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Enhanced Forage Yield and Water Productivity with Cereal-Legume Mixed Cropping and Deficit Irrigation under Arid Conditions

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ABSTRACT

Background: The increasing demand for food and feed necessitates the adoption of suitable crop production practices to enhance production while ensuring sustainability and conservation of scarce natural resources under the harsh environmental conditions in arid and semiarid regions. The mixed cropping of cereals and legumes is a critical component in sustainable agricultural system with improved forage yield. In addition, forage production with improved water use efficiency is vital in arid regions with limited irrigation water resources. The study investigated the combined effect of cereal-legume (barley-alfalfa) mixed cropping and deficit irrigation on the forage growth, dry matter yield and water productivity.

Methods: The experiment was conducted at the KISR Station for Research and Innovation, Kuwait. Barley was mixed cropped with alfalfa in three different seed rate combinations (1:3, 1:1, 3:1) in addition to the sole cropping of component crops under three different irrigation regimes, corresponding to full irrigation (100% ET_0) and two deficit irrigation (75% and 50% ET_0 of full irrigation) for two growing seasons (2017-2018 and 2018-2019).

Result: The barley-alfalfa mixed cropping under deficit irrigation enhanced water productivity and dry matter yield under arid environmental conditions. The plant height, number of tillers per meter square, number of nodes, dry matter yield and water productivity were significantly affected by irrigation application rates. The mixed cropping of barley and alfalfa in 1:1 followed by 1:3 seed rate ratio and sole cropping of alfalfa under 75% irrigation revealed better performance in terms of dry matter yield and water productivity.

Key words: Cereal-legume, Deficit irrigation, Mixed cropping, Water productivity.

INTRODUCTION

Rapidly growing population, urbanization and increasing living standard will increase global meat and dairy consumption by 73 and 58 per cent respectively over the current level by 2050 (Anonymous, 2011). Presently in Kuwait, large quantities of forages are being imported from different countries. In arid and semiarid regions, irrigation is a major contributor to food production where it covers 16% of cultivated land and accounts for 36% of global harvest (Anonymous, 2013). Dry matter yield per m^3 of water applied or consumed by the crop (water productivity) is one of the most critical factors for evaluating field crops for enhanced forage production in the arid and semiarid regions (Johnson and Henderson, 2002). Previous studies have reported that cereal-legume mixed cropping facilitates sustainable intensification as it makes better use of available water and nutrients with increased dry matter (DM) yield and forage quality ensuring financial stability (Kholgi *et al*., 2014; Mosebi *et al*., 2018). In addition, studies were conducted to compare the yield and water productivity of different genotypes of barley and alfalfa separately with the objective to select the best genotypes adaptable to local climatic conditions (Al- Menaie, 2013). The effect of different irrigation regimes on the growth and yield performance of barley as well as alfalfa crops was also carried out as individual crops was also evaluated (Al-Menaie, 2003; Al-Menaie *et al*., 2004). However, limited information is available on the performance of mixed cropping of alfalfa and barley using freshwater as well as its optimal irrigation regime in Kuwait as cereal legume mixed cropping is not a common way of farming in Kuwait. Thus the present study was conducted with a hypothesis that mixed cropping with deficit irrigation gives higher yields with maximum water productivity compared to sole cropping. In this regard, the growth, yield and water productivity of barley and alfalfa

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crops were determined in pure stands as well as in mixtures under different seed rate combinations and irrigation applications under Kuwait's environmental conditions.

MATERIALS AND METHODS

The study was conducted at KISR Station for Research and Innovation-KSRI, Kuwait using barley (Kuwait 2 variety) and alfalfa (var. Hejazi) as component crops. The physical and chemical analysis of soil was carried out according to previously established protocols (Schoeneberger *et al.*, 2012; Anonymous, 2017). The irrigation water was analyzed for electrical conductivity to determine water salinity using calibrated EC meter and the pH was measured using a pH meter calibrated with pH buffer solutions of pH 7 and pH 9 (Anonymous, 2014).

The recommended seeding rates for barley and alfalfa were 95 and 40 kg ha^{-1} respectively. For mixed cropping treatments, the legume component alfalfa was mixed with barley constituting 1:3, 1:1 and 3:1 proportions of barley seeding rate of 95 kg/ha in the plots. In addition, both barley and alfalfa were planted solely for comparison. Five treatments were tested in the experiment using a split plot design for two growing seasons (2017-2018 and 2018-2019). T1 [sole cropping of alfalfa (40 kg ha^{-1})], T2 [1B:3A mixed cropping of barley (23.75 kg ha^{-1}) and alfalfa (71.25 kg ha^{-1})], T3 [1B:1A mixed cropping of barley (47.5 kg ha^{-1}) and alfalfa (47.5 kg ha^{-1})], T4 [3B:1A mixed cropping of barley (71.25 kg ha^{-1}) and alfalfa (23.75 kg ha^{-1})] and T5 [sole cropping of barley (95 kg ha^{-1})]. The seeds were sown in broadcasting method within a plot area of 21 m^2 for each of the five different treatments. Each treatment was triplicated. The first cut covered the period from germination on 21 November 2017 to 4th March 2018, a period of 104 days. Following the first cut, the crop grew again for 28 days until the second cut on 1st April 2018. The total ET_0 as well as irrigation water applied during the period from germination to first cut and from first cut to second cut during this period is shown in Table 1. During both the growing seasons, the first cut of alfalfa was made at its late bud to the first flowering stage, while barley was cut in the advanced tillering stage. A sprinkler irrigation system with an automatic timer was used to irrigate the experimental plots. The full irrigation volume was determined from the estimation of evapotranspiration (ET) based on weather data (Allen *et al.*, 1998). The flow rate was adjusted to irrigate the plots at 50, 75 and 100% ET_0 using freshwater. Nitrogen, phosphorous and potassium fertilizers were added using the broadcasting method. Phosphorous in the form of single superphosphate (15.5% P_2O_5) at the rate of 60 kg P_2O_5 ha^{-1} and organic manure at the rate of 4 t ha^{-1} were applied at the land preparation stage. Potassium in the form of potassium sulphate (45.5% K_2O) at the rate of 100 kg K_2O ha^{-1} was applied in two equal doses during tillering and heading stages. For both seasons, the nitrogen was added as urea (46% N) at the rate of 20 kg N ha^{-1} at the seedling establishment stage and after each cutting.

Various growth and yield attributes of the component crops such as plant height, the number of shoots per meter square, the number of nodes, dry matter yield and water productivity were recorded in all the treatments. The results were presented as the average of two seasons in a series of tables for five treatments under 100, 75 and 50% ET_0 irrigation regimes for the first and second cuts. The 1000 grams of fresh plants were oven-dried at 70°C to constant weight for 72 h to determine the dry matter yield using standard calculation procedures (Castellanos-Navarrete, 2013). The dry matter yield for mixed cropping treatments, was determined by combining alfalfa and barley forage collected during the cut. The water productivity was calculated by dividing the plant DM yield in kg/m^3 of water used. Multifactor analysis of variance was performed to determine any significant difference in the mean values of the dependent variable under different irrigation as well as cropping treatments using Statistical Package for Social Sciences (SPSS) software. Treatments displaying significant differences were subjected to Duncan's multiple range test (DMRT) for mean separation at a 95% confidence level.

RESULTS AND DISCUSSION

Soil analysis

The soil was analyzed for physico-chemical properties up to a depth of 120 cm and corresponding data are presented in Table 2. The soil at the experimental site at all three depths was classified as sandy textures (Anonymous, 2017). The soil profile was described using the standards of USDA-NRCS (Anonymous, 2014). The soil taxa compared with the results from the soil survey of Kuwait (Anonymous, 1999a and 1999b) was correlated to the recently published Kuwait soil taxonomy (Shahid and Omar, 2022) as Typic torripsamments, mixed hyperthermic. The pH, electrical conductivity and total dissolved solids of the water used for irrigation were noted as 7.93, 234 µS cm^{-1} and 129 mg l^{-1}, respectively. The irrigation water was low in salinity (C1) as per the US Salinity Lab Staff classification (Zaman *et al.*, 2018). The low salinity water can be used for irrigation of most crops on most of the soils with little likelihood of developing soil salinity. In addition, the phosphate, nitrite

Table 1: Evapotranspiration and irrigation volume during the growth period.

	First cut		Second cut	
	Total ET_0 (mm)	Irrigation (m^3 ha^{-1})	Total ET_0 (mm)	Irrigation (m^3 ha^{-1})
First cut	405.6	4056	232	2320 m^3
Second cut	194	1940	142	1420

and nitrate contents in the irrigation water were recorded as < 0.1, <1.0 and 2.0 mg l^{-1}, respectively.

Effect of irrigation and mixed cropping on plant height

Irrigation imposed a significant effect on alfalfa shoot length in all the cropping treatments for the first cut. The T1, T2, T3 and T4 have shown the highest alfalfa height with irrigation at 100% ET_0 which however was on par with 75% irrigation (Table 3). In the second cut too, alfalfa height did not display any significant difference between 100% and 75% ET_0 irrigation treatments except for T2 which noted higher value with 75% ET_0. In case of barley, the plant height in T2 and T4 differed significantly between the irrigation regimes during the first cut in which 100% ET_0 irrigation increased the barley height by more than 25% when compared to 50% ET_0 irrigated crops (Table 3). Similarly, 100% ET_0 irrigation presented the highest barley height in the second cut also for all the treatments with a significant effect of irrigation on T3 and T4 cropping treatments.

Effect of irrigation levels and mixed cropping on the number of nodes per plant

The number of nodes per plant in alfalfa did not vary significantly between the irrigation levels both in the first and second cuts for any of the treatments, except T2 in the first cut which noted highest value under 75% ET_0 irrigation (Table 4). In contrast, the number of nodes in barley differed significantly between the irrigation levels in T2, T3 and T4 at first cut (Table 4). All the treatments recorded 5 number of nodes for barley under 75 and 50% ET_0. In the second cut, a significant difference was noted only for T2 displaying higher number of nodes with 100% ET_0. It was noted that irrigation at 75% and 50% ET_0 displayed the greatest number of nodes per plant for both alfalfa and barley in the first cut when compared to 100% ET_0 irrigation level.

Effect of irrigation and mixed cropping on the total number of shoots per square meter

The results of the first cut revealed the highest number of shoots with 100% ET_0 irrigation, although a significant difference between the three irrigation levels was noted only for T2 and T4. Alfalfa presented abundant shoots in comparison to barley in all of the cropping treatments with 100% ET_0 irrigation indicating legume was more competitive than barley in the mixtures (Table 5). Similarly, the second cut also revealed the highest total number of shoots at 100% ET_0 irrigation level except under T3, even

Table 2: Soil analysis.

	Parameters	Sample depth (cm) 0 to 30	30 to 60	60 to 90	90 to 120
	pHs	7.5	7.5	7.6	7.6
	EC_e (dS m^{-1})	3.30	2.13	3.26	3.07
	TDS (mg l^{-1})	2112.0	1363.2	2086.4	1964.8
Cations (mg/kg)	Ca^{+2}	107.03	88.18	152.46	119.13
	Mg^{+2}	13.30	13.15	22.51	40.16
	K^+	15.23	17.16	22.42	8.35
	Na^+	74.58	15.87	9.79	9.56
Anions (mg/kg)	Cl^{-1}	154.29	26.28	25.77	18.37
	CO_3^-	<10	<10	<10	<10
	HCO_3^-	98.99	33.59	15.40	12.48
	NO_3^-	1.60	3.60	1.60	1.20
	NO_2^-	0.52	0.84	0.80	0.80
	PO_4^{-3}	20.00	76.00	16.00	<10

EC_e: Electrical conductivity of extract from saturated soil paste; pHs (pH of saturated soil paste).

Table 3: Plant height (cm) of Alfalfa and Barley under different irrigation and cropping treatments.

Treatments	Alfalfa					Barley				
	First cut			Second cut		First cut			Second cut	
	100% Irrigation	75% Irrigation	50% Irrigation	100% Irrigation	75% irrigation	100% Irrigation	75% Irrigation	50% Irrigation	100% Irrigation	75% irrigation
T1 (Alfalfa)	52.00^b	48.67^b	28.33^a	44.67^a	52.00^a					
T2 (1B:3A)	54.00^b	53.33^b	38.00^a	42.33^a	54.00^b	66.33^b	61.00^b	49.67^a	36.67^a	31.00^a
T3 (1B:1A)	53.00^b	45.00^b	32.67^a	40.33^a	53.00^a	66.67^a	67.00^a	49.00^a	41.67^b	29.67^a
T4 (3B:1A)	55.00^b	53.33^b	32.33^a	38.33^a	55.00^a	65.67^b	58.67^{ab}	44.00^a	40.33^b	29.67^a
T5 (Barley)						63.00^a	55.33^a	63.00^a	46.00^a	42.67^a
Mean	53.50	50.08	32.83	41.42	53.50	65.42	60.50	51.42	41.17	33.25

a, b, c: values with different superscripts in each row in each subsection were significantly different (p≤0.05).

though the number of tillers did not differ significantly between the irrigation treatments in any of the mixed cropping treatments (Table 5).

Effect of irrigation and mixed cropping on the total dry matter yield

Dry biomass yield in response to mixed cropping and irrigation levels reported highest dry matter yield under deficit irrigation (50% ET_0) for T2, T3 and T5 in the first cut, even though significant differences were noted only in T2 and T5. In contrast, the T1 and T4 presented the highest dry matter yield with a 100% ET_0 irrigation level. In the second cut, T1, T2 and T4 recorded the highest dry matter yield with a 100% ET_0 irrigation level, whereas T3 and T5 presented the highest values with a 75% irrigation level (Table 6).

Effect of irrigation and mixed cropping on water productivity

The water productivity at first cut was significantly higher ($p<0.000$) with 50% ET_0 (Fig 1). While, there was no significant difference in water productivity between the 75 and 100 % ET_0 irrigation levels. Higher water productivity during second cut was displayed at 75% ET_0, however it did not differ significantly from 100% ET_0. But the 50% ET_0 irrigation level did not give any yield at second cut showing zero water productivity (Fig 2). The cropping treatments (T2 and T5) registered higher water productivity ($p<0.05$) with 50% ET_0 when compared to 75% and 100% ET_0 in the first cut. At the second cut, the highest water productivity was reported by T2, T3 and T5 irrigated at 75% ET_0 which however remained on par to 100% ET_0 (Fig 1 and 2).

The mixed cropping treatments (T2 and T3) as well as sole cropping of barley presented an increase in the dry matter yield under deficit irrigation (50% ET_0). Generally, the reduced availability of water decreases the yield. Similarly, deficit irrigation recorded increased crop water productivity in the first and second cuts, which however, was higher in the second than the first cut (Fig 1 and 2). This is likely because the crop has to develop from planting during the first cut in terms of the canopy cover, root system and tillers, while during the second cut these were already developed. The increased yield and crop water productivity under deficit irrigation can be attributed to the several mechanisms which includes increased root biomass which improves the nutrient and water uptake (Li *et al*., 2013) and resilience of the genetic material of the variety to water stress. The stress induced acclimatization process includes narrowing of the stomata opening that decrease the transpiration loss upon enhanced guard cell signal transduction network, promote higher osmotic adjustment, enhance leaf water retention and improve photosynthesis to transpiration rate which eventually improves water use efficiency and water productivity (Neal *et al*., 2011; Griffin *et al*., 2004). In addition, the adaptation also depends on the duration of the deficit cycle, in drought conditions

Table 4: Number of nodes in Alfalfa and Barley under different irrigation and cropping treatments.

Treatments	Alfalfa					Barley				
	First cut			Second cut		First cut			Second cut	
	100% Irrigation	75% Irrigation	50% Irrigation	100% Irrigation	75% irrigation	100% Irrigation	75% Irrigation	50% Irrigation	100% Irrigation	75% irrigation
T1 (Alfalfa)	8.00[a]	11.00[a]	8.00[a]	9.00[a]	8.00[a]					
T2 (1B:3A)	7.00[a]	10.00[b]	9.00[b]	8.00[a]	9.00[a]	3.00[a]	5.00[b]	5.00[b]	3.00[b]	2.00[a]
T3 (1B:1A)	7.00[a]	9.00[a]	9.00[a]	8.00[a]	8.00[a]	4.00[a]	5.00[b]	5.00[b]	4.00[a]	3.00[a]
T4 (3B:1A)	7.00[a]	8.00[a]	9.00[a]	9.00[a]	7.00[a]	4.00[a]	5.00[b]	5.00[b]	3.00[a]	3.00[a]
T5 (Barley)						4.00[a]	4.00[a]	5.00[a]	4.00[a]	3.00[a]
Mean	7.00	10.00	9.00	9.00	8.00	4.00	5.00	5.00	4.00	3.00

a, b, c: values with different superscripts in each row in each subsection were significantly different ($p \le 0.05$).

Table 5: Total number of shoots/m^2, total number of Alfalfa shoots/m^2, total number of Barley tillers/m^2 under different irrigation and cropping treatments.

Treatment	Total number of shoots/m^2					Total number of Alfalfa shoots/m^2					Total number of Barley tillers/m^2				
	First cut			Second cut		First cut			Second cut		First cut			Second cut	
	100% ET_0	75% ET_0	50% ET_0	100% ET_0	75% ET_0	100% ET_0	75% ET_0	50% ET_0	100% ET_0	75% ET_0	100% ET_0	75% ET_0	50% ET_0	100% ET_0	75% ET_0
T1 (Alfalfa)	542[a]	405[a]	490[a]	481[a]	337[a]	542[a]	405[a]	490[a]	481[a]	337[a]					
T2 (1B:3A)	521[b]	405[a]	397[a]	374[a]	308[a]	424[a]	410[a]	294[a]	350[a]	301[a]	97[a]	21[a]	102[a]	24[a]	7[a]
T3 (1B:1A)	447[a]	332[a]	382[a]	300[a]	333[a]	312[a]	265[a]	211[a]	263[a]	321[a]	134[a]	67[a]	171[a]	37[a]	12[a]
T4 (3B:1A)	467[b]	309[a]	398[b]	355[a]	286[a]	251[a]	234[a]	164[a]	294[a]	256[a]	216[a]	74[a]	234[a]	61[a]	30[a]
T5 (Barley)	306[a]	250[a]	296[a]	166[a]	107[a]						306[a]	250[a]	296[a]	166[a]	107[a]
Mean	457	340	393	335	274	382	329	290	347	304	188	103	201	72	39

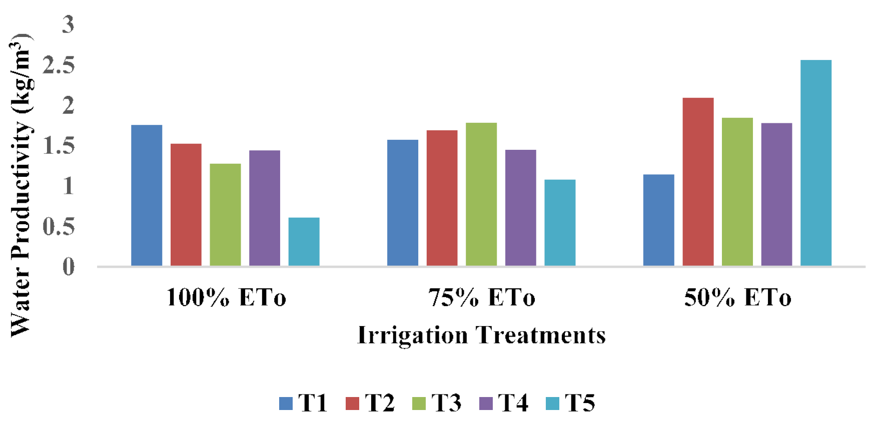
(Chaves *et al*., 2002, 2003) which is not the case in the present study, where irrigation was done on daily basis, therefore, the severity of the drought is overruled. However, at high level of irrigation, the water is likely to be lost through the high infiltration rate of sandy soil. Thus optimized regulated deficit irrigation was recommended in areas with a low amount of irrigation water. A former study conducted on barley reported highest water use efficiency of the crops under 50% full irrigation (Tabarzad *et al*., 2016). Likewise, several previous studies have reported the positive effect of limited irrigation on the yield and WUE of crops (Pardo *et al*., 2020; Kang *et al*., 2000; Djaman *et al*., 2020a). In contrast to barley, the sole cropping of alfalfa performed best with 100% ET_0 in the present study due to the high water requirement of alfalfa (Djaman *et al*., 2020b; Guo *et al*., 2007). It has been reported that the relationship between relative evapotranspiration and available water is different for alfalfa and barley (Abdul-Jabbar *et al*., 1983). Several other studies have reported a linear response between irrigation levels and alfalfa yield (Li *et al*., 2017; Li and Su, 2017; Arshad *et al.,* 2017).

Thus, water limited conditions were shown to improve yield and crop water productivity in mixed cropping treatments (T2 and T3). However, treatment T4 did not present any significant difference between the irrigation treatments. Several previous studies have noted that a mixed cropping system reduces runoff, conserves soil moisture and improves water use efficiency (Fan *et al*., 2012; Tanwar *et al*., 2014). The different root structures of alfalfa and barley, in this study have facilitated soil water sharing (Chen *et al.,* 2018) and improved water productivity. The improved nitrogen fixation of the legume component (Li *et al*., 2016), alfalfa in this study, has led to enhanced complementary growth of the cereal (barley in this study) that resulted in increased yield. Moreover, the temporal niche differentiation between the intercrops promotes nutrient uptake and nutrient use efficiency in cereal-legume mixed cropping (Li *et al*., 2011). Several previous studies noted higher yield and WUE under the intercropping system when compared to monoculture (Franco *et al*., 2018). In contrast, other studies recorded higher grain yield with 100% ET_c irrigation (El-Sherif and Ali, 2015). From an irrigation perspective, there would be no value in producing a second harvest if only 50% ET_0 irrigation is applied. However, if a second harvest is required, it should be irrigated at the 75% ET_0 level to produce yield and to maintain good water productivity. Irrigating the second cut at the 100% ET_0 level has not shown a significant change in water productivity when compared to 75% ET_0. The crop

Table 6: Combined dry matter yield (kg/ha) of Alfalfa and Barley under different irrigation and cropping treatments.

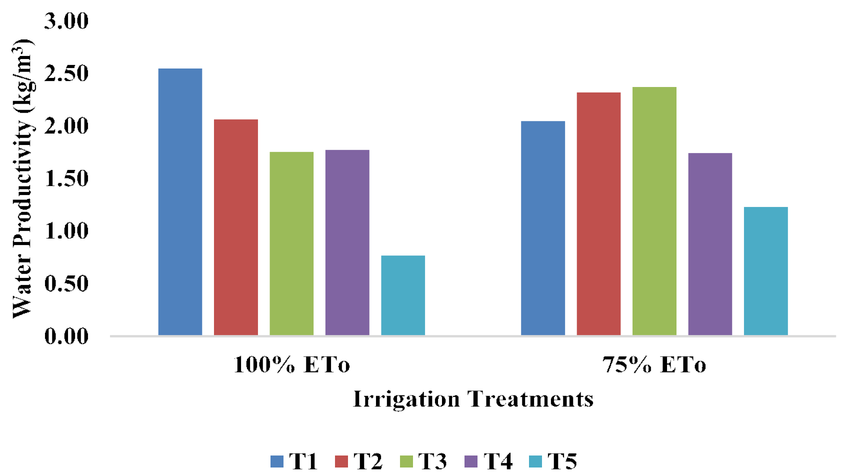
Treatments	Dry matter yield				
	First cut			Second cut	
	100% Irrigation	75% Irrigation	50% Irrigation	100% Irrigation	75% Irrigation
T1 (Alfalfa)	3909[a]	3339[a]	2312[a]	4945[b]	2979[a]
T2 (1B:3A)	3990[b]	3219[a]	4233[b]	4005[a]	3378[a]
T3 (1B:1A)	3238[a]	3623[a]	3730[a]	2310[a]	3453[b]
T4 (3B:1A)	4486[a]	3504[a]	3599[a]	3440[a]	2537[a]
T5 (Barley)	1816[a]	2813[a]	5180[b]	1490[a]	1790[a]
Mean	3488	3299	3811	3238	2827

a, b, c: values with different superscripts in each row in each subsection were significantly different (p≤0.05).



T1: Alfalfa sole cropping; T2: 1:3 barley-alfalfa mixed cropping; T3:1:1 barley-alfalfa mixed cropping; T4: 3:1 barley-alfalfa mixed cropping; T5: Barley sole cropping.

Fig 1: Water productivity with full irrigation (100% ET_0) and deficit irrigation (75% ET_0 and 50%) at the first cut.



T1: Alfalfa sole cropping; T2: 1:3 barley-alfalfa mixed cropping; T3:1:1 barley-alfalfa mixed cropping; T4: 3:1 barley-alfalfa mixed cropping; T5: Barley sole cropping.

Fig 2: Water productivity with full irrigation (100% ET_0) and deficit irrigation (75% ET_0) at the second cut.

water productivity and dry matter yield for the two cuts has shown higher values with mixed cropping treatment T3 followed by T2 and T1 at 75% ET_0 in comparison with other irrigation levels.

CONCLUSION

The mixed cropping treatment of barley (47.5 kg ha^{-1}) and alfalfa (47.5 kg ha^{-1}) at 1:1 seed rate ratio under 75% ET_0 was found to be the best mixed cropping treatment and irrigation application for high dry matter yield and crop water productivity under Kuwait's environmental conditions upon totaling the harvests from first and second cuts. Studies to understand the soil moisture level as well as leaf water potential during different stages of plant growth under each treatment could provide further insights into the development of efficient water management strategies. In addition, multi-location as well as multi-environmental trials need to be conducted to study the impact of the environment on crop yield and water productivity under mixed cropping with deficit irrigation.

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Conflict of interest

The authors declare no conflict of interest.

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