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Evaluating Supplementary Irrigation Water Depths for Improving Land and Water Productivity under Grown Tomato in a Semi-Arid Climate, Burkina Faso

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Abstract:
In the actual rainwater variability and the declining water resources context, the great challenge of agriculture in Burkina Faso is to produce more with less water. That may be possible through the optimal use of water in tomato production since the yield is decreasing while the demand is still increasing particularly in the rainy season. Therefore, an experiment was implemented to identify the irrigation water depth that will improve both the yield and the efficiency of water use. The design was a complete randomized block with four replications. Four irrigation water treatments representing 50 % (D50%), 75% (D75%), and 100% (D100%) of tomato water requirement were applied. The calculated and adopted irrigation interval was 2 days. After transplanting, a constant water depth (D50%) was used. The water treatments were initiated 15 days after transplanting. The water application was postponed to the next irrigation when the rain occurred. The results showed that the application of D75% increased the tomato yield from 4%. Although microbial activity was inhibited during the first year of experimentation, it increased significantly by 144% compared to the control in the second year. Moreover, results showed that the application of D50% increased the water productivity from 175% compare to full irrigation and appeared profitable. The application of supplementary irrigation of DI 50% should be adopted in rainfed tomato production for sustainable improvement of lands and water productivity.

Keywords: supplementary irrigation, lands productivity, water productivity, tomato

Introduction

In Burkina Faso, rainfall is concentrated over three months and is characterized by intermittent dry spells. This is compounded by poor soils, which affect agricultural yields. To remedy this situation, several initiatives have been developed, mainly focusing on water and soil conservation techniques. Indeed, following the droughts of the 1970s, soil conservation techniques such as Zai, half-moons, stone cordons, and grass strips were developed [1], [2]. These techniques have helped to promote the infiltration of runoff water, thereby increasing yields [2], [3], [4]. However, during prolonged periods of drought or low rainfall, these techniques lose their effectiveness [5] accentuating the effects of water stress on crops [6]. It should be noted that water stress is recognized as one of the most damaging phenomena to agricultural production [7], [8]. In the case of tomatoes, [9] demonstrates in its study that the reduction in yield is directly proportional to the reduction in irrigation water. Faced with this situation, supplementary irrigation (SI) therefore appears to be a solution that can help smallholders meet crop water requirements during long-term drought episodes. Numerous authors have investigated the effectiveness of this technique on production, yield, and water productivity parameters. [10]shows that supplementary irrigation led to an increase of over 60% in tomato yield and over 120% in onion yield compared with rain-fed agriculture. The studies by [11] showed that SI enables rice yields to be maintained at an acceptable level. There was no significant difference in terms of yield compared with rainfed (non-irrigated) lowland rice. [12], concluded that high potato and marketable tuber yields can be obtained in mollie Andosols when water stress during the growth phase is reduced by CI and an application of 130 kg /ha of Nitrogen (N). The effects of several doses of supplemental irrigation were evaluated on maize [13] in Ethiopia. The maximum yield (67 t/ha) was found to be obtained from the SI depth corresponding to 100% of water requirements, which was not significantly different from the dose corresponding to 75% of water requirements. However, the application of SI must take rainfall into account. Indeed,[14] stated in their study that applying a high ponded water depth, regardless of precipitation, may lead to water losses through percolation and/or surface runoff. It therefore appears that most research is focused on cereal crops, while vegetable crops are increasingly grown during the rainy season. The latter are also vulnerable to intermittent periods of drought. This is particularly the case for tomatoes, the second most produced crop after onions. In Ouagadougou, this crop contributes significantly to the creation of thousands of jobs [15]. On the other hand, tomatoes are among the most water-demanding crops [16]. Under water stress, plant photosynthesis can be greatly reduced, thus diminishing the quantity and energy of metabolites required for optimal development of above-ground and below-ground biomass [17]. SI could therefore be a palliative solution to tomato's water needs. Mastering this water management tool therefore becomes urgent to optimize agricultural production. This study aims to increase water productivity under tomato cultivation through SI.

Specifically, this study aims to determine the most advantageous SI depth on

- Tomato morphological parameters;
- Yield;
- Water productivity;
- Microbial activity

In this study, a trial was carried out on an experimental site where tomatoes are grown. It consists of three large blocks irrigated at three different rates: the normal rate, which covers all the tomato's water needs; the recommended rate, which covers 75% of the tomato's water needs; and the popularized rate, which covers 50% of the tomato's water needs. Tomato morphological parameters were monitored throughout the trial. Water productivity and yield were assessed at harvest. Soil sample was also collected at the harvest to assess soil microbial activity

2. Material and methods

2.1. Planting framework

The study was carried out in Ouagadougou, Burkina Faso, on the market garden site of the Pan African Institute For Development (PAID-WAS). The study area is located in the Wayalghin district on “Route Nationale N°4” linking Ouagadougou to Fada N'Gourma. It lies across latitude 12°23, 12°32 north and longitude 1°28, 1°0 west. The research was conducted during two years 2023 and 2024 rainy season. The area is characterized by a northern Sudanian climate marked by two alternating seasons: a long dry season of seven months (November-May) and a relatively short rainy season of five months (June-October). The average rainfall is about 800 mm, irregular, peaking in August. Average temperatures range from 25°C in January to 32°C in April. A minimum temperature of 11°C is observed between December and January, while maximum temperatures sometimes reach 41°C between April and May. The average relative humidity is 49%. The soil at the experimental site is sandy loam with a high sand percentage in the 0-20 cm. Soil layer may easily result in water seepage and fertilizer leachate. Therefore, soil water management is important in this area. The mean bulk density is 1.55 g/cm^3, the average field capacity is 18% and a wilting point of 1.4%.

2.2. The experimental design

The experimental setup was completely randomized, with four (04) replications and three (03) treatments. The treatment was the irrigation depth with three modalities: D100%, D75%, and D50% corresponding respectively to 100%, 75%, and 50% of the tomato's water requirements. Each irrigation depth was applied to an elementary plot of 12 m² each (6 m long by 2 m wide), separated from each other by 0.5 m. Replicates were spaced 1m apart. The dimensions of the entire set-up were 19 m*11 m, i.e. a surface area of 209 m².

2.3. Trial implementation

2.3.1. Setting up the nursery and experimental set-up

The experiment took place over two years, between the end of the dry season and the end of the winter season. A nursery was carried out with 3m long and 1m wide. Tomato seeds (Tropimech Tri Active Blue and Cobra 26 F1 varieties) were then broadcast in furrows and buried to a depth of around 2 cm. The nursery was watered two times a day, morning and evening, until transplanting.

The experimental set-up began with the clearing of the area to be farmed. The elementary plots were then delimited and the irrigation furrows were laid out. Each furrow was 0.2 m wide and 2 m long, and there were fifteen (15) per elementary plot. Once the soil had been prepared, the seedlings were transplanted in the evening to avoid the damaging effects of the sun and promote recovery. Transplanting was carried out at a rate of six 06 plants per furrow, i.e. 0.4m between bunches and 0.6m between rows, giving a density of 41,600 plants per hectare.

2.3.2. Crop care

Maintenance consists of monitoring the crop to ensure that it meets its needs at the right time for the plant to develop properly. After transplanting, we applied 50% of the tomato's water requirements every day for two weeks, to enable the plants to set properly. NPK was then applied at a rate of 250 kg/ha 15 day after transplanting (DAT). From then on, the treatments corresponding to each elementary plot were applied. The irrigation interval was two days, except on rainy days. In addition, a urea-based treatment (N46%) was applied on the 35th DAT just before flowering at a dose of 150 Kg/ha. BOMEC (abamectin), PACHA (lambda-cyhalothrin, acetamiprid), DEAN (imidacloprid) and CYPERCAL (cypermethrin) were also applied for disease control. We had got theses pesticides from "Societé Africaine des Produits Phytosanitaires et d'Insecticides (SAPHYTO)" located in Ouagadougou/Burkina Faso

2.4. Estimating tomato water requirements and irrigation management

Tomato water requirements were calculated using the FAO Penman-Monteith formula. Evapotranspiration was determined using FAO CROPWAT 8.0 software.

Irrigation depths were calculated (net irrigation, global irrigation, and interval irrigation interval) using the following standard formulas (1) and (2):

$$I_n = y \times (H_{CC} - H_{PF}) \times Z_r \qquad (1)$$

$I_n (mm)$: net Irrigation
H_{CC}(%) : soil water content at field capacity
H_{PF}(%) : soil water content at wilting point
Z_r(mm) : root profile
Y(%) : acceptable deficit

$$I_i = \frac{I_n}{ET_{max}} \qquad (2)$$

I_i(days) : irrigation interval
$I_n (mm)$: net irrigation
ETmax (mm/days) : maximum evapotranspiration

2.5. Agronomic data collection

It consisted of measuring the various agro-morphological parameters (height, stem diameter, and number of leaves) of the plant. To this end, plants on which the evolution of morphological parameters was observed throughout the experiment were identified. Two plants per furrow were selected, taking into account the border effect and the heterogeneity of the plot. This resulted in 30 plants per plot, i.e. 360 plants for the whole trial.

- Height of tomato plants: measured from the base to the highest leaf using a decameter.
- Stem diameter: measured at the collar of the plant using a caliper.
- Number of leaves: counted manually.
- Fruit characteristics: at each harvest, fruit characteristics such as length, diameter, and weight were measured.
- Yield: at each harvest, the sum of fruit weights was calculated for each elementary plot and converted into yield using the formula 3 below. At the end of the season, the sum of the yields of the individual plots for each harvest was calculated.

  $$Y = \frac{P \times 41\,600}{1000} \qquad (3)$$

  Y(kg/ha) : The yield per plant
  P(g) : The weight of fruit per plant

41600 is the number of plants per hectare.

- Water productivity: This is the ratio between the total fruit yield and the total volume of irrigation water applied per ha (m^3/ha). It is expressed in kg of fruit per cubic meter of irrigation water. Water productivity was determined using equations 4:

  $$WUE = \frac{Y}{Wu} \qquad (4)$$

  WUE (kg/m^3) : Water use efficiency
  Y (kg/ha) : Yield
  Wu (m^3/ha) : Water quantity used for the irrigation of the plot

2.6. Soil sample and microbial activity analysis

Soil had been sampled at three keys time point during the two years of experimentation; before establishment (just before experimental set up), during the first year (after the last harvest), and during second year of experimentation (after the last harvest). After each cropping season, soil cores (20 cm depth) were collected from each plot and then reconstituted into composite samples. A composites soil cores were processed and analyzed each year to determine microbial activity. This activity was measured through soil respiration, a biological process that reflects the metabolic activity of microorganisms present in the soil. Soil respiration corresponds to the release of carbon dioxide (CO_2) resulting from the decomposition of organic matter by microorganisms. The amount of CO_2 released, expressed in mg g^{-1} of soil, is given by the following formula 5 from Dommergue (1960)

$$Q = \frac{(VHCL_{contol} - VHCL_{treatment}) \times 2.2}{w} \qquad (5)$$

Q(mg. g^{-1} soil) : quantity of CO_2 released
$VHCL_{contol}$(ml) : volume of hydrochloric acid used to titrate the control
$VHCL_{treatment}$(ml) : volume of hydrochloric acid used to titrate the treatment
w(g) : sample weigh
2,2 mg de CO2 correspond 1 ml de HCl (0,1N)

2.7. Data Processing and Statistical Analysis

Data entry was performed using Microsoft Excel 2017. The collected data were analyzed through analysis of variance (ANOVA) using SPSS software version 21. For comparing treatment means, the Duncan test was employed when ANOVA indicated statistically significant differences at the 5% significance level.

3. Results and discussion

3.1. Results

3.1.1. Climate data

Figure 1 below shows monthly effective rainfall, and mean temperatures based on daily observations from May to October for both years of experimentation. The results indicate the second year of the experiment recorded 17% more effective rainfall compared to the first year of the experiment. Moreover, the mean temperatures recorded during the first and the second year of the experiment were respectively 29.62 °C and 29.39 °C.

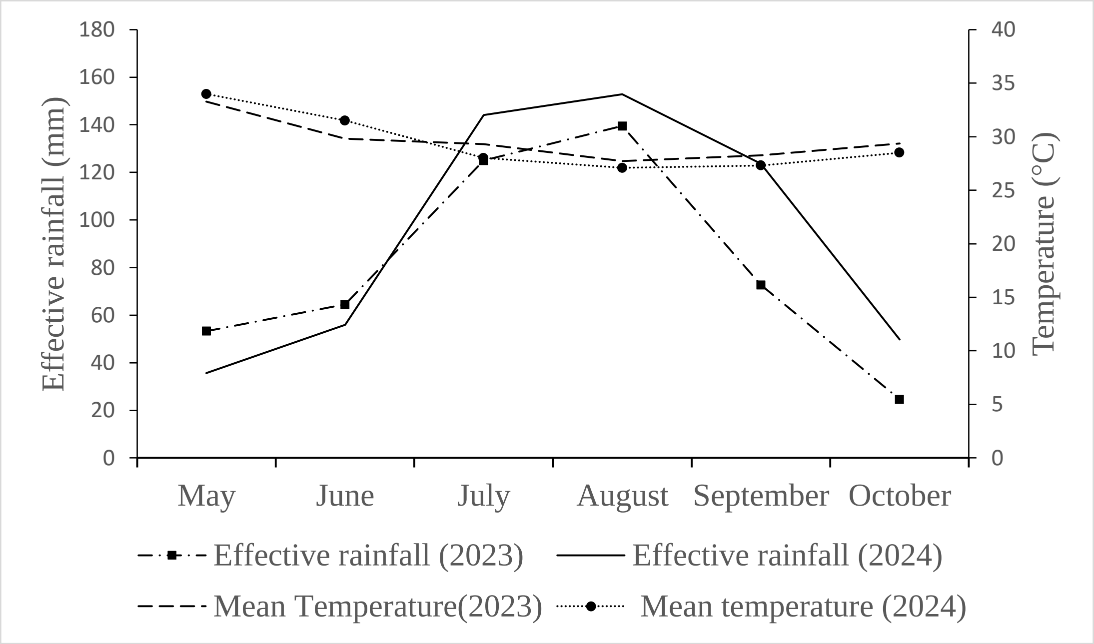

Figure 1: Monthly effective rainfall and average temperature for 2023 and 2024

3.1.2. Effect of SI depths on tomato growth parameters

(a) Plant height

The effects of the different treatments on tomato plant height are shown in Table 1. Statistical analysis showed no significant difference between treatments over the two years of experimentation. This was always the case regardless of the addition of NPK (Nitrogen, Phosphor, Potassium) and Urea. Nevertheless, the greatest heights were observed in the D100% and D75% treatments at 15 DAT and 25 DAT respectively. In SI, reduced irrigation rates did not have a significant effect on plant height.

Table 1: Effect of treatment on plant height (cm)

Irrigation depths	Height1 (15DAT)	Height2 (15DAT)	Average	Height1 (25DAT)	Height2 (25DAT)	Average
D100%	23.69± 0.89	25.23±0.55	24.46±0.53	33.37± 10.98	47.15±1.14	40.26±0.88
D75%	24.43± 7.50	24.26±0.52	24.35±0.43	34.70± 9.89	46.51±1.01	40.63±0.78
D50%	23.46± 6.69	23.99±0.55	23.73±0.41	32.74± 9.53	44.67±1.12	38.74±0.8
Probability	0.62	0.23	0.47	0.31	0.25	0.23
Signification	ns	ns	Ns	ns	ns	ns

ns means no significant.

Height1(15 DAT) means the height of plant in the first year of experimentation at 15 days after transplanting.

Height2(15 DAT) means the height of plant in the second year of experimentation at 15 days after transplanting.

Height1(25 DAT) means the height of plant in the first year of experimentation at 25 days after transplanting.

Height2(25 DAT) means the Height of plant in the second year of experimentation at 25 days after transplanting.

(b) Stem diameter

Table 2 shows the effects of the various treatments on the stem diameter of tomato plants. In general, the results of the statistical analyses indicate that the treatments only affected stem diameter at 25 DAT. The 50% reduction in irrigation doses resulted in a significant 8% drop in stem diameter compared with full irrigation. The best diameters were recorded in the D75% plot. Specific to each year, reduced irrigation rates had a significant impact on stem diameter at 25 DAT in the first year of experimentation, and at 15 DAT in the second year. These results suggest that changes in stem diameter are a function of the amount of water available to the plant. What's more, a 25% reduction in supplementary irrigation rates would produce stem diameters statistically similar to those obtained with full irrigation.

Table 2: Effect of treatment on stem diameter (mm)

Irrigation depths	SD1(15DAT)	SD2(15DAT)	Average	SD1(25DAT)	SD2(25DAT)	Average
D100%	4.75± 0.12	3.74±0.08b	4.25±0.08	6.03± 1.3a	5.8±0.12	5.92±0.08b
D75%	4.98± 1.08	3.62±0.07b	4.3±0.07	6.14± 1.5a	5.51±0.11	5.83±0.09b
D50%	5.29± 7.29	3.23±0.08a	4.22±0.36	5.37± 1.4b	5.58±0.13	5.42±0.08a
Probability	0.7	0	0.96	0	0.22	0
Signification	ns	***	Ns	***	ns	***

ns means no significant

*** means significant when P< 0,001

SD1(15 DAT) means the stem diameter of plant in the first year of experimentation at 15 days after transplanting

SD2(15DAT) means the stem diameter of plant in the second year of experimentation at 15 days after transplanting

SD1(25DAT) means the stem diameter of plant in the first year of experimentation at 25 days after transplanting

SD2(25DAT) means the stem diameter of plant in the second year of experimentation at 25 days after transplanting

(c) Number of leaves

The effect of SI depths on leaf numbers is shown in the table 3. Statistical analysis reveals that the various treatments only had a significant impact at 25 days. In fact, at this stage, a 25% reduction in irrigation doses resulted in a non-significant increase in leaf number compared with full irrigation. On the other hand, the D50% irrigation depth resulted in a significant drop of 8% compared with D75%. Specific to each year, the number of leaves was only significantly affected in the first year of experimentation. On the other hand, there was an overall 27% drop in the number of leaves from the second year of experimentation compared with the first year of experimentation. These results suggest that the number of leaves is a function of the amount of water available and the plant's stage of development. In addition, a 25% reduction in irrigation rates would result in a higher number of leaves compared with full irrigation.

Table 3: Effect of treatment on leave number

Irrigation depths	NF1(15DAT)	NF2(15DAT)	Average	NF1(25DAT)	NF2(25DAT)	Average
D100%	9.07± 0.26b	6.34±0.12	7.71±0.17	13.07± 0.52b	10.78±0.18	11.93±0.29ab
D75%	9.92± 0.31a	6.15±0.13	8.04±0.21	14.69± 0.64a	10.38±0.18	12.53±0.36b
D50%	9.32± 0.25ab	6.2±0.14	7.78±0.17	12.6± 0.51b	10.25±0.19	11.43±0.28a
Probability	0.08	0.5420602	0.421	0.02	0.09609694	0.045
Signification	ns	ns	Ns	*	ns	*

ns means no significant

* means significant when P< 0,005

NF1(15 DAT) means the Number of leaves in the first year of experimentation at 15 days after transplanting.

NF2(15 DAT) means the Number of leaves in the second year of experimentation at 15 days after transplanting.

NF1(25 DAT) means the Number of leaves in the first year of experimentation at 25 days after transplanting.

NF2(25 DAT) means the Number of leaves in the first year of experimentation at 25 days after transplanting

3.1.3. Effect of SI depths on fruit characteristics

(a) Dimensions of fruit

The effect of the different treatments on fruit size is shown in the table 4. Overall, the results show that reduced irrigation rates had no significant effect on fruit size. However, a specific analysis by year shows that only fruit length was significantly affected during the first year of the experiment. In fact, during this year 2023, the 50% reduction in irrigation doses led to a significant 16% increase in fruit length. It should also be noted that fruits from the second year of experimentation were 1.5 times longer and 2.05 times larger in diameter than those from the first year. These results suggest that in supplementary irrigation, the excess water applied has little influence on fruit size overall. However, the total amount of water available seems to play a role, particularly on fruit size, as shown by the impact observed on length in the first year and the overall larger fruit size in the second year.

Table 4: Effect of treatment on fruits dimensions (mm)

Irrigation depths	Fruit length1	Fruit length2	Average	Fruit diameter1	Fruit diameter2	Average
D100%	32.04± 1.55b	54.69±3.25	54.41±3.21	28.70± 1.36	52.79±3.13	52.49±3.09
D75%	32.08± 1.05b	51.15±0.24	50.69±0.24	28.26± 0.97	49.24±0.23	48.73±0.24
D50%	37.25± 9.86a	50.8±0.22	50.58±0.22	31.72± 1.18	48.81±0.13	48.54±0.14
Probability	0.01	0.26	0.246	0.07	0.23	0.205
Signification	*	ns	Ns	ns	ns	ns

ns means no significance.

* means significant when P< 0,05

Fruit length1 means fruit length in the first year of experimentation

Fruit length2 means fruit length in the second year of experimentation

Fruit diameter1 means the fruit diameter in the first year of experimentation

Fruit diameter2 means the fruit diameter in the second year of experimentation

(b) Weight of fruit

The effect of SI depths on fruit weight is shown in the table 5. Statistical analysis shows that, in general, a 50% reduction in irrigation doses results in a significant 2% increase compared with full irrigation. Specific to each year, in both year 1 and year 2, reducing irrigation doses by 25% and 50% led to an increase in fruit weight, although this increase was not always significant. These results suggest that, with SI, fruit weight increases as irrigation depths are reduced.

Table 5: Effect of treatment on fruit weight(g)

Irrigation depths	Weight of fruit1	Weight of fruit2	Average
D100%	19.22± 1.31b	63.11±0.48b	62.56±0.48b
D75%	20.58± 1.18b	64.99±0.37a	63.89±0.38ab
D50%	25.48± 2.14a	64.9±0.42a	64.25±0.43a
Probability	0.02	0	0.015
Signification	*	**	*

* means significant when P< 0,05

**means significant when P< 0,01

Weight of fruit1 means weight of fruit in the first year of experimentation.

Weight of fruit2 means weight of fruit in the second year of experimentation.

3.1.4. Effect of SI depths on yield and Water use productivity

(a) Effect of supplementary irrigation dose on yield

The effect of SI on yield is presented in the table 6. Statistical analysis indicates that reducing SI rates has no significant impact on crop yield. However, it is observed that in both the first and second years, a 25% reduction in irrigation doses (D75%) resulted in the highest tomato yields. These results suggest that, under SI, reduced irrigation doses do not affect tomato yields. However, a 25% reduction in doses could lead to better yields compared with full irrigation.

Table 6: Effect of treatment on yield (t/ha)

Irrigation depths	yield1	yield2	Average
D100%	18.7± 2.16	29.67±1.87	28.91±1.75
D75%	28.6± 3.59	30.47±1.14	30.29±1.1
D50%	22.1± 3.59	26.85±1.19	26.46±1.13
Probability	0.33	0.165	0.12
Signification	ns	ns	ns

ns means no significance.

yield1 means yield in the first year of experimentation.

yield2 means yield in the second year of experimentation.

(b) Effect of supplementary irrigation dose on water use productivity (WUE)

The table 7 illustrates the effect of different irrigation rates on WUE. The results of the statistical analysis reveal that reducing irrigation doses by 25% and 50% has a significant influence on irrigation water productivity. Indeed, an increase of 57% and 175% respectively, compared with the D100% treatment, was recorded following a reduction in water requirements of 25% and 50%. The results suggest that in SI, reducing water requirements leads to a proportional increase in water productivity.

Table 7: Effect of treatment on WUE (kg /m^3)

Irrigation depths	WUE1	WUE2	Average
D100%	2.45c	3.47±0.22c	3.4±0.2c
D75%	5.62b	5.35±0.2b	5.37±0.2b
D50%	8.74a	9.42±0.42a	9.36±0.4a
Probability	0	0	0
Signification	**	**	**

*** means significant when P< 0,01
WUE1(kg /m3) means water productivity in the first year of experimentation.
WUE2(kg /m3) means water productivity in the second year of experimentation

3.1.5. Effect of supplementary irrigation dose on microbial activity

The table 8 illustrates the effect of different irrigation rates on microbial activity. The results of the statistical analysis reveal that reducing irrigation doses by 25% and 50% has no significant influence on microbial activity. Indeed, during the first year of the experiment, there was a 57% reduction in microbial activity, while in the second year, it increased by 144% compared to the control soil sample. These variations suggest that soil microbial activity is likely influenced by complex factors, including climatic conditions, soil composition, and agricultural practices.

Table 8: Effect of treatment on microbial activity (mg/g de sol)

Irrigation depths	R1	R2
Control	7.54	
D50%	3.19±0.25	19.2±1.57
D75%	3.2±0.25	17.15±1.72
D100%	3.22±0.26	18.82±2.13
Probability	0.99	0.7
Signification	ns	ns

ns means no significance.
R1 means Respiration in the first year of experimentation.
R2 means Respiration in the second year of experimentation.

3.2. Discussion

In a context where water management is becoming crucial due to climate change and pressure on water resources, this study aims to evaluate the performance of tomato cultivation under conditions of limited water resources within the framework of supplementary irrigation (SI). SI consisted of covering 100%, 75%, and 50% of tomato water requirements (2800 m^3/ha/ irrigation) applied every other day, except in the event of rain, when irrigation was postponed. The results of this experiment showed that, as far as morphological parameters were concerned, the reduction in irrigation depths had little or no preponderant effect on plant height. Similar results were obtained by [12], [18], [19], [20]. However, in the presence of nitrogen, the results of [12] showed that plant height increased proportionally with the amount of nitrogen applied. Thus, nitrogen could be considered a factor of variability in plant height growth. Whereas in this study, nitrogen was applied uniformly to all plots, first at 15 DAT when NPK was applied (14-24-14), then at 35 DAT when urea was applied (46%). These applications had the effect of standardizing the height of tomato plants on all plots. Concerning stem diameter and number of leaves, the results of the statistical analysis revealed that the evolution of these two parameters depended on the stage of development. A significant incidence was only observed at 25DAT. This situation could be explained by the fact that from transplanting to 15 DAT, the D50% irrigation dose was applied uniformly to all the furrows in each plot, to ensure adequate recovery of the young plants. From 15 days to harvest, the most vigorous plants were observed in plots irrigated at 75%. The results showed a significant 6% increase in stem diameter and a 14% increase in number of leaves compared with the full D100% irrigation depth. Similar results were obtained by [19] who obtained a 46% increase in above-ground biomass in plots irrigated at the D75% rate compared with non-irrigated plots. These results suggest that the 75% irrigation dose provided optimum moisture, enabling plant roots to absorb soil minerals adequately. If plant development depends on the availability of nutrients in the soil, soil moisture is the key factor enabling the plant to draw these nutrients. Consequently, when it is excessive, water infiltrates by percolation, taking soil minerals with it. Conversely, when it is insufficient, it limits the mineralization of soil organic elements and the absorption of minerals by the roots. Indeed, in the event of water stress, stomata begin to close as a mechanism to reduce transpiration. As a result, carbon dioxide entry is also reduced [21]. Therefore, plant evapotranspiration becomes lower, leading to leaf wilting, reduced leaf area, reduced stem diameter growth, and stunted plant growth. This is why plants irrigated at D100% and D50% have poorly developed morphological criteria. The D75% irrigation dose was therefore sufficient to support plant growth while avoiding percolation and leaching of essential mineral elements.

Concerning yield components, the results show that neither fruit length nor diameter were significantly affected by the different irrigation depths. On the other hand, fruit weight seemed to increase with decreasing irrigation depths. Indeed, the heaviest fruits were observed in plots irrigated with the D50% dose, followed by those irrigated with the D75% dose, in each year of the experiment. The D50% irrigation depth induced a 2% increase in fruit weight compared with the average of the other two treatments. These results contrast with the majority of previous studies, which report a continuous decrease in tomato fruit size and weight with increasing water stress [22], [23]. Indeed, according to [24] water is the main determinant of the size of vegetables and fruits such as tomatoes. In the event of excess water, the fruit expands due to cell expansion and pericarp rupture, resulting in low-yielding cracks. The work of [23] also shows that a moderate water deficit during the sowing and flowering stages, followed by rehydration during the fruit expansion stage, significantly compensates for the water deficit accumulated during these phases. Furthermore, research by [25] indicates that water stress during the flowering phase generates larger fruits, both in weight and diameter, compared with those from plots not subjected to this stress. These findings reinforce the assertion that moderate regulated deficit irrigation in the early stages of development can significantly increase tomato size [26]. In this study, the results could be explained by the fact that the set-up was in a SI situation. Thus, the increase in effective rainfall observed in July and August (see fig.1) could have compensated for the water stress observed in the plots irrigated at D50%, resulting in higher fruit weights. Concerning yield, the results show that reducing irrigation rates does not affect tomato yield. Nevertheless, a 25% reduction in depth could lead to higher yields compared with full irrigation. These results could be explained, according to [27] by the fact that tomatoes prefer deep, well-drained silty soils. The D75% irrigation depth therefore provided sufficient aeration of the soil pore space, enabling plant roots to take up the minerals needed for growth and production. Similar results were obtained [19] who obtained higher carrot yields from a 25% reduction in water requirements under SI. [28] also found in his work that onion yields from D75% irrigation was not significantly lower than onion yields from D100% irrigation under SI.

In terms of water productivity, the reduction in water requirements led to a significant increase in water productivity. This was observed in every year of the experiment. In fact, the D75% and D50% irrigation depths resulted in an overall increase in productivity of 57% and 175% respectively, compared with full irrigation. Numerous previous studies have highlighted the positive correlation between moderate water deficit and increased water productivity [24], [26], [29]. These results can be explained by the fact that part of the rhizosphere, which also underwent some drying with the 50% reduction in irrigation doses, sent chemical messages to the aerial part of the plant. Although abscisic acid was identified as the predominant chemical message, other chemicals could be involved [17]. Non-hydraulic (chemical) signals can improve water use efficiency by inducing partial stomatal closure, thus reducing transpiration without causing detectable changes in the plant's water status [30]. This would appear to be a mechanism developed by tomato plants when subjected to water stress. In arid countries such as Burkina Faso, where water is the determining factor in agricultural production, water productivity is becoming the criterion for assessing the performance of agricultural production systems. Yield is no longer the objective, as land is not as limiting as water [31].

Regarding soil biological activity, analyses indicate that during the first year of experimentation, biological activity was inhibited. Specifically, there was a nearly 57% decrease in overall respiration compared to the control. Conversely, in the second year of experimentation, soil respiration increased by 144% relative to the control. This increase is partly attributable to climatic conditions, which were more humid compared to the first year (see Figure 1) [32]. Additionally, this observed increase in the second year may be due to the growth of microbial communities facilitated by improved substrate availability from the two years of experimentation [33]. Indeed, tomato crop residues could have led to an increase in organic matter content, labile carbon, pH, and soil texture, thereby affecting microbial activity [34].

In this study, the 25% (D75%) reduction in irrigation rates provided the best above-ground biomass and yield compared with other irrigation rates. On the other hand, the 50% (D50%) reduction in water requirements provided the best water productivity, with fruit yields statistically little different from those corresponding to D75%. Also, the D50% irrigation dose provides a considerable water saving of around 66%, which could be used to irrigate another site of the same size and thus optimize yield. Thanks to its prowess, the D50% irrigation rate is recommended for SI of tomato crops. This recommendation constitutes a SI strategy enabling growers to increase water productivity, reduce production costs, and save a large proportion of water without incurring a major loss in tomato yield.

4. Conclusion

This study provides information on water management for supplementary irrigation (SI) in tomato crops. It shows that reducing tomato water requirements by 25% results in vigorous plant growth and in increase of yield. On the other hand, a 50% reduction in the plant's water requirements not only saves considerable amounts of irrigation water but also significantly enhances water productivity without compromising yield. What's more, this level of irrigation produces more consistent fruit. Furthermore, the results underscore the importance of considering both climatic factors and agricultural practices in soil fertility management and the promotion of beneficial biological activity. In a climatic context where water is considered a scarce commodity and difficult to access due to its high cost, water productivity has become the key indicator of the performance of agricultural production systems. This is why D50% is the recommended dose for SI of tomato crops.

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