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Diagnostic Analysis of a Non-Conventional Irrigation System in the locality of Bafou, West Region of Cameroon

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ABSTRACT: In Cameroon, most farmers practice irrigation adapted to their budget and technical capacities. These low budget irrigation schemes are the mostly spread between small scale farmers which constitute the majority of Cameroonian producers, but relatively few studies have been carried out on many of them and few official information exists on them. This study hence focuses on characterization and performance evaluation of one of such systems. Irrigation is carried out from planting to the early development phase, by pumping with fuel as an energy source, and watering the farm with a walker hose, until visible saturation. The output per unit irrigated crop area is of the order of 13583USD/ha for a production of 3000crates sold at an average price of 8USD. This value represents the production output and not only the irrigation output. The relative irrigation supply however was not favorable, as it indicated that the water supplied by irrigation did not cover up to 20% of the plant water needs, most probably due to the high irrigation intervals, causing the plants to be maintained at MAD for long periods of time. Future studies should hence find methods of ameliorating the performances of this system by acting on the farmer's technical level and social setting.

KEYWORDS: characterization, irrigation, non-conventional, performance evaluation, performance indicators.

1 INTRODUCTION

Irrigation is the supply of water to crops by artificial means [9] and is a means to ensure that the plant has enough water to ensure optimum growth and yields, allowing farmers to increase their cropping amount and key to producing high-value crops [14], [27]. Irrigation is therefore a means for man to give more value to his crops.

Ref. [16] declared the potentially irrigable land in Cameroon to be of the order of 290,000 hectares (ha). According to [10], the area equipped for irrigation in Cameroon was reported to be 25 654ha, of which 22 450ha is in full/partial control schemes, 404 ha in equipped wetlands and 2 800ha in spate irrigation. Considering an arithmetical growth curve, this would mean that Cameroon has roughly exploited 10% of its irrigation potential. Furthermore, this information is mostly true for equipped conventional systems, run by great firms such as: *Plantations du Haut Penja* (PHP), Upper Noun Valley Development Authority (UNVDA), *Société Camerounaise des Palmeraies* (SOCAPALM), *Société de Développement du Coton* (SODECOTON) and *Société Sucrière du Cameroun* (SOSUCAM) practicing conventional irrigation on several thousand hectares of land, just to name a few. The widely spread adapted irrigation systems are sparsely counted in these figures.

The West Region of Cameroon is reputed for the production of vegetable and dairy crops. Bafou in this Region is a production zone of great quantities of vegetable crops such as tomatoes, cabbages, leeks, green pepper [24], [31]. However, with the monomodal climate characterized by a dry season lasting from November to April and a rainy season lasting from May to October, production is limited to the rainy season for most farmers. The farmers resorting to producing offseason crops, are generally small farmers with limited financial and technical capabilities, irrigating on less than 05ha of land. They therefore tend to recreate and adapt conventional irrigation systems to their context, creating new irrigation techniques.

The major irrigation systems present in the Bafou locality are sprinkler irrigation systems [25], [31]. A few farmers practice surface irrigation but have to stop due to water scarcity during the dry season. Another method however, was observed by [25] which consisted in attaching a perforated object at the end of a pipe and moving it to different parts of the farm, method which was less used due to its tediousness, especially on large farms. In the identified irrigation system, a combination of the latter and a system similar to furrow irrigation which consisted in filling furrows with water one by one using a walker hose pipe was practiced in two distinct phases. Quantifying performance and efficiency using conventional methods here therefore could prove to be erroneous, as the systems differ entirely in the physical aspect.

Water scarcity is the greatest challenge in the practice of irrigation [11], [25]. However, the main reason for the choice of an irrigation system (for approximately 80% of users), is the efficiency of the system, according to [25]. The limited means of most farmers in this locality have pushed them in the practice of less costly and usually less efficient irrigation methods on their small farmlands (using readily available and less costly materials) [25]. This study will hence consist in describing and providing a detailed analysis of one of these non-conventional irrigation systems, in view of formalizing the system and providing methods to ameliorate its technical performance.

2 MATERIALS AND METHOD

2.1 DESCRIPTION OF STUDY ZONE

This study took place in the West region of Cameroon, a country located in Central Africa. Precisely, the farm (Figure 1) was located in the Bafou village located in the Nkong-ni subdivision of the Menoua division. Bafou has a surface area of 178 km2, is located at 12km of the urban center of the Menoua division, Dschang, and is irrigated by a dense network of rivers [8], [35].

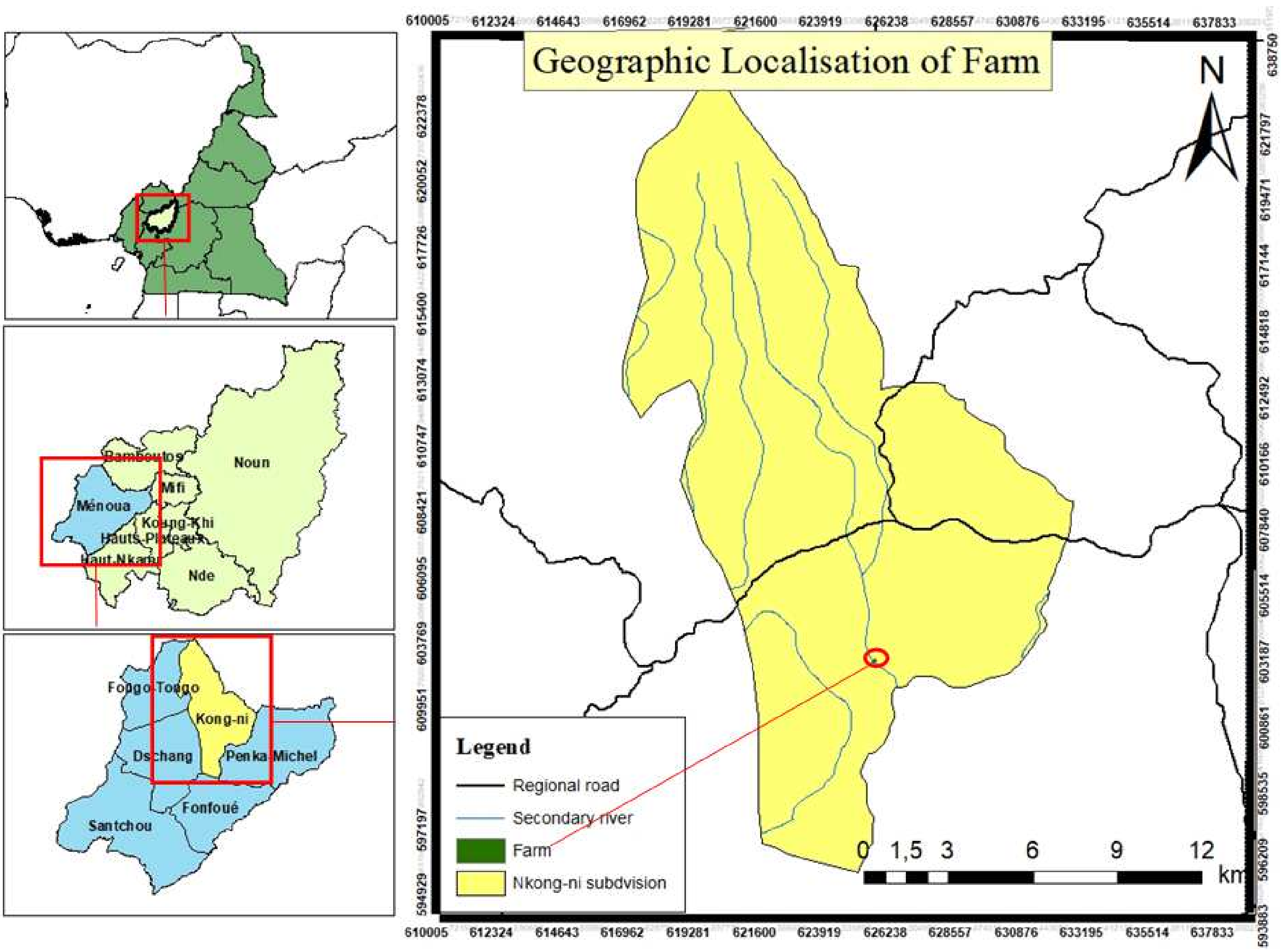


Fig. 1. Localization of Farm

Bafou is located in the Equatorial climatic zone which extends from 2° to 6° N and is characterized by average annual temperatures of about 25° with important vegetation cover. This implies moderate evapotranspiration observed in this zone for most cultural seasons. The ombrothermic curve as proposed by [1], revealed that the dry season lasts 3 months from November to January and the rainy season lasts six months from February to August. These values are not necessarily true for every cultural season due to climatic changes. Bafou has a mountainous character with a succession of mountains and valleys at various locations. Due to this configuration, the farms situated at higher altitudes than water sources use the motorized systems, while those situated at lower altitudes use gravity systems. Those that practice both are situated between at least two water sources situated at higher and lower altitudes [25]. The main rivers draining the Bafou area are Miamezo, Mianou, Mia-melieu, Mia-meloung and Atioyem, and together constitute a radial drainage system [33].

2.2 Characterization Of The Non-Conventional Irrigation System

The system was characterized by dividing the system into four components as proposed by [18] including the physical, cropping, economic and social-organizational systems.

The acreage was determined using a GARMIN GPSmap 78s Global Positioning System (GPS) receiver, by using the surface area calculation tool. The receiver was also used to record the coordinates of the farm and the slope profile was drawn using the ArcGIS 10.8 tool.

Concerning the physical system, the water source was described in terms of water quantity represented by flow rate (using the velocity area method) and water quality (pH, Salinity and Microbiological activity). The types of pumps were recorded through observation, as well as their nominal flow rates as prescribed by the fabricant. The flow rate of the pumps was also measured on farm using the volume method of water flow measurement. The pumping system here is influenced by the slope of the farm, the diameter and roughness of the pipes and the type of management. The water application subsystem was characterized using the following parameters: field geometry (length, width and configuration), water supply rate, slope (and levelness), infiltration rate, surface roughness, channel shape, and management. The water use subsystem was characterized using factors including the crop water requirement determined using the CROPWAT 8.0 tool, the soil texture and structure, and the soil type. The system of water removal from the soil was recorded using the presence of drainage facilities. This gives us information on the state of root aeration, soil salinity and the workability of the land.

The cropping management practices of the farmer were recorded according to the following criteria as recommended by [18]: Land preparation and tillage operations, Irrigation practices, Soil fertility management, Seedbed management, Crop management practices, Pest management, and Special management procedures.

The economic aspects of farm management were used to characterize the economic system, taking into account the factors of production used. The economic aspects of farm management include five broad categories: production activities, capital building activities, commercial activities, financing activities, and accounting activities [18].

The factors making up the farmers' situation, resulting in a set of behavioral patterns and decisions include the following, adapted from [18]: Setting, Culture, Structure and Processes.

2.3 Performance Evaluation Of The Non-Conventional Irrigation System

The irrigation system performance is measured using two types of indicators: internal indicators which show how close the irrigation event is to the ideal, and external indicators which informs us of the comparative performances of the irrigation scheme. In the course of this work, only external indicators shall be used, because of the absence of adequate installations to measure correctly the internal performance of the system. The following performance indicators were selected from literature to answer the questions related to the on-farm management [2], [3], [7], [12], [19], [32].

2.3.1 Water Delivery Indicators

The selected indicators here are relative water supply (RWS) and relative irrigation supply (RIS). Both RWS and RIS give some indication about the condition of water abundance or scarcity and how tightly supply and demand are matched [30].

2.3.1.1 Relative Water Supply

Relative water supply (RWS) is given by the ratio of total supplied water (irrigation + rainfall) (m^3) to the crop water demand of the crop (m^3), first presented by [17].

$$RWS = \frac{Total\ water\ supply}{Crop\ water\ demand} \quad (1)$$

Where:

Total water supply = surface diversion plus effective rainfall (m^3);

Crop water demand = ETc (m^3).

RWS was calculated for each period of the development stage, and a graph of the evolution of RWS over the cultivated period was plotted.

2.3.1.2 Relative Irrigation Supply

Relative irrigation supply (RIS) is given by the ratio of supplied irrigation water (m^3) to the irrigation demand of the crop (m^3), first presented by [26].

$$RIS = \frac{Irrigation\ supply}{Irrigation\ demand} \quad (2)$$

Where:

Irrigation supply = only the surface diversion for irrigation (m^3);

Irrigation demand = irrigation requirement (m^3)

RIS was calculated for each period of the development stage, and a graph of the evolution of RIS over the cultivated period was plotted.

2.3.2 Physical Indicators

These include the irrigation ratio and the water sustainability ratio as proposed by [28].

2.3.2.1 Irrigation Ratio

This is the ratio of currently irrigated area to irrigable command (nominal) area and tells the degree of utilization of the available command area for irrigated agriculture at a particular time [7]. It is given as:

$$Irrigation\ ratio = \frac{Irrigated\ crop\ area}{Command\ (nominal\ area)} * 100 \quad (3)$$

Where:

Irrigated crop area (ha) = the portion of the actual irrigated land in any given irrigation season;

Command area (ha) = the potential scheme designed command area,

2.3.2.2 Sustainability Of Irrigated Area (SIA)

This is the ratio of currently irrigated area to initially irrigated area when designed [2]. Irrigated area sustainability (SIA) tells us that the area under irrigation is contracting or expanding as compared to the area initially irrigated [7]. It is given by:

$$SIA = \frac{Currently\ irrigated\ area}{Initially\ irrigated\ area} \quad (4)$$

2.3.3 Agricultural Performance Indicators

Agricultural performance indicators relate the value of production in USD to the irrigated cropped area (ha), and consumed irrigation water supply (m^3) as an output of the scheme as described by [6] and [29].

2.3.3.1 OUTPUT PER UNIT IRRIGATED CROP AREA

It quantifies the total value of agricultural production per unit of area under irrigation during the period of analysis. In addition to water availability, soil type and fertility, land suitability, crop variety and agricultural inputs do have significant impact on land productivity [7]. It is given as: [20], [22].

$$Output\ per\ unit\ irrigated\ crop\ area = \frac{Value\ of\ production\ (FCFA)}{Annual\ Irrigated\ cropped\ area\ (ha)} \tag{5}$$

2.3.3.2 OUTPUT PER UNIT IRRIGATION WATER SUPPLY

This tells on how well the total annual diverted irrigation water from a source is productive [7], and is given by:

$$Output\ per\ unit\ water\ supply = \frac{Value\ of\ annual\ production\ (FCFA)}{Diverted\ irrigation\ water\ (m^3)} \tag{6}$$

2.3.3.3 OUTPUT PER TOTAL WATER SUPPLY

This is for the output per unit of total volume of water (effective rainfall + irrigation) diverted to the system. It gives a sound comparison between irrigation schemes with different rainfalls, because gross water supply was considered [7], given as:

$$Output\ per\ total\ water\ supply = \frac{Value\ of\ annual\ production\ (FCFA)}{Total\ water\ supply\ (m^3)} \tag{7}$$

2.3.3.4 OUTPUT PER UNIT WATER CONSUMED

This indicator informs on the output per unit volume of water consumed by actual evapotranspiration. Its value is highly dependent on climate. Moreover, less consumptive use coefficient due to water losses does not affect its value; as only the water consumptively used by the crops is considered. It is given as [22]:

$$Output\ per\ unit\ water\ consumed = \frac{Value\ of\ annual\ production\ (FCFA)}{Water\ consumed\ by\ ET\ (m^3)} \tag{8}$$

2.3.4 PRODUCTIVITY INDICATORS

2.3.4.1 CROP WATER PRODUCTIVITY

It is given here as the ratio of the economic yield with respect to the consumptive water use, which also expresses the water use efficiency given by:

$$CWP = \frac{Y_g}{ET} \tag{9}$$

Where:

CWP = crop water productivity or water use efficiency (crates/ m^3);

Y_g = economic yield (crates);

ET = consumptive water use (m^3).

2.3.4.2 LAND PRODUCTIVITY

The yield of major irrigated crops per unit area of land is an important indicator of on-farm management. It is a measure of the biophysical gain from the usage of a unit of irrigation water, quantified by crop productivity units, expressed in kg or tons per hectare. The yield here is calculated in terms of number of crates produced and therefore in this system, it shall be expressed in terms of crate/ha or crate/m^2.

It is given by:

$$P_l = \frac{Production}{Irrigated\ surface\ area} \quad (10)$$

2.3.4.3 System Productivity

System Productivity which gives us the ratio of production (number of crates) to the gross annual or to the seasonal irrigation water use (m^3).

$$P_s = \frac{Number\ of\ crates\ produced}{Quantity\ of\ water\ diverted} \quad (11)$$

2.3.4.4 Energy Productivity

Energy productivity measures the number of man hours and liters of fuel used per unit quantity of water diverted (m^3) during the irrigation period.

$$P_{em} = \frac{Number\ of\ manhours\ per\ day}{Quantity\ of\ water\ diverted} \quad (12)$$

$$P_{ef} = \frac{Liters\ of\ fuel\ per\ day}{Quantity\ of\ water\ diverted} \quad (13)$$

Where:

P_{em} = Energy productivity in terms of manhours;

P_{ef} = Energy productivity in terms of liters of fuel.

2.3.5 Water Balance And Water Service Indicators

2.3.5.1 Field Application Ratio

The field application ratio (FAR) is a measure of efficiency and is defined by [15] as follows:

$$FAR = \frac{ET_C - P_e}{Volume\ of\ water\ diverted\ to\ field} \quad (14)$$

Where:

ET_c = crop evapotranspiration;

P_e = effective precipitation.

The numerator of this indicator originally contains: 'the volume of irrigation water needed, and made available, to avoid undesirable stress in the crops throughout (considered part of) the growing cycle'. This 'volume' is expressed in terms of m3/ha or in terms of water depth [3].

2.3.5.2 Depleted Fraction

The depleted fraction (DF) is the ratio that compares three components of the water balance of an irrigated area, defined by [22] as:

$$DF = \frac{ET_c}{P_e + V_c} \quad (15)$$

Where:

ET_c = average crop evapotranspiration from the gross command area;

P_e = effective precipitation;

V_c = volume of surface water flowing into the command area.

It shows the ratio of crop evapotranspiration to the water brought to the field.

2.3.5.3 Delivery Performance Ratio

The simplest, and yet probably the most important, operational performance indicator is the delivery performance ratio (DPR) [4], [5], [21]. It is given by the ratio of outflow from the canal to inflow as follows:

$$DPR = \frac{Actual\ water\ flow}{Intended\ water\ flow} \quad (16)$$

The intended water flow is given by the delivery rate of the pump and the actual water flow is the flow rate at the end of the pipe.

2.3.5.4 Dependability Of Intervals Between Water Applications

The dependability of intervals between water applications (DIWA) is the pattern in which water is delivered over time is directly related to the overall consumed ratio of the delivered water, and hence has a direct impact on crop production. The rationale for this is that water users apply more irrigation water if there is an unpredictable variation in timing of delivered water. It is given by [3] as follows:

$$DIWA = \frac{Actual\ irrigation\ interval}{Intended\ irrigation\ interval} \quad (17)$$

2.3.6 Management Indicators

2.3.6.1 Management Operation Maintenance Productivity

It is the total management, operation and maintenance (MOM) cost of providing the irrigation and drainage service excluding capital expenditure and depreciation/renewals per irrigation season per unit area measured in USD/m^2 or USD/acre.

$$P_{MOM} = \frac{Total\ MOM\ Cost}{Total\ Irrigated\ Area\ serviced\ by\ the\ system} \quad (18)$$

Where:

P_{MOM} = Management Operation Maintenance Productivity

The total MOM cost was given by the table of operational costs of the system.

2.3.6.2 Evaluation Of The Advantages And Constraints In Irrigation

This was done through observation and using the irrigation system assessment sheet adapted from [18] as follows:

1. What are the farmers' perceptions about night and day irrigation, major water problems inhibiting increased yields and solutions to major water problems?
2. What is the farmer's decision-making processes related to crop production, that is when to irrigate a given crop, when to stop irrigation, water lift methods, and who applies water at given irrigation?
3. Farmers' estimations of infiltration depth of water, depth of the crop's, root penetration, crop water requirements, critical water demand periods and stages of growth, sources of major losses, magnitudes of losses, and waterlogging.
4. Tendency of farmers to cooperate in water lifting, trading of irrigation turns, farm implements and machinery sharing, sharing of workload, patterns of both formal and non-formal cooperation.
5. Farm management practices: cropping patterns and intensities, seedbed preparation, levels of farm technologies, seed rates, quality and seeding methods, fertilizer inputs, timing, amount and placement methods, harvest methods, storage methods, crop water requirements, soil characteristics, problem soils.
6. Farmer's view on adoption of improved technologies; rate of adoption, information sources used at each stage in the process, characteristics of the innovation, farmers trust in information sources.

7. Economic returns and costs, lifting water (alternative methods), various crop mixes, storage systems, transportation, marketing.
8. Legal and organizational factors, delivery of water to command area, distribution of water, pricing of water, settlement of disputes-formally and informally, farmers' interaction with irrigation officials, use of incentives.
9. Water supply and removal, conveyance efficiency, field application efficiency, water quality, consumptive use, return flow, field topography.
10. Information used for farm-level decision-making: marketing and irrigation schedules, closures, extension, quality and quantity of information

3 Results And Discussion

3.1 Characteristics Of The Non-Conventional Irrigation System

The surface area of the farm was found to be 1.7839ha. Concerning the slope, it is of the order of 20% in some areas of the farm, thus making it difficult to recommend surface irrigation. However, since the water body has a lower altitude than the farm, only pumped irrigation can be practiced here.

3.1.1 Characteristics Of The Physical System

3.1.1.1 Characteristics Of The Water Delivery Subsystem

The Water Source

The flow rate was found to be 0.0525m^3/s in the dry period, 0.256m^3/s at the end of the wet period and 1.186m^3/s at the peak of the rainy season. (Table 1)

Table 1. Evolution of the stream discharge

Period	Dry period	Wet period	Extremely wet period
Section surface (m^2)	0.150	1.266	5.548
Flow rate (m^3/s)	0.0525	0.256	1.186

The flow rate here hence gives us the quantity of water available throughout the year, especially during the irrigation periods.

Concerning water quality:

- The pH was found to be 7.2 upstream and 7.3 downstream, which indicates that there is a relatively low presence of bicarbonate salts in the water (the presence of bicarbonates is indicated by a pH higher than 7.5 [34]), if not any. The slightly more basic pH downstream might be due to the fertilizer's residue being washed away into the water body, but not sufficiently so to raise an alert for any presence of salts.
- Ref. [13] affirms that 16% of the Cameroonian country is covered by salt-affected soils (0–30 cm), dominating in the northern part of the country where the Sudano-Sahelian climate prevails. This did not raise any alerts concerning the salinization of salts in the Western part of the country since the last studies by [23]. In addition to the non-alerting pH, this justifies why this study did not extend its scope to the study of the salinity of soils.
- Microbiological analysis revealed the presence of coliforms (Enterobacteria spp), faecal coliforms (*Escherichia coli*), Streptococcus spp, Salmonella spp, Shigella spp, Staphylococcus spp and Vibrio spp. The water here is hence highly contaminated and should be treated before irrigation, to avoid plant contamination, and the spread of an epidemic. Basic treatment with sodium hypochlorite (Javel water) will greatly reduce the risk of contamination.

The Pumping System

Pumping was done in three steps including suction, pumping and repression (Figure 2).

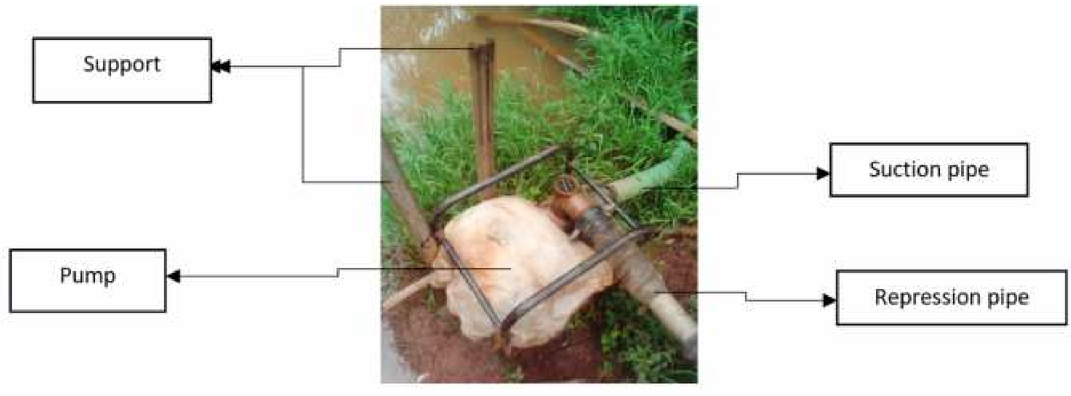


Fig. 2. Pumping System

The abrupt farm slope causes the farmer to use two pumps. The first pump (pump 1) covers the down slope and the lower part of the mid slope, while the second pump (pump 2) covers the upper part of the mid slope and the upper slope. The flow rate of pump 1 was found to be 4.17L/s (250L/min), giving us approximately 120m^3 of water pumped per day into the farm. The blatant difference in delivery volume might be due to the age of usage of the pump, and equally due to the different repairs carried out on the pump.

The pumping system is made up of pipes bound together with rubber bands to keep them from succumbing to pressure; the plastic bag on top of the pump was used to cover the pump in an attempt to protect it from harsh weather and dust and the support with two bamboo sticks planted firmly in the ground was to stop the pump from rolling back due to its kinetic energy during pumping.

The suction pipe was a 100mm diameter pipe and the repression pipe was a 63mm. This is less than the 80mm pipe prescribed by the fabricant. This might be due to the absence of adapted piped on the market and explains the use of rubber bands to tighten them together, and simultaneously, the drop in the efficiency of the pump. Two types of PVC pipes were used for aspiration (Figure 3): smooth and rigid; rough and flexible. These pipes were selected according to their market availability, however rough pipes tend to cause more friction and consume more energy for aspiration.

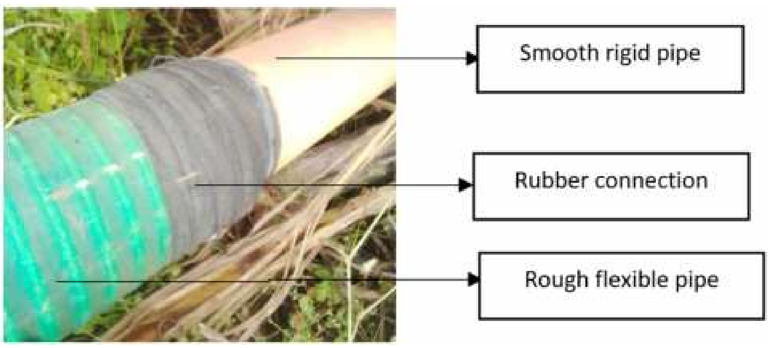


Fig. 3. Aspiration pipes

3.1.1.2 Characteristics Of The Water Application Subsystem

The field had an irregular shape, and for irrigation, the farm was divided into plots, that were irrigable according to the number of people present per day, at the different stages of irrigation. The repartition of plots was mostly done on the length than on the width (rectangular shaped plots). This was mainly due to the slope of the farm, which was abrupt, causing work advancement to be less difficult on the length than on the width.

Irrigation here was carried out in three phases: planting, where the ridges were watered directly using the walker hose; transplanting where water was applied to the outer part of the pocket, to avoid the splashing of chicken droppings out of the pocket due to high pressure (Figure 11); and part of the development phase, where the plants and surrounding soil was watered. This technique is similar to that observed by [25]. At each stage, the irrigation was carried out once a week, and twice if the plants showed signs of wilting.

The pipes used to bring water to the field were mainly 63mm smooth PVC pipes encased into each other (by heating them to expand them) for transport and a walker hose to distribute water on the farm, the two once again bound by a rubber connection.

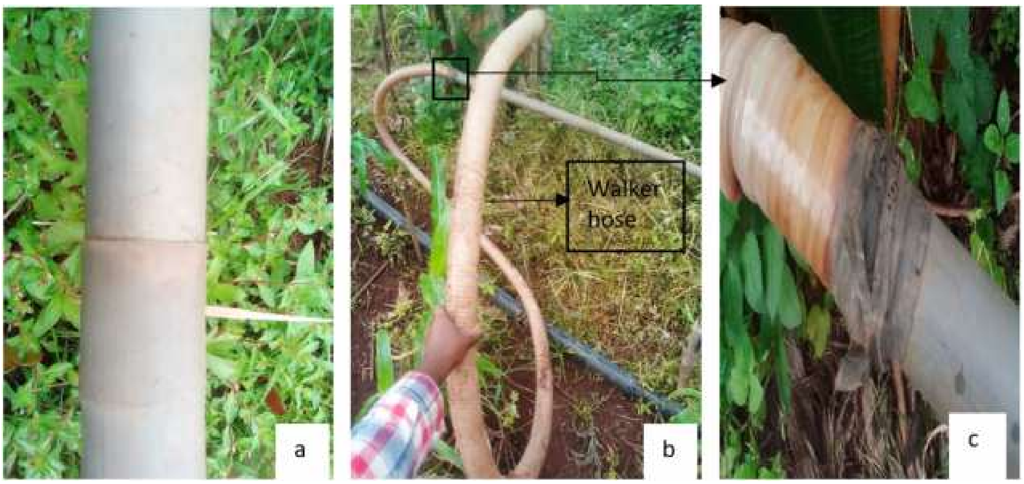


Fig. 4. System Components
(a) Encased pipes (b) Walker hose connection (c) Rubber connection

It can be seen that the rubber connections ware off with time and have to be changed regularly (after every two irrigations). These connections not being very solid, some objects such as banana tree trunks and chunks of wood were placed on the pipes to limit their movement and avoid disconnection (Figure 5).

Fig. 5. Stabilizing the pipes
(a) banana trunks (b) logs of wood

This measure was however not very viable, as losses were observed, due to high pressure at some points which caused disconnection of pipes, water and time wastage. Water loss at distribution was also observed due to noticeable holes in the pipes (Figure 6), which caused a decrease in pressure.

Fig. 6. Damaged pipe

The farmers measure good water supply rate by observing the pressure delivered at the end of the pipe. If the pressure caused a big splash, then it was sufficient pressure, if not it was considered low, mostly caused by a disconnection in the system (Figure 11). Concerning infiltration, saturation was considered to be reached when inundation was noticed on the irrigated surface. The disposition of the system is as shown in Figure 7.

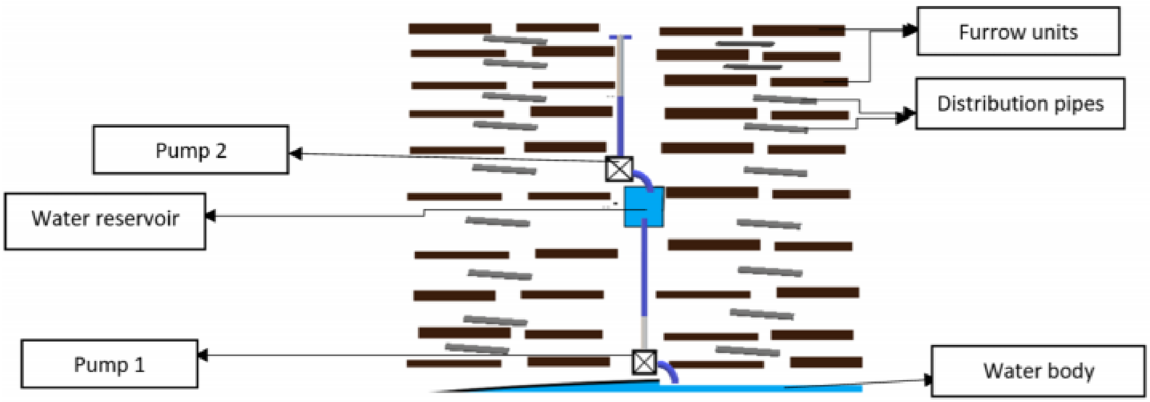


Fig. 7. Disposition of Water Application

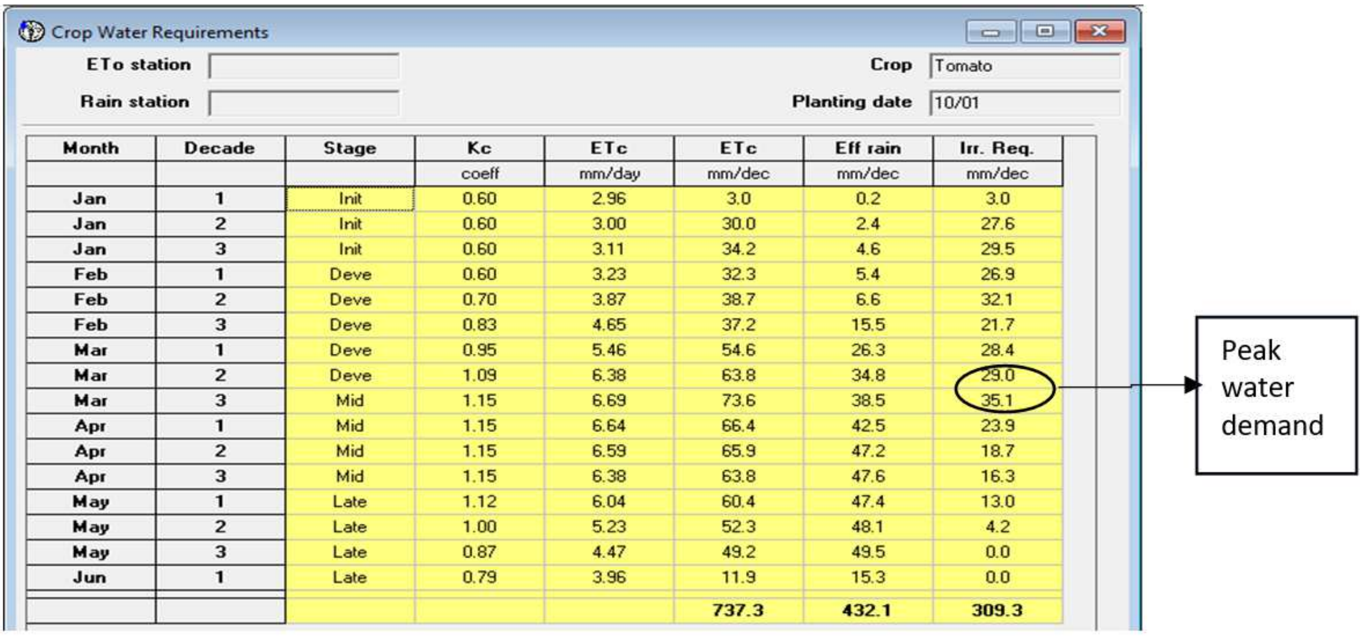
The pipes disposed in the farm were 63mm diameter pipes, waiting to be connected, once the corresponding area needed to be irrigated. The furrow units correspond to approximately ten furrows, arranged rectangularly. Water from pump 1 was pumped into a temporary reservoir which was a hole dug in the soil, intended to serve as a secondary water source for pumping uphill. This was a good measure to save money on buying a reservoir, but costs the pump wear off more easily, due to the high turbidity of the water. This measure hence calls for the farmer to change his pump filter as regularly as possible.

3.1.1.3 Characteristics Of The Water Use Subsystem

Traditionally, farmers determine the need for water through observation of the dryness of the soil, and the state of plants when the sun reaches the zenith. Plants needing water will generally show signs of fatigue (Figure 8).

Fig. 8. Plant showing signs of fatigue

The crop water requirement (CWR) (Figure 9) revealed the peak water requirement was most likely between the end of the development stage and the beginning of the mid-season stage, which is the heart of fruit formation.



Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	1	Init	0.60	2.96	3.0	0.2	3.0
Jan	2	Init	0.60	3.00	30.0	2.4	27.6
Jan	3	Init	0.60	3.11	34.2	4.6	29.5
Feb	1	Deve	0.60	3.23	32.3	5.4	26.9
Feb	2	Deve	0.70	3.87	38.7	6.6	32.1
Feb	3	Deve	0.83	4.65	37.2	15.5	21.7
Mar	1	Deve	0.95	5.46	54.6	26.3	28.4
Mar	2	Deve	1.09	6.38	63.8	34.8	29.0
Mar	3	Mid	1.15	6.69	73.6	38.5	35.1
Apr	1	Mid	1.15	6.64	66.4	42.5	23.9
Apr	2	Mid	1.15	6.59	65.9	47.2	18.7
Apr	3	Mid	1.15	6.38	63.8	47.6	16.3
May	1	Late	1.12	6.04	60.4	47.4	13.0
May	2	Late	1.00	5.23	52.3	48.1	4.2
May	3	Late	0.87	4.47	49.2	49.5	0.0
Jun	1	Late	0.79	3.96	11.9	15.3	0.0
					737.3	432.1	309.3

Fig. 9. CWR determination

From the Figure above, we can see that the irrigation requirement in this zone is approximately 42% of the total water requirement, mostly needed at the initial and early development stages of the plant. The graph below shows the variation between effective rainfall and the irrigation requirement (Figure 10).

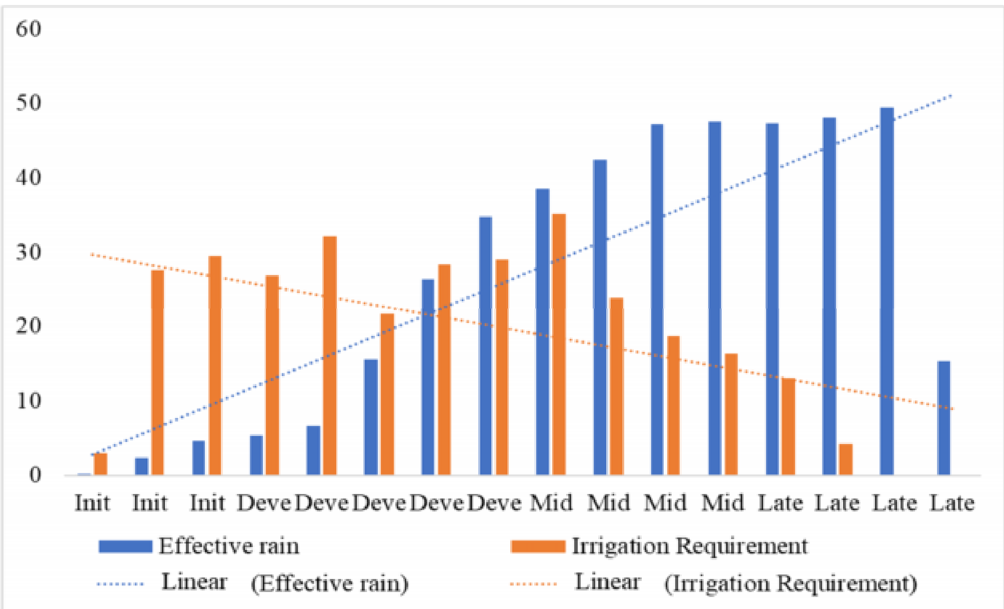


Fig. 10. Graph of effective rainfall against irrigation requirement

From the graph, we can see that there is a high possibility for precipitation in this area to be back before the peak demand season. This corresponds to the month of March which represents the wet season, when precipitation may not always be sufficient, and hence supplementary irrigation deemed necessary. It is during this period however, that irrigation was stopped. The precipitation occurring once a week at this period as planned on the irrigation calendar, was used to cover plant water needs, while irrigation was paused. If the rain was not back within ten days however, irrigation was practiced as a measure of deficit irrigation.

3.1.1.4 Characteristics Of The Water Removal Subsystem

The drainage onsite was done naturally due to the: high slope of the farm which favored runoff, and the sandy nature of the soil which favored deep percolation. This highly encourages the washing away of salts and the aeration of soil particles. The land was however difficult to maneuver especially when the soil was too highly drained, making it hard to work on.

3.1.2 Characteristics Of The Cropping System

Tillage operations were scheduled for three periods: planting, where ridges were formed in the nursery, on which tomato was planted, taking just over half a working day; transplanting, where pockets were formed in the farm, and chicken droppings were dropped in as amendment, taking three working days; and development, when ridges were to be formed on the farm surface when the transplanted plants would have acclimated well, to allow for the passage of water during the last irrigation phase, taking four working days. These operations were carried out using hoes, as the abrupt slope of this farm as well as the financial means of the farmer does not permit the usage of more sophisticated machinery. Naturally, the sharpened hoes worked faster than the lame ones.

The type of irrigation practiced and the corresponding schedule depended on the development phase of the plant: at planting, the water hose was used to water the plants manually; at transplanting (Figure 11), the water hose was used to water the pockets manually, disconnecting the pipes and reconnecting them, when moving from one zone to another; during development the irrigation consisted in watering in a first phase just like at transplanting to replace dead plants or plants having reached PWP a week after transplanting, and in a second phase of watering the plant each week until the return of the rain. This method although difficult and relatively slow (on average two working days scheduled for irrigation), caused less water losses than the old system which consisted in inundating the furrows, one by one. It was also planned however, that if the rain was not back by the late development phase, furrows would be formed and inundated with water for irrigation.

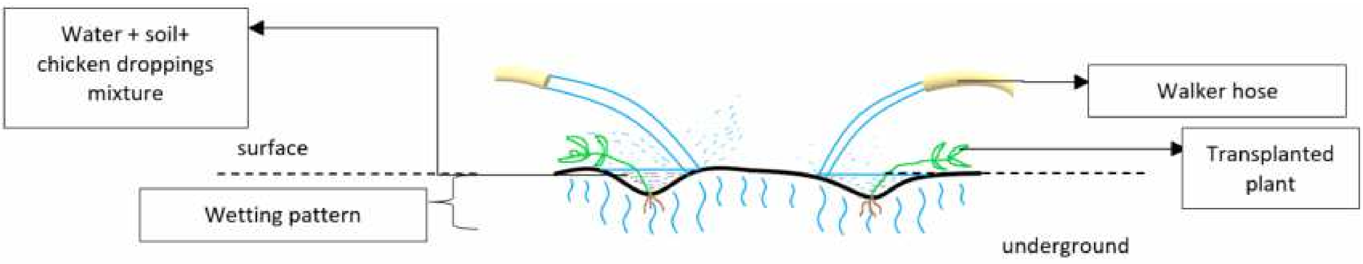


Fig. 11. Water application at transplanting

In addition to chicken droppings, when the plants were seen to have acclimated well after transplanting, NPK 20-10-10 fertilizer was applied, during the formation of ridges. The applied fertilizer, was carried and turned over in the soil, imitating the action of a moldboard plough, but using hoes.

The plant grown by this farmer was tomato (*Solanum lycopersicum raja*), and the furrows were arranged in pseudo steps (Figure 12), perpendicular to the slope of the farm to avoid erosion of the top soil and nutrients. The average spacing was about 80cm row spacing and 20cm plant spacing. To avoid soil impoverishment, tomato is planted here in a rotational pattern with maize.

Fig. 12. Configuration of ridges

The most redundant pathology encountered was bacterial withering, which could easily be confused with plant wilting, if one is not experienced. The difference can the observed at the level of the stem, which still remains fresh during a bacterial wilt (Figure 13), but if the problem is water, the shoot will show signs of weakness.

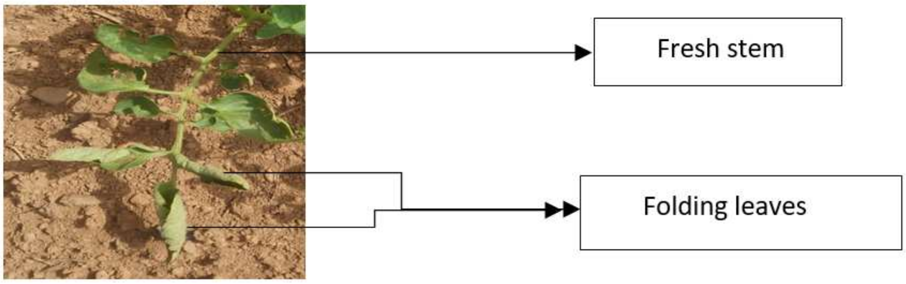


Fig. 13. Bacterial wilting

Other pathologies and weeds were not really observed due to the weekly chemical treatment of the plants. Treatment was done by pumping the water into 500L containers and mixing the product in them. Upslope, the water was fetched at the site of the river on the road, and transported in the car back to the farm. The presence of pests (essentials rats and mice) was greatly observed towards the end of the mid-season, when fruits were beginning to ripen in the farm. These were controlled using products such as rat poison.

3.1.3 Characteristics Of The Economic System

The economic characteristics of farm management in this system are as seen in table 2 below.

Table 2. Economic characteristics of farm management

Activity	Category	Tasks	Factors of Production
Production activities	Agricultural practices	Seedbed preparation Planting Pocket preparation Transplanting Tillage Staking Fertilizing Phytosanitary treatment Harvest	Land (cost of land, fertility of land, soil texture and structure), labor (cost of labor, efficiency of labor), available capital
	Irrigation practices	Water application Pipe maintenance Pump maintenance	Land (soil texture and structure), labor (cost of labor, both machine and manual), available capital
Capital building activities	Machinery and equipment purchase	Pump purchase Pipe purchase Rubber purchase Sprayer purchase Hoes and cutlasses purchase	Available capital
Commercial activities	Input purchase	Fertilizers Phytosanitary products Water Crates	Available capital, cost of water
	Marketing purchase	No direct marketing involved	
Accounting activities	Production and transaction records	Writing down of all production and transaction records of the farm	Land, labor, capital

The total operational costs of the farm were approximately 770USD, with approximately 260USD spent on irrigation.

3.1.4 Characteristics Of The Social System

The various operations in this farm carried out by hired workers (both adults and children), and the farmer's own children, on most weekends. During work hours, everyone is given work and paid according to his age and capacities. For instance, during harvesting, little 10year old children can get paid approximately 2USD/day, while adults get paid approximately 5USD/day.

The farmer's water resource is not a highly exploited resource according to him, because in that production zone, there are only two well established producers (having the largest cultivated surface area), who produce tomato during the dry season. If there were more exploiters on that resource, he would readily form an agreement with them to determine the best usage pattern an employ a proposed IWRM plan, to consider other users, especially as this resource has been labelled grossly polluted. For instance, he would readily accept alternating between day and night irrigation to have full access to the water resource. The problem of water scarcity here even during the dry season though, has not yet been encountered by the farmer.

3.2 Performance Of The Non-Conventional Irrigation System

The external indicators of performance of the system are as seen below.

3.2.1 Water Delivery Indicators

The table below shows the values used to calculate RWS and RIS.

Table 3. of values for RWS and RIS calculation

Month	Decade	Stage	Eff rain (m^3/dec)	Irri sup (m^3/dec)	TWS (m^3/dec)	CWD (m^3/dec)	Irri Req (m^3/dec)
Jan	1	Init	3.57	30	33,57	53.517	53,52
Jan	2	Init	41.03	30	71,03	535.17	494,14
Jan	3	Init	82.06	30	112,06	610.09	526,25
Feb	1	Deve	96.33	30	126,33	576.20	479,87
Feb	2	Deve	117.74	120	237,74	690.37	572,63
Feb	3	Deve	276.50	120	396,50	663.61	387,11
Mar	1	Deve	469.17	120	589,17	974.10	506,63
Mar	2	Deve	620.80	120	740,80	1138.13	517,33
Mar	3	Mid	686.80	120	806,80	1312.95	626,15
Apr	1	Mid	758.16	120	878,16	1184.51	426,35
Apr	2	Mid	842.00	120	962,00	1175.59	333,59
Apr	3	Mid	849.14	0	849,14	1138.13	290,78
May	1	Late	845.57	0	845,57	1077.48	231,91
May	2	Late	858.06	0	858,06	932.98	74,92
May	3	Late	883.03	0	883,03	877.68	0
Jun	1	Late	272.94	0	272,94	212.28	0
Total			**7702.98**	**960**	**8662.88**	**13152.69**	**5519.39**

Where:

Eff rain: Effective rain
Irri sup: Irrigation supply
Irri req: Irrigation requirement
TWS: Total water supply
CWD: Crop water demand corresponding to ETc

The graph in Figure 14 below shows the variation of RWS throughout the season.

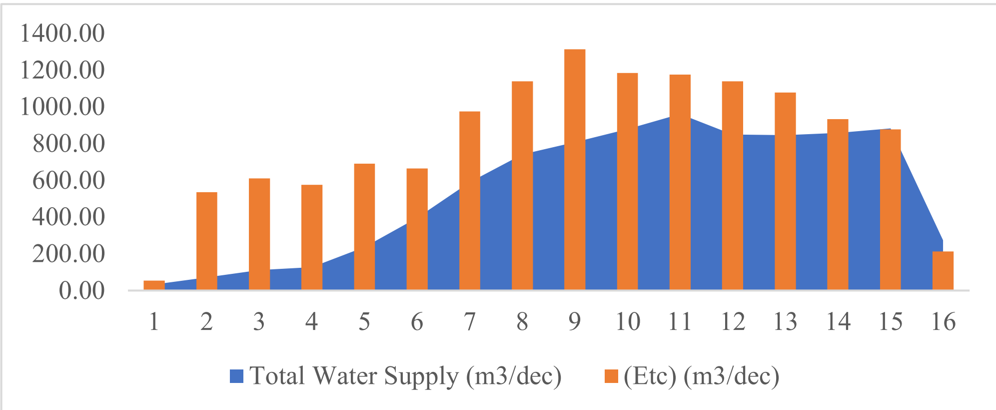


Fig. 14. RWS evolution during cultural season

The total RWS supply is 65.86%, meaning that approximately 35% of the water crop demand was not supplied during this season. From the graph, we can also see that throughout most of the season, the total water supply was less than the crop demand.

The graph in Figure 15 below shows the variation of RIS throughout the growing season.

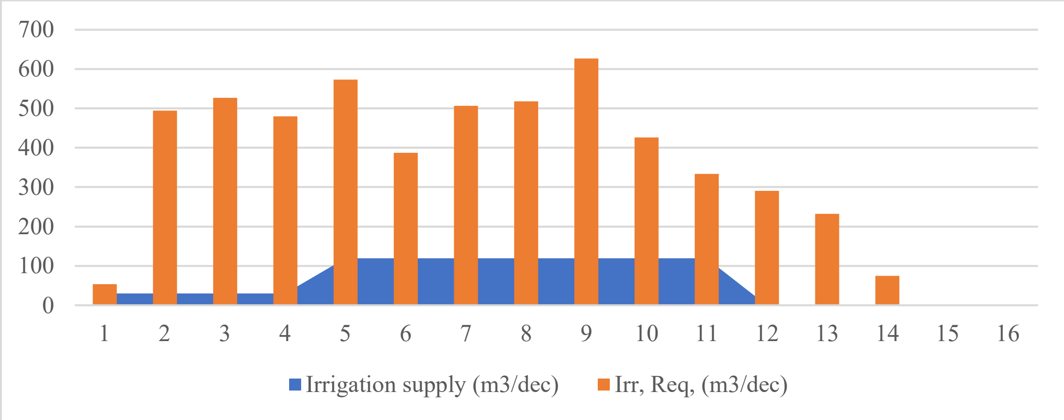


Fig. 15. RIS evolution throughout growing season

The graph in Figure 15 shows that the water supply for irrigation throughout the growing season is insufficient, as calculated total RIS gives 17.40%, meaning that irrigation does not cover up to 20% of the total water needs during the growing season.

From the results above, it can be seen that the water supplied to the farm through rainfall and irrigation does not meet the plant water needs. In addition to that, the contribution brought by irrigation to the farm, although not insignificant, is minimal. This can be explained by the high irrigation intervals and low irrigation time used by the farmers.

3.2.2 Physical Indicators

Both the irrigation ratio and SIA were 100%, as the farmer is a small-scale farmer, who invested relatively high value inputs in his farm. The total land surface exploited was hence irrigated throughout the season.

3.2.3 Agricultural Performance Indicators

This campaign produced approximately 3000 crates of tomato for an average unit price of 8USD.

The output per unit irrigated crop area is of the order of 13583USD/ha. This value represents the production output and not only the irrigation output. The output per unit irrigation water supply is 25USD/$m^{3,}$ representing the productivity if water in monetary terms. The output per total water supply is approximately 3USD/$m^{3,}$ implying that the gross water applied has less monetary value than the irrigated water. The output per unit water consumed is given by approximately 2USD/$m^{3,}$ meaning that each meter cube of consumed water cost approximately 2USD of output.

3.2.4 Productivity Indicators

The CWP was found to be 0.23crates/m^3 of water, meaning that one meter cube of water consumed, was needed to produce 0.23crates of tomato. The land productivity was found to be 1681.70crates/ha, and like the output per unit irrigated cropped area, does not only represent the biophysical gain from the usage of irrigation water but also from other factors. The system productivity was found to be 3.125crates/m^3 of water diverted. This large difference between the system productivity and crop water productivity, once again confirms the insufficiency of irrigation water throughout the growing season, as the crop water productivity could not express its full potential. The energy productivity in terms of manhours and fuel was found to be 0.07hr/$m^{3,}$ expressing the enormous advantage of pumped irrigation in the delivery of water to the field. In terms of fuel, we obtained 0.1L/m^3 of water pumped.

3.2.5 Water Balance And Water Service Indicators

The field application ratio was found to be 5.68 implying the volume of irrigation water needed was more than five times the volume of water diverted in the field. This result further supports the RIS obtained above, which informed us of the low level of water supply with respect to irrigation demand. This implies the irrigation time should be increased by at least five times and not only limited to the visible inundation observed.

The depleted fraction was 1.52 indicating that the crop evapotranspiration was 1.52 times more than the volume of water diverted in the field. This means that the total water supply brought in during this season was insufficient to attain complete irrigation.

The DPR was of the order of 25% and this could explain the low water delivery level to the farm. The DIWA was 100% as irrigation practices were planned and carried out each week until the beginning of the rainy season.

3.2.6 MANAGEMENT INDICATORS

The MOM was found to be 145USD/ha, meaning that approximately 145USD was spent per hectare on the management, operation and maintenance of the irrigation system throughout this season.

The identified advantages of this system are as follows:

- The land is not completely inundated and therefore does not consume much water;
- Not very onerous to practice;
- Relatively cheap.

The constraints of this system include:

- The constant undoing of the joints, causing wastage of water and time on the field;
- The rapid wearing of pumps and pipes which is often changed every cultural system;
- The absence of measuring equipment to follow up the usage of water in the field.

4 CONCLUSION

This work aimed at describing and analyzing a newly endowed approach to irrigation, by producing related data usable by both scientists and farmers of the Bafou locality. To attain this objective, the system was characterized and analyzed according to criteria adapted from different authors. The conclusions that can be driven from this work are as follows:

- The non-conventional system identified was a four phased irrigation system at scheduling, but due to the early arrival of rain, it became three phased.
- The water used for irrigation in this system is of poor quality and must imperatively be treated before irrigation.
- The irrigation system identified consisted in pumping water from a river, and distributing it to the field using a water hose. The pipe connection was strengthened either with rubber or simply by encasing them, system which was not very solid and often caused time and water wastage.
- The efficiency of the pump is greatly reduced by its age and by the usage of pipes of lesser diameters than those nominally prescribed by the pump, which additionally are not adapted with the appropriate equipment but rather tightened using rubber bands.
- The total operational costs of the farm were 770USD, with 260USD spent on irrigation.
- The workers in the farm were both hired workers and the farmer’s children, and the farmer was very open to collaborate with other farmers if the production basin were to expand. In this system, each worker gets paid according to age range and level of work.
- The total relative irrigation supply was 17.40%, meaning that irrigation did not cover up to 20% of the total water needs during the growing season, results supported by the field application ratio which was 5.68, and therefore a completely irrigated spot should not just be observed on the basis of the state of soil wetting.
- The crop water productivity revealed 0.23crates of tomato produced per hectare of irrigated land.
- The main guidelines concerning the enhancement and promotion of this system mainly include solving issues related to the farmer’s technical level and social setting.

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