying all the sprinklers needed to cover the entire farm in one irrigation episode, and on the other by the high cost of a fixed installation. Of those with fixed systems, over 70% are irrigators using fossil fuels (motor-driven pumps). Irrigation times per station depend on the energy source used, as shown in **Table 3**.

Table 3. Watering duration by energy source.

Energy source	Gravity	Electric	Fossil fuel
Watering duration range (h)	8 - 24	6 - 24	0.5 - 3
Average watering duration (h)	12.33	13.75	2.00
Standard deviation	2.56	6.28	0.91

The difference between these watering times is significant ($p < 0.0001$), with the fossil fuel time being different from the other two. Because of the relatively higher cost of fossil fuels, irrigators who use them have shorter watering times. This would lead to differences in application and requirement efficiencies.

Despite the difference in watering times by type of energy source used, there was no significant difference between the irrigation intervals practiced by irrigators. Observed irrigation intervals ranged from 2 to 14 days, with an average of 5 days (4.12, 4.61 and 6.50 days respectively for gravity, fossil and electric energy). The decision to irrigate is taken by most (58%) after observing the appearance of the soil and the plant. While some irrigators only return to a watering station once they have covered the entire farm, others are forced to observe an irrigation interval imposed by the availability of water at the source. To reduce the number of days needed to cover their farm entirely, those with the financial means install two to three "lines" (filter + water transport piping) to collect water by gravity.

Irrigation periods vary from 1 to 3.5 months, with an average of 2.63 months. In fact, some irrigators complete the crop cycle with irrigation after the departure of rain, meanwhile others start cultivation with irrigation and finish with the rains, and others cultivate from sowing to harvesting under irrigation. This depends on the availability of water and market prices.

Irrigation labor is essentially family-based (the irrigator himself or a member of his family) in 92% of cases, and the tasks performed include checking the water supply to the catchment pipes, moving the motor pump, switching the electric pump on and off, moving the turnstiles from one irrigation station to another, and so on. Those who use salaried labor entrust the running of the irrigation to a person who is paid monthly or after the harvest of the irrigated crop, according to an amount agreed in advance, which can be around 16.57 $/month.

- **Irrigation water management in the basin**

At basin level, there is no association of irrigators at *Bafou* North. There are three possible scenarios for the allocation of water withdrawals from water sources used by several irrigators:

- **No allocation and absence of conflicts**: each irrigator installs his catchment pipes or hydraulic machine in due course, and when the quantity of water available becomes insufficient for all, some withdraw and others are constantly (day and night) at the source to make sure they catch the water. This is observed in 33.33% of cases;

- **Existence of allocation**: withdrawal days are set per irrigator or per group of 2 to 4 irrigators. This system is used in 28.57% of cases by the irrigators we met, and is generally observed among irrigators who use a shared pond or a stream on which there are few of them;
- **No allocation and existence of conflicts**: each irrigator installs his catchment pipes or hydraulic machine in due course. When the quantity of water available becomes insufficient for all, we can record quarrel, fights, pipe sabotage, removal of pipes without the owners' knowledge, nocturnal presence (between 10 pm and 3 am) of irrigators at the river in order to be able to catch water. This situation, observed in 38.10% of cases, prevails in gravity-fed catchments. Conflicts are generally settled amicably between irrigators or in the presence of traditional authorities; officials (sub-divisional delegates) may be called upon to arbitrate.

In addition to conflicts between farmers over water resources, there are also conflicts between farmers and herders. In 1984, to ease tensions between farmers and herders, the administrative authorities arbitrarily set a boundary between agricultural and pastoral areas at an altitude of 2000 m. However, when water shortages become acute, irrigators move their pipes upstream from the watercourses, thus violating this boundary to gain access to places reserved for watering animals (cattle), and these pipes are sometimes sabotaged by these animals or by shepherds. Setting up a water management committee or a water users' association in the basin could help find lasting solutions to this conflictual situation.

Irrigators report that there is currently no State intervention in irrigation water management in the Basin, and most receive no advice/training on irrigation. Some irrigators have in the past received training from the German cooperation agency (GIZ); others who take part in the regional agro-pastoral fair have been awarded irrigation equipment as prizes. ACEFA program (*programme d'Amélioration de la Compétitivité des Exploitation Familiales Agropastorales*) has also subsidized producer groups with irrigation equipment. Irrigators also mention the initiatives of non-governmental organizations such as Erudef, which have worked on reforestation on the slopes of Mount Bamboutos, and the World Bank-funded Bamboutos reforestation project, whose reforestation activities and waterworks (boreholes and wells) for irrigation and animal watering are still awaited. he decline in water flows over the years, and the resulting shortage of water for irrigation, is attributable to the deforestation and destruction of raffia trees. Hence the initiatives taken by non-governmental organizations to tackle the issue through reforestation projects, which are welcomed by farmers.

3.1.2. Strengths, Weaknesses, Opportunities and Threats of Irrigation in the Southern Slopes of the Bamboutos Mountains

Analyses carried out on the types of irrigation systems, crops irrigated, water and energy resources used, and water management at farm and basin level, reveal the strengths, weaknesses, opportunities and threats presented in Table 4.

Table 4. Strengths, weaknesses, opportunities and threats (SWOT) of irrigation in the southern slope of the Bamboutos Mountains.

Strengths	Weaknesses
- Irrigation enables farmers to earn income all year round; - Irrigation improves local livelihoods; - Irrigation enables farmers to make more profit from land rental; - Irrigation yields satisfy irrigators; - The sprinklers used are locally manufactured; - Irrigators have several years' experience in irrigation (12 years on average); - Irrigation is accessible to many farmers.	- An increase in the number of irrigators over the years and a shortage of available water resources (less than 0.13 l/s available per irrigator at certain catchment points during periods of shortage); - Conflicts over water arise when river flows fall; - Irrigation materials and equipment are inadequate in most cases; - Irrigators' limited financial resources; - Irrigation is managed on the basis of subjective criteria (the plant's water needs are not taken into account); - The distribution of water withdrawals is sometimes unfavorable for crops planted by irrigators during the period in question; - There is no association of irrigators in the basin.
Opportunities	**Threats**
- Soils are favorable to agriculture; - Irrigated crops are less vulnerable to disease and pest attack; - The basin's topographical and climatic conditions are conducive to sprinkler irrigation; - The locality favors the use of solar energy for water pumping; - The market for off-season crops is secure, and prices are favorable; - Crops are generally scarce on the market in the off-season; - Roads and tracks are more practicable in the dry season (irrigation period).	- Conflicts with other water uses; - Low river flows have become increasingly pronounced over the years; - There is no support service for irrigators in the basin; - Irrigation equipment prices are very high on the market; - High fuel costs, voltage drops and power cuts; - Lower water availability leads to lower yields for 23% of irrigators; - Insufficient water resources force irrigated areas to be reduced; - The distance of the plots to be irrigated from the gravity-fed water collection point increases the cost of installing irrigation systems; - Irrigation equipment lost to upstream flooding when rains return.

3.2. Discussion

Irrigation systems on the southern slopes of the Bamboutos Mountains correspond to the description of individual-type irrigation installations given by [14]:

these are installations carried out by the producers themselves, generally without any prior study, and installed anarchically around water points, in a scattered manner, with irrigators working on them individually. Thanks to irrigation, farmers on the southern slopes of the Bamboutos Mountains produce year-round, generating a steady income to support their families. There has been a gradual modernization of irrigation equipment on the southern slopes of the Bamboutos Mountains. This is marked by the introduction of pipes for water transport, hydraulic machines (motor pumps, electric pumps) for water pumping and, more recently, solar installations. Years ago, sprinkler irrigation was done only by gravity, and all the channels used to transport water from the source to the plot were earthen and unpaved [7]. The reduction in the quantities of water available for irrigation over the years has prompted irrigators to acquire equipment and structures to improve the availability of water for their plots throughout the irrigation season. The Water Management Research Unit at the University of Dschang has been working on the understanding and improvement of hydraulic turnstiles. In this case, the work of [15], whose results led to the recommendation of a turnstile model with a length of 50 cm, a nozzle diameter of 4 mm and 2 nozzles. These features are markedly different from the characteristics of the turnstiles used by irrigators in the field (25 com maximum length, 3 mm nozzle diameter and 2 nozzles), and with which they have found satisfaction.

The percentages of farmers engaged in irrigated production of the various speculations follow the trends reported by [8]. According to their observations, potatoes, carrots and leeks are the most widely grown speculations in Bafou Nord, with 75%, 37% and 25% of farmers producing them respectively. Observed yields have improved over the years, in the case of leeks whose yield reported by [7] was 4 t/ha; this could be the result of improved irrigation efficiency or agronomic practices (fertilization, pest control, seed variety, etc.), in addition to the legendary fertility of the soils on the slopes of Mount Bamboutos. The access to water in the dry season that characterizes irrigated plots makes them highly prized in an environment where the pressure exerted by agriculture on land has increased with the development of market gardening since the 1980s [16].

Like the tube-well technology used in Burkina Fasso, Mali and Nigeria [17], the ponds made by irrigators in the southern slope of Mount Bamboutos enable shallow groundwater to be pumped (aquifers located at depths ranging from 0 to 20 m). However, unlike ponds, which have to be cleaned out every irrigation season, suitably protected tube wells can operate for several years, even in areas flooded during the rainy season.

For irrigators who use groundwater for irrigation, water availability is generally guaranteed throughout the irrigation season. As far as surface water is concerned, as pointed out by [8], almost all river water is withdrawn for irrigation purposes at the height of the low-water period (between mid-January and mid-March); hence the total drying up of the bed of certain rivers downstream of the withdrawals (**Figure 4(a)**). Despite these abusive withdrawals, surface water drying up is the main problem associated with irrigation, raised by 65% of irrigators surveyed. According to irrigators, the decline in river flows is becoming more pronounced and earlier as the years go by. This constraint was already pointed out by [16] who reported that farmers had been attesting to a decline in water volumes for around 20 years. This poses a threat to irrigation in the basin (especially for those without access to groundwater), as many are forced to reduce the areas they irrigate annually. This drop in water availability can be attributed to inter- and intra-seasonal climatic variability. Indeed, the results of analyses carried out by [18] on rainfall data from *Djuttista* (on the southern slope of the Bamboutos Mountains) from 1941 to 2013, reveal that the median annual rainfall of the early years (1660.8 mm) is higher than that of recent years (1496.4 mm), with a difference of 164.6 mm. They also show that the length of the rain-fed cropping season has decreased from 245 days to 221 days over the years. Based on their observations, the irrigators point out that the destruction of raffia has led to a decrease in available water over the years in the rivers and streams of the locality. This could be because deforestation accelerates soil erosion, leading to major disruptions to the runoff needed to replenish local streams and rivers. According to [10], the significant decline in stream flows and the drying up of some between January and March over the years is due to the gradual intensification of human action that is lowering the water table. In addition to withdrawals for irrigation purposes, [19] attributes the drying up of watercourses in the dry season to the dumping of solid waste in watercourses, which gradually leads to the thinning of riverbeds; this also results in flooding during the rainy seasons.

Faced with a shortage of irrigation water due to declining river flows over the years, irrigators are increasingly turning to groundwater as a means of guaranteeing water availability throughout the irrigation period. Irrigation on the southern slopes of the Bamboutos mountains is private and unregulated, as there is no control over the volumes of water withdrawn by individual irrigators. This context is similar to that presented by [20] in India, where an increase in the number of individual boreholes drilled for irrigation purposes (one every 240 metres) has led to over-exploitation of groundwater. Since groundwater mobilization is an option to be explored as a solution to the problem of surface water scarcity currently faced by irrigators, it should be under the supervision of the administration in charge of agriculture.

Power cuts last four to six hours in major cities, and in rural areas people can be plunged into darkness for three to four days [21]. The southern slope of the Bamboutos Mountains, a rural area, is indeed subject to load shedding lasting several days and this is harmful to irrigation with the national electricity network. Most irrigators are in favor of the transition from fossil fuels to renewable energies (hydroelectric and solar), but are limited by the distance of the electricity grid from their farm and the high cost of a solar installation. The increase in the price of petrol has accentuated the problem of the high cost of irrigation energy, which irrigators highlight as a constraint to irrigation. Indeed, fuel is sold in the villages at $ 0.17 more per liter than the price at the pump; an increase in the price at the pump would further encourage irrigators to switch to electric power, which is more affordable. However, despite the fact that the rate of access to electricity for households in *Bafou* North is estimated at 71.39% (adapted from [25]), the remoteness of farm from the national grid is a problem that could be solved by community solar installations.

Normally, the determination of the water quantity to be applied involves determining the crop's water requirements throughout its growth phase and determining the water storage capacity of the soil [9]. Once the water requirements of crops throughout their growth phase are known, the next step is to estimate the quantities of irrigation water to be supplied at farm level. To do this, it is necessary to know the soil data. This will enable us to determine the water storage capacity of the soil, and hence the irrigation dose to be applied at a frequency defined by the farmer, in order to cover the crop's water requirements. However, on the southern slopes of the Bamboutos Mountains, the quantity of water applied and irrigation frequencies are not generally set on the basis of plant water requirements, and do not always take soil properties into account. The practices (fixed or mobile system, watering duration and irrigation interval) adopted by most irrigators are imposed on them by the availability of water, the cost of irrigation energy and the quantity of their irrigation equipment. Those who are not subject to these constraints make the decision to irrigate by observing the appearance of the plants or the soil. It is therefore possible to over- or under-irrigate. This highlights the need for irrigators to be supported in their irrigation decisions.

Small-scale irrigators in the Bamboutos Mountains do not benefit from any form of support in the technical management of irrigation. This situation corroborates the lack of advisory support presented by [3] as one of the constraints suffered by informal irrigators. In reality, even in countries like Niger where irrigation extension services exist, informal irrigators are neglected for lack of administrative existence. The Ministry of Agriculture and Rural Development is one of the most decentralized ministries in Cameroon. Strengthening the irrigation skills of agricultural station chiefs could enable those whose work areas are small-scale irrigation zones to better support irrigators.

The system of irrigation water management with water allocation is similar to that of farmers in Zambia (Mkushi and Mpika regions) and in the highlands of southern Tanzania, whose collective organization to develop and manage small irrigated perimeters is conflict-free [22]. The absence of state support for irrigators may be due to the fact that the State has not yet built irrigation facilities. In fact, according to article 2 of Prime Ministerial Decree 2024/00176, the management procedures relate essentially to irrigated perimeters created by the State, decentralized local authorities, public establishments, a public enterprise or a private legal entity. In the northern region, for example, where the State has built the Logone dike and Maga dam for irrigation, SEMRY (a parastatal agency for agriculture, irrigation and drainage) supports 25,000 rice growers in the Logone zone [23]. It should therefore be noted that private or informal irrigation, such as that on the Bamboutos Mountains, is still awaiting legislation setting out the procedures for its supervision.

On the basis of the SWOT analysis of irrigation on the southern slopes of the Bamboutos Mountains, possible solutions for improving irrigation and the management of water and energy resources in the basin can be proposed.

It is therefore proposed that irrigators:

- Work together to apply the rotating water use model to highly competitive withdrawal points;
- Plan sowing of crops to be irrigated according to water availability;
- Organize themselves into associations of irrigators or water users, which can serve as a platform for training and information on climate forecasts, enabling adaptation to certain events (flash floods, early or prolonged drought, etc.);
- On plots far from the electricity grid, install run-of-the-sun pumping systems, which can be affordable in terms of investment costs, as the energy storage system (batteries, charge controller, etc.) usually accounts for more than 30%: while it is sunny, the water can be pumped and applied directly to the plot or stored in a tank for later irrigation. To make solar irrigation more accessible to smallholders, Non Governmental Organizations (such as International Development Enterprises), and African innovators such as Futurepump (in Kenya), SunCulture, have developed solutions such as the Sunflower pump (a high-performance piston pump powered by an 80-watt photovoltaic panel), the AgroSolar Irrigation Kit (ASIK), the AgroSolar which facilitates access to and reduces the cost of solar-powered irrigation. The introduction of similar solutions on the southern slope of the Bamboutos Mountains may be an avenue to be explored;
- Participate in reforestation operations currently underway on the slope.

To state and non-state structures (local elites, non-governmental organizations, international organizations, etc.) likely to carry out actions in the context of irrigation in the slope, it is suggested:

- Support irrigators (advice/training) in the technical management of irrigation for improved irrigation management and efficient use of water and energy resources. An avenue to explore for this purpose may be the implementation of a program like the Participatory Training and Extension of Water Management on Farms (FP&V/GEE), developed by the FAO [24]. An example of support for small-scale irrigators is the successful irrigation management transfer model adopted by Kenya in the development of small-scale irrigation [25];
- Support irrigators in acquiring irrigation materials and equipment;
- Support the construction of check dams on the main watercourses used for irrigation, and help irrigators set up water resource associations. Drawing on the lessons learned from irrigation projects in Malawi [26], capacity-building and governance systems for these water user associations should be considered, with a view to ensuring efficient use of irrigation infrastructure;

- Build groundwater catchment facilities (wells and boreholes) to guarantee water availability;
- Support initiatives such as reforestation, aimed at improving water availability in the basin;
- To support the extension of the electricity network in the basin to enable the pumping of irrigation water to plots that are far from the current electricity network;
- Support the installation of community solar fields for pumping irrigation water. This would be in line with paragraph 2 of Article 59 of the 2011 Electricity Law, which gives priority to decentralised production from renewable energy sources as part of decentralised rural electrification. The success of a pilot project to share a solar pumped irrigation system in a group of 49 farmers producing on 16.2 ha in Lallpura, India, reported by [27], is an inspiring example of group management of photovoltaic pumping.

Indeed, investment in solar irrigation systems is likely to offer a higher economic benefit over time, compared with fossil fuels [17]. In addition to the economic benefit, solar pumping of irrigation water is more environmentally friendly (reduced greenhouse gas emissions and noise pollution).

The African Union has defined four avenues to be combined to facilitate the growth and development of Africa's agricultural sector [1]. One of these is the development of farmer-supported irrigation, which is relatively inexpensive compared with large-scale irrigation, which requires substantial investment in infrastructure. To this end, diagnostic studies such as this one can be carried out in Cameroonian production basins where small-scale irrigation is practiced intensively. The improvements resulting from these studies could give rise to specific interventions, adapted to each context and with lasting positive impacts.

4. Conclusion

This work consisted in drawing up an inventory of small-scale irrigation systems on the southern slopes of the Bamboutos Mountains, with a view to contributing to knowledge of irrigation systems designed and managed by small-scale producers in developing countries. The study revealed that 84.96% of the irrigation systems installed were sprinkler irrigation systems and 15.04% were furrow irrigation systems. Around two decades ago, irrigation water in the basin was mobilized solely by gravity. Today, 50% of irrigation is by gravity, 34.51% by motor pump, 14.60% by electric pump and 0.89% by solar field pump. The decline in the amount of water available for irrigation over the years is the main reason for the changes observed in the types of irrigation systems and the sources of water and energy used. In addition to the constraint linked to the availability of water between mid-January and mid-March, the high cost of energy and irrigation equipment, as well as the lack of a formal association of irrigators, are the main difficulties encountered. These irrigation systems, which enable market gardeners to produce continuously and always have enough to meet the needs of their families, could be improved by interventions aimed at upgrading or developing water catchment structures, improving access to electrical power and organizing irrigators into a functional association. Subjective water management practices at plot level and the obvious shortage of irrigation water underline the need to assess the technical performances of these irrigation systems and the sustainability of water and energy use in this production basin. Given the decline in water available for irrigation over the years, it would also be interesting to study the trend in water resources in the watershed, based on hydroclimatic projections.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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