Journal of Sustainable Agriculture and Environment
WILEY
Global Initiative of Sustainable Agriculture and Environment
Harnessing Natural Resources

RESEARCH ARTICLE OPEN ACCESS

Strip Intercropping of Wheat (*Triticum aestivum*) With Coriander (*Coriandrum sativum*) Improves Wheat Yield and Water-Use Efficiency Under Reduced Irrigation

Katja Kampmann[1] | Valentin Gebhardt[2] | Bastian Leander Franzisky[1] | Claudia Kammann[2] | Miriam Athmann[3] | Christoph-Martin Geilfus[1]

[1]Department of Soil Science and Plant Nutrition, Hochschule Geisenheim University, Geisenheim, Germany | [2]Department of Applied Ecology, Hochschule Geisenheim University, Geisenheim, Germany | [3]Faculty of Organic Agricultural Sciences, University of Kassel, Witzenhausen, Germany

Correspondence: Christoph-Martin Geilfus (ChristophMartin.Geilfus@hs-gm.de)

Received: 3 September 2025 | **Revised:** 28 November 2025 | **Accepted:** 2 December 2025

Funding: Hessian Ministry of Science and Art.

Keywords: crude protein content | deficit irrigation | intercropping | photosynthetic performance | wheat grain yield

ABSTRACT

With climate change, prolonged droughts are expected, requiring agronomic strategies to ensure stable wheat yields. Intercropping presents a promising approach, yet knowledge on non-legume intercrops remains limited. Thus, this study investigated the effects of strip intercropping spring wheat (*Triticum aestivum* 'Quintus') with taprooted coriander (*Coriandrum sativum* 'Jantar') on growth, grain quality of wheat, and the water-use efficiency (WUE) of both cropping systems under two irrigation regimes: well-watered (ww, 60% of soil maximum water-holding capacity) and reduced irrigation (dw, 40%). Experiments were conducted in 120 L containers filled with sandy loam. Under reduced irrigation, when wheat was intercropped with coriander (WCO), wheat grain yield remained comparable to that of sole wheat (WHE), even though the intercropped pots contained only half as many wheat plants. WUE, calculated as total wheat grain yield per pot per liter of applied water, was significantly higher in the intercropping system compared to the system where wheat was growing alone under the same water regime. Moreover, wheat crude protein content was higher under reduced irrigation in both the intercropped and the stand-alone system when being compared to well-watered conditions. Coriander seed yield was not significantly affected by irrigation. These results indicate that wheat–coriander intercropping enhances WUE compared to the sole wheat system, stabilizing wheat yield under water-limited conditions.

1 | Introduction

In the context of climate change, prolonged drought periods are expected in large parts of Germany, depending on the prediction model used (Geilfus et al. 2024; Webber et al. 2018). This may lead to an increased demand for irrigation, particularly when site-specific factors are taken into account (Riediger et al. 2016). The resulting water scarcity can, in turn, lead to yield reductions (Anjum et al. 2017; Bismillah Khan et al. 2015; Hussain et al. 2008). Wheat is the most widely consumed cereal crop worldwide (Arzani and Ashraf 2017). It suffers yield losses of up to 60% under conditions of inadequate water availability (Zhao et al. 2020). Additionally, water deficit can adversely affect plant morphology, physiology, and biochemistry in numerous ways (Nyaupane et al. 2024). These include limiting effects on plant height (Poudel et al. 2020), dry weight, nutrient uptake, and photosynthesis (Nyaupane et al. 2024).

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2025 The Author(s). *Journal of Sustainable Agriculture and Environment* published by Global Initiative of Sustainable Agriculture and Environment and John Wiley & Sons Australia, Ltd.

Furthermore, drought stress can lead to a rapid increase in abscisic acid and accelerated leaf senescence. In response to water deficit, plants typically close their stomata to minimize water loss through transpiration and maintain essential cell turgor (Pirasteh-Anosheh et al. 2016). However, this response reduces CO_2 uptake, which in turn decreases photosynthetic activity (Z. Ahmad et al. 2018), ultimately leading to reduced yield (Sharifi and Mohammadkhani 2016). Consequently, in light of the growing global population, it becomes increasingly important to develop strategies to ensure food production under changing climatic conditions.

Intercropping describes the cultivation of two or more crops on the same field simultaneously, while in strip intercropping, two crops are grown in adjacent rows (Homulle et al. 2022). It is a promising strategy to mitigate drought-induced yield loss in wheat. In addition to enhancing yield relative to pure stands, intercropping can offer further benefits such as improved land utilization efficiency (Agegnehu et al. 2008), reduced incidence of weeds, pests and diseases (Jensen et al. 2015), as well as enhanced soil quality (Cong et al. 2015). Moreover, intercropping can improve water-use efficiency due to differing spatiotemporal water demand (Pelech et al. 2021). This can be achieved by increasing the utilization efficiency of limited resources such as nutrients, light, and water (Yin et al. 2020). To do so, it is essential to select crops that have different resource requirements in terms of demand, space, and time, and therefore exhibit complementary resource use to exploit available resources more efficiently than in monocultures (Ehrmann and Ritz 2014). Thus, the success of an intercropping system strongly depends on the choice of crop species.

While intercropping was studied primarily in cereal-legume systems (e.g., Hupe et al. 2021; Timaeus et al. 2022), there is a lack of research on non-legume intercropping partners like coriander, especially under water-limiting conditions. As a globally essential staple crop, providing a major source of calories and protein for billions, wheat is highly significant in agricultural systems. However, coriander is also becoming more relevant because of its increasing importance of the phytopharmaceutical market, for instance in Germany (Pforte 2013). Coriander holds both culinary and medicinal value and is widely cultivated in Asia, Central Europe, and North Africa (Laribi et al. 2015). In addition to its growing economic relevance, coriander is characterized by several properties that make it a potentially suitable intercropping partner for wheat. Notably, it has a contrasting root architecture. Coriander has a taproot, while wheat is fibrous-rooted. This could be beneficial for a more efficient water uptake. Furthermore, coriander shows a different shoot growth morphology compared to wheat. Its herbaceous habitus, including the formation of multiple branches (Gupta et al. 1991), contrasts sharply with the erect wheat canopy, potentially reducing mutual shading and allowing more photosynthetically active radiation to penetrate to the lower canopy. This altered light distribution can therefore lead to an improved whole-system photosynthesis. The anticipated complementarity in resource use could offer an effective strategy to stabilize wheat yields under conditions of limited water availability.

The central hypothesis of this study is that strip intercropping of coriander with wheat enhances wheat yield under reduced irrigation by improving resource use efficiency. Specifically for wheat, we expect that intercropping improves photosynthetic performance, water-use efficiency, and grain quality (crude protein content), reflecting complementary use of water and light between the two species.

2 | Materials and Methods

2.1 | Plant Cultivation in 120-liter Pots and Experimental Set-Up

The experimental soil was a silty-loamy sand (subsoil) from Volkmarsen, Hesse, Germany (51° 25′ N, 9° 7′ E). The soil was air-dried and sieved to a particle size of 2 cm. Soil analysis revealed the following composition: pH 7.2, 8.4% clay, 45.2% silt, 46.4% sand, 8.7 mg P, 8.4 mg K and 7 mg Mg per 100 g dry soil, as well as 0.11% $N_{(total)}$ and 2% $C_{(org)}$. The dry soil was placed into large containers with a volume of 120 L, which were located in the mesh house within the open-field experimental area at Hochschule Geisenheim University (49°59′01.1″N 7°57′23.0″E). The containers were arranged in 4 blocks of 10 containers (Supplementary Figure 1) and randomized twice per week.

The experiment was conducted from April 2024 to August 2024 using the spring wheat variety *Triticum aestivum* L. 'Quintus' grown in pure stand (WHE) and in strip intercropping with the coriander variety *Coriandrum sativum* L. 'Jantar' (WCO). Two irrigation treatments were applied: well-watered (ww), corresponding to 60% of the maximum water-holding capacity of the soil, and reduced irrigation (dw), corresponding to 40% of the maximum water-holding capacity. Each treatment group was replicated biologically ten times. The maximum water-holding capacity was determined in separate containers by measuring the weight of dry soil, saturating the soil with water, and weighing the containers again after drainage ceased. Soil moisture levels were monitored by weighing the containers every 24 h (Supplementary Figure 2), and irrigation was adjusted accordingly. Starting from the wheat growth stage BBCH 47 (flag leaf sheath swollen), the reduced irrigation treatment was implemented by decreasing the water supply to 40% of the maximum water-holding capacity of the soil. To avoid water input during rainfall, containers were transferred to a greenhouse during precipitation events.

Spring wheat was sown on April 10, 2024, and coriander on April 15, in four alternating rows per container, with 30 wheat and 20 coriander seeds per row. Following germination, the plants were thinned to 18 wheat plants per row and an average of 14 coriander plants per row. The row spacing was 10 cm, and the distance between the outermost rows and the edge of the container was 5 cm (Supplementary Figure 3). Fertilization was applied in three stages, aligned with wheat development stages: tillering, stem elongation, and heading. The fertilizer used was Kristalon® Blaumarke (YARA GmbH & Co. KG, Dülmen, Germany), which contains 19% N (11.9% NO_3^--N, 7.1% NH_4^+-N), 2.6% P, 16.6% K, 1.8% Mg, 3% S, 0.01% Cu, 0.04% Mn, 0.025% Zn, 0.025% B, 0.07% Fe, and 0.004% Mo. On May 24, 2024, the growth regulator Prodax® (3.28 g L-1, BASF SE, Ludwigshafen am Rhein, Germany) was applied to the wheat to keep it smaller, thereby improving the lodging resistance of the wheat and creating better light conditions for the coriander. Pest management measures on wheat were implemented according to local infestation levels and in compliance with German regulations. Throughout the experimental period, the average air temperature at the experimental site was

18°C, with an average of 7.18 h of sunshine, vapor pressure deficit of 0.67 kPa and relative humidity of 70% per day.

2.2 | Measurement of Aboveground Biomass and Grain Yield

Wheat was manually harvested at BBCH stage 92 (full ripeness) on July 22, 2024. Height measurements were taken from 5 randomly selected plants per container. Next, wheat was cut 5 cm above the soil surface, and ears were removed. Total straw biomass per container was recorded. Husk removal was done manually to determine total grain weight per container. Coriander was harvested on August 5, 2024, when most seeds had reached physiological maturity. Plants were harvested similarly to the wheat, cut 5 cm above the soil surface. Biomass was dried at 60°C for 48 h in a drying oven. Total aboveground dry biomass of coriander per container was determined gravimetrically. Seeds were separated manually from plant material, and seed yield per container was quantified gravimetrically.

2.3 | Crude Protein Content and Carbon Content of Wheat Grains

To determine crude protein content in wheat, as well as the carbon content, grains were ground using a centrifugal mill (Cyclotec 293, FOSS GmbH, Hamburg, Germany) to obtain fine flour. A 0.25 g portion of each sample was weighed and analyzed with an organic elemental analyzer (Vario MAX cube, Elementar Analysensysteme GmbH, Langenselbold, Germany). The analysis followed the combustion method according to Dumas. The total nitrogen content (N%) determined through this method was multiplied by the factor 5.7, as specified in ISO 16634-2:2016 (DIN Media GmbH 2016), to calculate the crude protein content.

2.4 | Harvest Index of Wheat and Coriander

The Harvest Index (HI) is a metric used to assess the efficiency of yield formation (Donald 1968). This index is determined for wheat in pure stand, wheat intercropped with coriander, and for coriander in the intercropping system. It is calculated as follows:

$$HI = \frac{Yield \quad (g)}{Total\ aboveground\ biomass \quad (g)}$$

2.5 | Water-Use Efficiency of the Cropping Systems

Water-use efficiency (WUE) of the cropping systems was calculated based on yield, defined as the combined mass of wheat and coriander grains per container. Total water consumption for each container was aggregated from the initiation of differential irrigation treatments at ear emergence (6 weeks after emergence, BBCH 47 of spring wheat). Because both crops were cultivated together within the same containers, their water consumption was not independently assessed. In this study, the WUE for both cropping systems is determined. The WUE was calculated using a methodology applied by Tränkner et al. 2016, by quantifying the ratio of total yield per container to the cumulative water consumption, as expressed by the following formula:

$$WUE = \frac{Total\ yield \quad (g)}{Total\ water\ consumption \quad (L)}$$

2.6 | Gas Exchange and PAM Measurements on Wheat

Transpiration and CO_2 assimilation of the upper flag leaves of spring wheat were measured using the gas exchange device GFS-3000 (Heinz Walz GmbH, Effeltrich, Germany). Measurements were taken at 9 (BBCH 62 of spring wheat, early flowering), 10 (BBCH 65 of spring wheat, flowering), 11 (BBCH 72 of spring wheat, fruit development), and 12 (BBCH 75 of spring wheat, fruit development) weeks after wheat emergence. The measurement chamber conditions were set as follows: Impeller: 7, Flow: 750 $\mu mol\ s^{-1}$, CO_2: 400 ppm, PAR: 800 $\mu mol\ m^{-2}\ s^{-1}$, Temperature: 23°C, Relative humidity: 65%. Measurements were carried out on one randomly selected plant from the center row of each pot and lasted for 10 min. At this point, stable values were observed. Chlorophyll fluorescence measurements with the HEXAGON-IMAGING-PAM (Heinz Walz GmbH) were used to assess the following parameters: maximum quantum yield of PSII (F_v/F_m), effective quantum yield of PSII (ΦPSII), non-photochemical quenching (ΦNPQ), non-regulated energy dissipation (ΦNO), and electron transport rate (ETR). Measurements were conducted on the upper flag leaf of spring wheat 9, 10 and 11 weeks after wheat emergence. It should be noted that gas exchange and chlorophyll fluorescence measurements were conducted on a single plant per container, which may limit the capture of within-pot variability. The plants were initially dark-adapted for 20 min. The subsequent initial saturation pulse for determining F_v/F_m was 4100 $\mu mol\ m^{-2}\ s^{-1}$. After this, 10 measurements were taken, where the leaves were illuminated with an actinic light of 800 $\mu mol\ m^{-2}\ s^{-1}$ for 1 min each. After each minute, a saturation pulse was applied until stable values were reached after 10 min.

2.7 | Statistical Analysis

Statistical analyses were conducted using R software (R Core Team 2024), version 4.3.3 within the integrated development environment RStudio (Posit team 2024), version 2024.12.0.467. The normality of the residuals was assessed via the Shapiro-Wilk test, while homogeneity of variances was evaluated using Levene's test. For data meeting the assumptions of normality and homoscedasticity, a two-way analysis of variance (ANOVA) was performed. The biomass variables of coriander were analyzed using a one-way ANOVA, as only the factor irrigation was considered for coriander. If the residuals were not normally distributed, a transformation was applied based on Tukey's Ladder of Power. To analyze the aboveground biomass of wheat, an implausible outlier was removed using the IQR method. In case of significance, post-hoc pairwise comparisons were carried out with Tukey's HSD test, applying an adjustment for multiple comparisons through the "emmeans"-package (Lenth and Russell 2024). Where assumptions were

violated, the non-parametric Kruskal-Wallis test was applied, with subsequent pairwise comparisons performed using Dunn's test. All statistical tests were conducted at a significance threshold of $\alpha = 0.05$.

3 | Results

3.1 | Wheat Aboveground Biomass Under Reduced Irrigation Unaffected By Cropping System

With regard to wheat aboveground biomass dry matter per pot (sum of straw, grains, etc.), a two-way ANOVA revealed a significant effect of the irrigation treatment ($p < 0.001$), the cropping system ($p = 0.012$), and the interaction between both factors ($p < 0.0048$). The wheat grown in pure stand under well-watered conditions (wwWHE) showed the highest value, averaging 268.8 g (±49.7 SD), as shown in Figure 1A. No significant differences were observed between the other treatment groups. The treatments under reduced irrigation (dw, representing 40% of the maximum water-holding capacity of the soil) tended to have lower total aboveground dry mass, with 221.2 g (±21.5) for wheat when grown in pure stand (dwWHE) and 223.6 g (±15.6) for wheat when strip intercropped with coriander (dwWCO). However, this was not a significant effect.

The wheat straw weight per pot was significantly affected by the irrigation treatment ($p < 0.001$), the cropping system ($p < 0.001$), and their interaction ($p < 0.001$). The reduced irrigation treatment resulted in the significantly lowest total wheat straw weights, with 83.8 g (±3.9) in the wheat–coriander intercropping system and 84.0 g (±7.5) in the wheat pure stand (Figure 1B). However, under reduced irrigation, there were no significant differences between the intercropped wheat and the wheat grown in pure stand. Under well-watered conditions, wheat grown in pure stand produced the significantly highest straw weight at 107.3 g (±3.7), followed by intercropped wheat under well-watered conditions with 95.0 g (±4.5).

Regarding grain yield per pot, a two-way ANOVA revealed significant effects of the irrigation treatment ($p < 0.001$), the cropping system ($p = 0.0029$), and their interaction ($p = 0.0031$). Wheat in pure stand under well-watered conditions showed the significantly highest total grain weight, with 130.7 g (±4.3) (Figure 1C). Intercropped wheat under well-watered conditions tended to have a slightly lower grain weight of 114.2 g (±10.1), which was higher than the values observed under reduced irrigation, though the differences were not statistically significant. Under reduced irrigation, wheat grown in pure stand and wheat intercropped with coriander had grain weights of 110.7 g (±14.8) and 110.6 g (±15.4), respectively.

In terms of plant height, a significant effect of the irrigation treatment was observed ($p < 0.001$), whereas no significant effects were found for the cropping system ($p = 0.53$) or the interaction of both ($p = 0.28$). The tallest wheat plants were

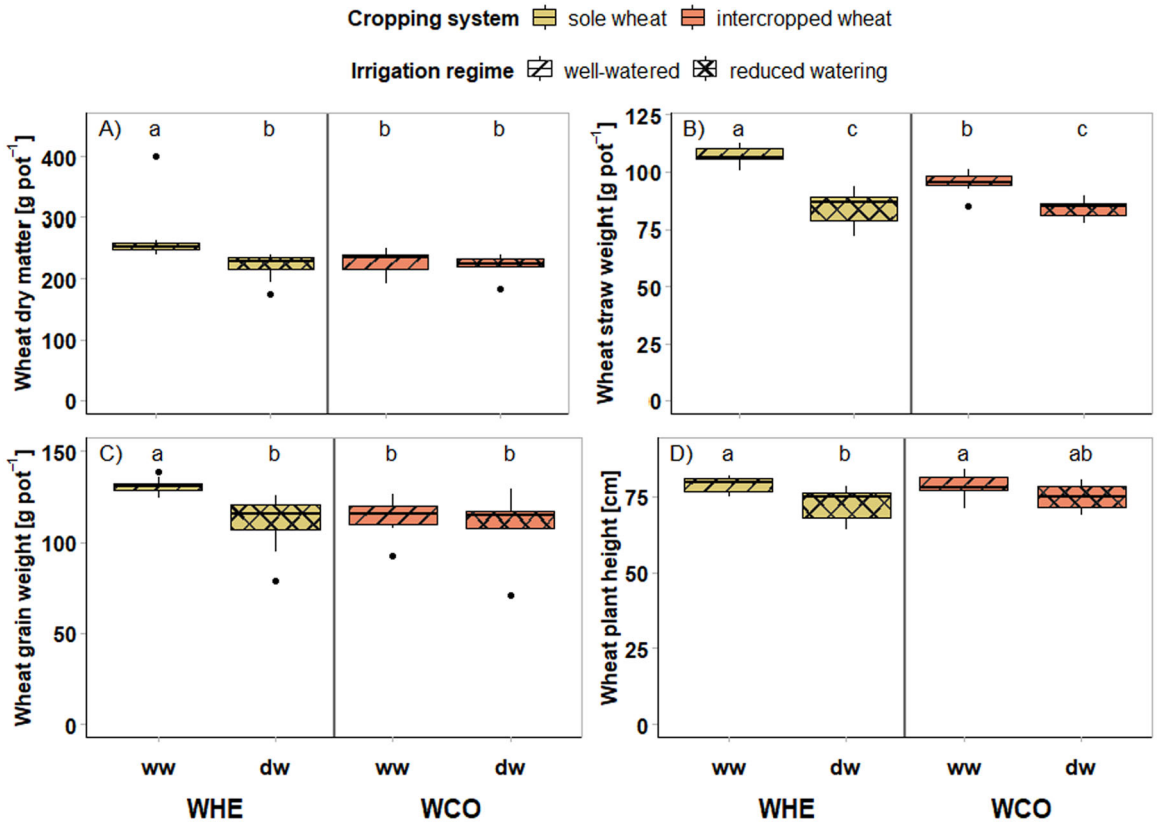


FIGURE 1 | A: wheat aboveground dry matter, presented in g pot^{-1}; B: wheat straw weight, presented in g pot^{-1}; C: wheat grain weight, presented in g pot^{-1}; D: wheat plant height, presented in cm. WHE = wheat in pure stand, WCO = wheat strip intercropped with coriander, ww = well-watered irrigation, dw = reduced irrigation. Cropping system is color-coded (yellow: wheat in pure stand, orange: wheat intercropped with coriander), with irrigation regimes shown by different hatch patterns. $N = 10$, except A, where $N = 9$. Significant differences are indicated by different letters, as determined by two-way ANOVA with Tukey's HSD test ($\alpha \leq 0.05$). Created using R and RStudio.

observed under well-watered conditions, with 79.1 cm (±2.5) in the pure stand and 78.5 cm (±3.9) in the intercropping system (Figure 1D). Wheat plants grown under reduced irrigation tended to be shorter overall. In this treatment, intercropped wheat reached a height of 74.8 cm (±4.3), which was slightly taller than wheat in pure stand (72.6 cm ± 5.0) but still shorter than both well-watered variants. Wheat in pure stand under reduced irrigation was significantly shorter than its well-watered counterparts.

3.2 | Coriander Aboveground Biomass Unaffected By Reduced Irrigation

No significant effect of the irrigation treatment was observed on coriander aboveground dry biomass ($p = 0.15$) or seed yield ($p = 0.16$) per pot. The total above-ground dry matter of coriander in the intercropping system with wheat, considering the irrigation regime, is shown in Figure 2A. No significant difference was observed. However, the well-watered variant, with 18.33 g (±5.76), tends to have a higher value compared to coriander cultivated under reduced irrigation, which recorded 14.29 g (±6.32). A similar trend is observed for coriander seed yield (Figure 2B). Again, the well-watered variant, with 8.39 g (±2.53), shows higher values than the reduced irrigation variant, which yielded 6.63 g (±2.92).

3.3 | Wheat Tends to Have a Higher Harvest Index Compared to Coriander in the Intercropping System

A Kruskal-Wallis test revealed a significant harvest index (HI, Figure 3, $p = 0.018$). For pure sown wheat (WHE), wheat intercropped with coriander (WCO), and coriander in the intercropping system with wheat (COR) reveals that the well-watered wheat in pure stand has a significantly higher value with 49.76% (±6.52) compared to well-watered coriander in the intercropping system with wheat, which recorded 46.04% (±2.64). No significant differences were observed between the other variants. In general, coriander tends to exhibit a lower HI than wheat.

3.4 | Intercropping Significantly Increases Combined Water Use Efficiency Regardless of Irrigation Treatment

The water use efficiency was significantly affected, as indicated by a Kruskal-Wallis test ($p < 0.001$), with the highest value observed in strip intercropping compared to the pure wheat stand, irrespective of water supply (Figure 4). Wheat intercropped with coriander under reduced irrigation showed a tendency for higher water use efficiency at 11.6 g L^{-1} (±1.9) compared to well-watered wheat intercropped with coriander at 7.8 g L^{-1} (±1.9). In the pure wheat stand, well-watered wheat exhibited a water use efficiency of 2.4 g L^{-1} (±0.1). In contrast, wheat in pure stand under reduced irrigation demonstrated a water use efficiency of 3.6 g L^{-1} (±0.9), showing a tendency for higher values compared to well-watered wheat.

3.5 | Wheat Crude Protein Content Increases Under Reduced Irrigation

A Kruskal-Wallis test for the crude protein content in wheat grains was significant ($p < 0.001$) and tended to be higher under reduced

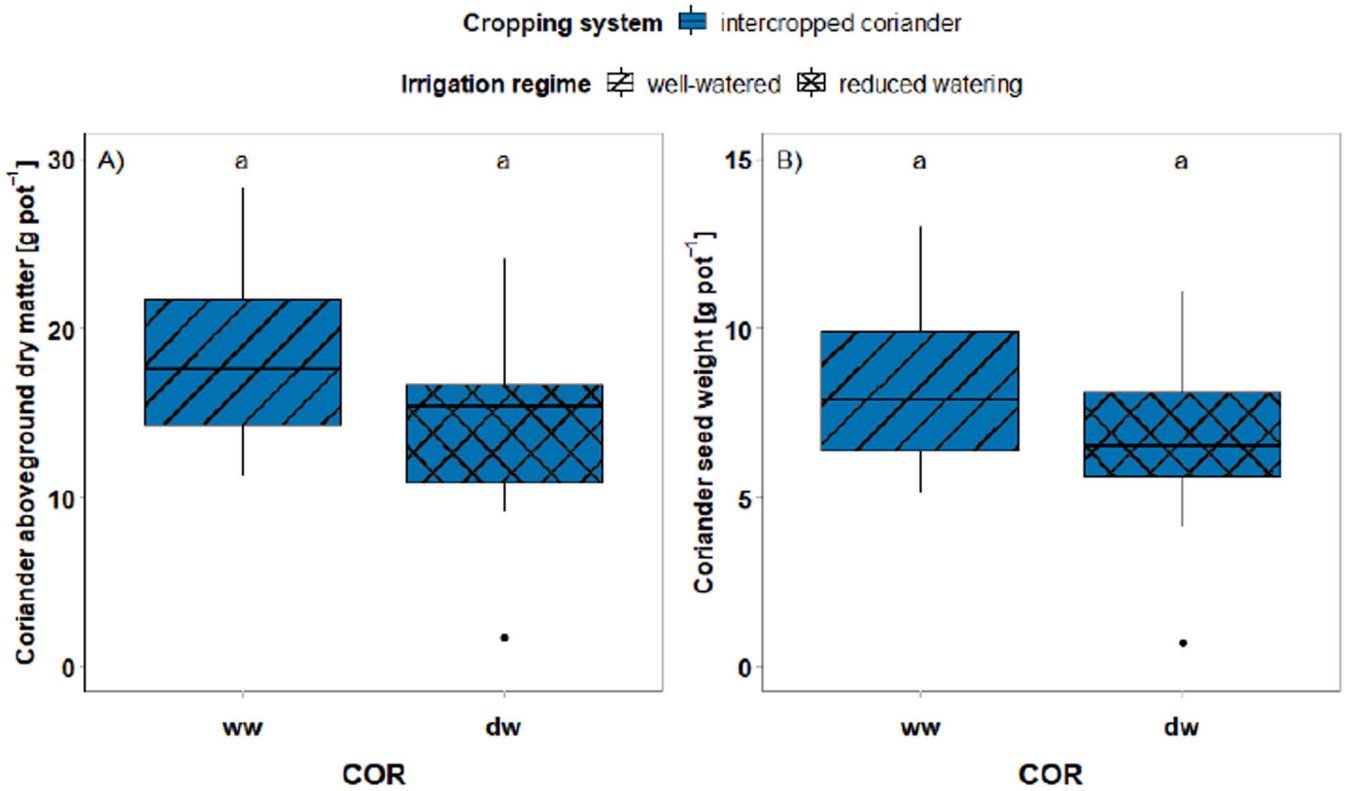


FIGURE 2 | A: coriander aboveground dry matter, presented in g; B: coriander seed weight, presented in g; COR = coriander strip intercropped with wheat, ww = well-watered irrigation, dw = reduced irrigation. Irrigation regimes are shown by different hatch patterns. $N = 10$. Significant differences are indicated by different letters, as determined by one-way ANOVA with Tukey's HSD test ($\alpha \leq 0.05$). Created using R and RStudio.

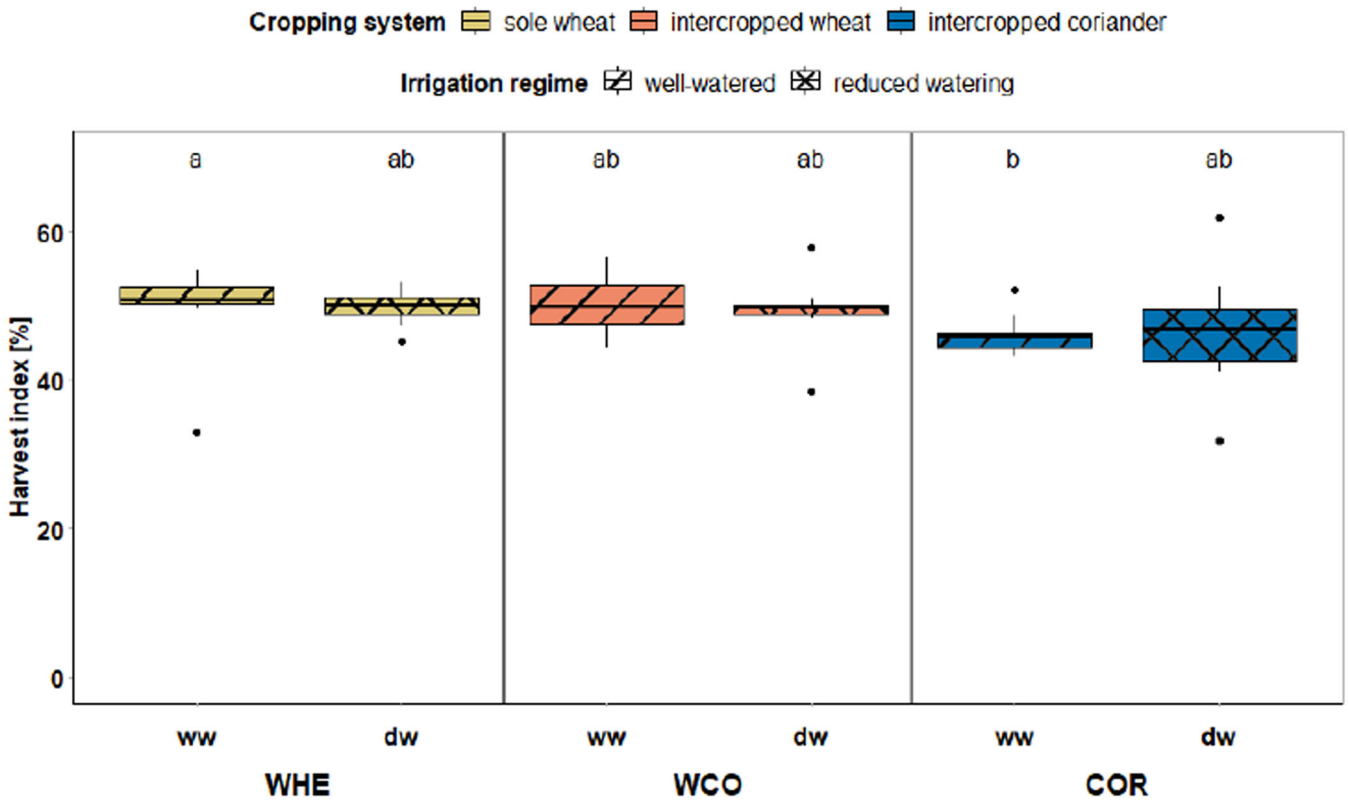


FIGURE 3 | Harvest Index in % of wheat in pure stand, wheat intercropped with coriander and coriander in the intercropping system with wheat. WHE = wheat in pure stand, WCO = wheat strip-intercropped with coriander, COR = coriander strip intercropped with wheat, ww = well-watered irrigation, dw = reduced irrigation. Cropping treatment is color-coded (yellow: wheat in pure stand, orange: wheat intercropped with coriander, blue: coriander intercropped with wheat), with irrigation regimes shown by different hatch patterns. $N = 10$. Significant differences are indicated by different letters, as determined by Kruskal-Wallis test with Dunn's post hoc test ($\alpha \leq 0.05$), because residuals were not normally distributed. Created using R and RStudio.

irrigation compared to well-watered conditions (Figure 5A). In this context, wheat grown in pure stand under reduced irrigation showed the highest value at 12.5% (±1.2), significantly differing from well-watered wheat in pure stand with 11.1% (±0.9) and well-watered wheat intercropped with coriander with 10.8% (±0.5). Wheat intercropped with coriander under reduced irrigation exhibited a significantly higher crude protein content of 12% (±0.9) than well-watered wheat intercropped with coriander. Within the irrigation treatments, there were no significant differences between the respective strip intercropping and pure wheat cultivation.

3.6 | Carbon Content in Wheat Grains Unaffected By Irrigation and Cropping System

A Kruskal-Wallis test performed on the carbon content in wheat grains (Figure 5B) showed no significant effect ($p = 0.079$). The values were identical across all treatments. Pure sown wheat under reduced irrigation (41%) showed difference from the other conditions (pure sown wheat ww, and intercropped wheat under both irrigation regimes).

3.7 | Higher Transpiration and CO_2 Assimilation of Wheat in Intercropping 12 Weeks After Emergence Under Well-Watered Conditions

At this time point, a two-way ANOVA showed a significant effect of the irrigation treatment ($p = 0.0059$), whereas the cropping system ($p = 0.16$) and the interaction between both factors ($p = 0.64$) were not significant. So, wheat intercropped with coriander under well-watered conditions showed a significantly higher transpiration rate (2.49 ± 1.05 mmol m^2 s^{-1}) compared to wheat under reduced irrigation in pure stand (0.62 ± 0.6 mmol m^2 s^{-1}) 12 weeks after wheat emergence. At the other sampling time points, the intercropping variants tended to have higher transpiration rates than wheat grown in pure stand. Regarding this, no significant effect of the cropping system was observed at 9 ($p = 0.09$), 10 ($p = 0.59$), and 11 ($p = 0.33$) weeks after wheat emergence. Additionally, well-watered variants generally exhibited higher transpiration rates than reduced irrigation variants. A two-way ANOVA did not reveal a significant effect of the irrigation treatment. P-values of 0.053, 0.36, and 0.98 were obtained for 9, 10, and 11 weeks after wheat emergence.

Regarding CO_2 assimilation, significant differences were also only observed 12 weeks after wheat emergence (Figure 6B). At this stage, well-watered wheat intercropped with coriander showed a significantly higher CO_2 assimilation rate (5.81 ± 2.3 μmol m^2 s^{-1}) than well-watered wheat in pure stand (2.9 ± 1.83 μmol m^2 s^{-1}), wheat intercropped with coriander under reduced irrigation (0.88 ± 0.84 μmol m^2 s^{-1}), and wheat under reduced irrigation in pure stand (0.21 ± 0.28 μmol m^2 s^{-1}). A two-way ANOVA revealed that the irrigation treatment ($p < 0.001$) and the cropping system ($p = 0.019$) were significant at this time point, while the interaction between both factors ($p = 0.12$) was not. Furthermore, at other sampling time points, the trend was observed that wheat intercropped with coriander within the respective irrigation regimes

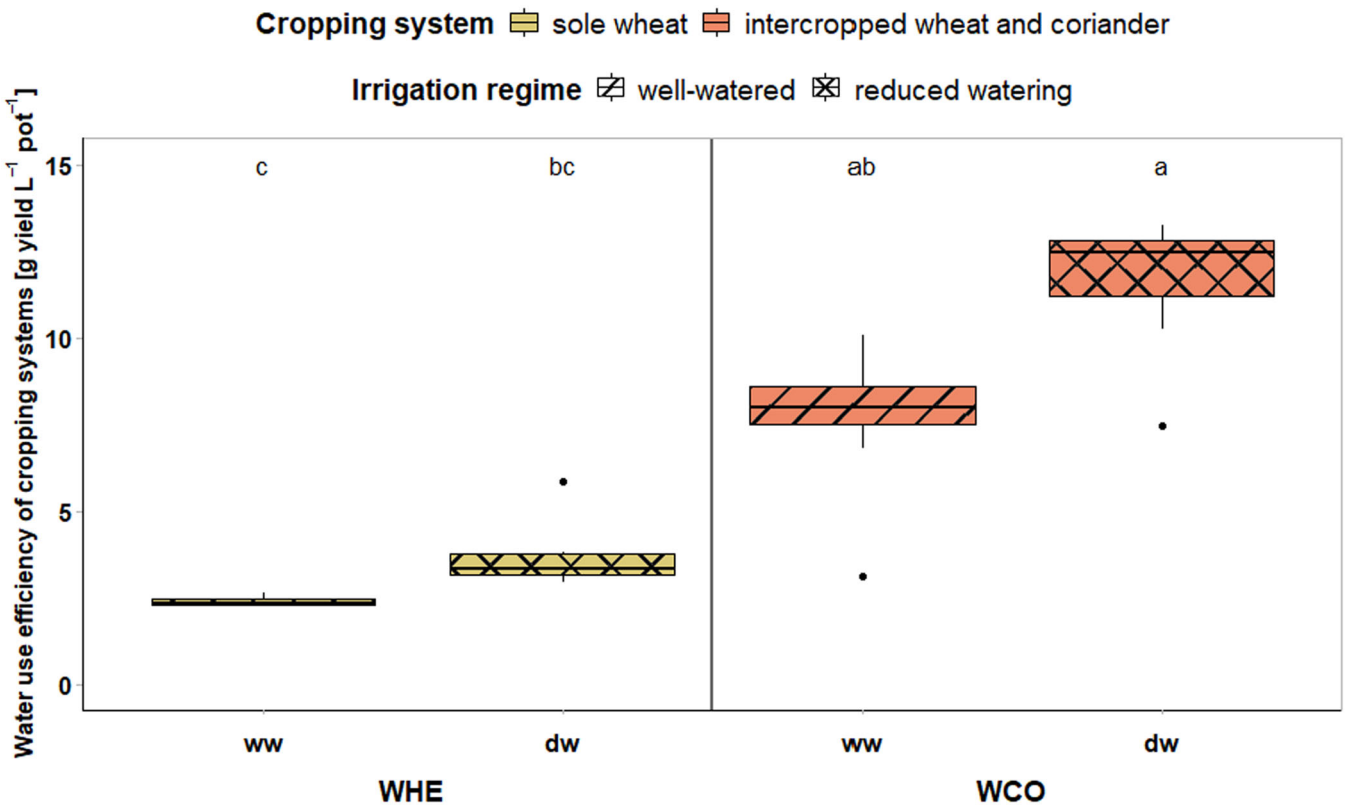


FIGURE 4 | Water use efficiency of wheat as pure stand and wheat combined with coriander, expressed in g l^{-1} pot^{-1}. WHE = wheat in pure stand, WCO = wheat strip intercropped with coriander, ww = well-watered irrigation, dw = reduced irrigation. Cropping system is color-coded (yellow: wheat in pure stand, orange: wheat intercropped with coriander), with irrigation regimes shown by different hatch patterns. $N = 10$. Significant differences are indicated by different letters, as determined by Kruskal-Wallis test with Dunn's post hoc test ($\alpha \leq 0.05$), because residuals were not normally distributed. Created using R and RStudio.

exhibited higher CO_2 assimilation than wheat grown in pure stand. For the cropping system, P-values of 0.26, 0.096, and 0.067 were obtained at 9, 10, and 11 weeks after wheat emergence. The well-watered variants also displayed this trend compared to the reduced irrigation variants. Regarding the irrigation treatment, p-values of 0.12, 0.25, and 0.28 were found at 9, 10, and 11 weeks after wheat emergence.

No distinct trends between the different variants and sampling stages were observed for ΦPSII, ΦNPQ, and ΦNO (Table 1). However, wheat intercropped with coriander generally exhibited higher values than wheat in pure stand for electron transport rate under both irrigation regimes, and this trend was also apparent for maximum quantum yield of photosystem II (F_v/F_m). However, for the electron transport rate, no significant effects were observed for the cropping systems at 9 ($p = 0.45$), 10 ($p = 0.55$), and 11 ($p = 0.97$) weeks after wheat emergence. For F_v/F_m, significant effects of the cropping system were found at 9 ($p = 0.043$) and 10 ($p = 0.0011$) weeks after wheat emergence, but not at 11 weeks ($p = 0.2$). Furthermore, F_v/F_m tended to show lower values 11 weeks after wheat emergence.

4 | Discussion

4.1 | Less Aboveground Biomass in Sole Cropped Wheat Under Reduced Irrigation

Reduced irrigation (i.e., 40% of the soil's maximum water-holding capacity for 48 days; see progression of water treatment in Supplementary Figure 2) resulted in lower biomass variables per pot in pure sown spring wheat compared to well-watered conditions (Figure 1). The biomass reduction reflects a well-established response to water scarcity, e.g., observed in maize (Anjum et al. 2017; Bismillah Khan et al. 2015), sunflower (Hussain et al. 2008), and wheat (Anjum et al. 2016; Zörb et al. 2017). Although no visible symptoms such as leaf curling were observed, the data confirm that the reduced irrigation treatment induced water deficit. However, in comparison to other studies, such as Zörb et al. 2017, the water deficit imposed here was milder and led to less pronounced growth arrest and yield reduction.

4.2 | Stable Yield in Intercropping Under Reduced Irrigation

Under sufficient irrigation, the sole crop yielded significantly more wheat aboveground biomass per pot than the intercropped variant (Figure 1A). Consistent with this, Khatun et al. 2012 observed the highest wheat yields in sole wheat stand under adequate water supply compared with intercropping variants. Dietz et al. 2021 showed that drought during vegetative growth can reduce crop yield. In the current experiment, such an effect was only observed in the pure sown wheat but not in the intercropped system (Figure 1C). This suggests that the negative effects of reduced irrigation are less pronounced when wheat is strip-intercropped with coriander, which could be attributed to the reduced plant density, as wheat could

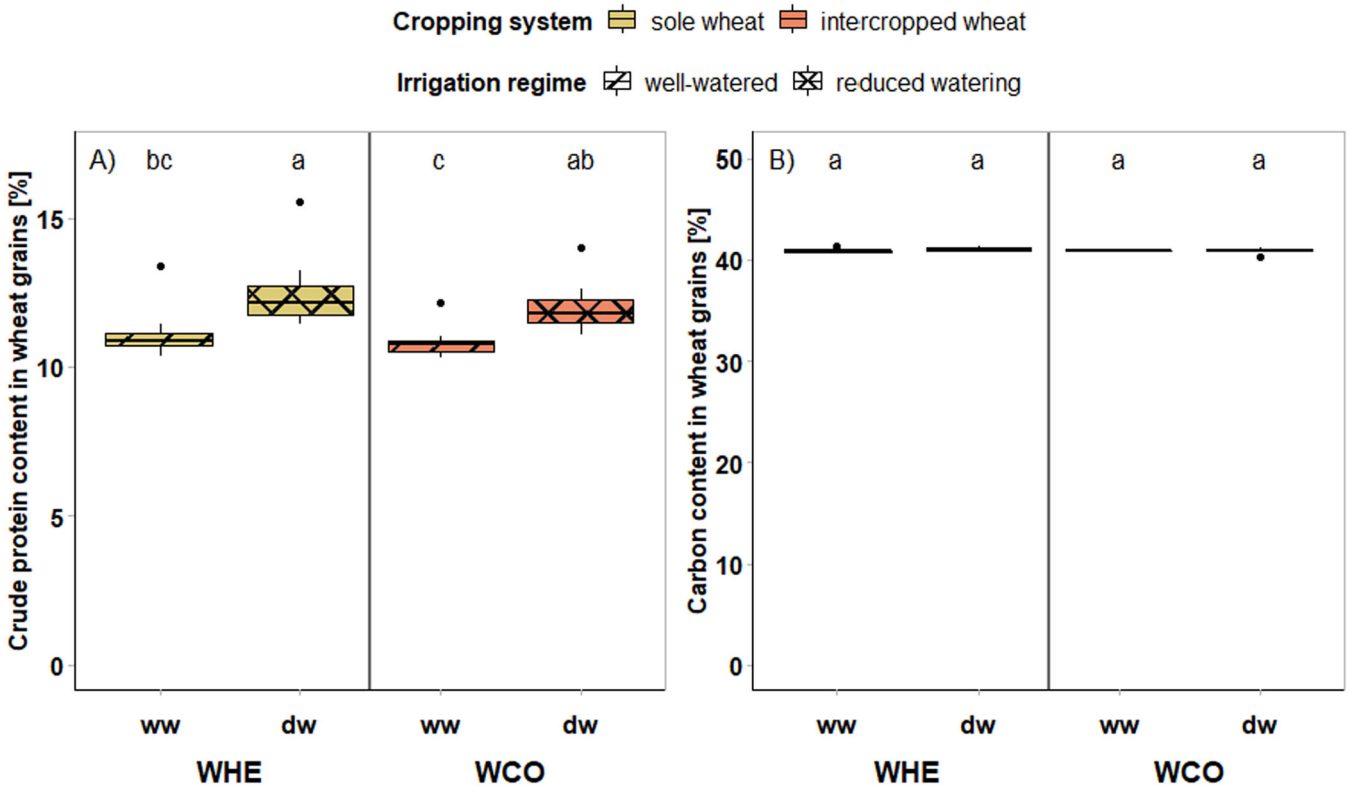


FIGURE 5 | A: Crude protein content of wheat grains, presented in %. B: Carbon content of wheat grains, presented in %. WHE = wheat in pure stand, WCO = wheat strip intercropped with coriander, ww = well-watered irrigation, dw = reduced irrigation. Cropping system is color-coded (yellow: wheat in pure stand, orange: wheat intercropped with coriander), with irrigation regimes shown by different hatch patterns. $N = 10$. Significant differences are indicated by different letters, as determined by Kruskal–Wallis test with Dunn's post hoc test ($\alpha \leq 0.05$), because residuals were not normally distributed. Created using R and RStudio.

exhibit a compensation effect (Whaley et al. 2000). This is supported by the thousand-kernel weight of wheat (Supplementary Figure 5), which did not differ significantly between treatments. Therefore, the grains did not vary in weight across variants, suggesting that the intercropped wheat produced a higher number of grains per plant.

Also, considering the HI (Figure 3) in the intercropping system, it appears that wheat tends to produce more yield per unit of aboveground biomass than coriander. This could indicate that wheat was more competitive in this system than coriander, thereby allowing it to utilize more resources for yield formation. Nevertheless, coriander yield was not significantly affected by the irrigation treatment (Figure 2), indicating that coriander productivity remained stable within the intercropping system. To further elucidate the beneficial effects of both cropping partners on subsequent yields, additional research including sole-cropped coriander is required. To gain more insights in a possible density effect, cultivating sole-cropped wheat with a reduced planting density, could be required in further research.

Moreover, under reduced irrigation, no significant differences in biomass parameters were observed between the pure sown and intercropped wheat. As the pure stand contains twice as many wheat plants per vessel as the intercropped variant, the absence of differences in biomass production and yield suggests that coriander in an intercropping system with spring wheat is capable of stabilizing wheat yield by increasing the yield per wheat plant under reduced irrigation. These findings suggest that intraspecific competition in sole-cropped wheat is stronger than interspecific competition in the intercropping system. This is consistent with the findings of Adler et al. 2018. However, this beneficial effect appears to be restricted to water-limited conditions. A plausible explanation is that under well-watered conditions, the greater water availability reduces intraspecific competition, as the water supply is sufficient for all plants.

4.3 | Adaptive Wheat Growth in Intercropping May Prolong Wheat Photosynthesis

Another possible explanation for the stabilized wheat yield is that intercropping leads to an altered canopy structure, which enhances light interception (Awal et al. 2006), potentially improving photosynthetic performance and thus yield formation. In this experiment, the intercropped variant exhibited only a tendency towards higher photosynthetic activity, reflected in increased CO_2 assimilation (Figure 6B) and in tendentially higher values of the effective quantum yield of photosystem II (F_v/F_m, Table 1). It should be noted, however, that CO_2 assimilation measurements were performed in cuvettes under constant light conditions, and thus potential effects of enhanced light interception resulting from adapted canopy might not have been fully captured. Nevertheless, further research is required to investigate the hypothesized improvement in light interception within this intercropping system.

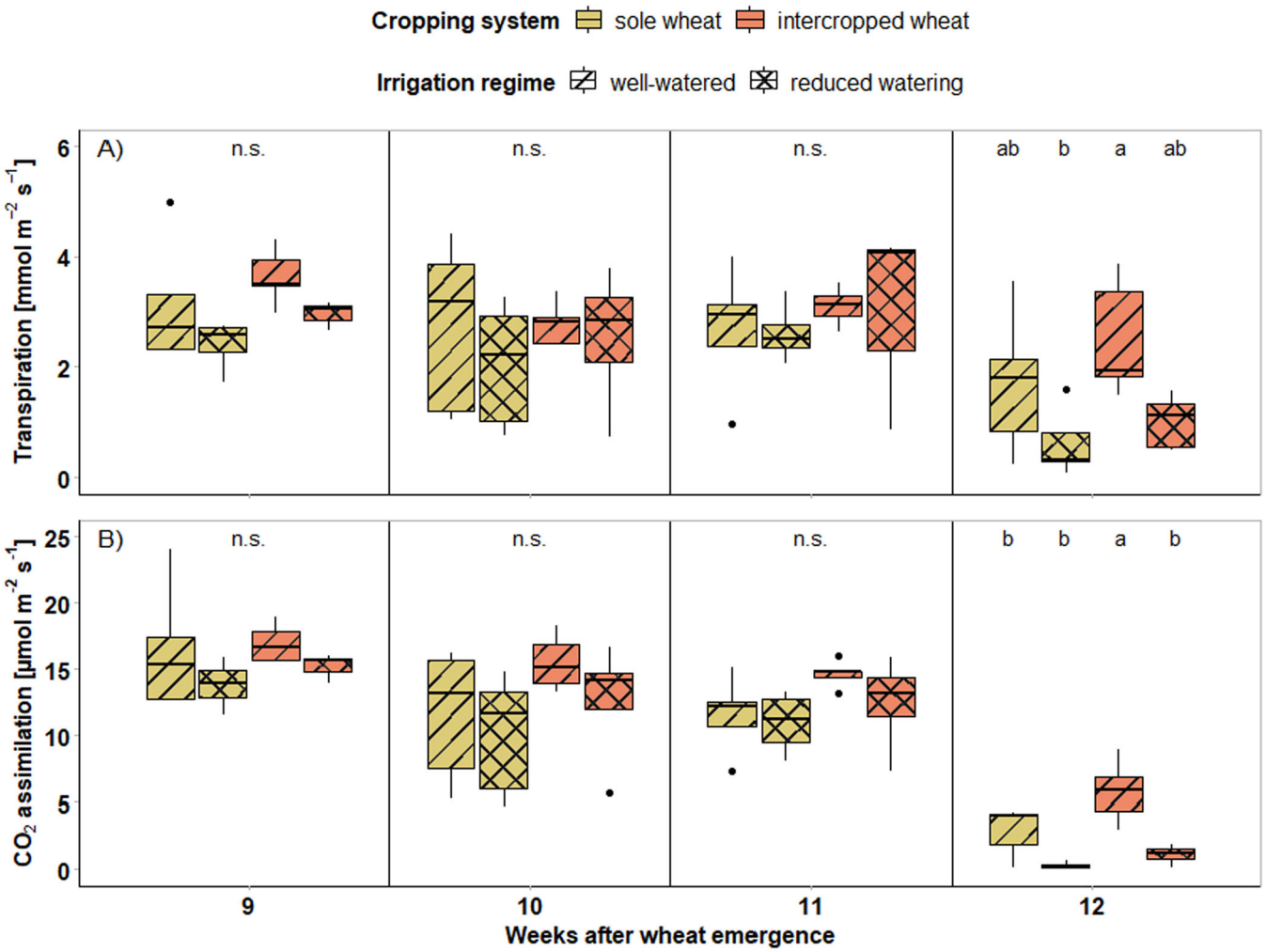


FIGURE 6 | A: Transpiration of spring wheat as pure stand and wheat combined with coriander during different weeks after emergence of wheat, expressed in mmol m^{-2} s^{-1}. B: CO_2 assimilation of spring wheat as pure stand and wheat combined with coriander during different weeks after emergence of wheat, expressed in µmol m^{-2} s^{-1}. WHE = wheat in pure stand, WCO = wheat strip intercropped with coriander, ww = well-watered irrigation, dw = reduced irrigation. Cropping system is color-coded (yellow: wheat in pure stand, orange: wheat intercropped with coriander), with irrigation regimes shown by different hatch patterns. $N = 5$. Significant differences are indicated by different letters, as determined by two-way ANOVA with Tukey's HSD test ($\alpha \leq 0.05$). Created using R and RStudio.

In addition to the suggested improved light interception in the intercropping variant, a delaying of the senescence of the wheat flag leaves occurred under well water supply. This was indicated by the significantly higher CO_2 assimilation rates during grain filling (BBCH stage 75) at 12 weeks after wheat emergence, while CO_2 assimilation rates in both the water-limited variants and the well-watered wheat pure stand were already declining due to senescence. F_v/F_m (Table 1) tends to show lower values in pure sown wheat starting from 10 weeks after emergence compared to wheat intercropped with coriander, which implies a more sustained higher photosynthetic capacity. However, since a significant effect of the irrigation treatment was observed only for transpiration and CO_2 assimilation at 12 weeks after wheat emergence, the applied water deficit may have been too mild to cause severe impairments of photosynthesis. Nevertheless, the significant effects at this time point may also reflect the additional impact of a prolonged 'stay-green' phase in the intercropped variants, as indicated by higher NDVI values of the wheat flag leaves (Supplementary Figure 4).

4.4 | Enhanced Water-Use Efficiency in the Wheat–Coriander Intercropping System

The cumulative effects of water supply and intercropping on photosynthetic performance and yield formation were evaluated using water-use efficiency (WUE) as an integrative indicator. In the wheat–coriander intercropping variants, more yield was produced per liter of water per pot than in the sole wheat crop (Figure 4). This was true for both the well-watered and the water-limited conditions. Therefore, it highlights the potential of intercropping these species for water-saving yield production under both ample and limited water supply, reducing the amount of water required per yield by 69% (rounded down). These findings indicate that water is used more efficiently in the wheat–coriander intercropping system. Therefore, in water-limited environments, this practice is likely to maintain wheat yields at levels comparable to monocultures, while simultaneously providing a secondary crop yield. However, these findings need to be verified in a field setting.

Similarly, Y. Wang et al. 2016 observed higher WUE in intercropped winter wheat compared to pure stands under different

TABLE 1 | ΦPSII, ΦNPQ, ΦNO, ETR and Fv/Fm of spring wheat as pure stand and wheat combined with coriander during different weeks after emergence of wheat. WHE = wheat in pure stand, WCO = wheat strip intercropped with coriander, ww = well-watered irrigation, dw = reduced irrigation. Cropping system is color-coded (yellow: wheat in pure stand, orange: wheat intercropped with coriander), with irrigation regimes shown by different hatch patterns. $N = 5$. Significant differences are indicated by different letters, as determined by two-way ANOVA with Tukey's HSD test ($\alpha \leq 0.05$). Created using R, RStudio and Microsoft Excel.

Experimental treatment	Weeks after emergence	ΦPSII	ΦNPQ	ΦNO	ETR	Fv/Fm
wwWHE	9	0.22 ± 0.06 a	0.7 ± 0.08 a	0.2 ± 0.01 a	36.23 ± 21.18 a	0.8 ± 0.01 a
dwWHE	9	0.15 ± 0.04 a	0.68 ± 0.08 a	0.18 ± 0.02 a	50.91 ± 13.45 a	0.82 ± 0.03 a
wwWCO	9	0.14 ± 0.07 a	0.66 ± 0.1 a	0.21 ± 0.01 a	48.14 ± 23.71 a	0.84 ± 0.01 a
dwWCO	9	0.16 ± 0.06 a	0.67 ± 0.11 a	0.29 ± 0.16 a	55.41 ± 19.29 a	0.83 ± 0.02 a
wwWHE	10	0.2 ± 0.05 a	0.59 ± 0.04 a	0.21 ± 0.01 a	65.81 ± 18.08 a	0.78 ± 0.03 ab
dwWHE	10	0.2 ± 0.06 a	0.59 ± 0.05 a	0.21 ± 0.02 a	65.83 ± 20.57 a	0.77 ± 0.03 b
wwWCO	10	0.17 ± 0.04 a	0.62 ± 0.04 a	0.2 ± 0.02 a	57.28 ± 14.88 a	0.83 ± 0.03 a
dwWCO	10	0.2 ± 0.01 a	0.6 ± 0.01 a	0.2 ± 0.02 a	65.93 ± 3.67 a	0.83 ± 0.01 a
wwWHE	11	0.16 ± 0.07 a	0.64 ± 0.08 a	0.22 ± 0.02 a	53.46 ± 24.48 a	0.76 ± 0.05 a
dwWHE	11	0.2 ± 0.13 a	0.6 ± 0.12 a	0.26 ± 0.2 a	52.91 ± 25.74 a	0.61 ± 0.3 a
wwWCO	11	0.16 ± 0.05 a	0.63 ± 0.06 a	0.22 ± 0.02 a	53.67 ± 17.14 a	0.78 ± 0.06 a
dwWCO	11	0.16 ± 0.06 a	0.65 ± 0.08 a	0.24 ± 0.11 a	53.3 ± 20.96 a	0.77 ± 0.01 a

irrigation treatments. Chen et al. 2018 also found enhanced WUE in pea–maize strip intercropping systems compared to sole crops. The authors attribute this to potential water compensation and sharing between intercropping partners. The synergistic effects of intercropping discussed here occur both intraspecifically (e.g., Wang et al. 2018) and interspecifically (e.g., Chen et al. 2018). This offers a considerable potential for water saving by selecting suitable intercropping partners, without experiencing yield losses.

4.5 | Intercropping May Improve Wheat Grain Quality

Previous studies reported increased crude protein content in wheat grains as a result of drought stress (Zörb et al. 2017). Consistent with this, grain crude protein content was significantly higher in both the sole stand and intercropping variant (Figure 5A). An increased crude protein content enhances grain quality, given its positive association with baking quality (Zörb et al. 2017). However, Zörb et al. (2017) argue that under drought wheat tends to develop fewer grains, leading to increased allocation of protein to the remaining grains, whereas starch accumulation remains unchanged, likely due to reduced photosynthetic activity. The carbon content in the wheat grains examined in this study, which did not differ significantly (Figure 5B), supports this assumption. These findings support the idea proposed by Zörb et al. (2017) that reduced irrigation does not affect starch accumulation but may result in a relative increase in protein allocation per grain. As neither carbon content (Figure 5B) nor thousand-kernel weight (Supplementary Figure 5) differed significantly, the higher crude protein concentration observed in our study cannot be attributed to a concentration effect caused by smaller grains. Effects of intercropping on grain crude protein content have previously been observed mostly in cereal-legume variants. For instance, Dvořák et al. 2022 observed higher crude protein levels in wheat intercropped with legumes, and Trydeman Knudsen et al. 2004 reported increased nitrogen content in barley grains when intercropped with pea and faba bean, but not with lupin, highlighting that the choice of intercrop partner can significantly affect grain protein content. Consistent with this species-specific response, the grain protein content was not significantly increased under either the well-watered or water-limited condition, indicating a limited effect of wheat-coriander intercropping on grain protein accumulation.

5 | Conclusion

Intercropping spring wheat with coriander positively influences photosynthetic performance, water-use efficiency, and yield of wheat, especially under water-limited conditions. This might be due to improved light interception as a result of altered canopy architecture and delayed senescence under ample water supply. Furthermore, water saving of up to 69% per unit yield is achieved by intercropping spring wheat with coriander. Consequently, wheat intercropping with coriander could represent a promising agronomic strategy to mitigate the negative effects of water scarcity and enhance wheat productivity amid the growing challenges of climate change.

Author Contributions

All authors listed have significantly contributed to the development and the writing of this paper.

Acknowledgements

We thank the Hessian Ministry of Science and Art (HMWK) for LOEWE Focus Funding. The help of the technician from the Department of Soils Science and Plant Nutrition, HGU, is highly appreciated. Open Access funding enabled and organized by Projekt DEAL.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

Data will be made available on request.

References

Adler, P. B., D. Smull, K. H. Beard, et al. 2018. "Competition and Coexistence in Plant Communities: Intraspecific Competition is Stronger than Interspecific Competition." *Ecology Letters* 21, no. 9: 1319–1329. https://doi.org/10.1111/ele.13098.

Agegnehu, G., A. Ghizaw, and W. Sinebo. 2008. "Yield Potential and Land-Use Efficiency of Wheat and Faba Bean Mixed Intercropping." *Agronomy for Sustainable Development* 28, no. 2: 257–263. https://doi.org/10.1051/agro:2008012.

Ahmad, Z., E. A. Waraich, S. Akhtar, et al. 2018. "Physiological Responses of Wheat to Drought Stress and its Mitigation Approaches." *Acta Physiologiae Plantarum* 40, no. 4: 80. https://doi.org/10.1007/s11738-018-2651-6.

Anjum, S. A., U. Ashraf, and M. Tanveer, et al. 2017. "Drought Induced Changes in Growth, Osmolyte Accumulation and Antioxidant Metabolism of Three Maize Hybrids." *Frontiers in Plant Science* 8: 69. https://doi.org/10.3389/fpls.2017.00069.

Anjum, S. A., M. Tanveer, S. Hussain, et al. 2016. "Exogenously Applied Methyl Jasmonate Improves the Drought Tolerance in Wheat Imposed at Early and Late Developmental Stages." *Acta Physiologiae Plantarum* 38, no. 1: 25. https://doi.org/10.1007/s11738-015-2047-9.

Arzani, A., and M. Ashraf. 2017. "Cultivated Ancient Wheats (Triticum spp.): A Potential Source of Health-Beneficial Food Products." *Comprehensive Reviews in Food Science and Food Safety* 16, no. 3: 477–488. https://doi.org/10.1111/1541-4337.12262.

Awal, M. A., H. Koshi, and T. Ikeda. 2006. "Radiation Interception and Use by Maize/Peanut Intercrop Canopy." *Agricultural and Forest Meteorology* 139, no. 1–2: 74–83. https://doi.org/10.1016/j.agrformet.2006.06.001.

Bismillah Khan, M., M. Hussain, A. Raza, S. Farooq, and K. Jabran. 2015. "Seed Priming With CaCl2 and Ridge Planting for Improved Drought Resistance in Maize." *Turkish Journal of Agriculture And Forestry* 39: 193–203. https://doi.org/10.3906/tar-1405-39.

Chen, G., X. Kong, and Y. Gan, et al. 2018. "Enhancing the Systems Productivity and Water Use Efficiency Through Coordinated Soil Water Sharing and Compensation in Strip-Intercropping." *Scientific Reports* 8, no. 1: 10494. https://doi.org/10.1038/s41598-018-28612-6.

Cong, W. F., E. Hoffland, L. Li, et al. 2015. "Intercropping Enhances Soil Carbon and Nitrogen." *Global Change Biology* 21, no. 4: 1715–1726. https://doi.org/10.1111/gcb.12738.

Dietz, K. -J., C. Zörb, and C. -M. Geilfus. 2021. "Drought and Crop Yield." *Plant Biology (Stuttgart, Germany)* 23, no. 6: 881–893. https://doi.org/10.1111/plb.13304.

DIN Media GmbH. 2016. *Food products - Determination of the total nitrogen content by combustion according to the Dumas principle and calculation of the crude protein content - Part 2: Cereals, pulses and milled cereal products (ISO 16634-2:2016); German version EN ISO 16634-2:2016*. DIN Media GmbH. https://doi.org/10.31030/2406476.

Donald, C. M. 1968. "The Breeding of Crop Ideotypes." *Euphytica* 17, no. 3: 385–403. https://doi.org/10.1007/BF00056241.

Dvořák, P., I. Capouchová, M. Král, P. Konvalina, D. Janovská, and M. Satranský. 2022. "Grain Yield and Quality of Wheat in Wheat-Legumes Intercropping Under Organic and Conventional Growing Systems." *Plant, Soil and Environment* 68, no. 12: 553–559. https://doi.org/10.17221/276/2022-PSE.

Ehrmann, J., and K. Ritz. 2014. "Plant: Soil Interactions in Temperate Multi-Cropping Production Systems." *Plant and Soil* 376, no. 1–2: 1–29. https://doi.org/10.1007/s11104-013-1921-8.

Geilfus, C. -M., C. Zörb, J. J. Jones, M. A. Wimmer, and S. M. Schmöckel. 2024. "Water for Agriculture: More Crop Per Drop." *Plant Biology (Stuttgart, Germany)* 26, no. 4: 499–507. https://doi.org/10.1111/plb.13652.

Gupta, K., K. K. Thakral, S. K. Arora, and D. S. Wagle. 1991. "Studies on Growth, Structural Carbohydrate and Phytate in Coriander (Coriandrum Sativum) During Seed Development." *Journal of the Science of Food and Agriculture* 54, no. 1: 43–46. https://doi.org/10.1002/jsfa.2740540106.

Homulle, Z., T. S. George, and A. J. Karley. 2022. "Root Traits with Team Benefits: Understanding Belowground Interactions in Intercropping Systems." *Plant and Soil* 471, no. 1–2: 1–26. https://doi.org/10.1007/s11104-021-05165-8.

Hupe, A., F. Naether, and T. Haase, et al. 2021. "Evidence of Considerable C and N Transfer from Peas to Cereals via Direct Root Contact but not via Mycorrhiza." *Scientific Reports* 11, no. 1: 11424. https://doi.org/10.1038/s41598-021-90436-8.

Hussain, M., M. A. Malik, M. Farooq, M. Y. Ashraf, and M. A. Cheema. 2008. "Improving Drought Tolerance by Exogenous Application of Glycinebetaine and Salicylic Acid in Sunflower." *Journal of Agronomy and Crop Science* 194, no. 3: 193–199. https://doi.org/10.1111/j.1439-037X.2008.00305.x.

Jensen, E. S., L. Bedoussac, G. Carlsson, E. P. Journet, E. Justes, and H. Hauggaard-Nielsen. 2015. "Enhancing Yields in Organic Crop Production by Eco-Functional Intensification." *Sustainable Agriculture Research* 4, no. 3: 42. https://doi.org/10.5539/sar.v4n3p42.

Khatun, S., A. K. Azad, and P. Bala. 2012. "Intercropping with Wheat Affected Crop Productivity." *Bangladesh Research Publications Journal* 6: 414–419.

Laribi, B., K. Kouki, M. M'Hamdi, and T. Bettaieb. 2015. "Coriander (Coriandrum Sativum L.) and Its Bioactive Constituents." *Fitoterapia* 103: 9–26. https://doi.org/10.1016/j.fitote.2015.03.012.

Lenth, R. V. L., and V. Russell (2024). emmeans: Estimated Marginal Means, aka Least-Squares Means (Version R package version 1.10.6) [Computer software]. https://CRAN.R-project.org/package=emmeans.

Nyaupane, S., M. R. Poudel, B. Panthi, A. Dhakal, H. Paudel, and R. Bhandari. 2024. "Drought Stress Effect, Tolerance, and Management in Wheat – a Review." *Cogent Food & Agriculture* 10, no. 1: 2296094. https://doi.org/10.1080/23311932.2023.2296094.

Pelech, E. A., B. C. S. Alexander, and C. J. Bernacchi. 2021. "Photosynthesis, Yield, Energy Balance, and Water-Use of Intercropped Maize and Soybean." *Plant Direct* 5, no. 12: e365. https://doi.org/10.1002/pld3.365.

Pforte, L. 2013. "Der Phytopharmazeutika-Markt Und Sein Bedarf An Arzneipflanzen." *Fachagentur Nachwachsende Rohstoffe* 44: 21–23.

Pirasteh-Anosheh, H., A. Saed-Moucheshi, H. Pakniyat, and M. Pessarakli. 2016. "Stomatal responses to drought stress." In *Water Stress and Crop Plants*, edited by P. Ahmad, 24–40. Wiley. https://doi.org/10.1002/9781119054450.ch3.

Posit team. (2024). RStudio: Integrated Development Environment for R [Computer software]. Boston, MA: Posit Software, PBC: Posit Software, PBC. http://www.posit.co/.

Poudel, M. R., S. Ghimire, M. P. Pandey, K. H. Dhakal, D. B. Thapa, and H. K. Poudel (2020). Evaluation of Wheat Genotypes Under Irrigated, Heat Stress and Drought Conditions.

R Core Team. (2024). R: A Language and Environment for Statistical Computing [Computer software]. Vienna, Austria. https://www.R-project.org/.

Riediger, J., B. Breckling, N. Svoboda, and W. Schröder. 2016. "Modelling Regional Variability of Irrigation Requirements Due to Climate Change in Northern Germany." *Science of the Total Environment* 541: 329–340. https://doi.org/10.1016/j.scitotenv.2015.09.043.

Sharifi, P., and N. Mohammadkhani. 2016. "Effects of Drought Stress on Photosynthesis Factors in Wheat Genotypes During Anthesis." *Cereal Research Communications* 44, no. 2: 229–239. https://doi.org/10.1556/0806.43.2015.054.

Timaeus, J., O. D. Weedon, and M. R. Finckh. 2022. "Harnessing the Potential of Wheat-Pea Species Mixtures: Evaluation of Multifunctional Performance and Wheat Diversity." *Frontiers in Plant Science* 13: 846237. https://doi.org/10.3389/fpls.2022.846237.

Tränkner, M., B. Jákli, E. Tavakol, et al. 2016. "Magnesium Deficiency Decreases Biomass Water-Use Efficiency and Increases Leaf Water-Use Efficiency and Oxidative Stress in Barley Plants." *Plant and Soil* 406, no. 1–2: 409–423. https://doi.org/10.1007/s11104-016-2886-1.

Trydeman Knudsen, M., H. Hauggaard-Nielsen, B. Jørnsgård, and E. Steen Jensen. 2004. "Comparison of Interspecific Competition and N Use in Pea–Barley, Faba Bean–Barley and Lupin–Barley Intercrops Grown at Two Temperate Locations." *Journal of Agricultural Science* 142, no. 6: 617–627. https://doi.org/10.1017/S0021859604004745.

Wang, X., Y. Ren, Y. Chen, and S. Zhang. 2018. "Competitive Interaction Between Mixed-Planting Maize Cultivars Enhanced Yield and Water-Use Efficiency in a Semi-Arid Region." *Turkish Journal of Field Crops* 23, no. 1: 1–11. https://doi.org/10.17557/tjfc.413808.

Wang, Y., Y. Zhang, and W. Ji, et al. 2016. "Cultivar Mixture Cropping Increased Water Use Efficiency in Winter Wheat Under Limited Irrigation Conditions." *PLoS One* 11, no. 6: e0158439. https://doi.org/10.1371/journal.pone.0158439.

Webber, H., F. Ewert, J. E. Olesen, et al. 2018. "Diverging Importance of Drought Stress for Maize and Winter Wheat in Europe." *Nature Communications* 9, no. 1: 4249. https://doi.org/10.1038/s41467-018-06525-2.

Whaley, J. M., D. L. Sparkes, M. J. Foulkes, J. H. Spink, T. Semere, and R. K. Scott. 2000. "The Physiological Response of Winter Wheat to Reductions in Plant Density." *Annals of Applied Biology* 137, no. 2: 165–177. https://doi.org/10.1111/j.1744-7348.2000.tb00048.x.

Yin, W., Q. Chai, and C. Zhao, et al. 2020. "Water Utilization in Intercropping: A Review." *Agricultural Water Management* 241: 106335. https://doi.org/10.1016/j.agwat.2020.106335.

Zhao, W., L. Liu, and Q. Shen, et al. 2020. "Effects of Water Stress on Photosynthesis, Yield, and Water Use Efficiency in Winter Wheat." *Water* 12, no. 8: 2127. https://doi.org/10.3390/w12082127.

Zörb, C., E. Becker, N. Merkt, S. Kafka, S. Schmidt, and U. Schmidhalter. 2017. "Shift of Grain Protein Composition in Bread Wheat Under Summer Drought Events." *Journal of Plant Nutrition and Soil Science* 180, no. 1: 49–55. https://doi.org/10.1002/jpln.201600367.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Supplementary Figure 1: Experimental block, consisting of 10 containers arranged in two rows of five. Four such blocks were included in the experiment, with the containers randomized twice per week in position. **Supplementary Figure 2**: Soil water content as a percentage of maximum water-holding capacity from the start of reduced irrigation (6 weeks after wheat emergence) until the harvest of wheat. DwWHE, reduced irrigation with wheat in pure stand; dwWCO, reduced irrigation with wheat and coriander in strip intercropping; wwWHE, well-watered irrigation with wheat in pure stand; wwWCO, well-watered irrigation with wheat and coriander in strip intercropping. **Supplementary Figure 3**: Container with a row-sown spring wheat pure stand. The spacing between the rows is 10 cm, and the distance between the outer rows and the container edge is 5 cm. A PVC tube is centrally placed, allowing the insertion of the soil moisture sensor Diviner 2000 (Sentek Pty Ltd, Stepney, Australia). **Supplementary Figure 4:** NDVI of wheat as pure stand and strip intercropped with coriander during different weeks after emergence of wheat. WHE = wheat in pure stand, WCO = wheat strip-intercropped with coriander, ww = well-watered irrigation, dw = reduced irrigation. Cropping system is color-coded (yellow: wheat in pure stand, orange: wheat intercropped with coriander), with irrigation regimes shown by different hatch patterns. N = 10. Significant differences are indicated by different letters, as determined by Kruskal-Wallis test with Dunn's post hoc test ($\alpha \leq 0.05$), because residuals were not normally distributed. Created using R and RStudio. **Supplementary Figure 5:** Thousand kernel weight of wheat grains in pure stand and strip intercropped with coriander, presented in g pot-1. WHE = wheat in pure stand, WCO = wheat strip-intercropped with coriander, ww = well-watered irrigation, dw = reduced irrigation. Cropping system is color-coded (yellow: wheat in pure stand, orange: wheat intercropped with coriander), with irrigation regimes shown by different hatch patterns. N = 10. Significant differences are indicated by different letters, as determined by two-way ANOVA with Tukey's HSD test ($\alpha \leq 0.05$). Created using R and RStudio.