

Article

Effects of Deficit Irrigation and Intercropping of Dry Beans with Two African Leafy Vegetable Crops on Growth and Yield

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Abstract: The instability between water demand and availability is making it challenging to cultivate viable, sustainable crops. To address this, improved irrigation scheduling regimes need to be adopted, focusing on full crop water requirements to determine optimal water allocation. This study aimed to identify suitable intercropping combinations of leguminous dry bean plants with indigenous African leafy vegetables (specifically *cleome gynandra* and *cucumis myriocarpus*) that could enhance interactions with regulated deficit irrigation. The experiment was designed in 3 (irrigation levels: 100%, 75%, and 50%) × 5 (three monocrops and two intercrops) split plot arrangement within a randomized complete block design (RCBD), replicated three times across four growth stages. The study was designed to rigorously assess the effectiveness of two intercrops compared to three monocrops, each cultivated under varying irrigation levels of 100%, 75%, and 50%. There was an increase in selected gaseous parameters, such as stomatal conductance and photosynthesis rates when dry beans were intercropped with *cucumis myriocarpus* and subjected to 75% deficit irrigation during the mid-pod stage of the dry bean. In contrast, decreased gaseous parameters were noted under a 50% deficit irrigation across all dry bean growth stages, which also negatively affected the growth of African leafy crops. Regarding yield, an inverse relationship was observed between the crops. The yield of dry beans significantly increased under 75% irrigation during the mid-pod stage. Meanwhile, yields of *cucumis myriocarpus* increased under both 75% and 100% irrigation levels during the early-pod stage of the dry beans, which corresponded to the vegetative stage of the two African leafy crops. In conclusion, regulating irrigation under 75% deficit irrigation during the mid-growth stage is recommended as an ideal irrigation level for intercropping dry beans with *cucumis myriocarpus*, and this can potentially save 25% of water.

Keywords: chlorophyll; *cleome gynandra*; *cucumis myriocarpus*; dry bean pod yield; leaf gaseous exchange; number of pod/plant photosynthesis; pod size; stomatal conductance



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1. Introduction

Future predictions indicate that reduced rainfall, rising temperatures, and increased variability will adversely affect agricultural performance and regional development goals in many southern parts of Africa [1]. Global warming is predicted to further worsen global water cycle issues; its variability and precipitation might lead to intensified drought and unpredictable rainfall patterns, especially in areas dependable on rainfall [2]. Implementing irrigation science-based approaches can significantly boost crop profitability while safeguarding the environment by effectively managing crop water stress [3]. Conversely,

poor irrigation practices can lead to excessive water usage, diminishing farmers' economic returns and harming environmental sustainability [4]. Water is essential for agricultural production worldwide [5]. Numerous studies have highlighted the impact of water scarcity on crop production, which may result in decreased crop yields [6]. Maximizing plant growth and health depends on providing the precise amount of water needed at the right time. By utilizing cutting-edge monitoring and control strategies that consider critical factors like soil moisture, weather patterns, and plant health, remarkable water optimization can be achieved. Traditional irrigation methods often lead to pitfalls of over- or underwatering, which not only lead to water wastage but also deplete vital nutrients from the soil [7].

Deficit irrigation is a critical strategy that relies on daily data from remote weather stations, historical climate records, and daily evapotranspiration measurements [8]. When water supply is limited, it is imperative to adjust deficit irrigation scheduling to effectively safeguard crops from excessive water stress during crucial growth periods [9]. This approach has been proven to significantly enhance water use efficiency and eliminate water wastage in agricultural practices [10]. In areas with scarce water resources, regulated deficit irrigation dramatically improves water use efficiency (WUE). Temporary water stress during the maturity and ripening stages of vegetable crops leads to notable growth and the increased accumulation of glucose and fructose in plants [11]. Irrigation scheduling is defined as a procedure of applying water at the correct time to obtain full crop production levels based on weather conditions (temperature, rainfall, humidity levels, and evapotranspiration), soil moisture, and plant data [12]. Maintaining plant water status within the specific limits of deficit irrigation periods is essential for optimal plant growth, especially during non-critical phenological stages [13]. Any sudden increase in evaporative demand can jeopardize yield and fruit quality, resulting in significant losses. Extended periods of drought, which are becoming more common globally due to climate change, may have an impact on the growth and yield of both conventional and climate-adaptive crops [14].

Determining the level of deficit irrigation begins with accurately defining full crop evapotranspiration (ET_c) [15]. Evapotranspiration serves as the most reliable estimate for irrigation delivery in agricultural systems. Nevertheless, it is crucial to gather additional data on actual crop evapotranspiration (ET_c) since plants endure varying stress levels throughout different growth stages [16]. By identifying the ideal timing in the drying cycle for water application and understanding how much plant-available water the soil can retain, farmers can significantly enhance their water-use efficiency, leading to more sustainable and productive farming practices [17]. Water deficit irrigation plays a crucial role in influencing stomatal density, which is vital for how plants adapt to challenging drought conditions [18]. When water stress occurs, it significantly reduces minimum evapotranspiration due to the closure of stomata, leading to decreased carbon assimilation and lower biomass production [19]. Stomatal conductance is determined by various factors, including the plant's water status, CO_2 levels, and light availability [20]. Evidence demonstrates that reduced stomatal opening results in decreased CO_2 assimilation and photosynthesis rates, and under extreme drought stress, stomata may completely close [21,22]. Photosynthesis is a complex and essential process that involves multiple key steps, including the capture of solar energy and its conversion into usable forms. This process encompasses the transfer of excitation energy, the electron transfer from water for ATP generation, and various enzymatic reactions that assimilate CO_2 and produce carbohydrates [23]. However, during periods of water scarcity, the stomata tend to close, which significantly reduces leaf conductance and impairs photosynthesis in leaves [24]. Chlorophyll is an important plant pigment responsible for the green color in the plants. Various factors such as nutrient availability and environmental stresses such as drought, salinity, and heat greatly influence the amount of chlorophyll in the leaf tissues of the plant [25]. Chlorophyll is considered proportional to

leaf nitrogen content [26,27]. Plants with nitrogen deficiency indicate significantly low leaf nitrogen and chlorophyll contents and a reduction in photosynthetic capacity [28].

Intercropping legumes with non-legume crops has demonstrated significant benefits in boosting crop production and enhancing overall plant growth. Recent studies have primarily examined the effects of intercropping legumes with grains—such as cereals, maize, sorghum, and wheat—on plant growth and physiology [29,30]. The impact of intercropping legumes with African leafy vegetables remains largely underexplored. It is crucial to investigate how intercropping legumes with African leafy crops under moderate or limited irrigation can effectively combat water scarcity without hindering plant development and yield. Intercropping has consistently been shown to increase yields; however, understanding how to combine this technique with deficit irrigation could unlock new possibilities for enhancing both crop yields and water use efficiency [31]. Exploring this combination is not just a research necessity; it holds the potential to revolutionize agricultural practices in water-scarce regions. Legume plants, particularly dry beans, are vital sources of plant proteins that play a crucial role in sustaining both human and animal diets. Their significance extends far beyond nutrition; they contribute to food security by generating income, enhancing soil fertility, providing essential livestock feed, conserving water, and serving as a renewable source of fuel [32]. As low-input crops, legumes are environmentally friendly, helping to mitigate greenhouse gas emissions and fix atmospheric nitrogen, thereby promoting ecological balance [33]. Dry beans are a staple food globally, particularly in many African countries, where they greatly enhance food security for low-income and self-sufficient households [34]. Originating from Central and South America within the genus *Phaseolus*, these legumes have been adapted and cultivated in Southern Africa as well [35]. Moreover, South Africa is rich in indigenous plants known for their medicinal benefits, making the cultivation of these crops even more imperative for both health and economic prosperity [36]. Investing in the cultivation of legume crops is a sustainable choice that promotes nutrition, economic development, and environmental health.

African leafy vegetable crops such as *cucumis myriocarpus* and *cleome gynandra* are recognized for their numerous uses in society, significantly supporting food and nutrition security as well as promoting diversity. These plants can withstand water shortages and often yield higher economic returns than other crops [37]. They are rich in micronutrients, and the awareness of their nutritional benefits contributes to indigenous knowledge systems [38]. Research has shown that cultivating indigenous and African leafy plants has the potential to enhance economic value and produce greater yields, even in water-scarce conditions. These plants can also withstand water deficits and still produce high economic value and yields [37]. *Cucumis myriocarpus* is native to several Southern African countries, including South Africa, Zambia, Botswana, Mozambique, and Lesotho [39]. This plant belongs to the Cucurbitaceae family, which includes a diverse range of species indigenous to South Africa, primarily used for medicinal purposes and as food sources [40]. In many parts of South Africa, the entire leafy parts of these plants are consumed as vegetables, while the stems and roots are utilized in traditional medicine [41]. *Cucumis* species are known for their drought tolerance and ability to survive with minimal water supplies [41]. Their physiological and morphological characteristics enable them to compete effectively, remain dormant in arid environments, and exhibit intermediate resistance to diseases such as downy mildew, scabs, and the mosaic virus [35]. *Cleome gynandra* is an indigenous plant commonly found or cultivated in Africa and Asia. It is recognized as a significant source of vitamins and minerals, especially in impoverished communities [42]. *Cleome gynandra* has medicinal value due to its high levels of secondary metabolites and pharmacological importance as it possesses anti-inflammatory properties, free radical scavenging capabilities, and anticancer agents [42]. Additionally, the plant is consumed as a vegetable

and is traditionally used to treat conditions such as migraines, headaches, and stomach aches [43]. Exploring the effects of intercropping legumes with African leafy crops under moderate or limited irrigation conditions will be instrumental in combating water scarcity and enhancing both crop growth and yield in sustainable agriculture. To reach our goal, our study objectives aimed to thoroughly examine the performance of two intercrops (dry bean $\times$ *cucumis myriocarpus* and dry bean $\times$ *cleome gynandra*) alongside three monocrops (dry bean, *cucumis myriocarpus*, and *cleome gynandra*). Furthermore, our study focused on assessing their responses in terms of leaf gas exchange parameters, growth, and yield across three varying irrigation levels (100%, 75%, and 50%).

2. Materials and Methods

2.1. Study Area

The study was conducted at the University of Limpopo's experimental farm (UL Farm), located in a research block defined by the coordinates 23.531° S and 29.4415° E. The study was conducted from November 2023 to February 2024, which is during summer conditions. Temperatures range from a minimum of ± 18 °C to ± 22 °C at night to a maximum of ± 28 °C to ± 38 °C during the day. Humidity levels are a minimum of $\pm 30\%$ to $\pm 40\%$ and a maximum of $\pm 85\%$ to $\pm 95\%$, creating diverse conditions for plant growth. Furthermore, the soil in this study area has been classified as Bainsvlei [44].

2.2. Experimental Design

The experiment was designed using a split-plot arrangement with 3 irrigation levels, 5 cropping systems, and 4 growth stages, all organized within a randomized complete block design (RCBD) with 3 replications. The first factor consisted of three irrigation levels: 1. water applied at 100% of field capacity (control), 2. water applied at 75% deficit irrigation, 3. water applied at 50% deficit irrigation. The second factor involved 5 cropping systems: 1. monocrop Ped dry beans, 2. monocropped *cucumis myriocarpus*, 3. *cleome gynandra*, 4. dry beans intercropped with *cucumis myriocarpus*, 5. dry beans intercropped with *cleome gynandra*. The third factor pertaining to irrigation was based on 4 key growth stages of dry beans, as outlined by [45]: 1. Irrigation level withdrawn at the 50% flowering stage (R2), 2. irrigation level withdrawn at the early-pod stage (R3), 3. irrigation level withdrawn at the mid-pod stage (R4), 4. irrigation withdrawn at the early seed-filling stage (R5).

2.3. Sampling Procedure

2.3.1. Soil Sampling

Since there was no visible topological variation within the farm, the sampling strategy that was employed was simple random sampling. A composite soil sample of 2 samples per treatment (4 growth treatments) was collected randomly from a depth of 0–30 cm using an auger. The samples were then crushed and sieved through a 2 mm sieve. This procedure was conducted to prepare the soil for the assessment of soil fertility. This depth was selected because the roots of dry beans (*Phaseolus vulgaris* L.), *cucumis myriocarpus*, and *cleome gynandra* typically grow within this depth of soil.

2.3.2. Irrigation Scheduling

Regulated deficit irrigation was established based on reference crop evapotranspiration (ET_c), with values obtained from an automated weather station (AWS) sourced from climate datasets for South Africa by the Agricultural Research Council. Irrigation scheduling was based on reference evapotranspiration (ET_c) and a crop factor. Reference evapotranspiration (ET_c) values were obtained from an automatic weather station (AWS); the AWS calculates ET_c daily according to Penman–Monteith's method [46]. The crop coefficient (K_c) values

used were for spinach, where the K_c initial = 0.4, K_c med = 1.52, and K_c late = 0.35 [47]. Using these values of K_c and ET_o from the AWS, the crop water requirement (ET_c) was then calculated as follows: $ET_c = ET_o \times K_c$ where ET_c = crop water requirement, ET_o = reference evapotranspiration, and K_c = crop factor [46].

2.4. Data Collection

Selected physical properties, such as the analysis of soil texture, were determined using the hydrometer method [48], and soil bulk density ($P_w = Mw/Vw$) was determined as the ratio of oven-dry soil mass in relation to its volume [49]. Available phosphorus was extracted using the Bray-1 Method [50]. Selected chemical properties (pH, electrical conductivity, magnesium, calcium, and potassium) that influence the productivity of dry beans (*Phaseolus vulgaris*) and African leafy vegetables (*cucumis myriocarpus* and *cleome gynandra*) were assessed. The pH and electrical conductivity of soil samples were determined in a 1:2.5 soil/water suspension, as outlined in [51].

The physiological parameters of the plants and leaf gas exchange characteristics, including sub-stomatal, stomatal conductance, photosynthesis rate, and transpiration rate, were measured at two critical growth stages of dry beans, namely the early-pod stage and the mid-pod stage. In addition, data for two African leafy crops were collected during the maturity stage and harvest growth stage. Measurements were taken on the abaxial side of the leaves using a portable photosynthesis system. All physiological parameters were recorded simultaneously under optimal conditions, with sunlight exposure from 10:00 a.m. to 2:00 p.m. [52]. To further assess plant growth, leaf chlorophyll content was measured using a SPAD 502 chlorophyll meter (Konica Minolta Co., Ltd., Osaka, Japan). In addition, we carefully assessed key growth and yield components—such as plant height, root diameter, stem diameter, stem length, and pod length—utilizing a leaf tapeline measuring tool. Finally, biomass (g), root weight (g), and pod weight (g) were accurately measured with a scale, providing a comprehensive overview of plant performance.

2.5. Data Analysis

The data were analyzed using a two-way factorial analysis of variance (ANOVA) with Statistics 10 software. To assess the significance of growth and yield, mean separation was conducted using Tukey's HSD (Height Significant Difference) test at a 5% significance level at $p \leq 0.05$.

3. Results

3.1. Pre-Soil Results

The soil fertility variables analyzed prior to the implementation of deficit irrigation, intercropping, and monocropping treatments are summarized in Table 1. The soil pH of the composite sample before irrigation was measured to be alkaline, with a water pH level of 8.1 and a pH of 8.06 in KCl. The soil's electrical conductivity (EC) was recorded at 252 $\mu\text{S}/\text{cm}$, indicating that the soil is not saline (adding a reference to the norms assessed). Additional soil chemical properties, such as calcium (Ca), potassium (K), phosphorus (P), and magnesium (Mg), are also detailed in the table.

Table 1. Pre-soil analysis.

Property	Units of Measurement	
Soil Texture	%	Loamy Sand (7.6% slit, 10.4% clay, 82% sand)
Soil Bulk Density	g/cm ³	0.03 g cm ^{−3}
pH (H ₂ O)	-	8.1
pH (KCl)	-	8.06
Electrical Conductivity (EC)	μS/cm	252
Calcium (Ca)	mg/kg	116
Potassium (K)	mg/kg	203
Phosphorus (P)	mg/kg	41
Magnesium Mg	mg/kg	147

3.2. Crop Physiology and Leaf Gaseous Parameters

Crop physiology and leaf gaseous parameters were analyzed and interpreted using the bar graph, and each treatment was represented based on key abbreviations below. The figures also present results that were significant at $p = 0.05$.

Key abbreviations in the figures explained.

1. SD = Sole-planted dry bean
2. SD × SC (SD1) = Dry bean intercropped with *cucumis myricarpus* (dry bean leaf measurement)
3. SD × SC (SC1) = Dry brean intercropped with *cucumis myriocarpus* (*cucumis* leaf measurement)
4. SC = Sole-planted *cucumis myriocarpus*
5. 5.SD × SCG (SD1) = Dry bean intercropped with *cleome gynandra* (dry bean leave measurement)
6. SD × SCG (SCG1) = Dry bean intercropped with *cleome gynandra* (cleome leave measurement)
7. SCG = Sole-planted *cleome gynandra*

3.2.1. Sub-Stomata and Stomatal Conductance

The study revealed significant differences in sub-stomata measurements during the early-pod stage, highlighting the crucial role of timing in dry bean cultivation. While no notable variations were observed during the mid-pod stage, this underscores the importance of early irrigation strategies. Additionally, for leafy vegetable crops, significant findings were recorded at the maturity growth stage, whereas results at harvest were less impactful. This highlights the shorter growth cycle of leafy vegetables compared to dry beans, reinforcing the necessity for tailored management approaches. Increased sub-stomata were mainly observed at 75% DI under the intercropping of SD × SC on the dry bean leaf measured at 81 vpm. The lowest number of sub-stomata was observed at the 50% DI level under all five cropping systems when water was entirely withdrawn at the 50% flowering stage (R2) (Figure 1A). This might have been exacerbated by the stomatal closure due to extreme deficit irrigation levels [53]. Furthermore, increased stomatal openings at the 75% DI level, particularly when irrigation was withdrawn at the mid-pod stage (R4) (Figure 1D), presents an opportunity for enhancing crop resilience. These results align with the research of [54], which identified significant increases in stomatal conductance during the critical pod-filling phase of maize and soybean intercropping. In contrast, findings from [55], which reported reduced stomatal conductance under an 80% irrigation deficit, further underscore the need for smart, targeted irrigation strategies that optimize plant growth and yield potential.

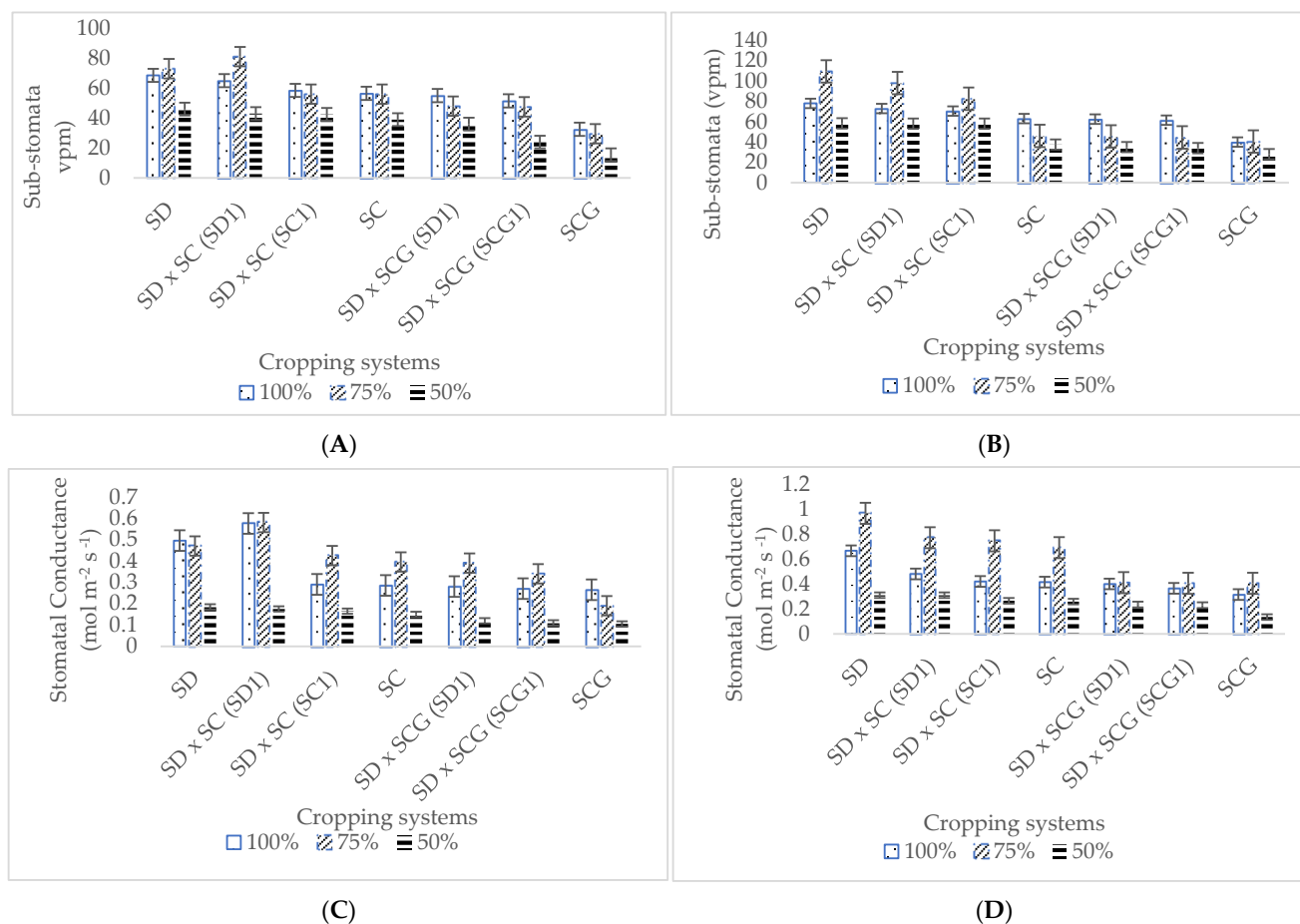


Figure 1. Response of sub-stomata and stomatal conductance to different irrigation levels and intercropping and monocropping of dry beans and two vegetable crops. (A) (Irrigation levels withdrawn at the 50% flowering stage (R2) on sub-stomata); (B) (irrigation levels withdrawn at the early-pod stage (R3) on sub-stomata); (C) (irrigation levels withdrawn at the 50% flowering stage (R3) on stomatal conductance); (D) (irrigation level withdrawn at the mid-pod stage (R4) on stomatal conductance).

3.2.2. Photosynthesis Rate

The authors identified significant differences in stomatal conductance when data were collected during the early-pod stage, while observations at the mid-pod stage did not yield significant changes. Notably, a photosynthesis rate of 35 was observed. A value of $14 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ was recorded for dry beans intercropped with *cucumis myriocarpus* under 75% irrigation when water levels were withdrawn at the mid-pod stage (Figure 2C). This finding is consistent with the research conducted [56], which demonstrated that tolerable water deficits of 75% can enhance photosynthesis, stomatal conductance, and water use efficiency (WUE). This enhancement may be attributed to an increased transpiration rate, which facilitates a greater CO_2 influx and subsequently boosts the photosynthesis rate [57]. In addition, the study by [58] found that sole-planted maize exhibited higher photosynthesis rates compared to maize intercropped with cowpea. Interestingly, similar photosynthesis rates were observed when irrigation was withdrawn at the early-pod stage under both 100% and 75% irrigation conditions (Figure 2B). Furthermore, during the 50% flowering stage and the early fill stage, withdrawing irrigation at the 75% level resulted in increased photosynthesis rates compared to the 100% and 50% irrigation levels for both sole dry beans and those intercropped with *cucumis* (Figure 2A).

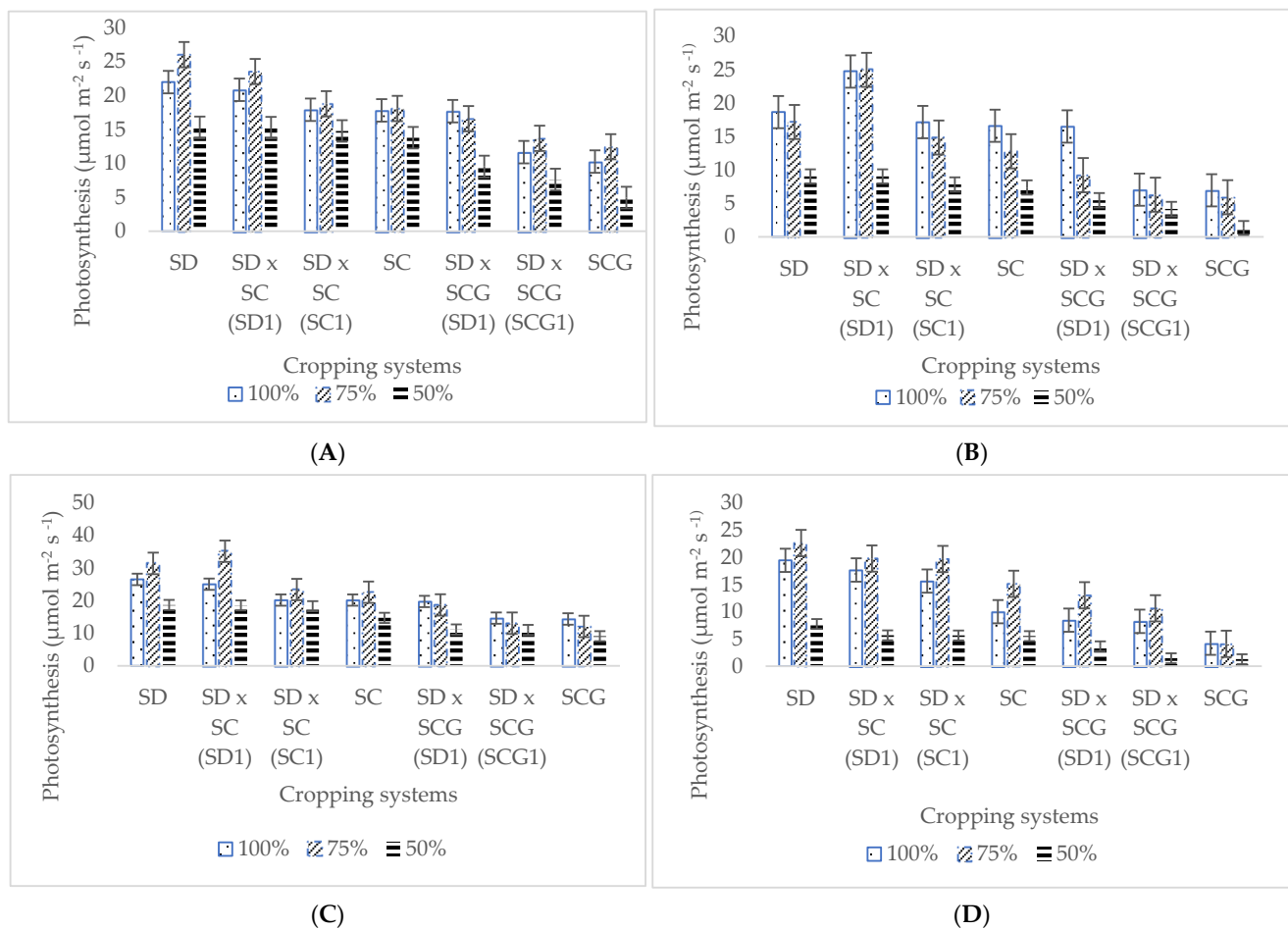


Figure 2. Response of photosynthesis rate to different irrigation levels and intercropping and monocropping of dry beans and two vegetable crops. (A) (Irrigation level withdrawn at the 50% flowering stage (R2)); (B) (irrigation level withdrawn at the early-pod stage (R3)); (C) (irrigation level withdrawn at the mid-pod stage (R4)); (D) (irrigation withdrawn at the early seed-filling stage (R5)).

3.2.3. Transpiration Rate

Significant differences in transpiration rates during the mid-pod stage are clear, while the early-pod stage shows no noteworthy variations. This establishes the mid-pod stage as a crucial factor for understanding plant transpiration behavior. The plants exhibited considerably lower transpiration rates across all treatments under 50% deficit irrigation (DI) when irrigation was withdrawn at the 50% flowering stage (R2). In this context, sole cleome and cleome intercropped with dry beans recorded the lowest transpiration rates, at $2.1 \text{ mol m}^{-2} \text{s}^{-1}$ and $2.5 \text{ mol m}^{-2} \text{s}^{-1}$, respectively (Figure 3A). Additionally, a significant decline in transpiration was noted in all treatments at 50% DI when irrigation levels were withdrawn during the early-pod stage (R3) (Figure 3B). Under 75% DI, when irrigation was withdrawn at the mid-pod stage (R4), both dry beans intercropped with *cucumis* and dry beans intercropped with *cleome* demonstrated notably higher transpiration rates compared to monocropped plants (Figure 3C). These findings highlight the critical role of strategic irrigation practices in enhancing plant performance and resilience at different growth stages.

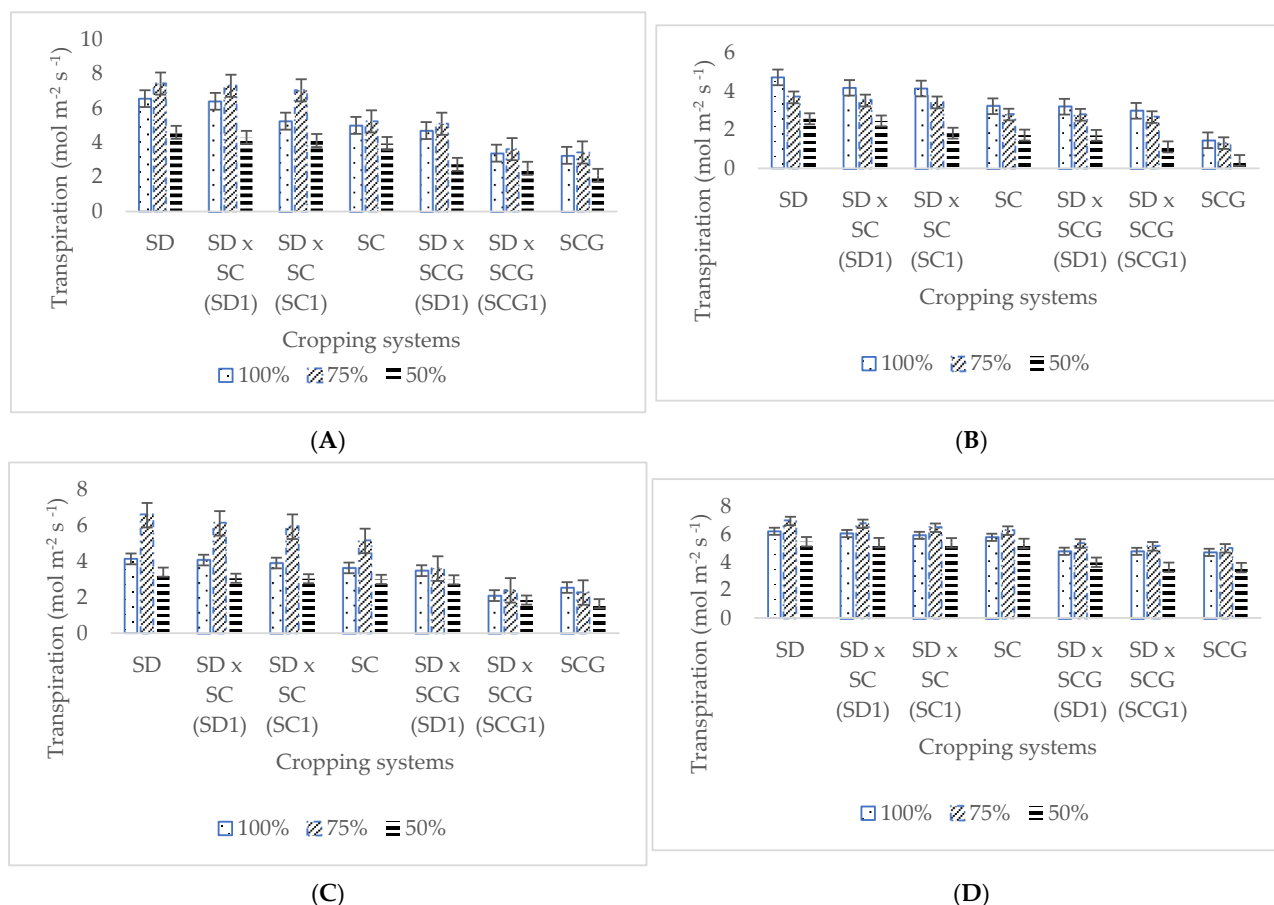


Figure 3. Response of transpiration to different irrigation levels and intercropping and monocropping of dry beans and two vegetable crops. (A) (Irrigation level withdrawn at the 50% flowering stage (R2)); (B) (irrigation level withdrawn at the early-pod stage (R3)); (C) (irrigation level withdrawn at the mid-pod stage (R4)); (D) (irrigation withdrawn at the early seed-filling stage (R5)).

3.2.4. Chlorophyll Content

Chlorophyll content showed remarkable and significant results in this analysis. Importantly, intercropping dry beans with cucumis under 75% deficit irrigation led to a notable increase in chlorophyll content across all growth stages. This contradicts the findings of [59], who reported a decline in chlorophyll levels under water deficit conditions. Furthermore, there was a significant decrease in chlorophyll levels observed under 50% deficit irrigation (Figure 4A–D).

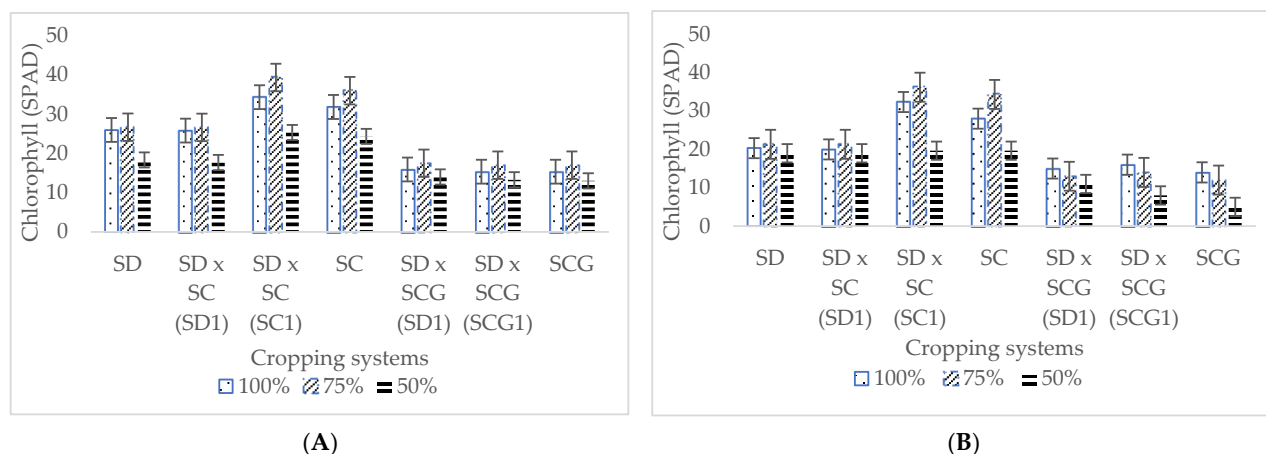


Figure 4. Cont.

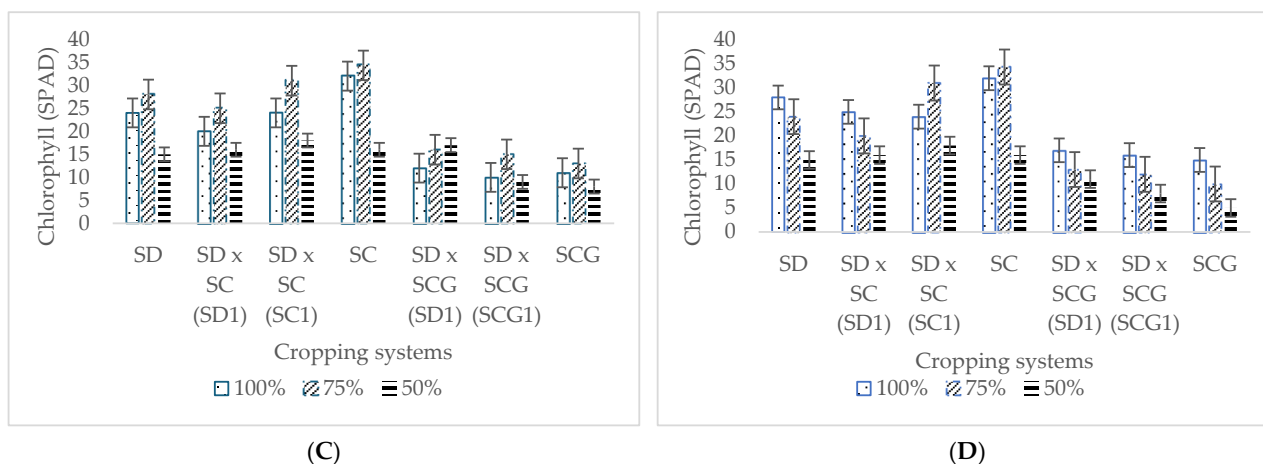


Figure 4. Response of chlorophyll content to different irrigation levels and intercropping and monocropping of dry beans and two vegetable crops. (A) (Irrigation level withdrawn at the 50% flowering stage (R2)); (B) (irrigation level withdrawn at the early-pod stage (R3)); (C) (irrigation level withdrawn at the mid-pod stage (R4)); (D) (irrigation level withdrawn at the early seed-filling stage (R5)).

3.3. Yield

3.3.1. Response of Yield When Irrigation Levels Were Withdrawn at the 50% Flowering Stage (R2)

Table 2: A notably significant difference was observed in the selected yield parameters. Sole dry beans demonstrated an impressive root weight of 8.53 g under 100% full irrigation when irrigation levels were reduced at the 50% flowering stage (R2). Consequently, there were also increases in root diameter, shoot length, and plant height under 100% irrigation conditions. In terms of plant biomass weight, sole dry beans achieved higher values of 245.5 g under 75% drought irrigation (DI) and 248.33 g under 100% full irrigation. In contrast, the intercrops exhibited the lowest root weight, diameter, and shoot length under 50% DI. While *cleome* displayed the lowest biomass weight, it surprisingly showed superior plant physiology, achieving greater shoot length and plant height under 100% full irrigation compared to the *cucumis* plant.

Table 2. Response of yield when irrigation levels were withdrawn at the 50% flowering stage (R2).

Treatments) Irrigation × Intercropping	Root Weight (g)	Root Diameter (cm)	Shoot Length (cm)	Biomass Plant Weight (g)	Stem Diameter (cm)	Plant Height (cm)
sole dry bean × full irrigation (FI)	8.53 ^a	9.06 ^a	9.06 ^a	248.33 ^a	4.27 ^a	57.66 ^a
sole dry bean × 75% DI	8.37 ^{ab}	8.5 ^{ab}	8.5 ^{ab}	245.5 ^a	3.91 ^{ab}	56.33 ^a
sole dry bean × 50% DI	8.13 ^{abc}	8.4 ^{abc}	8.4 ^{abc}	242.33 ^{ab}	3.67 ^{ab}	55 ^{ab}
dry bean + <i>cucumis</i> (dry bean) × full irrigation (FI)	7.62 ^{abcd}	8.2 ^{abcde}	8.34 ^{abcd}	242.33 ^{ab}	3.52 ^{abc}	50.26 ^{abc}
dry bean + <i>cucumis</i> (dry bean) × 75% DI	7.46 ^{abcde}	7.9 ^{abcdef}	8.33 ^{abcd}	239 ^{ab}	3.39 ^{abc}	49.67 ^{abc}
dry bean + <i>cucumis</i> (dry bean) × 50% DI	7.3 ^{bcdef}	7.66 ^{abcdefg}	8.2 ^{abcde}	238.67 ^{ab}	3.36 ^{abc}	34 ^{cdef}
dry bean + <i>cucumis</i> (<i>cucumis</i>) × full irrigation (FI)	7.3 ^{bcdef}	7.5 ^{abcdefgh}	6.7 ^{efgh}	236 ^{abc}	3.34 ^{abc}	31.33 ^{def}
dry bean + <i>cucumis</i> (<i>cucumis</i>) × 75% DI	7.28 ^{bcdef}	7.4 ^{bcdefgh}	6.63 ^{efgh}	231 ^{abc}	3.32 ^{abc}	30.33 ^{def}
dry bean + <i>cucumis</i> (<i>cucumis</i>) × 50% DI	7.2 ^{cdef}	7.33 ^{bcdefgh}	6.53 ^{fgh}	226.67 ^{abcd}	3.3 ^{abc}	29.66 ^{def}
<i>cucumis</i> × full irrigation (FI)	7.17 ^{cdef}	7.23 ^{bcdefgh}	6.3 ^{gh}	225.67 ^{abcd}	3.13 ^{abc}	26.66 ^{ef}
<i>cucumis</i> × 75% DI	6.97 ^{def}	7.06 ^{bcdefgh}	6.80 ^{defgh}	221.13 ^{abcd}	3.1 ^{abc}	23 ^f
<i>cucumis</i> × 50% DI	6.8 ^{defg}	6.96 ^{bcdefgh}	5.96 ^h	217.67 ^{abcd}	3.08 ^{abc}	23 ^f
dry bean + <i>cleome</i> (dry bean) × full irrigation (FI)	6.73 ^{defgh}	8.34 ^{abcd}	7.9 ^{abcdef}	213.67 ^{abcd}	2.9 ^{abc}	48 ^{abc}

Table 2. Cont.

Treatments) Irrigation × Intercropping	Root Weight (g)	Root Diameter (cm)	Shoot Length (cm)	Biomass Plant Weight (g)	Stem Diameter (cm)	Plant Height (cm)
dry bean + <i>cleome</i> (dry bean) × 75% DI	6.7 defgh	8.33 abcd	7.67 abcdefg	206.33 abcd	2.79 abc	45 abcd
dry bean + <i>cleome</i> (dry bean) × 50% DI	6.53 defg	6.86 cdefgh	7.5 abcdefgh	200.67 abcd	2.63 abc	43.33 abcd
dry bean + <i>cleome</i> (<i>cleome</i>) × full irrigation (FI)	6.33 efghi	6.8033 defgh	7.4 bcdefgh	197.33 abcd	2.33 abc	42.66 abcde
dry bean + <i>cleome</i> (<i>cleome</i>) × 75% DI	6.06 fghij	6.7 efgh	7.3 bcdefgh	190.2 abcd	2.24 abc	41.67 abcde
dry bean + <i>cleome</i> (<i>cleome</i>) × 50% DI	5.7 ghij	6.63 efgh	7.23 bcdefgh	188.33 abcd	2.2 abc	39.67 bcde
<i>cleome</i> × full irrigation (FI)	5.63 hij	6.53 fgh	7.06 bcdefgh	181.33 bcd	2.13 bc	38.33 cdef
<i>cleome</i> × 75% DI	5.27 ij	6.3 gh	6.96 bcdefgh	174.67 cd	2.03 bc	35 cdef
<i>cleome</i> × 50% DI	5.08 j	5.96 h	6.86 defghh	168.33 d	1.43 c	34 cdef
Critical Value for Comparison Response	1.293 *	1.786 *	4.394 *	70.232 *	2.376 *	18.46 **

Column means followed by the same letter are not significantly different ($p < 0.05$) according to Turkey's HSD test. HSD (means are separated for comparison). Response ** (highly significant ($p \leq 0.01$), * (significant $p \leq 0.05$)).

3.3.2. Response of Yield When Irrigation Levels Were Withdrawn at the Early-Pod Stage (R3)

Table 3: The effect on yield parameters was significantly notable when irrigation levels were withdrawn during the crucial early-pod stage (R3). The sole cultivation of *cleome* exhibited the lowest root weight (6 g) and root diameter (5.56 g), emphasizing the necessity of effective irrigation strategies. In contrast, biomass weight demonstrated considerable increases when dry beans were cultivated under full irrigation and 75% irrigation, highlighting the advantages of optimal water management. Plant height markedly increased with the interaction of the dry beans and *cleome* under full irrigation. The shortest plant height was recorded at under 50% deficit irrigation across all cropping types, illustrating the detrimental effects of insufficient water supply. Furthermore, *cleome* exhibited enhanced shoot length when intercropped with dry beans under both 75% deficit irrigation (11.36 cm) and full irrigation (11.46 cm), showcasing superior growth when compared to sole *cleome*.

Table 3. Interactive effect of RDI and intercropping effect on yield when irrigation levels were withdrawn at the early-pod stage (R3).

Treatments) Irrigation × Intercropping	Root Weight (g)	Root Diameter (cm)	Shoot Length (cm)	Biomass Plant Weight (g)	Stem Diameter (cm)	Plant Height (cm)
sole dry bean × full irrigation (FI)	9.6 abc	12.13 a	11.6 ab	240.67 a	6.4 a	58.33 ab
sole dry bean × 75% DI	11.1 a	12.46 a	11.93 a	238.33 a	5.56 a	62.66 a
sole dry bean × 50% DI	9.3 abcde	8.86 bc	11.2 abc	235.67 a	4.2 b	57 abc
dry bean + <i>cucumis</i> (dry bean) × full irrigation (FI)	9.48 abcd	10.76 ab	11.4 a	229.67 a	4.16 bc	56 abcd
dry bean + <i>cucumis</i> (dry bean) × 75% DI	10.26 ab	10.93 a	11.56 ab	207.33 b	3.96 bc	54.66 abcd
dry bean + <i>cucumis</i> (dry bean) × 50% DI	8.73 bcdef	8.7 c	10.7 abc	205.67 b	3.93 bc	54 abcde
dry bean + <i>cucumis</i> (<i>cucumis</i>) × full irrigation (FI)	8.53 bcdefg	8.6 bc	9.3 abcdef	203.33 bc	3.86 bc	37.66 cdef
dry bean + <i>cucumis</i> (<i>cucumis</i>) × 75% DI	8.56 bcdegh	8.46 cd	8.86 bcdef	195.67 bcd	3.73 bcd	36.66 def
dry bean + <i>cucumis</i> (<i>cucumis</i>) × 50% DI	8.53 bcdefg	8.46 cd	8.4 cdef	182.67 cde	3.7 bcde	34.66 ef
<i>cucumis</i> × full irrigation (FI)	8.26 cdefghi	8.23 cde	7.76 def	177 de	3.63 bcde	33 f
<i>cucumis</i> × 75% DI	8.3 cdefgh	7.93 cdef	7.66 ef	175 de	3.56 bcde	32.33 f
<i>cucumis</i> × 50% DI	7.86 cdefghi	7.56 cdefg	6.76 f	167 ef	3.48 bcde	26.33 f
dry bean + <i>cleome</i> (dry bean) × full irrigation (FI)	7.8 cdefghi	7.2 cdefh	11.36 ab	165.67 ef	3.33 bcde	53.33 abcde
dry bean + <i>cleome</i> (dry bean) × 75% DI	7.63 defghi	6.53 defgh	11.46 ab	165.67 ef	3.1 cde	42.66 bcdef

Table 3. Cont.

Treatments) Irrigation × Intercropping	Root Weight (g)	Root Diameter (cm)	Shoot Length (cm)	Biomass Plant Weight (g)	Stem Diameter (cm)	Plant Height (cm)
dry bean + <i>cleome</i> (dry bean) × 50% DI	7.6 defghi	6.36 efgh	10.63 abcd	162 ef	3.003 cde	42 bcdef
dry bean + <i>cleome</i> (<i>cleome</i>) × full irrigation (FI)	7.433 efghi	6.37 efgh	10.56 abcde	152 fg	2.8 def	40.66 bcdef
dry bean + <i>cleome</i> (<i>cleome</i>) × 75% DI	6.83 fghi	6.2 fgh	10.5 abcde	151.33 fg	2.66 ef	40.33 bcdef
dry bean + <i>cleome</i> (<i>cleome</i>) × 50% DI	7.13 fghi	5.9 gh	10.26 abcde	150.33 fg	1.76 fg	39.33 bcdef
<i>cleome</i> × full irrigation (FI)	6.43 hi	5.8 gh	10.13 abcde	150.33 fg	1.3 g	39 bcdef
<i>cleome</i> × 75% DI	6.66 ghi	5.56 h	9.43 abcdef	147 fg	1.3 g	38.66 cdef
<i>cleome</i> × 50% DI	6.03 i	5.56 h	9.33 abcdef	135.67 g	1.267 g	38 cdef
Critical Value for Comparison Response	1.961 *	1.967 *	2.915 **	21.456 *	1.0628 *	19.697 **

Column means followed by the same letter are not significantly different ($p < 0.05$) according to Turkey's HSD test. HSD (means are separated for comparison). Response ** (highly significant ($p \leq 0.01$), * (significant $p \leq 0.05$)).

3.3.3. Response of Yield When Irrigation Levels Were Withdrawn at the Mid-Pod Stage (R4)

Table 4: The yielded results indicate a significant advantage, particularly at 75% deficit irrigation (DI) in a dry bean and *cucumis* intercropping system, especially when irrigation was withheld during the crucial mid-pod stage (R4). It is noteworthy that plant biomass remained consistently high, with weights ranging from 238 to 248 g across both sole dry beans and intercropped dry beans with *cucumis* under all irrigation treatments. This was closely followed by dry beans intercropped with *cucumis* under 75% DI. These compelling findings align with research by [60], which demonstrated marked increases in the grain yield of maize intercropped with dry beans at 75% of crop evapotranspiration (ETc), showing no significant differences in yields compared to those at 85% and 100% irrigation level. Moreover, *cleome* intercropped with dry beans displayed notable growth in both shoot and plant height under 100% and 75% irrigation conditions, underscoring the potential advantages of these cropping strategies.

Table 4. Interactive effect of RDI and intercropping on yield when irrigation levels were withdrawn at the mid-pod stage (R4).

Treatments) Irrigation × Intercropping	Root Weight (g)	Root Diameter (cm)	Shoot Length (cm)	Biomass Plant Weight (g)	Stem Diameter (cm)	Plant Height (cm)
sole dry bean × full irrigation (FI)	9.53 b	11.56 ab	11.86 ab	267 ab	5.2 a	61.33 ab
sole dry bean × 75% DI	11.4 a	13.06 a	13.06 a	273 a	5.43 a	64.33 a
sole dry bean × 50% DI	9.43 bc	11.16 b	11.63 abc	257.33 abc	4.7 ab	54 abc
dry bean + <i>cucumis</i> (dry bean) × full irrigation (FI)	7.86 cde	11.167 b	9.66 bcdef	247 abcd	4.36 abcd	39.66 bcdef
dry bean + <i>cucumis</i> (dry bean) × 75% DI	8.53 bcd	11.13 b	9.33 bcdef	255 abcd	4.53 abc	39 bcdef
dry bean + <i>cucumis</i> (dry bean) × 50% DI	7.5 def	11 b	9.1 bcdef	246 abcd	3.93 bcd	37 cdef
dry bean + <i>cucumis</i> (<i>cucumis</i>) × full irrigation (FI)	7 defg	10.2 bc	8.7 bcdefg	238.67 bcde	3.83 bcde	36.33 cdef
dry bean + <i>cucumis</i> (<i>cucumis</i>) × 75% DI	7.05 defg	9.9 bcd	8.4 cdefg	233.33 cde	3.73 bcde	29.66 def
dry bean + <i>cucumis</i> (<i>cucumis</i>) × 50% DI	6.96 defg	8.9 cde	8.23 defg	222.67 def	3.53 cde	29.33 def
<i>cucumis</i> × full irrigation (FI)	6.86 efg	8.66 cdef	6.9 efg	211.67 efg	3.5 cde	28.66 def
<i>cucumis</i> × 75% DI	6.83 efgh	8.53 cdef	6.43 fg	196.67 fgh	3.5 cde	28.33 ef
<i>cucumis</i> × 50% DI	6.36 efghi	8.46 cdef	5.63 g	196 fgh	3.33 def	27 f
dry bean + <i>cleome</i> (dry bean) × full irrigation (FI)	6.33 efghi	8.16 def	11.63 abc	181.67 ghi	3.21 efg	49.67 abcd
dry bean + <i>cleome</i> (dry bean) × 75% DI	6.16 fghi	8.13 def	11.3 abcd	169.67 hij	3.2 efg	51 abcd

Table 4. Cont.

Treatments) Irrigation × Intercropping	Root Weight (g)	Root Diameter (cm)	Shoot Length (cm)	Biomass Plant Weight (g)	Stem Diameter (cm)	Plant Height (cm)
dry bean + <i>cleome</i> (dry bean) × 50% DI	5.96 fghi	7.96 ef	11.3 abcd	156 ijk	3.03 efgh	46.33 abcdef
dry bean + <i>cleome</i> (<i>cleome</i>) × full irrigation (FI)	5.83 ghij	7.1 efg	11.1 abcd	153 ijk	2.33 fghi	44.67 abcdef
dry bean + <i>cleome</i> (<i>cleome</i>) × 75% DI	5.73 ghij	7.06 fg	11.06 abcd	145 jk	2.13 ghi	44.66 abcdef
dry bean + <i>cleome</i> (<i>cleome</i>) × 50% DI	5.26 ghij	6.06 fg	11 abcd	144 jk	2.03 hi	43 abcdef
<i>cleome</i> × full irrigation (FI)	5.13 ij	6 gh	10.9 abcd	137.67 jk	1.8 i	42 abcdef
<i>cleome</i> × 75% DI	5.13 ij	5.46 gh	10.66 abcd	136.67 k	1.56 i	41 bcdef
<i>cleome</i> × 50% DI	4.66 j	5.2 h	10.133 abcde	135.67 k	1.53 i	40 bcdef
Critical Value for Comparison Response	1.5842 *	1.8271 *	3.2683 *	32.461 **	3.2683 *	1.8271 **

Column means followed by the same letter were not significantly different ($p < 0.05$) according to Turkey's HSD test. HSD (means are separated for comparison). Response ** (highly significant ($p \leq 0.01$), * (significant $p \leq 0.05$)).

3.3.4. Response of Yield When Irrigation Levels Were Withdrawn at the Early Seed-Filling Stage (R5)

Table 5: Yield parameters revealed a significant decline when irrigation was withdrawn during the early seed-filling stage (R5), with values considerably lower than those recorded when irrigation was suspended at the 50% flowering stage (R2), which underwent severe deficit irrigation. This indicates that the timing of irrigation withdrawal had a profound effect on yield, suggesting that withdrawing irrigation at the early seed-filling stage impacts yield less dramatically than at the 50% flowering stage. In contrast, [59] reported substantial yield increases in dry beans during the vegetative and ripening phases, under 75% and 100% irrigation, pointing to a heightened sensitivity to water deficits during the flowering period. Similarly, [60] enhanced yield in maize and dry bean intercrops was found 30 days after the flowering stage of common dry beans. Additionally, while the root weight (1.633 g) and root diameter (2.4 cm) were lower under sole *cleome*, notable increases in plant height (63 cm and 53 cm) and shoot length (11 cm and 9.66 cm) were observed when *cleome* was intercropped with dry beans under both 100% and 75% deficit irrigation, respectively. These findings underscore the critical importance of strategic irrigation management to optimize yield outcomes.

Table 5. Interactive effect of RDI and intercropping on yield when irrigation levels were withdrawn at the early seed-filling stage (R5).

Treatments) Irrigation × Intercropping	Root Weight (g)	Root Diameter (cm)	Shoot Length (cm)	Biomass Plant Weight (g)	Stem Diameter (cm)	Plant Height (cm)
sole dry bean × full irrigation (FI)	8.16 a	11.16 a	12 a	207.67 a	5.63 a	66 a
sole dry bean × 75% DI	7.85 ab	10.2 ab	10.66 ab	204.33 ab	5.43 ab	56.33 ab
sole dry bean × 50% DI	7.76 ab	9.53 abc	10.13 abc	196.67 abc	4.7 abc	55.33 ab
dry bean + <i>cucumis</i> (dry bean) × full irrigation (FI)	7.76 ab	8.7 bcd	5.53 e	191 abc	4.03 abcd	53.33 abc
dry bean + <i>cucumis</i> (dry bean) × 75% DI	7.46 abc	8.46 bcd	5.5 e	182.67 abc	3.69 abcd	50 abc
dry bean + <i>cucumis</i> (dry bean) × 50% DI	7.33 abc	7.96 bcde	5.5 e	170 abcd	3.68 abcd	49.33 abc
dry bean + <i>cucumis</i> (<i>cucumis</i>) × full irrigation (FI)	7.26 abcd	7.467 cdef	5.4 e	168.67 abcd	3.36 abcd	48 abcd
dry bean + <i>cucumis</i> (<i>cucumis</i>) × 75% DI	7 abcde	7.23 cdef	5.13 e	162 abcd	3.35 abcd	47.66 abcd
dry bean + <i>cucumis</i> (<i>cucumis</i>) × 50% DI	6.8 abcde	6.933 defg	5.13 e	159 abcd	3.08 abcd	45 abcde
<i>cucumis</i> × full irrigation (FI)	6.73 bcde	6.83 defg	5.1 e	156 abcd	3.06 abcd	45 abcde
<i>cucumis</i> × 75% DI	6.33 cdef	6.63 defg	5 e	156 abcd	2.99 abcd	43 abcde
<i>cucumis</i> × 50% DI	6.33 cdef	6.56 defg	4.93 e	155.33 abcd	2.94 abcd	41.66 abcde

Table 5. Cont.

Treatments) Irrigation × Intercropping	Root Weight (g)	Root Diameter (cm)	Shoot Length (cm)	Biomass Plant Weight (g)	Stem Diameter (cm)	Plant Height (cm)
dry bean + <i>cleome</i> (dry bean) × full irrigation (FI)	6.3 cdef	6.4 defg	8.93 bcd	155 abcd	2.79 abcd	41 abcde
dry bean + <i>cleome</i> (dry bean) × 75% DI	6.16 cdef	5.96 efg	7.5 cde	154.67 abcd	2.46 bcd	40.33 bcde
dry bean + <i>cleome</i> (dry bean) × 50% DI	5.93 defg	5.76 efg	7.4 cde	152 abcd	2.44 bcd	37 bcde
dry bean + <i>cleome</i> (<i>cleome</i>) × full irrigation (FI)	5.8 efg	5.73 efg	6.9 de	151.67 abcd	2.35 cd	37 bcde
dry bean + <i>cleome</i> (<i>cleome</i>) × 75% DI	5.73 efg	5.73 efg	6.73 de	151.33 abcd	2.15 cd	34.33 bcde
dry bean + <i>cleome</i> (<i>cleome</i>) × 50% DI	5.73 efg	5.73 efg	6.7 de	144 abcd	2.03 cd	32.66 bcde
<i>cleome</i> × full irrigation (FI)	5.13 fg	5.46 fg	6.43 de	140.67 bcd	2.01 cd	29 cde
<i>cleome</i> × 75% DI	4.73 g	5.1 fg	5.83 e	136.67 cd	1.76 cd	23 de
<i>cleome</i> × 50% DI	4.63 g	4.96 g	5.73 e	109.67 d	1.56 d	20.66 e
Critical Value for Comparison Response	1.394 *	2.3948 *	2.9092 *	64.872 *	3.0348 *	25.631 **

Column means followed by the same letter were not significantly different ($p < 0.05$) according to Turkey's HSD test. HSD (means are separated for comparison). Response ** (highly significant ($p \leq 0.01$), * (significant $p \leq 0.05$)).

3.4. Response of Dry Bean Pod Yield to Intercropping and Regulated Deficit Irrigation

The results of this study emphasize the significant influence of irrigation timing on soybean pod yield. Notably, withdrawing irrigation at the key 50% flowering stage (R2) and the early-pod stage (R3) led to substantial reductions in yield. The highest average number of pods per plant, 12.22, was recorded under sole dry bean cultivation with 100% irrigation (Figure 5A,B). Conversely, when irrigation was reduced at the early-pod stage (R4), the best outcomes were observed when intercropping dry beans with cucumis under 75% deficit irrigation, highlighting the effectiveness of strategic cropping combinations (Figure 5B). Additionally, seeds per pod indicated that dry beans maintained a consistent seed count under both 75% and 100% irrigation when intercropped with either cucumis or *cleome*. However, intercropping dry beans with *cleome* under 50% deficit irrigation resulted in the lowest average of just four seeds per pod. While there was no significant change in the number of seeds per plant when irrigation was withdrawn at the early-pod stage (R3), a notable increase in the number of seeds per pod was observed during mid-pod withdrawal (R4) (Figure 5C) compared to the severe water stress experienced at R2. In conclusion, the highest average number of seeds per pod was found in the combination of dry beans intercropped with cucumis under 75% irrigation (averaging nine seeds), closely followed by the 100% irrigation scenario (averaging eight seeds) (Figure 5D). These findings not only underscore the importance of tailored irrigation strategies but also suggest that optimizing intercropping practices can significantly enhance yields in dry bean production.

The weight of pods remained consistent when comparing sole dry beans to dry beans intercropped with cucumis and *cleome* at 100% irrigation, with average weights of 3.53 g, 3.15 g, and 3.06 g, respectively (Figure 6B). Importantly, the length of the pod did not affect the weight of the seeds inside. The study found no significant differences in pod length when irrigation levels were reduced during the early-pod stage (R3). However, significant variations were observed when irrigation was decreased at the 50% flowering stage (R2) (Figure 6C) and again at the early seed-filling stage (R5) (Figure 6D), which is closer to crop maturity. This clearly indicates that pod length is highly influenced by irrigation levels, particularly as the crop approaches maturity. Establishing adequate irrigation is essential for maximizing both pod weights.

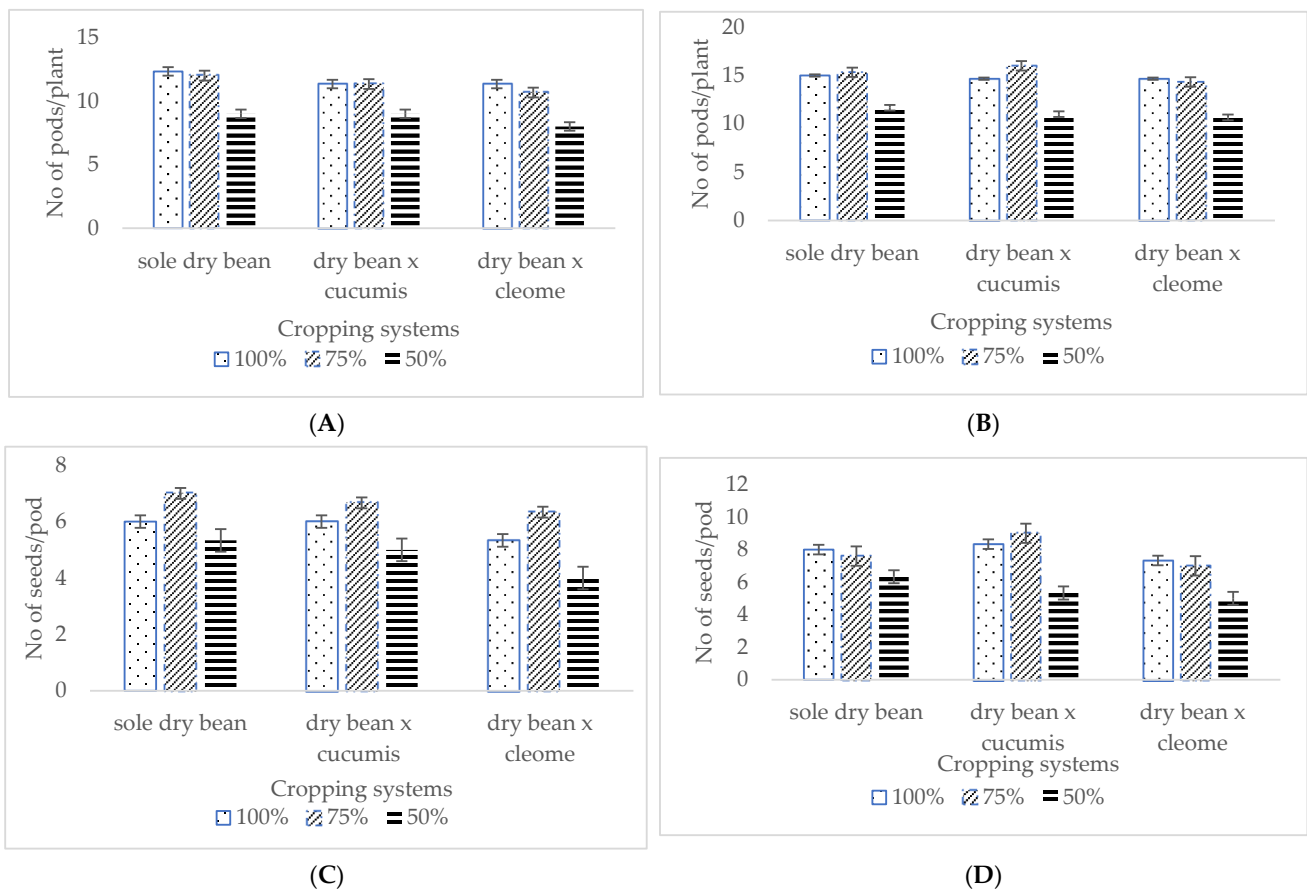


Figure 5. Response based on the number of pods/plants. (A) (Irrigation level withdrawn at the 50% flowering stage (R2), no. of pods/plants; (B) (irrigation level withdrawn at the early-pod stage (R3), no. of seeds/pods; (C) (irrigation level withdrawn at early-pod stage (R3)); (D) (irrigation level withdrawn at the mid-pod stage (R4)).

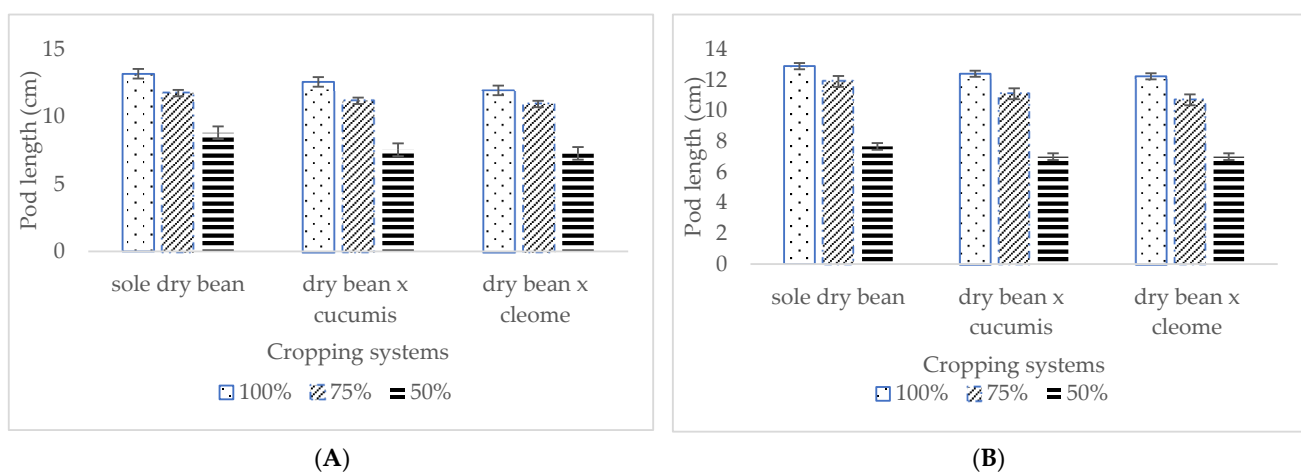


Figure 6. Cont.

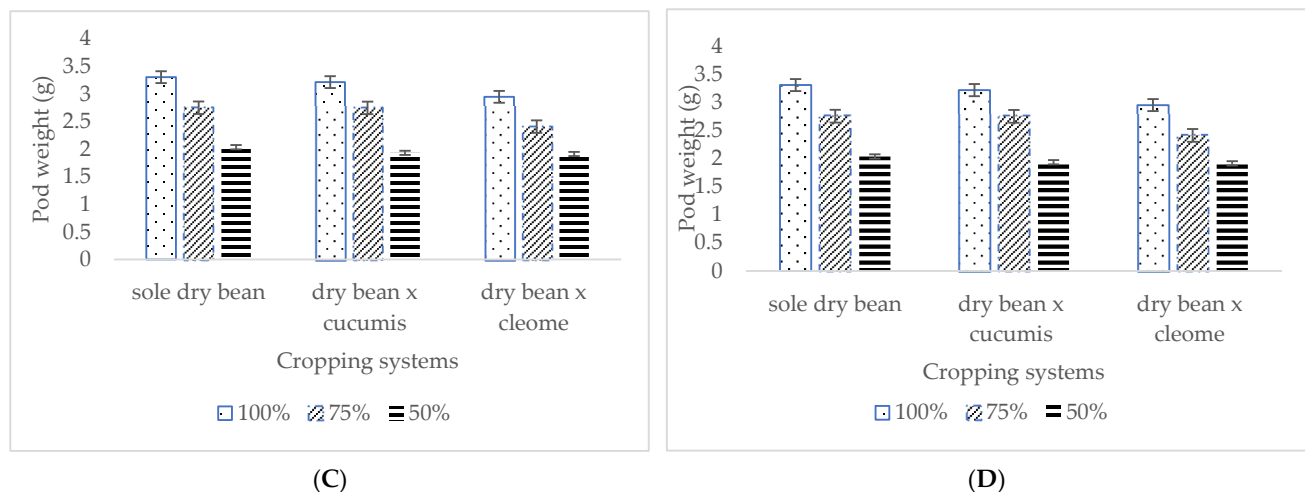


Figure 6. Response of pod weight. (A) (Irrigation level withdrawn at early-pod stage (R2)), pod weight; (B) (irrigation level early seed-filling stage (R5)), pod length; (C) (irrigation level withdrawn at early-pod stage (R3)), pod length; (D) (irrigation levels early seed-filling stage (R5)).

4. Discussion

Deficit irrigation and intercropping present effective strategies for combating water scarcity in the semiarid regions of South Africa. Research indicates that strategically regulating deficit irrigation during critical growth phases can significantly influence crop physiology and yield. Water stress directly affects stomatal openings; when the stomata close, gas exchange between the leaf interior and the surrounding air becomes severely limited, which leads to a decline in photosynthetic activity [61]. This study found that a 50% deficit irrigation level resulted in reduced stomatal openings, particularly during the early-pod stage, while increased stomatal openings were noted when irrigation levels were reduced during the mid-pod stage. These findings showed significant effects ($p \leq 0.05$) on both crop physiology and growth parameters in this study. A moderate water supply can enhance growth and water productivity in maize production. For instance, withdrawing 75% of irrigation at the mid-pod stage yielded favorable results for dry beans intercropped with **cucumis myriocarpus**, while a full 100% irrigation level during the early-seed stage supported optimal growth for dry beans intercropped with **cleome gynandra** [31]. In contrast, 50% deficit irrigation led to a considerable decrease ($p \leq 0.05$) in growth across all stages for both intercrops and monocrops. Furthermore, a moderate water supply contributes to increased growth and enhanced water productivity in maize [31]. Additionally, intercropping legumes with non-legume crops has proven beneficial in intensifying crop production and improving overall growth [62]. Recent studies have also explored the effects of intercropping legumes with grains, such as cereals, maize, sorghum, and wheat, on plant growth and physiology [29]; [63]. By implementing these practices, farmers can optimize water usage and enhance agricultural productivity in challenging environments.

Intercropping has been consistently proven to enhance crop yields; however, there are still questions regarding whether combining intercropping with deficit irrigation can effectively improve both yield and water productivity (WP) at the same time. Research indicates that intercropping dry beans with two African vegetable crops (*cucumis myriocarpus* and *cleome gynandra*) can lead to significant yield increases under 75% irrigation levels. It is essential to recognize that the growth and quality of crops heavily rely on both the quantity of water applied and the timing of its application. Furthermore, studies show that withdrawing irrigation during critical growth phases, particularly in the early-pod development stage of African leafy vegetables, can lead to notable yield enhancements. This underscores the importance of refined irrigation scheduling, which serves as a vital tool

for optimizing water use efficiency while aligning with the specific water requirements of crops [6]. Additionally, temporary water stress during the maturity and ripening stages can lead to significant growth and yield improvements in plants [11]. In contrast, implementing deficit irrigation during the reproductive stage resulted in substantial maize yields and improved water productivity [64]. Therefore, it is crucial to adopt deficit irrigation strategies that correspond to various growth stages, allowing for water conservation without compromising essential crop development and yield [10]. By embracing these approaches, farmers can promote sustainable agricultural practices while maximizing their output in a resource-constrained environment. Research indicates that yield parameters—such as root weight, plant biomass, stem diameter, and pod yield—significantly improve when dry beans are either sole-planted or intercropped with **cucumis myriocarpus**. Notably, plant height is enhanced when dry beans are intercropped with *cleome gynandra* under deficit irrigation (DI) from flowering to maturity. This variation in yield response underscores the importance of recognizing a crop's sensitivity to water stress, particularly during critical growth stages [65]. These resilient plants not only tolerate water deficits but also achieve higher economic value and yields compared to other crops [37]. Furthermore, indigenous and African leafy vegetables can play a vital role in attaining significant yields and economic returns in water-scarce conditions [66]. While intercropping has been consistently shown to enhance yields, the potential benefits of integrating intercropping with deficit irrigation merit further exploration to optimize both crop yield and water productivity (WP) [31]. Embracing these innovative practices could be transformative for agricultural productivity in challenging climates.

5. Conclusions

The authors observed significant anomalies in the growth and yield of dry beans based on irrigation levels adjusted during four critical growth stages: the 50% flowering stage (R2), early-pod stage (R3), mid-pod stage (R4), and early seed-filling stage (R5). Each growth stage distinctly influences growth and yield parameters, underscoring the importance of precise irrigation management. For instance, the findings indicate that stomatal conductance and photosynthesis rates are maximized when irrigation is withdrawn at the mid-pod stage, with transpiration rates and chlorophyll content following a similar pattern. In contrast, the yield of monocropped dry beans shows significant increases when irrigation is withheld during the early-pod stage. Moreover, when dry beans are intercropped with *cucumis myriocarpus* and *cleome gynandra*, yields significantly improve when irrigation levels are regulated at the mid-pod stage, demonstrating a clear relationship between irrigation timing and growth outcomes. Utilizing 75% deficit irrigation resulted in optimal performance for both growth and yield in dry beans and *cucumis intercropped*, while full irrigation (100%) yielded the best results for intercropped dry beans and *cleome gynandra*. Consequently, the authors conclude that implementing a 75% deficit irrigation strategy during the mid-growth stage is not only advantageous but also ideal for intercropping dry beans with *cucumis myriocarpus*. This method could lead to substantial water savings—up to 25%—while enhancing overall crop productivity.

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