

Efficiency of Pressurized Irrigation Systems in Tomato (*Solanum lycopersicum* L.) Production During the Dry Season at Katibougou, Mali

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Abstract

In Sahelian regions, the increasing scarcity of water resources represents a major constraint to the sustainable development of irrigated agriculture. Improving water use efficiency has become a priority in order to ensure food security while preserving available water resources. The present study aims to assess the hydraulic and agronomic performance of three pressurized irrigation systems (Californian, sprinkler, and drip irrigation) applied to tomato (*Solanum lycopersicum* L.) cultivation under the agroecological conditions of Katibougou, Mali.

The experiment was conducted using a completely randomized block design according to Fisher, with several replications. The evaluated parameters included crop water requirements, vegetative growth characteristics, yield components, and water productivity. The results show that the drip irrigation system exhibited the best performance, with water consumption limited to 224.26 mm compared to 557.91 mm and 608.26 mm for the sprinkler and Californian systems, respectively. This system also recorded the highest yield at 49.87 t/ha, compared to 20.27 t/ha for the Californian system. Plants irrigated by drip irrigation produced more fruits and showed better vegetative development.

The study highlights the relevance of drip irrigation as a technology adapted to Sahelian conditions due to its ability to simultaneously improve agricultural yields and water productivity. Its adoption could contribute to more sustainable management of water resources in vegetable production systems in Mali.

Keywords: Pressurized irrigation; Drip irrigation; Water productivity; Tomato; Yield

1. Introduction

Irrigated agriculture plays a decisive role in improving global agricultural production and contributes significantly to food security. However, in arid and semi-arid regions, the limited availability of water resources requires more efficient management of this strategic resource (Pereira et al., 2011). This issue is particularly critical in the Sahelian zone, where climate variability and increasing water demand intensify pressure on available water resources.

The Koulikoro region has surface and groundwater resources that are exploited for agricultural activities. According to Smith et al. (2014), the availability and control of these resources largely determine the performance of irrigated systems. The choice of Katibougou as the experimental site is therefore justified by its representativeness of vegetable production conditions encountered in many agricultural zones of Mali.

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Tomato cultivation occupies an important place in local vegetable production systems due to its high economic value and strong demand in urban markets. The pedoclimatic conditions of the site thus provide an appropriate framework for the comparative evaluation of the performance of different pressurized irrigation systems.

1.1. Presentation of the Study Area

The study was conducted at the experimental station of the Rural Polytechnic Institute for Applied Training and Research (IPR/IFRA) of Katibougou, located in the rural municipality of Koulikoro, Mali. The site is situated approximately 60 km northeast of Bamako and belongs to the Sudano-Sahelian agroecological zone.

The climate of the area is characterized by the alternation of two distinct seasons: a rainy season generally extending from June to October and a long dry season lasting from November to May. Average annual temperatures range between 25 °C and 35 °C, with maximum temperatures that may exceed 40 °C during the hottest months. These climatic conditions are favorable to off-season vegetable production under irrigation (Miyakou Tchivounda, 2009).

The soils of the station are predominantly sandy-loam to loamy-sand in texture, with relatively good drainage and characteristics suitable for conducting irrigation experiments. However, as in most Sahelian regions, water availability remains a limiting factor for agricultural production during the dry season.

The Koulikoro region is endowed with both surface and groundwater resources that are exploited for agricultural activities. According to Smith et al. (2014), the availability and effective management of these resources largely determine the performance of irrigated systems. The choice of Katibougou as the experimental site is therefore justified by its representativeness of vegetable production conditions encountered in many agricultural areas of Mali.

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2. Materials and methods

2.1. Plant material

The plant material used in the experiment was the tomato variety Roma VF (*Solanum lycopersicum* L.), which is widely cultivated in Mali for its agronomic and commercial qualities. This variety is appreciated for its good adaptation to local climatic conditions, relatively high productivity, and technological quality of fruits intended for fresh consumption and processing.

2.2. Irrigation equipment

Three (3) pressurized irrigation systems were evaluated:

- Californian system ;
- Sprinkler irrigation system ;
- Drip irrigation system.

The Californian system consists of a low-pressure pipeline network conveying water to the plots. The sprinkler system distributes water in the form of artificial rainfall through rotating sprinklers. The drip irrigation system is composed of lateral lines equipped with emitters that allow localized application of water at the plant root zone.

Water supply was ensured by a pumping system capable of maintaining the service pressures required for each irrigation system.

2.3. Experimental design

The trial was conducted using a completely randomized block design according to Fisher, with several replications. This experimental layout helped reduce the effect of field heterogeneity and improve the accuracy of comparisons between treatments.

Two factors were studied:

- Irrigation system ;

- Biological phytosanitary treatments based on plant extracts.
- The different treatment combinations were randomly distributed within each block.

2.4. Crop management

Seedlings were produced in a nursery before being transplanted to the experimental plots. Cultural practices were carried out in accordance with recommended vegetable production practices for tomato cultivation in the study area.

Irrigation was applied according to crop water requirements, taking into account the specific characteristics of each irrigation system. Maintenance operations included weeding, replacement of missing plants, and phytosanitary protection.

2.5. Observed parameters

Observations focused on water-related, vegetative, and productive parameters of the crop.

- Water parameters:
 - Crop water requirements ;
 - Volume of water applied;
 - Water productivity.
- Growth parameters:
 - Plant height;
 - Number of leaves;
 - Vegetative vigor.
- Yield parameters:
 - Average number of fruits per plant ;
 - Average fruit weight;
 - Marketable yield per hectare.

2.6. Data analysis

Collected data were subjected to analysis of variance (ANOVA) to assess the effect of treatments on the studied parameters. When significant differences were observed, means were compared at the 5% probability level. Interpretation focused mainly on water use efficiency, agronomic performance, and productivity achieved under each evaluated irrigation system.

3. Results

3.1. Effect of irrigation systems on tomato water requirements

Analysis of crop water requirements revealed substantial differences among the evaluated irrigation systems. The Californian system recorded the highest water consumption at 608.26 mm, followed by the sprinkler system with 557.91 mm. In contrast, the drip irrigation system showed the lowest water requirement at only 224.26 mm.

This significant reduction in water application under drip irrigation reflects better efficiency of water delivery to the root zone. The system limited losses due to direct evaporation, surface runoff, and deep percolation, resulting in water savings exceeding 60% compared to the Californian system.

These observations confirm the findings of Phocaidés (2008), who reported that localized irrigation considerably reduces the volumes of water required for crop development. Similarly, Kulker (1988) reported that micro-irrigation systems can reduce water requirements by more than half compared to conventional irrigation methods.

According to Calcet et al. (2016), the hydraulic performance of drip irrigation is mainly explained by the limitation of wetted surface areas and the application of low flow rates directly near the roots. The results obtained at Katibougou also corroborate the conclusions of Pereira et al. (2011), who consider localized irrigation as one of the most suitable technologies for sustainable water management in water-deficit regions.

This total water consumption by irrigation system is clearly illustrated in Figure 1.

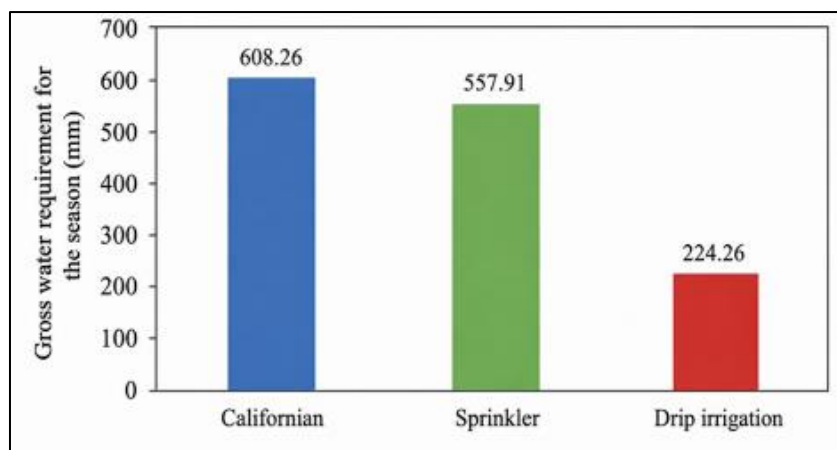


Figure 1 Seasonal water requirements of tomato under different irrigation systems at Katibougou

3.2. Effect of irrigation systems on vegetative growth of tomato

Irrigation systems significantly influenced vegetative growth of tomato plants. Observations throughout the crop cycle showed that plants under drip irrigation exhibited better vegetative vigor, characterized by more regular growth, greater leaf development, and better canopy cover.

Plants irrigated under the Californian and sprinkler systems also showed satisfactory growth, but it remained lower than that observed under drip irrigation. This difference appears to be related to the more regular availability of water in the root zone under localized irrigation.

According to Doorenbos and Kassam (1979), vegetative growth is strongly conditioned by continuity of water supply. Significant fluctuations in soil moisture can slow plant physiological development. The results are consistent with those of Miyakou Tchivounda (2009), who emphasized that tomato is particularly sensitive to water deficits during active growth phases.

Moreover, Howell (2003) reported that irrigation systems with better distribution uniformity generally result in more homogeneous crop growth. The effects of irrigation systems and biopesticide treatments on plant height (cm) are illustrated in Figure 2.

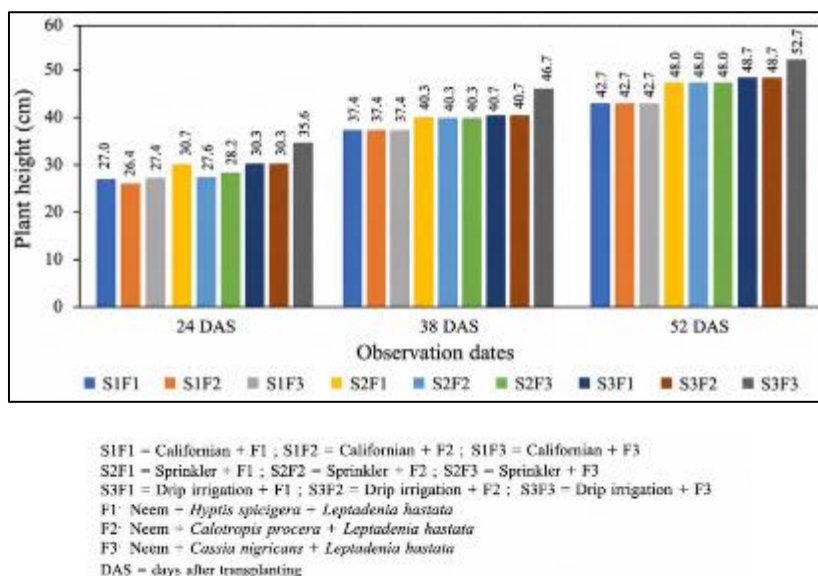


Figure 2 Evolution of average tomato plant height under different irrigation systems

3.3. Effect of irrigation systems on yield components

Yield components were strongly influenced by the irrigation system used. The best results were recorded under drip irrigation, with an average of 17 fruits per plant and an average fruit weight of 36.77 g.

The sprinkler and Californian systems showed lower values for both fruit number and average fruit weight, reflecting lower physiological efficiency of plants under these irrigation methods.

Fruit formation in tomato is closely linked to plant water status during flowering and fruiting stages. According to Doorenbos and Kassam (1979), water deficits during these stages can cause flower drop, poor fruit set, and reduced fruit size.

The results are consistent with the findings of Calcet et al. (2016), who demonstrated that drip irrigation significantly improves yield components due to better soil moisture control. Similarly, Phocaidis (2008) reported that continuous water availability in the root zone enhances nutrient transport to reproductive organs and improves fruit quality.

These performances are illustrated in Figure 3.

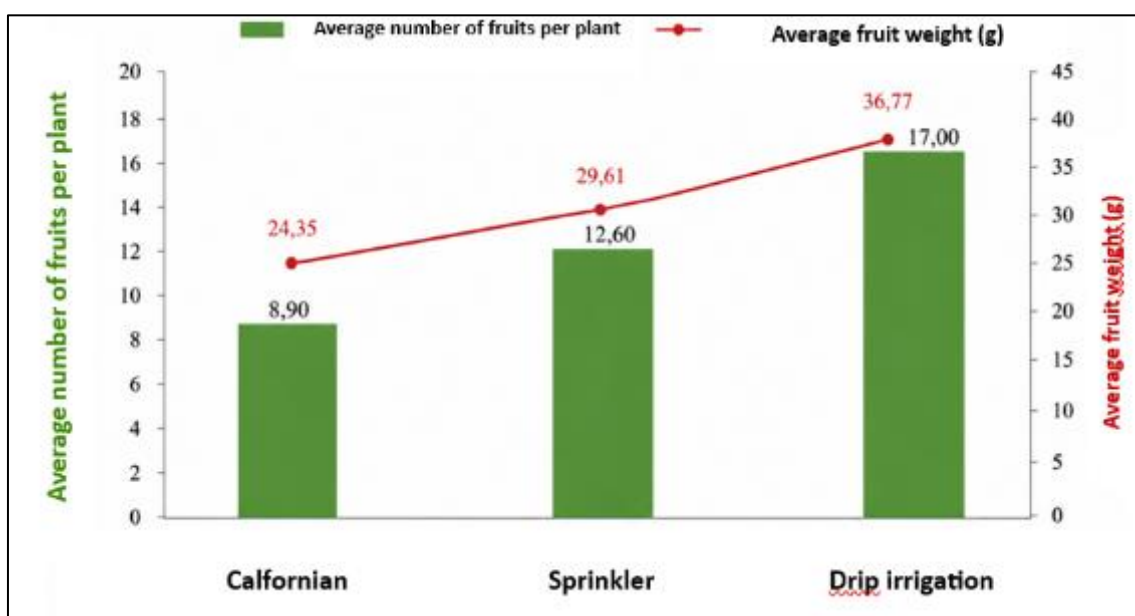


Figure 3 Effects of irrigation systems on tomato yield components

3.4. Effect of Irrigation Systems on Yield and Water Productivity

The highest marketable yield was obtained under the drip irrigation system, with 49.87 t/ha, compared to only 20.27 t/ha under the Californian system. Yields recorded under sprinkler irrigation were intermediate between these two values.

This substantial increase in yield under drip irrigation highlights the agronomic advantage of localized irrigation under the agroecological conditions of Katibougou. Despite significantly lower water consumption, this system achieved the highest production.

The combination of low water consumption and high yield resulted in a significant improvement in water productivity. The results show that each unit of water used under drip irrigation generated more production than under the other irrigation systems studied.

These observations corroborate the conclusions of Belder et al. (2004), who defined water productivity as a key indicator for evaluating irrigated systems. According to these authors, the most efficient systems are those capable of maximizing both agricultural production and water use efficiency.

The results also align with the findings of Pereira et al. (2011), who emphasized that the future of irrigated agriculture depends on technologies capable of producing more with less water. In Sahelian regions subject to increasing water constraints, drip irrigation thus appears to be a particularly suitable solution for sustainably improving agricultural productivity.

Finally, Bouarfa et al. (2020) noted that productivity gains achieved under localized irrigation not only contribute to water resource conservation but also improve the economic profitability of farms. The performances observed in this study confirm this trend and highlight the strong potential of drip irrigation for the sustainable development of irrigated vegetable farming in Mali. These observations are illustrated in Figure 4.

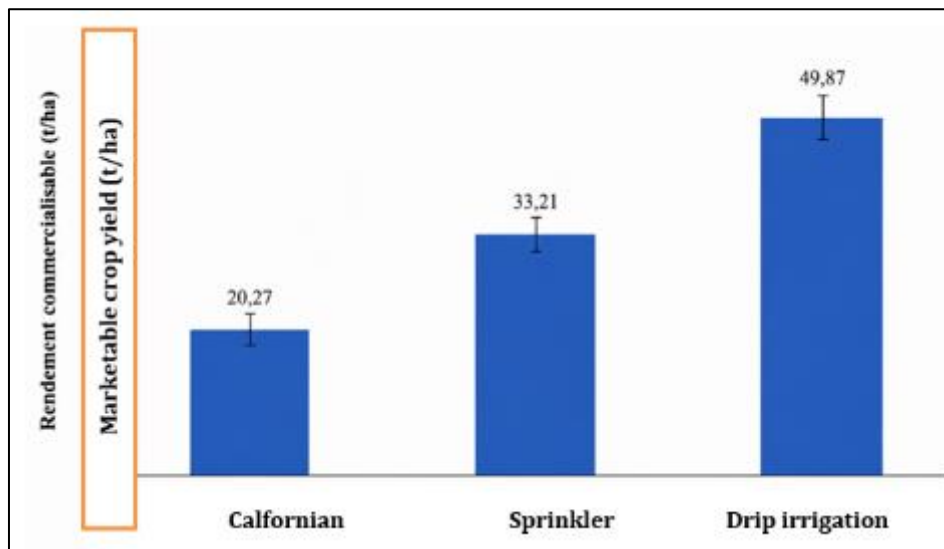


Figure 4 Marketable tomato yields under different irrigation systems

4. Discussion

4.1. Influence of Irrigation Systems on Tomato Water Requirements

The results obtained show that the drip irrigation system significantly reduced crop water requirements compared to the Californian and sprinkler systems. This difference is mainly explained by the localized mode of water application, which limits losses due to evaporation, runoff, and deep percolation.

According to Phocaides (2008), one of the main advantages of drip irrigation lies in its ability to supply water directly to the root exploration zone while maintaining relatively stable soil moisture around the roots. This feature significantly improves water application efficiency compared to conventional irrigation systems.

The water savings observed in this study are consistent with the findings of Kulker (1988), who reported reductions in water consumption ranging from 40% to 70% under micro-irrigation. Similarly, Calcet et al. (2016) highlighted that localized irrigation systems can achieve efficiencies exceeding 90%, compared to generally lower efficiencies under sprinkler and surface irrigation.

In the Sahelian context, characterized by limited water availability, these results are of particular importance. They confirm that adopting drip irrigation can be an effective strategy for improving agricultural water management and enhancing the resilience of production systems to climate change.

4.2. Influence of Irrigation Systems on Vegetative Growth

The superior vegetative performance observed under drip irrigation reflects better water availability in the root zone throughout the crop cycle. This regular water supply promotes physiological processes responsible for plant growth, including nutrient uptake, photosynthesis, and cell elongation.

According to Doorenbos and Kassam (1979), water deficits directly affect vegetative growth by reducing photosynthetic activity and biomass production. Conversely, regular water supply allows crops to fully express their genetic potential.

The results obtained are consistent with the observations of Miyakou Tchivounda (2009), who emphasized that tomato is particularly sensitive to soil moisture variations during vegetative development stages. Irregular water supply may lead to slowed growth, reduced leaf area, and decreased overall plant vigor.

Furthermore, Howell (2003) indicated that the agronomic performance of an irrigation system largely depends on its distribution uniformity. The homogeneous growth observed under drip irrigation in this study may therefore be attributed to better spatial and temporal distribution of water.

4.3. Influence of Irrigation Systems on Yield Components

The differences observed in the number of fruits per plant and average fruit weight indicate that irrigation systems directly influence yield formation mechanisms in tomato.

The higher number of fruits obtained under drip irrigation likely reflects better fruit set and reduced flower abortion. According to Doorenbos and Kassam (1979), the flowering and fruiting stages are the most sensitive to water stress. Insufficient water supply during these stages generally leads to significant yield losses.

The findings of this study support those reported by Phocaidés (2008), who emphasized that maintaining relatively stable soil moisture enhances nutrient transport toward reproductive organs and improves crop productivity.

Similarly, Calcet et al. (2016) showed that localized irrigation systems produce more uniform and higher-quality fruits due to better control of water supply. The performances recorded at Katibougou confirm that regular water availability is a key factor in tomato productivity.

4.4. Influence of Irrigation Systems on Yield and Water Productivity

The high yield obtained under drip irrigation, combined with low water consumption, demonstrates the superiority of this system in terms of water productivity. This result is particularly important in a context where sustainable water management has become a priority for irrigated agricultural systems.

According to Belder et al. (2004), water productivity is currently one of the most relevant indicators for evaluating the overall performance of production systems. A system is considered efficient when it simultaneously maximizes agricultural output and water use efficiency.

The results confirm the conclusions of Pereira et al. (2011), who argued that future agricultural development strategies must rely on technologies capable of “producing more with less water.” From this perspective, drip irrigation appears particularly suitable for Sahelian regions facing increasing water constraints.

Moreover, Bouarfa et al. (2020) emphasized that improving water productivity not only preserves natural resources but also enhances farm economic profitability. The performances observed in this study suggest that adopting drip irrigation could generate agronomic, economic, and environmental benefits for tomato producers in Mali.

5. Conclusion

The present study aimed to evaluate the hydraulic and agronomic performance of three pressurized irrigation systems (Californian, sprinkler, and drip irrigation) applied to tomato cultivation under the agroecological conditions of Katibougou, Mali.

The results revealed significant differences among the evaluated systems. Drip irrigation stood out by substantially reducing crop water requirements, with total water consumption of **224.26 mm**, compared to **557.91 mm** and **608.26 mm** for sprinkler and Californian systems, respectively. This water saving reflects better application efficiency and reduced water losses at the field level.

Improved water management translated into enhanced agronomic performance. Drip-irrigated plants exhibited more vigorous vegetative growth, characterized by greater leaf development and better stand uniformity. Regular water availability in the root zone promoted essential physiological processes necessary for crop growth and development.

Yield components were also strongly influenced by the irrigation method. Drip irrigation recorded the highest number of fruits per plant and the greatest average fruit weight, indicating better utilization of water and nutrients throughout the crop cycle.

As a result, the marketable yield under drip irrigation reached **49.87 t/ha**, more than double that obtained under the Californian system. Combined with low water consumption, this high production led to a remarkable improvement in water productivity, confirming the overall superiority of drip irrigation.

Based on these findings, the research hypothesis that drip irrigation enables better water use efficiency and significantly improves tomato agronomic performance is confirmed. This technology appears particularly well adapted to Sahelian conditions characterized by increasing pressure on water resources and the need for sustainable agricultural intensification.

From an operational perspective, promoting drip irrigation could improve vegetable farm productivity, secure farmers' incomes, and ensure more rational water resource management. Its integration into agricultural development policies would represent an important lever for strengthening the resilience of production systems to climate change.

However, large-scale adoption of this technology requires a better understanding of its economic profitability in family farming systems. Further research focusing on cost-benefit analysis, equipment durability, network maintenance, and socio-economic acceptability would help strengthen the recommendations derived from this study.

Ultimately, drip irrigation appears to be the most efficient system for dry-season tomato cultivation at Katibougou. Its development could significantly contribute to improving water productivity and the sustainability of vegetable production systems in the Sudano-Sahelian zones of Mali.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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