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ORIGINAL PAPER

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SAVING WATER USED FOR VEGETABLE PRODUCTION BY APPLYING REGULATED DEFICIT IRRIGATION PRACTICES

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ABSTRACT

Water deficit during the growing season is a major factor limiting vegetable production. Therefore, saving water used for vegetable production by applying regulated deficit irrigation (RDI) can be a strategy to reduce water supply. The effects of different RDI levels from irrigation systems on vegetable yields, yield components, water use, and water use efficiency (WUE) of maize, lettuce, and garland chrysanthemum were investigated in a pot experiment. Plants were subjected to four irrigation levels, as follows: full irrigation as a control (RDI-100), 70% of full irrigation (RDI-70), 50% of full irrigation (RDI-50), and 30% of full irrigation (RDI-30). The WUE values of maize and lettuce were significantly higher with RDI-30 than other treatments, yet a significant reduction of WUE in garland chrysanthemum was detected compared to other treatments. There were significant correlations of WUE_i with WUE_{yield} and $WUE_{biomass}$ in maize plants, indicating that WUE_i can be a useful nondestructive estimator of yields and biomass contents in maize. Moreover, a significant correlation between WUE_i and WUE_{yield} in lettuce plants was observed. This index was correlated with economic production, and can be used to assess fresh weights and as an index of the irrigated water content. These results for evaluating water deficits in plants used nondestructive measurements that are applicable to large-scale water management of vegetable plants, thereby enabling scarce water resources to be conserved.

Key words: garland chrysanthemum (*Glebionis coronaria*), irrigation management, lettuce (*Lactuca sativa*), maize (*Zea mays*), water use efficiency

INTRODUCTION

Water stress is considered a predominant factor determining the global geographic distribution of vegetation and restrictions of crop yields in agriculture. However, effective management of cropping systems and irrigation water in the face of limited water resources will crucially depend on the ability to maximize crop water productivity rather than simply maximizing yields [Debaeke and Aboudrare 2004]. Irrigated agriculture currently delivers 40% of the world's food supply from just 20% of the cultivated land, and provides crucial stability for global food security [Garces-Restrepo et al. 2007]. Using water sparingly can be an efficient way to maintain the sustainability of water resources, increase productivity, and produce yield stability of cropping systems that may be a challenge due to expanding human populations and increased needs for food.

Regulated deficit irrigation (RDI) is an efficient water-saving irrigation technique, which tries to ensure an optimal crop water status in phenological phases

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most sensitive to water stress, and restrict irrigation in the most resistant crop phases [Costa et al. 2016, Marsal et al. 2016, Galindo et al. 2018]. It is particularly useful in areas where water is drastically restricted during summer months because of severe drought or priorities for urban uses [Fereres et al. 2012]. RDI has a great impact on the growth, development, yield, and quality of crops [Ji et al. 2015], and usually improves the water use efficiency (WUE) [Roccuzzo et al. 2014, Rop et al. 2016].

Irrigation of plants according to their water status can minimize irrigation water waste. Many types of physiological stresses occur when plants encounter a water deficiency. Variability in maize yields on account of soil water deficits is a function of severity and timing of water deficits, available soil water at planting, and effective rainfall and irrigation [Payero et al. 2009]. Soil water stress directly affects maize plants' ability to capture resources needed for photosynthesis and the efficiency with which they convert these physical resources into biological materials, i.e., biomass and grain yields [Yi et al. 2010], reduced dry biomass [Igbadun et al. 2008], plant height [Cakir 2004], leaf area (LA) index [Mansouri-Far et al. 2010], and grain yields [Djaman et al. 2013]. Furthermore, the effects of WUE on maize yields and yield components have also been discussed [Paredes et al. 2014, Kresovic et al. 2016].

The objectives of this study were to evaluate and compare the effects of various RDI values on yields, certain yield components, and the WUE of maize, lettuce, and garland chrysanthemum plants. WUE can be used to detect water-stressed areas of farms composed of a variety of crop species with contrasting phonologies [Chai et al. 2016]. The WUE variable can be used as a nondestructive estimation of yield and biomass accumulation if these indices are correlated with yield and biomass contents in leaves of tested plants. The long-term goal of our work is to help breed drought-tolerant maize, lettuce, and garland chrysanthemum varieties to be grown in extreme climates of Taiwan. The RDI with the WUE system may be useful when screening for drought-tolerant plants. Understanding and evaluating a plant's ability to cope with water stress in specific/localized environments will lead to better-informed decisions on the suitability of irrigation management practices.

MATERIALS AND METHODS

Seeds of maize (Zea mays var. 'Huachen'), lettuce (*Lactuca sativa* L. var. *capitata*), and garland chrysanthemum (*Glebionis coronaria* var. 'HV-255') were purchased from Known-You Seed Co. (Taipei, Taiwan). Seeds were germinated and grown on plastic plug trays (Blackmore, Belleville, MI, USA) with 72 cells per tray (112.5 cm^3 $cell^{-1}$) for 25 days after seedling (DAS). Seedlings were then transplanted into 30.0-cm plastic pots (14845.8 cm^3) for maize plants and 18.0-cm pots (3030.1 cm^3) for both lettuce and garland chrysanthemum plants, and grown in climate-controlled rooms at National Taiwan University (25°00'47.0" N 121°32'47.1" E) 111 days after transplantation (DAT) for maize, and 46 DAT for lettuce and garland chrysanthemum. The environment of these rooms was controlled to a 16/8-h day/night photoperiod at 26/22°C temperatures with a relative humidity of 85%, and 490 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux (PPF). Plants were grown for 3.5 weeks, and those with a uniform size were selected and randomly separated into different groups for the RDI experiments. The medium used was a commercial potting mix of peat moss and perlite (4:1 v/v). A 500X of fertilizer diluted rate to lettuce and garland chrysanthemum, and 250X to maize of a compound fertilizer solution (N-P_2O_5-K_2O, 20-20-20, Peters Professional, Uhrichsville, OH, USA) were applied once a week.

All plants were fully watered in the evening before beginning the experiment. Plants were then subjected to four irrigation levels differentiated by the amount of irrigation water applied during 50~85 days from the early vegetative stage until fruit maturity (maize) or plant harvest (lettuce and garland chrysanthemum). They included a full irrigation treatment (RDI-100, no water deficiency treatment) as the control, and three deficit irrigation treatments as follows: 70% of full irrigation (30% deficit, RDI-70, as mild deficit irrigation), 50% of full irrigation (50% deficit, RDI-50), and 30% of full irrigation (70% deficit, RDI-30, as severe deficit irrigation treatments). All plants were watered once a day in the late afternoon, and watered manually at 100% of the transpiration rate. Water amounts applied were based on the previous day's water used by the control treatment, which was estimated by weighing the pots every day. Pots were sealed in plastic bags fitted around the base of each plant stem to minimize soil evaporation [Wakrim et al. 2005]. Transpiration was calculated from the difference of pot weights between successive days. Irrigation treatments were arranged in a completely randomized design with six replicates.

Six plants of each species representative of each irrigation treatment were randomly selected to measure the following phenotypic traits and WUE at the end of the experimental period:

1. Leaf area (LA), as measured by a portable LAI-3000C Plant Canopy Analyzer (LI-COR; Lincoln, NE, USA) in plastic pots;

2. Plant height, measured as the height (cm) above the soil;

3. Root length (cm), measured as the longest main root under the soil surface;

4. Fresh weight of shoots and roots, measured as green shoot and roots, and clipped at the soil surface to assess biomass accumulation;

5. Dry weight of shoots and roots, measured as shoots and roots after drying in an oven at 70°C for 48 hrs;

6. Fresh and dry weights of maize, at harvest, the cobs from each plant were removed from the stalks and weighed as mentioned above; and

7. WUE parameters were calculated per treatment using the following formula:

(1) WUE_i [Fischer and Turner 1978] was evaluated by calculating the net photosynthetic rate ($\mu mol \cdot m^{-2} \cdot s^{-1}$) divided by transpiration ($mmol \cdot m^{-2} \cdot s^{-1}$).

Net photosynthetic rate ($\mu mol \cdot m^{-2} \cdot s^{-1}$) of the 2^{nd} or 3^{rd} mature and expanded leaves (with an LA of 3 cm^2) was determined using a portable photosynthesis system (GFS-3000,Walz, Germany) from 10:00 to 16:00 in a typical irrigation period on February 13, 2017 (maize and lettuce) and April 15, 2017 (garland chrysanthemum). The measurement was conducted in the above-mentioned environmentally controlled room at 25°C and 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for maize or 800 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for lettuce and garland chrysanthemum.

(2) WUE_{yield} [Shao et al. 2008] was calculated as the economic production (g) per treatment divided by the total irrigation water supplied liter (L).

(3) $WUE_{biomass}$ [Clifton-Brown and Lewandowski 2000] was calculated as the total dry weight (g) per treatment divided by the total irrigation water supplied liter (L).

Measurements of phenotypic traits were analyzed by a completely randomized analysis of variance (ANOVA) that compared the different irrigation treatments for each parameter of each species. For significant values, means were separated by the least significant difference (LSD) test at $p \leq 0.05$ using Costat 6.29 (CoHort Software, Berkeley, CA, USA). Correlation analyses were used to examine relationships among WUE_i, WUE_{yield}, and $WUE_{biomass}$ of each species.

RESULTS

Effects of irrigation on crop growth, yields, and water usage: Table 1 shows the effects of different levels of RDI on the average LA, lengths of ears and roots, fresh and dry weights per plant, and total water usage of the three crops. In general, there were no significant differences in any horticultural characteristics of maize among different RDI treatments and control (fully irrigated treatment RDI-100). Most leaves of maize appeared healthy and green under control and various RDI treatments (Fig. 1A). The total amount of water applied to control maize was 9 L. Compared to this amount, deficit treatments RDI-70, RDI-50, and RDI-30 respectively received 30% (6.3 L), 50% (4.5 L), and 70% (2.7 L) significantly less irrigation water.

However, the maximum LA (1310.93 cm^2) of lettuce was observed for the RDI-50 treatment, whereas the lowest maximum LA of 807.96 cm^2, a significant reduction of 39%, was observed in the RDI-30 treatment. The root lengths of lettuce among all treatments were relatively similar, ranging 12.58~14.50 cm. A significantly higher fresh shoot weight of lettuce (71.46 g per plant) was observed in the RDI-50 treatment than in the control (44.88 g per plant) and RDI-30 treatments (42.03 g per plant) (Table 1, Fig. 1B). Nevertheless, the fresh root weight did not significantly differ among all treatments. Total fresh weights of lettuce were significantly depressed in control (48.95 g per plant) and RDI-30 treatments (48.02 g per plant) compared to RDI-50 treatment (75.51 g per plant). Patterns of dry weights of lettuce in shoots, roots, and total were similar to those of fresh weights, where RDI-50 produced relatively higher shoot (2.40 g per plant) and total dry weights (3.52 g per plant) compared to the other treatments.

In garland chrysanthemum, following RDI application, LA gradually decreased in all treatments. There

Table 1. Effects of different levels of regulated deficit irrigation on the horticultural characteristics and toatal water usage of *Zea mays*, *Lactuca sativa*, and *Glebionis coronaria*

Irrigation treatments	Leaf area (cm^2)	Length (cm)		Fresh weight (g·per plant)				Dry weight (g·per plant)				Total water usage (liter)
		ear	root	ear	shoot	root	total	ear	shoot	root	total	
Zea mays 'Huachen'												
RDI 100	2502.57 a	14.75 a	26.67 a	147.25 a	133.84 a	50.69 a	330.51 a	30.49 a	30.46 a	8.38 a	69.33 a	9.00 a
RDI 70	2370.57 a	14.67 a	26.50 a	149.26 a	137.66 a	67.08 a	354.00 a	28.77 a	27.60 a	11.19 a	67.56 a	6.30 b
RDI 50	2493.55 a	14.17 a	27.00 a	155.81 a	120.44 a	82.72 a	349.31 a	34.50 a	31.37 a	12.24 a	72.16 a	4.50 c
RDI 30	2277.13 a	14.67 a	26.17 a	151.02 a	138.98 a	85.56 a	385.72 a	32.74 a	27.77 a	13.13 a	74.32 a	2.70 d
Lactuca sativa L. var. *capitata* L.												
RDI-100	850.13 b	–	12.67 a	–	44.88 b	4.07 a	48.95 b	–	1.64 b	0.23 a	1.87 b	1.49 a
RDI-70	1033.80 ab	–	13.58 a	–	57.01 ab	6.25 a	63.26 ab	–	2.27 ab	0.45 a	2.72 ab	1.04 b
RDI-50	1310.93 a	–	12.58 a	–	71.46 a	4.05 a	75.51 a	–	2.40 a	0.43 a	3.52 a	0.74 c
RDI-30	807.96 b	–	14.50 a	–	42.03 b	4.60 a	48.02 b	–	2.01 b	0.40 a	2.59 ab	0.46 d
Glebionis coronaria												
RDI-100	649.88 a	–	22.33 a	–	32.36 a	9.09 a	41.45 a	–	1.48 a	0.62 a	2.10 a	1.46 a
RDI-70	556.19 a	–	23.50 a	–	24.74 ab	6.99 ab	31.73 ab	–	1.13 a	0.42 ab	1.56 b	1.02 b
RDI-50	522.23 a	–	22.40 a	–	20.55 b	5.09 b	25.59 b	–	1.10 a	0.31 b	1.41 b	0.73 c
RDI-30	250.49 b	–	23.25 a	–	11.16 c	4.88 b	16.04 c	–	0.59 b	0.20 c	0.86 c	0.44 d

Means in the same column within treatments of each species followed by different letters are significantly different at $p \leqq 0.05$ by LSD.
RDI-100 is full (100%) irrigation. RDI70, RDI50, and RDI30 are deficit irrigation, 70%, 50%, and 30% of irrigation amount in RDI-100, respectively

was markedly lower LA expansion (250.49 cm^2) compared to other irrigation treatments with LA ranging 522.23~649.88 cm^2. Non-significant relations among treatments and root length of garland chrysanthemum were observed (Table 1, Fig. 1C), but irrigation treatments resulting in differences in fresh and dry weights of shoots and roots. In general, fresh and dry weights of shoots and roots in garland chrysanthemum decreased with decreasing water application, and RDI-30 treatment gave significantly lower total fresh (16.04 g per plant) and dry (0.86 g per plant) weights than the other treatments.

Effects of irrigation on crop WUE values: Table 2 presents results of WUE_i, WUE_{yield}, and $WUE_{biomass}$ of crops under different RDI treatments, and WUE in all crops increased with decreasing water application, except for WUE_i in garland chrysanthemum with RDI-30 treatment. WUE_i of maize was significantly higher in RDI-30 (19.77 mmol $CO_2 \cdot mol^{-1}$ H_2O) than the other RDI treatments and control, which ranged 7.76 to 13.8 mmol $CO_2 \cdot mol^{-1}$ H_2O. In lettuce, there were also significant differences of WUE_i among the irrigated treatments, where RDI-30 showed a significantly higher WUE_i value (20.66 mmol $CO_2 \cdot mol^{-1}$ H_2O) compared to the other treatments. Yet, a significant reduction in WUE_i (1.29 mmol $CO_2 \cdot mol^{-1}$ H_2O) in garland chrysanthemum was found in treatment that received 30% irrigation water. Significant higher WUE_i values were detected in lettuce (11.83~15.51 mmol $CO_2 \cdot mol^{-1}$ H_2O) than those in maize (7.76~13.18 mmol $CO_2 \cdot mol^{-1}$ H_2O) and garland chrysanthemum (3.41~3.75 mmol $CO_2 \cdot mol^{-1}$ H_2O) under control, RDI-70, RDI-50 treatments.

In all irrigation treatments, RDI-30 and RDI-100 displayed significantly higher and lower WUE_{yield} values in maize (59.70 g·L) and lettuce (30.12 g·L),

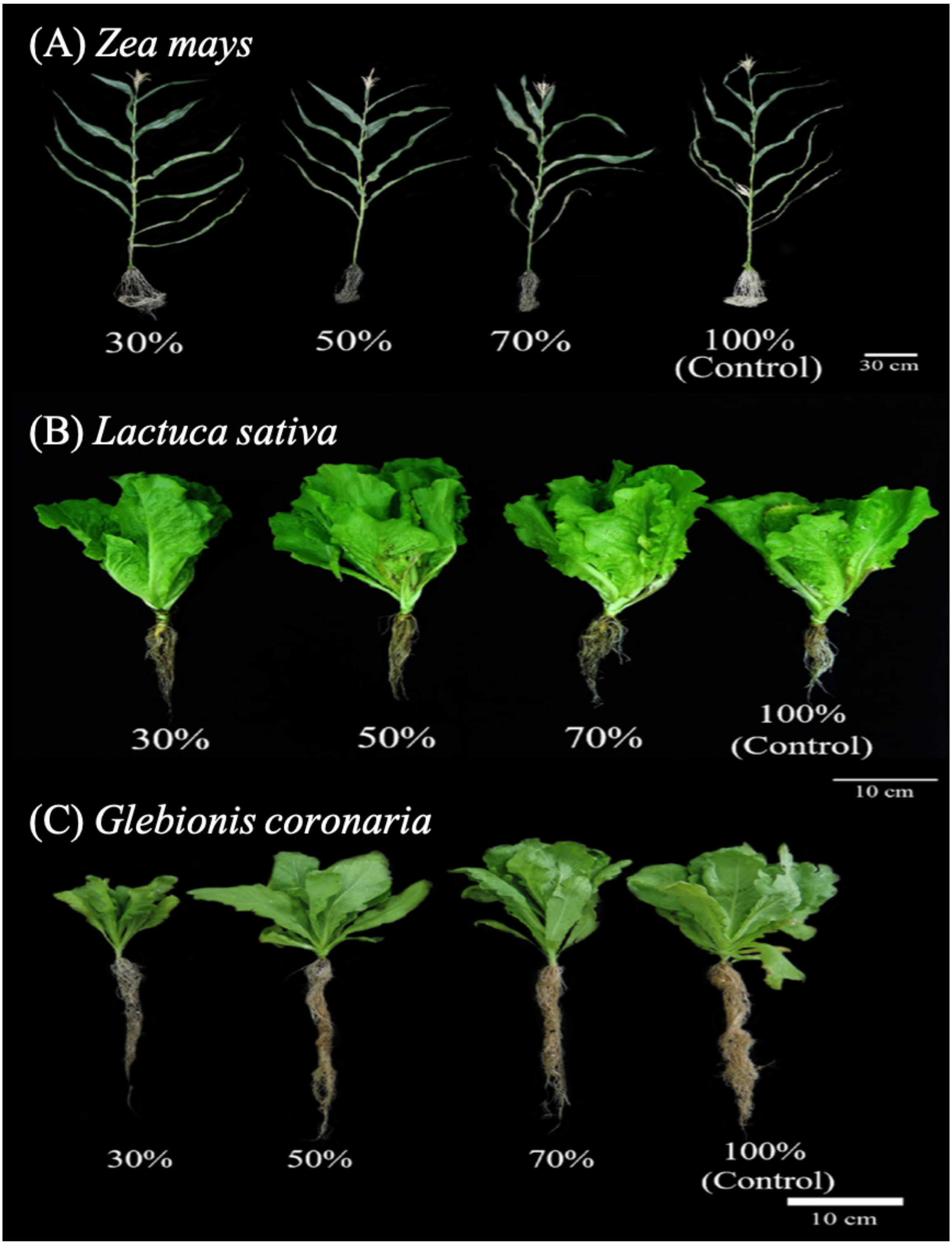

Fig. 1. Effect of different levels of regulated deficit irrigation on the appearance of (A) *Zea mays*, (B) *Lactuca sativa*, and (C) *Glebionis coronaria*

respectively. However, there were no marked differences in the WUE_{yield} of garland chrysanthemum (28.39~39.77 g·L) among the different treatments. Significantly higher WUE_{yield} values were detected in lettuce (30.12~104.41 g·L) than those in maize (16.36 ~ 59.70 g·L) under all treatments.

Values of $WUE_{biomass}$ in maize and lettuce were significantly higher in the RDI-50 (16.04 and 4.92 g·L, respectively) and RDI-30 treatments (27.53 and 5.70 g·L), respectively, compared to RDI-70 (10.72 and 2.62 $g \cdot m^{-3}$, respectively) and control treatments (7.70 and 1.26 g·L), respectively. There were no significant differences in $WUE_{biomass}$ values of garland chrysanthemum (1.44~2.96 g·L) among irrigation treatments. Maize with all water applications had significantly higher $WUE_{biomass}$ values (ranging 7.70~27.53 g·L) compared to those of lettuce (ranging 1.26~5.70 g·L) and garland chrysanthemum (ranging 1.44~2.96 $g \cdot m^{-3}$).

Relationship among WUE variables in crops: Table 3 illustrates the correlation between WUE_i of crops and their WUE (yield and biomass). Significant correlations of WUE_i with WUE_{yield} ($p < 0.001$) and $WUE_{biomass}$ ($p < 0.001$) were observed in maize. A significant correlation between WUE_i and WUE_{yield} ($p < 0.01$) was also obtained in lettuce, but insignificance was found between WUE_i and $WUE_{biomass}$. Furthermore, non-significant correlations were observed among WUE variables in garland chrysanthemum.

DISCUSSION

Adverse impacts of global climate changes on crop production are expected in the world's most important agricultural regions. Consequently, an appropriate choice of irrigation schedules to maximize WUE is needed. Water deficits resulted in varying severities of crop water stress among these RDI treatments, which produced yield and biomass reductions. None of the horticultural characteristics of maize among all RDI treatments significantly differed (Table 1), although there was a substantial difference in the amount of water applied. There were, however, significant differences in all WUE parameters among treatments (Table 2). A beneficial increase was found in WUE_i in the RDI-30 treatment, because the WUE_i significantly increased as a consequence of lower crop transpiration in the RDI-30 treatment compared to other treatments. This increase in WUE_i under RDI-30 compared to other treatments may have been related to the decreased leaf area and its effect on the net photosynthesis-to-crop transpiration ratio. These results suggest that the effect of RDI on maize growth and development may be mitigated with adequate timing of water application during the flowering stage, and the timing of water application had a greater impact on the growth and development of maize than the amount of water applied [Greaves and Wang 2017]. Many studies reported that moderate water deficits from

Table 2. Water use efficiency (WUE_i, WUE_{yield}, $WUE_{biomass}$) of *Zea mays*, *Lactuca sativa*, and *Glebionis coronaria* under different regulated deficit irrigation treatments

Irrigation treatments	WUE_i (mmol $CO_2 \cdot mol^{-1}$ H_2O)			WUE_{yield} ($g \cdot m^{-3}$)			$WUE_{biomass}$ ($g \cdot m^{-3}$)		
Crops	*Zea mays* 'Huachen'	*Lactuca sativa* L. var. *capitata* L.	*Glebionis coronaria*	*Zea mays* 'Huachen'	*Lactuca sativa* L. var. *capitata* L.	*Glebionis coronaria*	*Zea mays* 'Huachen'	*Lactuca sativa* L. var. *capitata* L.	*Glebionis coronaria*
RDI 100	7.76 cB	11.83 cA	3.41 aC	16.36 dB	30.12 cA	28.39 aA	7.70 cA	1.26 cA	1.44 aB
RDI 70	7.93 cB	11.98 cA	3.62 aC	23.69 cC	54.82 bA	31.10 aB	10.72 cA	2.62 bA	1.52 aB
RDI 50	13.18 bB	15.51 bA	3.75 aC	32.48 bB	96.57 aA	36.77 aB	16.04 bA	4.92 aA	2.05 aC
RDI 30	19.77 aA	20.66 aA	1.29 bC	59.70 aB	104.41 aA	39.45 aC	27.53 aA	5.70 aA	2.96 aB

Means in the same column within four irrigation treatment followed by different small letters are significantly different at $p \leqq 0.05$ by LSD.
Means in the same row within treatments in three species followed by different capital letters are significantly different at $P \leqq 0.05$ by LSD.
RDI-100 is full (100%) irrigation. RDI70, RDI50, and RDI30 are deficit irrigation, 70%, 50%, and 30% of irrigation amount in RDI-100, respectively

evapotranspiration do not seem to decrease yields of maize, and only mild reductions occur with even higher water deficits [El-Hendawy and Schmidhalter 2010, Sampathkumar et al. 2012]. Moreover, Meena et al. [2019] illustrated that initial crop establishment requires limited water, and application of less irrigation in the early stages may be adopted as a general practice to avoid excessive irrigation during initial crop growth stages. Therefore, our results can be used to explore whether the RDI method can save water and at the same time benefit maize more than regular irrigation, thus providing fundamental research and a reference point for irrigation management decisions in agriculture in semi-arid areas under water limitations in the future.

Different crops may prepare for water-stress damage by RDI and the WUE. The water stress level influences the growth and morphology of these crops, and RDI and the WUE can be used to optimize the growth and development of plants in water-controlled settings. In lettuce, the shoot weight was affected more than the root length and weight under various irrigation treatments. Compared to the control, mild deficit irrigation (50% of full irrigation amount, RDI-50) significantly increased WUE_{yield} (96.57 g·L) and $WUE_{biomass}$ (4.92 g·L), and greatly with improved LA (1310.93 cm^2), total fresh weight (75.51 g), and dry weight (3.52 g) of lettuce. Since the total water used by transpiration was reduced by half in both water-deficit treatments, these plants had a significant higher WUE than the control.

Deficit irrigation can save up to 50% of irrigation water, and it is possible to maintain relatively high lettuce yields when employing 50% deficit irrigation as a water management strategy. However, judicious planning is required so that water deficits are minimized in critical growth stages, and best management practices for localized conditions are identified. Furthermore, the increase in WUE_i was a result of a larger decline in plant transpiration due to a reduced LA as a consequence of water deficits. In garland chrysanthemum, higher values of WUE_i were obtained when at least 50% of full irrigation (RDI-50) was scheduled. The LA decreased with decreased water application, and this reduction in treatment LA (250.49 cm^2) relative to RDI-30 was an influential factor in these treatments having a lower WUE_i (1.29 mmol $CO_2 \cdot mol^{-1}$ H_2O). Farré and Faci [2009] noted that leaf expansion is usually the first process affected by water deficits. Deficient irrigation also reduced fresh and dry weights of garland chrysanthemum. Although both lettuce and garland chrysanthemum are C3 plants, lettuce displayed significantly higher WUE_i and WUE_{yield} values under all limited water treatments (Table 2). Chen et al. [2019] and Michelon et al. [2020] have shown that lettuce (*Lactuca sativa*) displayed higher WUE yield under the water deficit irrigation treatments with plastic or rice straw covered.

From our observations, the leaves and roots of garland chrysanthemum and lettuce looked epinastic and senescent after RDI-30 treatment compared to the other treatments (Fig. 1B, C). Drought stress had a harmful effect on leaves of both species, and some of the damage was irreversible once drought injury occurred. The trends and rates of the decreases in leaves and roots under RDI stress differed between the two species. The leaves and roots of garland chrysanthemum obviously decreased, and chlorosis of the plants increased during RDI-50 and RDI-30 conditions, indicating that water relationships of all tested plants were affected during water stress periods. However, the leaves, roots, and total fresh and dry weights of lettuce under the RDI-50 treatment showed relatively higher contents than other treatments, and significant drought injury was evident from the appearance of the leaves and roots of lettuce plants subjected to RDI-30. In maize, lesser extents of drought injury during all RDI treatments (Fig. 1A) seemed to be a result of water saving by these plants. Water saving is also linked to saving of electricity used for operating tube wells. Irrigation scheduling allows for maximizing crop yields and efficiently using scarce water resources. In the case of an insufficient natural water supply, use of deficit irrigation in dry land conditions is recommended.

Restrictions placed on water use by farmers have prompted the development of irrigation management projects aimed at water savings of economically important crops. This research focused on RDI to aid in the development of effective irrigation management strategies to improve agricultural water use for irrigated crop production. Values presented in Table 2 show that WUE_{yield} values were higher than WUE_i and $WUE_{biomass}$ values in each species. Essentially, as all WUE variables are functions of the yield, the higher water productivity variable depends on how much of the total water used is supplied by supplemental irrigation. Farré and Faci [2009] reported that the yield vs. irrigation water applied to maize is economically more important as a fraction of the WUE which comes from sources other than irrigation (i.e., stored soil water and effective rainfall). Greavesa and Wang [2017] also demonstrated that irrigation water applied to maize did not provide all of the crop water used resulting in irrigation WUE values were higher compared to WUE values. Using deficit irrigation reduces water usage without significant yield losses, while maintaining relatively high WUE values and supporting the sustainability of agriculture in the southern part of Taiwan. These WUE variables are also useful in screening for drought-tolerant plants, and different water stress culture systems can achieve production of commercial species by utilizing rapid, large-scale, precise management practices.

WUE_{yield} and $WUE_{biomass}$ are measured by destructive testing, and damage to plants make further experiments impossible. Instead, using WUE_i as an irrigation indicator provides guidance as to the best timing for irrigating crops in order to prevent or mitigate water stress. Table 3 demonstrates the impacts of the WUE and irrigation on yields and biomass procured at harvest in various crops. Significant correlations were observed among the maize yield, biomass, and WUE_i, suggesting that yield and biomass accumulation will be reduced as either the WUE_i or irrigation water application decreases, irrespective of the growth stage of the water deficit. WUE_i is suitable for selecting maize cultivars with high yields and biomass potential under an RDI-30 condition. These relations are beneficial in water management applications for assessing the benefits of irrigation and evaluating irrigation strategies. Agricultural water used to irrigate maize on a level basin surface can be improved, and it is possible to maintain relatively high maize yields when employing deficit irrigation as a water management strategy. In lettuce, a significant correlation was observed between the yield and WUE_i, indicating that the yield is highly dependent on water availability and water use. The economic production of maize, lettuce, and garland chrysanthemum can be used to assess fresh weights and as an index for irrigated water contents, and significant savings in water used and increases in water use efficiency were seen with the RDI-70 and

Table 3. Correlation between WUE_i, $WUE_{yield,}$ and $WUE_{biomass}$ in different species under regulated deficit irrigation

	Zea mays	
WUE_i vs	correlation equation	R^2 value
relative WUE_{yield}	$y = 0.0861x^2 + 0.4891x + 12.122$	$R^2 = 0.8476$***
relative $WUE_{biomass}$	$y = -0.0069x^2 + 1.4377x – 0.8228$	$R^2 = 0.8207$***
	Lactuca sativa	
WUE_i vs	correlation equation	R^2 value
relative WUE_{yield}	$y = 0.4003x^2 – 5.2071x + 55.468$	$R^2 = 0.7514$**
relative $WUE_{biomass}$	$y = 0.0087x^2 + 0.0656x + 0.6547$	$R^2 = 0.5784$
	Glebionis coronaria	
WUE_i vs	correlation equation	R^2 value
relative WUE_{yield}	$y = -1.2057x^2 + 12.546x + 11.115$	$R^2 = 0.4228$
relative $WUE_{biomass}$	$y = 0.1569x^2 – 1.0708x + 3.1563$	$R^2 = 0.4263$

** $p < 0.01$; *** $p < 0.001$

RDI-50 treatments. These relations are beneficial for water management applications for assessing the benefits of irrigation and/or evaluating irrigation strategies, and offer opportunities for farmers to improve their agricultural water footprint, without incurring too much risk in profits and without making inter-seasonal adjustments to water applications regarding growth stages. This method will be more widely applicable, *i.e.*, to situations where soil water characteristic data are not available, and where agro-metrological data are not timely or readily available for estimating irrigation requirements based on crop transpiration.

CONCLUSIONS

The most effective RDI strategy for maize was RDI-30 treatment which showed the highest WUE rate and maintained the similar yield compared to the other RDI treatments. However, a higher yield and better WUE of lettuce were observed in the RDI-50 treatment than the other RDI treatments. Garland chrysanthemum under RDI-70 treatment displayed the result that corresponded to improving the WUE and maintaining the yield compared to the other RDI treatments. RDI and the WUE affected yields and yield components of maize, lettuce, and garland chrysanthemum, indicating that irrigation is strongly required for crop cultivation. RDI treatments significantly affected the LA and fresh and dry weights compared to the control, especially in the RDI-50 and RDI-100 approaches, and may be a good strategy for increasing the WUEs of lettuce and garland chrysanthemum, respectively. In addition, significant correlations among WUE (yields, biomass) and WUE_i in maize were developed. Therefore, WUE_i is more comprehensively applicable to nondestructively estimate yield and biomass contents of plants and can indicate the water usage capacity. The study provides information for field management practices in areas where water-saving irrigation is needed for crop production. Our results can help regional growers save water in maize, lettuce, and garland chrysanthemum cultivation through the choice of appropriate irrigation schedules.

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