EXCELLENT PUBLISHERS

International Journal of Current Research in
Biosciences and Plant Biology

Volume **10** • Number **7** (July-2023) • ISSN: 2349-8080 (Online)

Journal homepage: www.ijcrbp.com

Original Research Article **doi:** https://doi.org/10.20546/ijcrbp.2023.1007.001

Variation in agro-physiological parameters of *Vigna radiata* (L. R. Wilczek) under different supplemental irrigation frequencies

Adama Pascal Kihindo*, Razacswendé Fanta Ouedraogo, Edmond Dondasse, Abdoulaye Sawadogo and Badoua Badiel

Université Joseph KI-ZERBO, Laboratory of BIOSCIENCES, Team of Plant Ecophysiology, 03 BP 7021 Ouagadougou 03, Burkina Faso

*Corresponding author; e-mail: kihindoadamapascal@gmail.com

Article Info

Keywords:
Drought pocket
Harvest index
Mungbean
Productivity
Supplemental irrigation

Abstract

The study was aimed at investigating the effect of supplemental irrigations on physiological and agronomic responses of mungbean through evaluation of transpiration, leaf water potential, chlorophyll content and seeds yield during drought pockets. A completely randomized block device with three replications was used to conduct the rainy season study. Four watering regimes were applied from the 26th day after seed sowing and during drought pockets: rain only (0J), tap water after 5 days without rain (5J), after 10 days without rain (10J) and after 15 days without rain (15J). Supplemental irrigation had a significant effect on transpiration, leaf water potential and chlorophyll content of plant leaves. Leaf water potential was the lowest and the highest transpiration at 70 DAS under the 5J supplemental irrigation regime, with higher chlorophyll content. The study also revealed that the frequency of irrigation every 5 days without rain significantly improved the harvest index ($p \leq 0.004$), the number and mass of seeds per plant ($p \leq 0.001$), justifying the choice of this water treatment for a better production of well-filled seeds and tops.

• *Received: 02 May 2023* • *Revised: 26 June 2023* • *Accepted: 01 July 2023* • *Published Online: 6 July 2023*

Introduction

Projections of seasonal rainfall distribution using Cordex data from the RCP4.5 and RCP8.5 scenarios, both of them reveal that, for the periods from 2021 to 2050, Burkina Faso will face increasingly severe drought pockets (Diasso, 2013). To this situation can be added the threat of temperatures rising by 2 °C in 2030, 2.4 °C in 2050 and 3 °C in 2080, with the consequences of intensifying severe drought pocket by 2050 (Röhrig et al., 2021). This situation is likely to have a major impact on several sectors of activities, specifically agriculture (MEEVCC, 2021). An analysis of temperature and rainfall trends shows Burkina Faso often experiences both late starts of the rainy season and periods of drought and floods, which cause both crop losses and accelerated land degradation (Sarr et al., 2015). Developing countries like Burkina Faso, would be the most vulnerable to climate change. The country must undertake adaptation measures to climate change which range from the development and introduction of resilient crop varieties. These varieties should also be tolerant to extreme temperatures, the use of improved or restored land, and the choice of regions with suitable rainfall for the variety. These elements are currently at the core of a number of research projects and programs, such as the introduction of the mungbean. *Vigna radiata*, a species belonging to the Fabaceae family and originating from India and South-East Asia has a short lifespan (60-65days) and is used as a vegetable for its seeds, which are consumed as a vegetable (Somta and Srinives, 2007). Nutritionally, mungbean is an important source of dietary protein (24%-28%) and carbohydrates (59%-65%). It is also well tolerated by children (Pal et al., 2010). According to Srinives (1990), the agricultural advantage of this species is that it can be used after fallow or in rotation with other crops. Indeed, mungbean also contributes to the restoration of land fertility through its ability to fix atmospheric nitrogen and is an essential element in sustainable land management strategies in rain-fed agricultural systems (Singh et al., 2011; Jat et al., 2012).

But growing short-cycle varieties including mungbean is nowadays limited by irregular rainfall during the rainy season, resulting in drought pockets. According to Chotechuen (1996), various biotic and abiotic factors are responsible for low mungbean yields. Among abiotic stresses, water deficit is the most important. Water stress, caused by drought pockets, has harmful effects on plant's physiology. The consequences of water stress are reduced stomatal opening and reduced photosynthetic activity (Kim and van Iersel, 2011). The aim of our study is to develop cultivation techniques that are resilient to drought pockets that the mungbean variety would experience during the rainy season. One of the techniques adopted in this study is supplemental or top-up irrigation in the event of a drought pocket.

The specific objectives of this work are:

(i) to evaluate effects of different supplemental irrigation regimes on transpiration, leaf water potential and chlorophyll content;
(ii) to better understand the influence of variations in these physiological parameters on mungbean productivity in Burkina Faso, and
(iii) to determine the optimum supplemental irrigation frequency or frequencies for good mungbean productivity.

Materials and methods

Experimental site

This experiment was conducted within the garden of UFR/SVT of *Université Joseph KI-ZERBO* in Ouagadougou from August to November. The experimental plot is located at an altitude of 319m, 12° 22' 45,6" North latitude and 001° 29' 52,3"West longitude (Thiombiano and Kampmann, 2010). The area has a Sudano-Sahelian climate. The trial was conducted under natural conditions of light, temperature and humidity.

Plant material

The plant material used was mung bean seeds of the "*Belem Wend Tiiga*" variety obtained from BELWET Burkina farm. The species was chosen for its short cycle, appreciable yields and high nutritional values.

Descriptive and phenological characteristics of the plant are provided in Table1. The plants were grown in 5-liter pots on a sandy-loam soil having the following particle size composition: 3.92% clay, 21.57% silt and 74.51% sand. This soil was taken from the surface of a natural formation at Gampéla (12°25′45″ North 1°23′20″ West) dried at room temperature and sieved to 2 mm. The quantity of soil allocated to each pot was 5 kg. The bottom of each pot was previously perforated to allow water to drain off after rain or watering.

Table 1. Mungbean descriptive and phenological characteristics.

Features	Mungbean
Origin	Indian subcontinent
Port	Erected to semi-erect
Life cycle Days	Ripens in 50-65 days after sowing
Flowering time DAS	30-70 DAS
Growth	Growth up to 1.5 m high.
Leaf color	Dark green
Seed color	Generally green

DAS: days after sowing.

Experimental setup

The experimental device adopted is a fully randomized block with three replicates. Each block or replication consists of 36 pots including 09 pots per experimental unit, with 4 levels of watering frequency applied at field capacity. These frequencies are:

- A 5J watering frequency, i.e. one liter of water irrigated every 5 days without rain;

- A 10J watering frequency, i.e. one liter of water irrigated every 10 days without rain;
- A 15J watering frequency, i.e. one liter of water irrigated every 15 days without rain;
- A 0J watering frequency, only watered when it rains.
- A total of 108 pots were used.

Conducting the study

Sowing was carried out at a rate of five seeds per pot, followed by a thinning at one plant per pot 14 days after sowing (DAS). Pots watered at 0J did not receive supplemental irrigation; they were watered only by rain until the end of the experiment. Data were collected from all 108 plants, starting from 26 DAS, the starting date for implementing watering regimes. The quantity of water supplied to the plants from 26th DAS was strictly 1000 ml per pot throughout the treatment, corresponding to the field capacity of the soil.

The number of supplemental irrigations per watering frequency during the experiment is shown in Table 4. For crop maintenance, pots were regularly weeded and phytosanitary treatments were applied as required. Décis (deltamethrin as active ingredient) was applied against insects and Delta cal against worms.

Measuring environmental parameters

Temperature and relative air humidity

During the study, temperature (°C) and relative air humidity (%) were recorded using a HANNA HI 9564 thermohydrometer to assess the influence of environmental factors on functioning of plants. Measurements were taken daily at 6 a.m., 2 p.m. and 6 p.m. from sowing to harvest.

Soil temperature

Soil temperature was also determined at 6a.m., 2p.m. and 6p.m. from 26 DAS to harvest using a Brannan soil thermometer.

Rainfall and number of supplemental irrigations

Rainfall was also measured using a direct-reading rain gauge to determine the amount of water received during the study. The number of supplemental irrigations per treatment was determined in order to identify the optimal frequency of supplemental irrigation per water regime.

Measuring physiological parameters

Leaf water potential

Leaf water potential was measured at flowering stage on 70 DAS, using a Scholander pressure chamber requipped with a digital pressure gauge (accurate to 10-3MPa) and a flow regulator. The minimum potential (Ψm) obtained at mid-day (1 pm to 3 pm) was measured on the first young leaf, fully developed and healthy from the apex.

Leaf transpiration

Leaf transpiration was also estimated on 66 DAS, based on variations in the weight of pots measured at regular time intervals using a 0.001 g Sartorius electronic balance. The pots, covered with plastic bags to prevent evaporation, were regularly weighed every hour from 06 a.m. to 6 p.m.

The quantity of transpired water is given by the following relationship. Tr = (PPn+1 - PPn); where PPn and PPn+1 are the weights of the pots taken at consecutive measurement times and Tristhe transpiration measurement (Kihindo et al., 2016).

Leaf chlorophyll content

Leaf chlorophyll content is determined at flowering stage using the SPAD 502 chlorophyll meter. Values are measured on the first young, fully developed and healthy leaf from the apex. Values are provided in units known as SPAD (Soil Plant Analysis Development).

Measurement of agronomic parameters

Number of seeds per plant (NGr)

Harvested pods were husked progressively on all plants. Seeds were counted manually.

Seed dry mass per plant (MSGr)

After husking the harvested pods, the dry mass of the seeds in grams (g) per plant was determined using a DENVER Instrument AC-1200D electronic balance, precision 0.001 g.

Harvest index (Ir)

The harvest index (Ir) is calculated as the ratio of total seed dry mass to haulm dry mass (total dry above-ground biomass).

Data analysis

The results obtained were subjected to a variance analysis (ANOVA). Tests for comparing averages were performed using the Newman-Keuls method. Levels of treatments significance were determined at a probability threshold of 0.05. All analyses were conducted using GENSTAT DISCOVERY software.

Results and discussion

Measuring environmental parameters Air temperature and relative humidity

The daily averages of air temperature and relative humidity recorded during the experiment are presented in Table 2. August had a significant (p = 0.003) lower temperature average (28.52°C±0.61) and a higher relative humidity average (71.31%±0.61) than September and October.

Table 2. Average variation in air temperature and relative humidity.

Month	Temperature (°C)	Relative humidity (%)
August	28.52 ± 0.61^{b}	71.31 ± 0.61^{a}
September	31.64 ± 0.89^{a}	66.00 ± 2.21^{b}
October	32.79 ± 0.69^{a}	63.12 ± 2.21^{b}
p	**0.003**	**0.041**

°C=degree Celsius; %=percentage, values followed by the same letters in a column are not significantly different at 5% threshold, p: probability.

Soil temperature

Table 3 shows average soil temperatures at different times of the day and average soil temperatures during the study according to watering frequency. The result of variance analysis reveals a highly significant difference (p<0.001) between supplemental irrigation regimes for all survey times. 5J treatment had the lowest soil temperature values, while the other three treatments showed statistically identical values.

Rainfall and number of supplemental irrigations

Table 4 shows that the amount of rainfall decreases from August (92.61 mm) to October (34.9 mm). It also shows that the number of days of drought period in October is the highest.

Measuring physiological parameters Leaf water potential

At flowering stage, the result of variance analysis showed a highly significant difference (p<0.001) between treatments. The highest water potential values were observed for 5J irrigation regime (-0.68 MPa), followed by the 10J irrigation regime (-1.33 MPa). The lowest value of -1.76 MPa was observed for the 15J and 0J irrigation regimes (p<0.001; Fig. 1).

Leaf transpiration

Generally speaking, plants from 5J water regime sweated the most (13.1 g/h). On the other hand, the lowest transpiration was recorded for plants under 0J regime (6.6 g/h). Similar and intermediate values were observed under 10J and 15J regimes. Fig. 2 shows the evolution curve of hourly leaf transpiration. During all measurement hours, transpiration of irrigated plants (under 5J, 10J, 15J) is significantly (p<0.001) higher than that of non-irrigated plants (under 0J). However, the hourly transpiration curves had a similar appearance for both irrigated and non-irrigated plants. The lowest transpiration values are observed at 6 a.m. and the highest values between 11 a.m. and 3 p.m. Between 12 a.m. and 1 p.m., a decrease in transpiration is observed, corresponding to the mid day depression. Average transpirations of plants irrigated every 5 days without rain (141.01±0.81 g/d) is significantly higher than that of plants irrigated every 10 days without rain (104.33±1.63 g/d), every 15 days without rain (105.32±1.01 g/d) and those (0J) watered only by rain (81.66±0.80 g/d).

Leaf chlorophyll content

The result of variance analysis about chlorophyll content reveals a highly significant difference ($p<0.001$; Fig. 3) between water regimes. Indeed, supplemental irrigation increased chlorophyll content of plants under 5J irrigation regime compared to ordinary plants (non-irrigated plants). Under 10J and 15J regimes, chlorophyll content is practically the same as that obtained under 0J (Fig. 4).

Measurement of agronomic parameters Number of seeds per plant (NGr)

Statistical analysis reveals a highly significant effect ($p<0.001$; Table 5) between water regimes on this parameter. 0J treatment gives the lowest number of grains with an average of 28±3, while the highest is observed under 5J regime with an average of 113± 2grains. Under 10J and 15J, the average number of grains is higher than under 0J. However, this number differs between 10J and 15J, with 52±5 grains and 37±1 grains respectively.

Seed dry mass per plant (MSGr)

The results show that supplemental irrigation improves yield, with grain dry mass 3.9 times higher under 5J, 2.8 times higher under 10J and 1.5 times higher under 15J than under the 0J regime ($p<0.001$; Table 5).

Harvest index (Ir)

Variance analysis reveals a significant effect ($p=0.004$) between treatments for this parameter. Plants subjected to 5J, 10Jand15J water regimes showed the best harvest index compared to untreated plants (Table 5).

The lowest soil temperature averages during the study were obtained with the 5J watering frequency. This regular irrigation would increase humidity, which in turn would reduce the temperature of the growing medium. According to Hantz (2005), air, which is moisture-hungry evaporates a part of the available water while taking up the latent heat of vaporization which ultimately leads to cooling the soil. The lower soil temperature enables rhizobia bacteria to operate properly, which could explain the higher number of nodules in plants compared to other systems (Somasegaran and Hoben, 1994; Ouedraogo et al., 2021). Watering every 5 days without rain would help maintain soil moisture and lowers soil temperature, which favors nodule metabolism and rhizogenesis. These conditions would enable rhizobia to mobilize atmospheric nitrogen for soil enrichment and improve, at plant level, not only for good plant water uptake, but also assimilate synthesis for pod production and grain filling (Kihindo et al., 2016). According to Vadez (2012) and Ouedraogo et al. (2021), high root biomass improves plant water uptake to maintain an optimal rate of above-ground growth. Average temperatures measured during the experiment showed that the application of water regimes to the different plants coincided with a period of high temperature, at 2 p.m., which can reach 45 °C. According to Sharma et al., (2016), these temperature averages correspond to temperatures beyond which mungbean grain yield drops by 35 to 40%. According to Cruz (2000), plants are subject to environmental stresses such as extreme temperatures, which induce water deficit. Water stress caused by atmosphere drought, which occurred during drought pockets, is said to have caused a state of water regulation within the plant, manifested by stomatal closure and regulation of osmotic potential (Brisson and Delecoller, 1992). This regulation of osmotic potential would have led to a reduction in the minimum leaf water potential of plants. Indeed, 0J water regime had a lower leaf water potential than that of plants irrigated every 5J and 10J. The low level of leaf water potential would suggest an osmotic mechanism (osmotic adjustment) with the aim of continuing to take up the little water available before a rain, in order to continue its physiological activity despite the soil water constraint (Kihindo et al., 2016; Kabore et al., 2019). This osmotic regulation would not have been sufficient to prevent grain production for the 0J frequency, but significant enough to result in low NGr and MSGr. Under 15J frequency, leaf water potential was equivalent to that observed under 0J. This indicates that osmotic regulation was also ineffective in preventing a reduction in seed number under 15J. However, at 10J, the higher potential than the one observed at 0J led to an increase in the number and dry mass of seeds per plant compared to the 0J condition. Osmotic regulation therefore seems to be more favorable to pod filling with seeds. 5J watering frequency, applied three times in September and fourth in October led to the highest water potential. This would have enabled plants to achieve good productivity in terms of number and dry mass of seeds, thanks to the availability of sufficient water in the root zone to fulfill photosynthesis. Plants transpire according to the available water content.

Plants under 5J water regime transpired more than those under 0J, 10J and 15J water regimes. This difference could be explained both by the frequency of plants watering and by a significant positive correlation between transpiration and relative water content. A plant placed under non-limiting water conditions has a high sweating activity, and the more the soil moisture increases, the more the sweating activity increases the amount of water transpired. Under the limiting watering frequencies (0J and 15J), plants reduced their leaf transpiration during drought pockets. This situation reduces the number of open stomata and contributes to store water resources, thus increasing the survival of plants (Lebon et al., 2004). Good seed production in plants under 5J water regimes is also linked to a higher transpiration rate, resulting in a significant gain in CO_2 needed for photosynthesis in order to synthesize organic elements (Kihindo et al., 2016).

The increase in chlorophyll under 5J plants is due to the availability of water in the root zone, resulting in a low soil temperature. It can therefore be assumed that the lower the soil temperature, the higher the chlorophyll content. This result is in the same framework as the one from Hikosaka et al. (2006), who observed that the amount of chlorophyll in leaves can be influenced by a number of environmental factors, such as temperature and water availability. Harvesting indices (Ir) of plants under different treatments revealed a highly significant difference at the threshold limit of 5%. In fact, watered plants showed a similar and higher harvest index than non-watered plants. This means that watering frequency enabled appreciable photosynthesis from the source (leaf), which in turn favored good migration of photo assimilates to fill the sink (seed) (Omid, 2009). Severe water stress affects factors related to seed formation, including photosynthesis and translocation of assimilates.

Table 3. Average soil temperatures over time during cultivation.

Water regimes	Time/Period			Daily average
	6 h	12 h	18 h	
0J	24.25±0.33^{a}	45.19±5.56^{a}	32.01±2.60^{a}	33.82±2.45^{a}
5J	22.70±0.21^{b}	36.11±2.39^{b}	29.54±2.26^{b}	29.45±1.07^{b}
10J	24.16±1.43^{ab}	43.41±5.35^{ab}	31.59±2.38^{a}	33.05±2.21^{ab}
15J	24.79±2.23^{ab}	43.64±5.17^{ab}	31.75±2.55^{a}	33.39±2.24^{a}
p	**<0.001**	**<0.001**	**<0.001**	**<0.001**

Values followed by the same letters in a column are not significantly different at 5% threshold; p:probability. 5J=5-day supplemental irrigation; 10J=10-day supplemental irrigation; 15J=15-day supplemental irrigation; 0J=rain-only irrigation.

Table 4. Rainfall and number of supplemental irrigations.

Month	Monthly rainfall (mm)	Number of rains	Drought pocket ≥ 5 days	Supplemental irrigations			
				0J	5J	10J	15J
August	92.61	8	0	0	0	0	0
September	84.3	8	3	0	3	1	0
October	34.9	6	4	0	4	1	1

mm: millimeter 5J=5-day supplemental irrigation; 10J=10-day supplemental irrigation; 15J=15-day supplemental irrigation; 0J=rain-only irrigation

Table 5. Components of plant yields under irrigation regimes (0J, 5J, 10J, 15J).

Irrigation regimes	NGr	MSGr(g)	Ir
0j	28±3^{d}	1.41±0.12^{c}	0.31±0.01^{b}
5j	113±2^{a}	4.51±0.11^{a}	0.48±0.06^{a}
10J	52±5^{b}	2.82±0.23^{b}	0.51±0.03^{a}
15J	37±1^{c}	2.45±0.11^{b}	0.52±0.06^{a}
p	**<0.001**	**<0.001**	**0.004**

NGr: number of seeds per plant; **MSGr:** dry mass of seeds per plant; **Ir:** harvest index. Values followed by the same letters in a column are not significantly different at 5% threshold; **p:** probability.

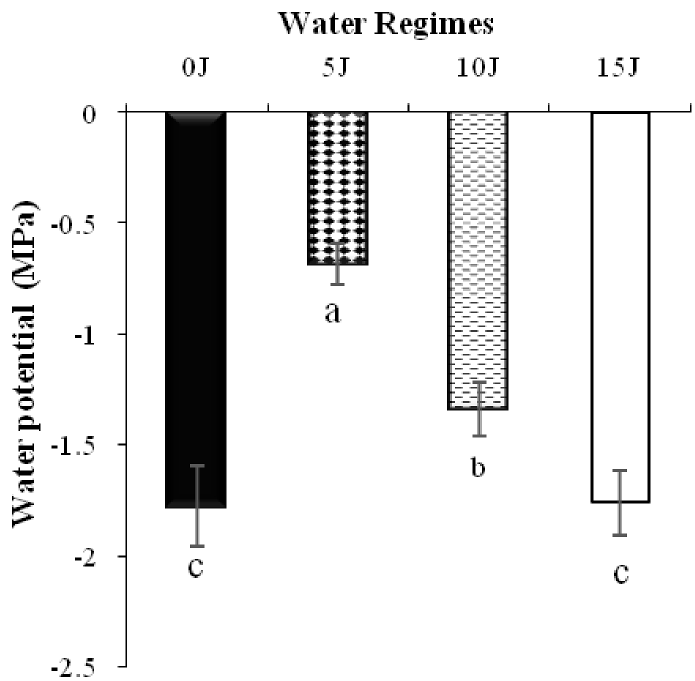

Fig. 1: Distribution of water potential under different water regimes. 0J=rainfall irrigation only; 5J=5-day supplemental irrigation; 10J=10-day supplemental irrigation; 15J=15- day supplemental irrigation; Histograms, assigned by the same letter, do not differ from each other at 5% threshold.

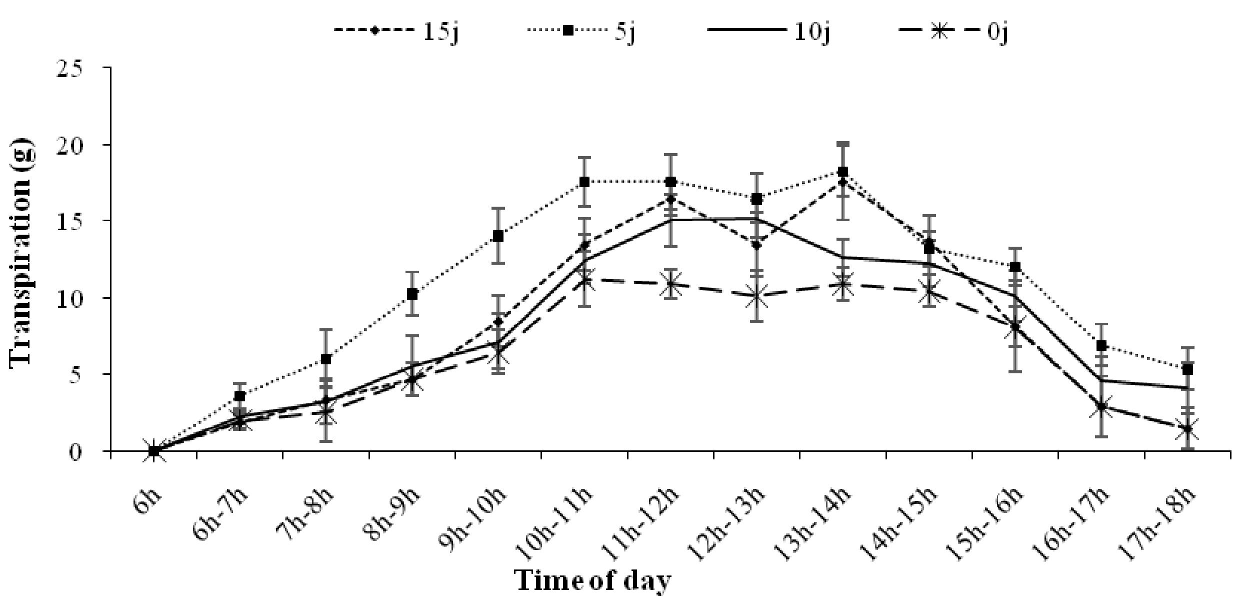

Fig. 2: Transpiration curves under different water regimes. 0J=rainfall irrigation only; 5J=5-day supplemental irrigation; 10J=10-day supplemental irrigation; 15J=15- day supplemental irrigation; Histograms, assigned by the same letter, do not differ from each other at 5% threshold.

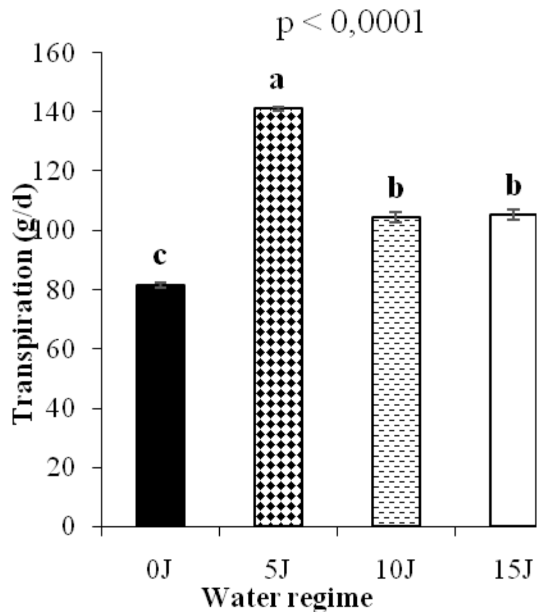

Fig. 3: Transpi²rations at 66 days after sowing of plants under different water regimes. 0J=rainfall irrigation only; 5J=5-day supplemental irrigation; 10J=10-day supplemental irrigation; 15J=15- day supplemental irrigation. Error bars, assigned with the same letter, do not differ from each other at 5%threshold.

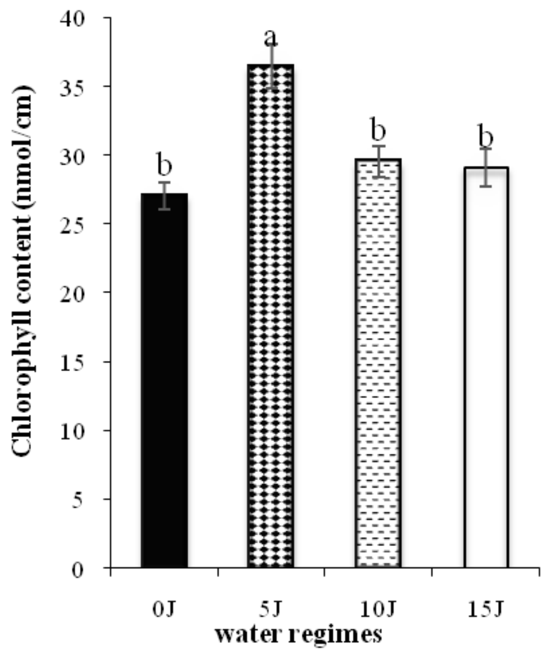

Fig. 4: Distribution of chlorophyll content in plants under different water regimes. 0J=rainfall irrigation only; 5J=5-day supplemental irrigation; 10J=10-day supplemental irrigation; 15J=15- day supplemental irrigation. Error bars, assigned with the same letter, do not differ from each other at 5%threshold.

Indeed, photosynthesis, being the primary factor in total production, is often disrupted by water deficit, which causes closure of stomata. Translocation of assimilates from leaves to seeds would be easier under 5J watering regime (watering every five days when there is no rain, applied ninth during the trial), which produced more seeds with a higher seed weight per plant.

Conclusions

Rain-fed agriculture is highly dependent on weather conditions. To make this agriculture independent from these climatic variations, supplemental irrigation would be one of the solutions. The results show that supplemental irrigation improved transpiration, water potential, leaf chlorophyll content, harvest index, the number of seeds produced per plant, and their weight, attesting the importance of water for seed production and pod filling. 5J watering frequency enabled mungbean plants to achieve higher agronomic performance. This regime is therefore recommended for good seed production when drought pockets occur during mungbean cultivation in wet or rainy seasons. The results of this study also demonstrate that supplemental irrigation is effective in improving and stabilizing yields in arid and semi-arid zones where rain-only irrigation is a limiting factor in production. Supplemental irrigation technique applied in this study, which enabled to obtain good yields of mungbean seeds, should therefore be disseminated among farmers in arid and semi-arid zones where drought pockets are frequent during wet seasons.

Conflict of interest declaration

The authors declare that they have no conflicts of interest.

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How to cite this article:
Kihindo, A. P., Ouedraogo, R. F., Dondasse, E., Sawadogo, A., Badiel, B., 2023. Variation in agro-physiological parameters of *Vigna radiata* (L. R. Wilczek) under different supplemental irrigation frequencies. Int. J. Curr. Res. Biosci. Plant Biol., 10(7): 1-10. **doi:** https://doi.org/10.20546/ijcrbp.2023.1007.001