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Design and Implementation of a Sprinkler Irrigation System for plantain cultivation in the M'batto region (Central-East Côte d'Ivoire)

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ABSTRACT
Objective: In Côte d'Ivoire, climate variability severely threatens the productivity of plantain (*Musa paradisiaca*), a crop highly dependent on rainfall. This study, conducted in M'Batto (Moronou Region, Central-East Côte d'Ivoire), aims to design and evaluate an optimal sprinkler irrigation system to compensate for crop water deficits.
Methodology and Results: The methodology relies on climate data processing using CLIMWAT 2.0 and CROPWAT 8.0 software to estimate reference evapotranspiration (ET_0) and crop water requirements based on the Penman-Monteith approach. The hydraulic network dimensioning was modelled using IRRICAD Pro V16, Global Mapper, and AutoCAD software. The results reveal an annual ET_0 of 1,037.87 mm against a maximum crop water requirement estimated at 2,000 mm, highlighting a critical water deficit of 962.13 mm/year. To address this deficit, a sprinkler irrigation network with an overall capacity of 24.1 m³/h was designed for a 0.77-hectare pilot plot. The developed optimal layout comprises 3 irrigation blocks and 75 sprinkler risers (25 per block) operating at a sectoral flow rate of 10 m³/h. On-site field tests confirm hydraulic efficiency and uniform water distribution, offering a replicable technical solution to secure plantain yields in the region.
*Conclusion and Application of results***:** In conclusion, this engineered sprinkler layout successfully mitigates severe seasonal moisture stress in the Moronou region. To maximize agricultural resilience, it is recommended that local smallholders and agricultural cooperatives adopt this sectorized network configuration. Furthermore, transitioning toward solar photovoltaic pumping is highly recommended to eliminate fossil fuel dependency and reduce long-term operational costs.
Keywords: Agricultural engineering, Water requirements, CROPWAT, Hydraulic design, *Musa paradisiaca*.

INTRODUCTION

Agriculture remains the central pillar of Côte d'Ivoire's economy, contributing significantly to the Gross Domestic Product (GDP) (Jean, 1989; Doumbia and Depieu, 2013). Among staple cash crops, plantain (*Musa paradisiaca*) holds a strategic position for food security and rural household income (Sawadogo, 1977: Yao, 1988; Jean, 1989). Traditionally confined to the country's humid forest zone, its cultivation is actively expanding into the transition forest of the Central-East, particularly in the M'Batto region (Yao, 1988, Doumbia and Depieu, 2013). However, the productivity of this monocotyledonous crop is currently severely compromised by climate disruptions (Mermouo, 2004). Plantain possesses a shallow fasciculate root system and a large leaf biomass, making it extremely sensitive to moisture stress. The decline and erratic distribution of rainfall observed in recent decades induce severe drought pockets during growth cycles, leading to drastic yield drops (FAO, 2008; Doumbia & Depieu, 2013; Boni, 2015). Faced with this biophysical constraint, water management through irrigation has emerged as an essential parameter to stabilize and intensify production. While localized irrigation (drip) is frequently discussed, sprinkler irrigation remains highly suited to the configuration and density of plantain plantations, as it simulates a favourable humid microclimate beneath the vegetative canopy (Altchenko *et al*., 2022). Nevertheless, the adoption of this technology often faces technical design flaws, such as improper pump sizing, excessive head loss, and poor distribution uniformity, leading to the economic failure of agricultural engineering projects. To address this local issue, the present study was initiated in M'Batto. The primary objective is to rigorously design, size, and field-test an optimal and technically viable sprinkler irrigation system. Specifically, the study aims to: (i) precisely model the monthly water requirements and deficits of plantain under the current climatic conditions of M'Batto, and (ii) perform the complete hydraulic dimensioning and in-situ technical evaluation of the proposed irrigation network.

MATERIALS AND METHODS

Study Area and Plant Material: The study was carried out in M'Batto, a locality situated in the Moronou region (Central-East Côte d'Ivoire) (figure 1). The experimental site covers a net area of 0.77 hectares dedicated to plantain (*Musa paradisiaca*) cultivation. Perimeter delineation and topographic surveys of the site were performed using a GPS receiver, and the geographical coordinate data were subsequently integrated into Google Earth and Global Mapper software to generate an accurate plot map.

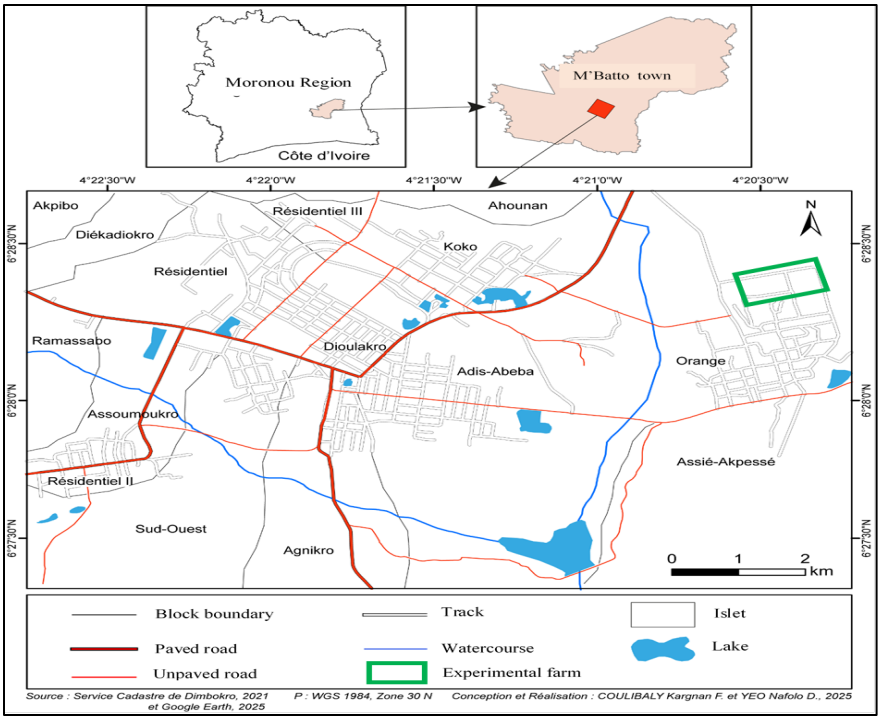


Figure 1. Geographic location map in M'Batto, Moronou Region, Côte d'Ivoire

Climate Data Collection and Water Requirement Modelling: To establish the water balance of the area, historical monthly climate data were extracted via CLIMWAT 2.0 For Cropwat software (figure 2) by selecting the Dimbokro meteorological station, which exhibits the closest and most representative bioclimatic characteristics to the M'Batto site.

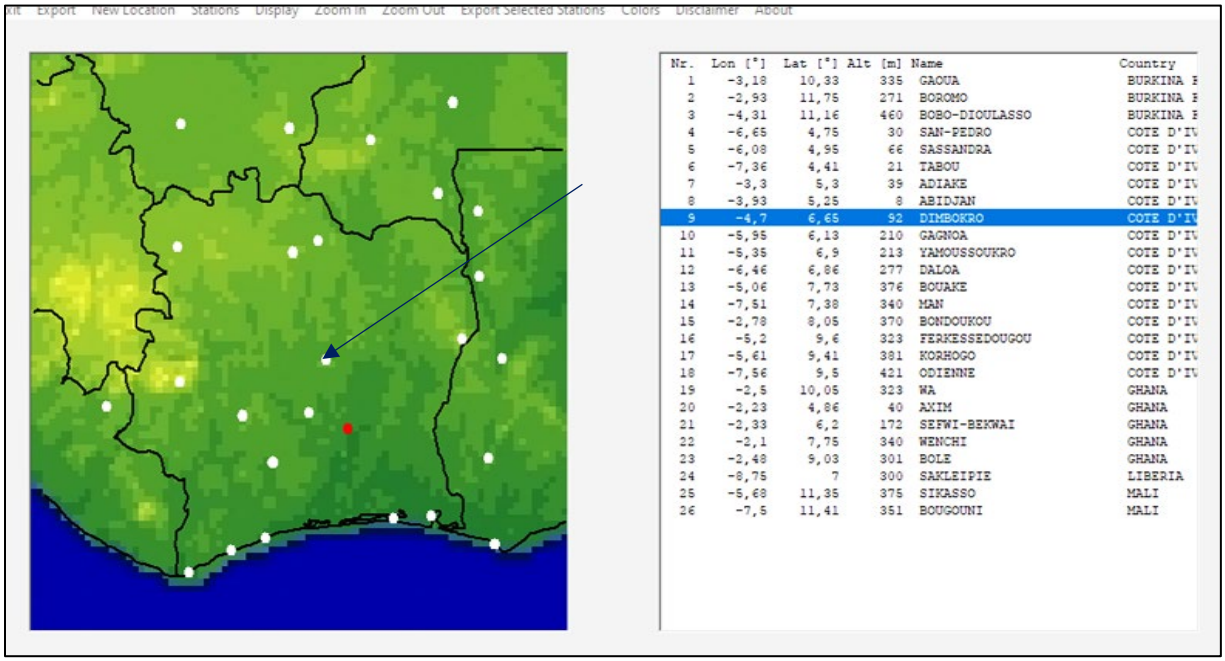


Figure 2. CLIMWAT 2.0 for Cropwat software interface illustrating the selection of the Dimbokro meteorological station for hydroclimatic data extraction

These climatic variables (rainfall, minimum and maximum temperatures, relative humidity, wind speed, sunshine duration) were then inputted into CROPWAT 8.0 software (figure 3). Reference evapotranspiration (ET_0) was calculated on a monthly basis using the standardized Penman-Monteith equation (Diaw *et al*., 2002). The maximum crop water requirements (ET_m) were determined according to the FAO (Smith, 1990; Richard & Allen, 1998;) equation 1:

$$ET_m = K_C \times ET_0 \quad (1)$$

Where K_C represents the specific crop coefficient for the different phenological stages of plantain (initial, development, mid-season, and late-season stages), calibrated according to the standard database of the software. The water deficit to be compensated by irrigation was calculated as the difference between ET_m and effective rainfall P_{eff} (Diaz & Manuel, 2006)

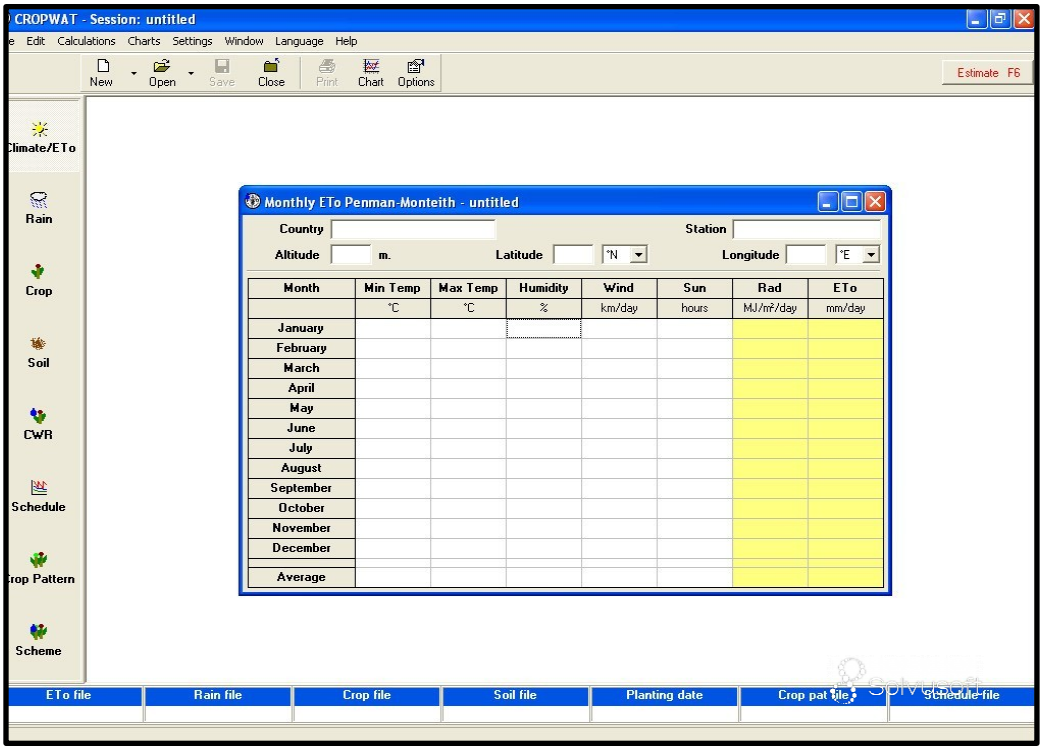


Figure 3. CROPWAT 8.0 software interface displaying the reference evapotranspiration (ET_0) calculation matrix based on the Penman-Monteith approach.

Hydraulic Dimensioning and Network Design: The pressurized sprinkler irrigation network was modeled and sized using the specialized IRRICAD Pro V16 software, coupled with AutoCAD for the spatial structuring of components. The hydraulic calculations integrated into the software allowed the determination of the design flow rate at the source, the distribution of operating pressures, and the optimal pipe sizing to mitigate linear and localized head losses. The designed network was segmented into three distinct irrigation blocks or shifts to optimize the delivery capacity of the available borehole. The distribution infrastructure includes:

- Main Polyvinyl Chloride (PVC) pipes of Nominal Diameter (ND) 63 mm, with a Nominal Pressure (NP) rating of 10 bars.
- Sub-main networks and laterals made of PVC and Polyethylene (PE) with ND 50 mm and ND 25 mm (NP 10).
- A filtration and safety system connected to the ND 50 mm main master valve at the outlet of the booster pump unit.

Sprinkler Layout and Field Implementation: For irrigation, a network of 75 sprinklers with a nominal wetted radius of 10 meters was selected. Technical assembly consisted of mounting the sprinkler heads on 50-cm vertical DN 25 PVC risers, stabilized on the ground by wooden support stakes. Threaded connections were sealed using Teflon tape, while the assembly of male-female components was reinforced with high-pressure PVC solvent cement. The network was split into 25 sprinklers per cultivation block (3 blocks in total). In-situ operational performances were evaluated by measuring hydraulic pressure at the outlets, the overall sectoral flow rate delivered by each shift, and the ground-level rainfall distribution uniformity.

RESULTS AND DISCUSSION

Evaluation of Water Requirements and Crop Hydrological Balance: Processing historical climate data under CROPWAT 8.0 quantified the reference evapotranspiration (ET_0) in M'Batto, reaching an annual cumulative value of 1,037.87 mm. By applying the specific phenological crop coefficients (K_c) for plantain, the annual maximum crop water requirement (ET_m) amounted to 2,000 mm. Comparing this biophysical demand with effective rainfall (P_{eff}) highlights a critical annual water deficit of 962.13 mm. Monthly data analysis reveals that the intense moisture stress period spans from November to April, coinciding with the major dry season of the Moronou region (Table 1).

Table 1: Monthly hydrological balance for plantain (*Musa paradisiaca*) cultivation in M'Batto: comparative analysis of maximum evapotranspiration (ET_m), effective rainfall (P_{eff}), and net moisture deficit.

Month	ET_m (mm/month)	P_{eff} (mm/month)	Rainfall Deficit (mm/month)
July	24.9	75.9	+51.0 (Surplus)
August	24.3	59.0	+34.7 (Surplus)
September	26.3	91.6	+65.3 (Surplus)
October	35.8	99.1	+63.3 (Surplus)
November	51.2	43.9	-7.3
December	60.9	16.7	-44.2
January	84.9	12.6	-72.3
February	126.9	40.9	-86.0
March	153.2	86.6	-66.6
April	161.6	97.9	-63.7
May	93.1	98.1	+5.0 (Surplus)

The results indicate that from May to October, rainfall fully satisfies evapotranspiration demands. Conversely, starting in November, the water deficit widens rapidly, peaking in February (-86.0 mm). This prolonged lack of water severely alters the leaf area index and delays plantain floral initiation, justifying controlled water application during this period.

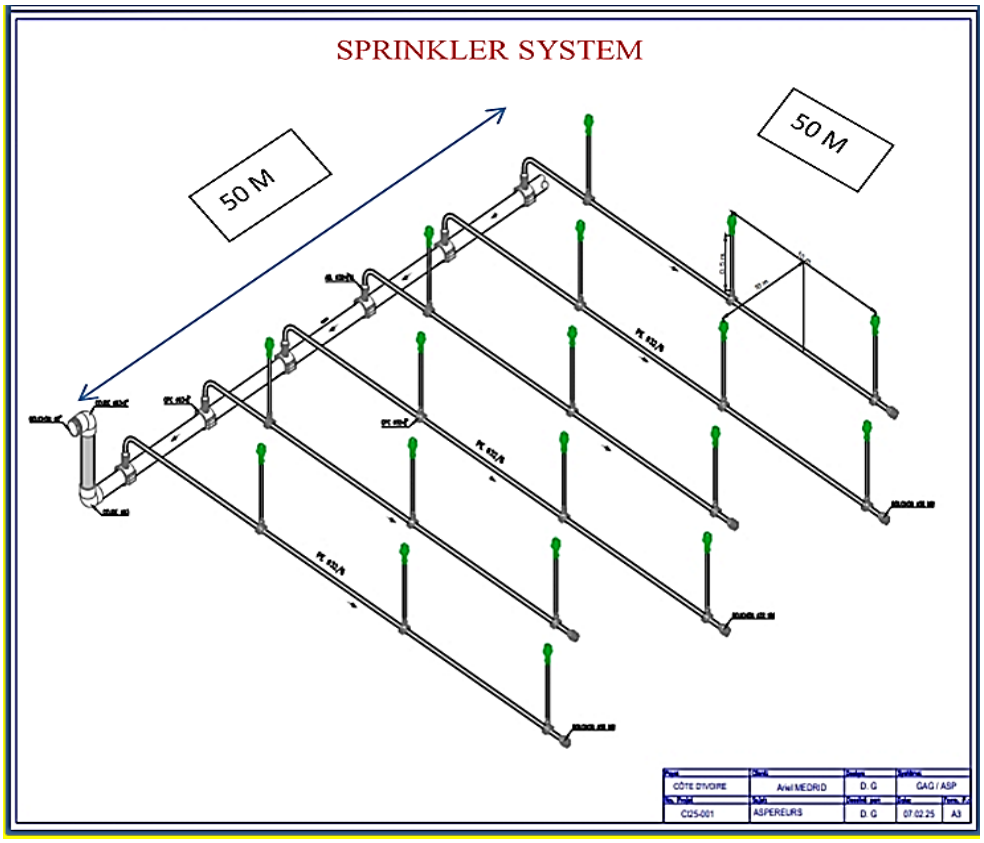
Hydraulic Dimensioning and Designed Network Characteristics: To offset this

deficit on the 0.77-ha pilot plot, IRRICAD Pro V16 software modeled a sprinkler irrigation network subdivided into three autonomous operational blocks or shifts. The specific hydraulic parameters of each block are detailed in Table 2.

Table 2. Synthesis of hydraulic descriptors and operational performance parameters of the sprinkler irrigation network sectorized by blocks on the pilot plot (0.77 ha).

Irrigation Block	Net Area (ha)	System Precipitation (mm/h)	Required Irrigation Time (h)	Design Flow (Q) (m^3/h)	Required Block Pressure (mWH)	Required Source Pressure (mWH)
Block 1	0.30	3.1	1.8	9.3	23.6	45.0
Block 2	0.25	2.9	1.8	7.7	24.3	45.0
Block 3	0.22	3.3	1.8	7.1	25.2	45.0
Total	**0.77**	—	—	**24.1**	—	**45.0**

Note: mWH = meters of water head; Q = nominal flow rate in cubic meters per hour (m^3/h).



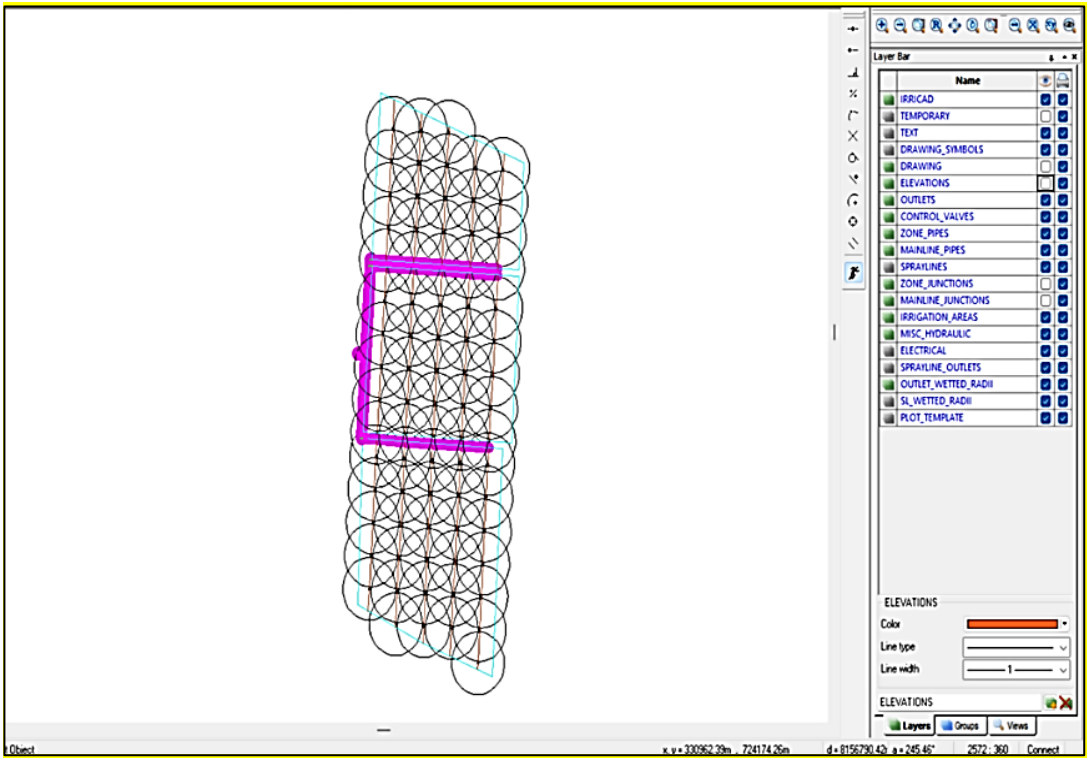


Figure 4. Three-dimensional hydraulic modeling and layout design of the sprinkler irrigation network sectorized into three operational blocks using IRRICAD Pro V16.

Subdividing the network stabilizes the flow demand at the source. Sectoral peak flow rates range between 7.1 m^3/h (Block 3) and 9.3 m^3/h (Block 1), which remains within the safe delivery potential of the borehole, evaluated globally at 24.1 m^3/h (figure 4). The required source pressure (45 mWH or 4.5 bars) ensures a minimum irrigation pressure of at least 23.6 to 25.2 at the most remote sprinkler risers, effectively compensating for calculated head losses in the PE sub-mains.

Performance Evaluation During Implementation: Field testing phases following assembly (50-cm PVC risers stabilized by wooden stakes, sealed with Teflon and high-pressure solvent cement) demonstrated an excellent correlation with theoretical simulations:

- **Pressure and Radius:** The booster unit delivered the necessary operating head, maintaining the nominal wetted radius of the sprinklers at 10 meters, thereby preventing dry patches (dead zones).
- **Distribution Uniformity:** The average observed application rate on the ground (around 3.1 mm/h) ensures homogeneous infiltration into the superficial rhizosphere of the plantain crop, without triggering surface runoff or diffuse soil erosion. Figure 5 present visual overview of the plantain (*Musa paradisiaca*) plot before and after the deployment of the hydro-agricultural network.

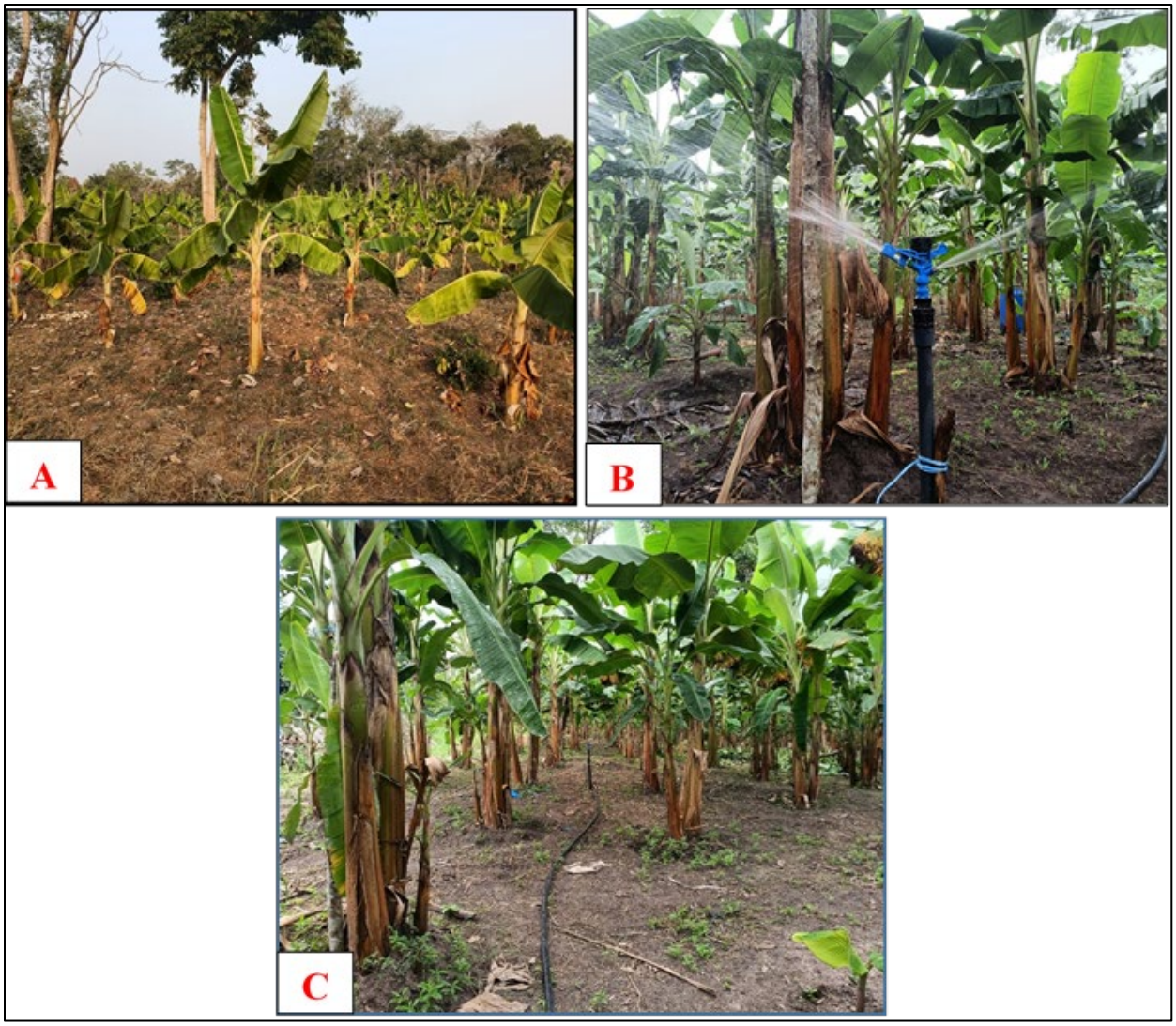


Figure 5. Visual overview of the plantain (*Musa paradisiaca*) plot before and after the deployment of the hydro-agricultural network: severe moisture stress condition of the plantation under traditional rainfed cultivation (A), operational activation of the elevated sprinklers ensuring homogeneous foliar wetting (B), and maintenance of rhizospheric moisture and sub-canopy microclimate post-irrigation (C).

DISCUSSION

The engineering of irrigation networks in tropical zones demands a rigorous synergy between hydroclimatic flux modelling and the geospatial precision of the distribution infrastructure (Diaw *et al.*, 2002; Diaz & Manuel, 2006). In this study, the joint integration of CROPWAT 8.0, Global Mapper, and IRRICAD Pro V16 enabled the design of a tailor-made system for the M'Batto site. Unlike sector-specific approaches based on manufacturer software such as the Caprari suite, which is primarily optimized for pump unit selection (Melle 2021), the IRRICAD Pro V16 platform offers comprehensive systemic modelling. It simultaneously integrates linear and localized head losses, three-dimensional terrain topography, and pressure constraints at the sprinkler terminals. This high level of digital granularity guarantees the technical viability of the network prior to its physical

implementation, thereby mitigating the risk of economic failure frequently observed in regional hydro-agricultural development projects. This predictive approach proves indispensable in the face of escalating climate variability in the M'Batto sub-prefecture (Diomande et *al.*, 2013). Analysis of the time-series data highlights a clear disruption of traditional rainfall balances, characterized by a shortening of transitional seasons and increased severity of low-flow periods. In the transitional forest zone of Côte d'Ivoire, these disturbances expose rainfed agriculture to unpredictable drought pockets during the vegetative cycle, inducing drastic drops in biomass and yield (Diomande et *al.*, 2013). For a giant monocotyledon like the plantain banana (*Musa paradisiaca*), which possesses a shallow fasciculate root system and a high leaf area index, this moisture instability constitutes the primary limiting factor for productivity (Rosales et *al*., 2010). The confrontation of the ecophysiological requirements of the plantain banana with the local water balance reveals a critical structural deficit. While the peak water requirements of the crop reach 2,000 mm/year (Diobo, 2003; Rosales et *al*., 2010) under high-density intensification conditions, the reference evapotranspiration (ET_0) calculated using the Penman-Monteith method amounts to 1,037.87 mm/year. The annual deficit to be compensated thus stands at 962.13 mm. Monthly data analysis refines this finding: although rainfall satisfies requirements from May to October, moisture stress becomes extreme from November to April, peaking in February (-86.0 mm). During these days of intense insolation, daily evapotranspiration reaches 6 to 7 mm, requiring a biological input exceeding 50 liters of water per day for an adult plant. Natural inputs, occasionally falling below the critical monthly threshold of 180 mm required to maintain the atmosphere near saturation, validate the necessity of controlled irrigation to prevent the inhibition of floral initiation (Diobo, 2003; Rosales et *al*., 2010). To offset this deficit on the 0.77-ha pilot plot, sprinkler irrigation was selected over localized drip irrigation. Although drip irrigation theoretically offers higher water application efficiency, the morphological and cultural constraints of the plantain banana restrict its usage (Diobo, 2003). The massive development of suckers, superficial root crowding, and frequent mechanical interventions for plantation maintenance expose drip lines to high risks of shearing or crushing. Consequent network ruptures would cause supply heterogeneities and severe localized moisture stress (Amal et al, 2023). Conversely, the designed sprinkler system, structured into 3 autonomous blocks of 25 sprinklers each, offers excellent operational robustness. In-situ tests confirm that by maintaining a stable source pressure of 45 mWH, the network delivers an average precipitation rate of 3.1 mm/h, which is perfectly adapted to the soil's infiltration capacity. This sprinkler distribution mode effectively simulates the humid microclimate typical of tropical rainforest fringes, promoting stomatal opening and optimizing photosynthetic assimilation without generating erosive runoff (Wedhah, 2015). Beyond the technical validation on the 0.77-ha pilot plot, the transferability of this hydro-agricultural design model to the scale of agricultural cooperatives in the Moronou region represents a major perspective for food security. Standardizing the configuration into autonomous blocks and using standard PVC pipe diameters (ND 63 and ND 50 mm) facilitate the replicability of the system to larger surface areas. However, scaling up requires precise mapping of regional groundwater resources (Abdi & Bomakel, 2019). Although the peak flow rate required per block (7.1 to 9.3 m^3/h) is perfectly tolerated by the borehole at this site, the collective intensification of plantain cultivation will demand concerted aquifer management to avoid overexploitation, alongside a rigorous

rotation schedule for water shifts among producers. Finally, the long-term viability of this sprinkler irrigation system remains intrinsically linked to its energy dependence. Utilizing a booster pumping unit to maintain a constant source pressure of 45 mWH represents a critical operational cost. The conventional use of diesel motor pumps or thermal electrical generators exposes producers to fuel price fluctuations and increases the carbon footprint of the farm. In a context of agroecological transition, hybridizing or completely converting the system to solar photovoltaic pumping appears to be the most promising alternative (Aichouche, 2023). Although the initial investment is higher, coupling a photovoltaic array with the IRRICAD-designed sectorized network would allow rapid infrastructure depreciation, eliminate energy operating costs, and guarantee the autonomy of smallholders in the face of future energy challenges and climate challenges of Côte d'Ivoire.

CONCLUSION AND APPLICATION OF RESULTS

This study successfully designed, dimensioned, and field-tested a sprinkler irrigation system technically adapted for plantain (*Musa paradisiaca*) cultivation in the M'Batto sub-prefecture. Agro-hydrological modelling performed using CROPWAT 8.0 revealed a critical annual water deficit of 962.13 mm, predominantly concentrated during the major dry season from November to April. Faced with this major biophysical constraint exacerbated by local climate variability, artificial water application proves indispensable to safeguard crop yields and enable high-density cultivation intensification.The utilization of specialized IRRICAD Pro V16 software, coupled with Global Mapper, resulted in an optimal and sectorized hydraulic network layout for a 0.77-hectare pilot plot. Structured into three autonomous operational blocks to stabilize flow demand at the borehole (24.1 m³/h in total), the system relies on a grid of 75 elevated sprinkler risers. In-situ evaluation tests confirmed an excellent correlation with theoretical simulations, characterized by homogeneous operating pressure (45 mWH at the source), uniform ground-level water distribution (3.1 mm/h) infiltrating without erosive runoff, and the creation of a favorable humid microclimate beneath the vegetative canopy. Beyond local technical success, this work demonstrates the strategic importance of integrating advanced agricultural engineering digital tools to optimize agricultural investments in tropical zones. To ensure the long-term viability and replicability of this model across cooperatives in the Moronou region, two fundamental levers must be activated: concerted groundwater resource governance to prevent aquifer overexploitation, and a transition toward solar photovoltaic pumping technologies. Adopting these sustainable energy solutions will overcome dependence on fossil fuels, reduce operational costs for smallholders, and sustainably strengthen food security in Côte d'Ivoire (Zella, 2007).

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