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Response of fodder cropping sequences to irrigation scheduling in arid environment

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ABSTRACT

A field experiment was conducted at Jodhpur during *kharif, rabi* and summer seasons for three consecutive years (2008-09, 2009-10 and 2010-11) to assess the fodder production potential, water use, water use efficiency and fodder quality of different cropping systems under variable moisture regimes. The main plot treatments consist of four cropping sequences, i.e. bajra–lucerne, cowpea– oat – bajra, *Cenchrus ciliaris* - *C. ciliaris* + lucerne, bajra + cowpea (1:1) – oat–sorghum and three irrigation levels, i.e. 50, 75 and 100 mm CPE in subplots with three replications. Among the crop sequences round the year, maximum mean green fodder yield was recorded from cowpea-oat-bajra sequence, which was *at par* with bajra + cowpea – oat – sorghum sequence but significantly higher than *C. ciliaris* +lucerne and bajra–lucerne sequences. Similarly, dry matter yield was also maximum from cowpea– oat –bajra sequence which was also at par with *C.ciliaris*–*C. ciliaris*+lucerne and bajra + cowpea – oat – sorghum sequences but was only significantly higher than bajra – lucerne sequence. During *rabi* season all crops produced significantly higher green fodder yield at 50 mm CPE level than 75 and 100 mm CPE levels but dry matter yield was at par at 50 and 75 mm CPE levels. Green and dry matter yields of summer crops were significantly higher at 50 mm CPE level than that of 75 and 100 mm CPE. This showed that irrigation at 75 CPE level optimized dry fodder yield during *rabi* season and 50 mm CPE during summer season. The fodder yield of *C. ciliaris* + lucerne system at 50 mm CPE and 75 mm CPE was at par but significantly higher than that of 100 mm CPE while fodder yield of bajra + cowpea (1:1)-oat–sorghum and cowpea –oat–bajra at 50 mm CPE was significantly higher than that of 75 mm CPE. Water use efficiency (WUE) and water productivity were higher with bajra, *C. ciliaris* and oat grown with sprinkler irrigation. Among cropping sequences *C. ciliaris* -*C. ciliaris*+ lucerne system had maximum WUE and water productivity but statistically at par with cowpea-oat –bajra sequence. Water use was higher at 50 mm CPE irrigation level but water use efficiency and water productivity were higher with 75 and 100 mm CPE level. Protein yield was maximum with bajra – lucerne system followed by cowpea –oat– bajra while *C. ciliaris*-*C. ciliaris* + lucerne system had lowest protein yield being at par with bajra + cowpea–oat–sorghum sequence. Protein yield was higher with 50 mm CPE level as compared to 75 and 100 mm CPE in all cropping sequences. Irrigation at 75 mm CPE was best for *C. ciliaris* + lucerne intercropping system and 50 mm CPE for bajra + cowpea, oat – bajra, cowpea–oat–sorghum and bajra-lucerne crop sequence for getting higher productivity of quality fodder under arid conditions.

Key words: Dry matter yield, Fodder cropping sequences, Green fodder yield, Irrigation levels, Protein yield

Livestock are valuable component of sustainable and economically viable farming systems in arid region of India. The arid zone covers about 10.16% of total area of country out of which about 62% areas is in the state of Rajasthan sustaining 29.11 million livestock (Census 2007). These livestock also contribute to food security to small farmers and provide diversification to agriculture but the productivity of livestock is very low in arid zone due to chronic shortage of feed and fodder. The deficiency of fodder in arid zone of Rajasthan was estimated 35.9% and 79.9% during normal and drought year, respectively (Pratap Narain and Kar 2005). The increasing deficiency of fodder availability is due to decaying and deterioration of pastures and grazing landscoupled with decline in cultivated crop producing fodder. During normal year, the dual purpose crops contribute major portion of fodder but in drought years fodder production from these crops reduces resulting fodder crises in arid Rajasthan. There are little possibilities of any tangible increase in area of fodder crops due to competition from commercial and food crops. Therefore, there is need to increase forage production within the existing farming system by developing intensive fodder production system to get year round fodder and economise livestock feeding system. A cropping system needs to be developed to obtain maximum forage yield per unit area round the year where irrigation

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facilities are available for the dairy and small farmers. Low water requiring crops like pearl millet, grasses, oat and legumes can be included in cropping systems. Induction of legumes in cropping systems improves fertility, stability of soil and helps in increasing the yield of succeeding crops (Balyan 1997) and quality of fodder (Patidar *et al.* 2008). Irrigation scheduling in arid environment has great significance in forage crops because of their high water requirement for luxuriant vegetative growth on one hand and limited water holding capacity of soil on the other hand. Hence, their production calls for strategic measures like adopting water saving irrigation technologies. One such technology is sprinkler irrigation which provides the benefit of water saving and an increase in water use efficiency over flood irrigation method (Bandhopadhyay *et al.* 2010). Under limited water availability sprinkler irrigation system can be a useful tool for water saving and increasing fodder production with some quantum of water supply. Pandey *et al.* (2001) reported that with a limited water supply, water managers can either provide water to a few growers to meet full crop demand or adopt efficient irrigation method of water supply to a large number of farmers providing more equitable distribution of resources. Because of the difference in variability in environmental and agricultural practices, information specific to this segment is needed for developing cropping systems under limited irrigation. Therefore, the study was undertaken to assess the fodder production, potential water use, and water use efficiency and fodder quality of different cropping systems under variable moisture regimes.

MATERIALS AND METHODS

The experiment was conducted during *kharif, rabi* and summer seasons for three consecutive years (2008-09, 2009-10 and 2010-11) at CR farm of Central Arid Zone Research Institute, Jodhpur, Rajasthan. The climate of the region is typically hot arid characterized by low rainfall (100-500 mm/yr.), high temperature (40-46°C) and high wind velocity (20-40 km/hr). The rainfall is largely monsoon driven which comes between June and September. Monsoon rains account for about 95% of the total rainfall with high coefficient of variation (40-60%) and erratic distribution. Total rainfall received during the years 2008, 2009 and 2010 were 437.8, 212.0 and 562.2 mm, respectively. The soil was coarse loamy sand, low in organic carbon (0.18%) and available N (145 kg/ha) and medium in available phosphorus (12.4 kg/ha) with pH 8.2. The treatments consist of four cropping sequences, i.e. bajra–lucerne, cowpea– oat – bajra, *Cenchrus ciliaris* + lucerne, bajra + cowpea(1:1) – oat–sorghum with three irrigation levels, i.e. 50, 75 and 100 mm CPE. These treatments were evaluated in split plot design with three replications keeping cropping sequences in main plots and irrigation levels in sub plots. Fodder crops, viz. bajra, cowpea and *C. ciliaris* and bajra + cowpea (1:1) were grown during *kharif* season. Oat was grown after cowpea and bajra + cowpea intercropping while lucerne was grown after sole bajra andin inter space of *C. ciliaris* during *rabi* season. Bajra and sorghum were grown in summer season. Lucerne and *C. ciliaris* were continued in the same plot as per treatments during summer season. Crops were raised using recommended package of practices given in Table 1. *Kharif* crops were grown under rain fed condition while *rabi* and summer crops were grown under irrigated condition. Kharif crops were sown with the onset of monsoon in the month of July every year but the grass was established in July 2008 at 60 cm row spacing using 5 kg seed/ha. *Rabi* and summer crops were sown during the month of October and April, respectively. Presowing irrigation in *rabi* and summer crops was applied uniformly for identical germination and good plant stand; thereafter irrigation water was applied through sprinkler as per treatments. The daily pan evaporation was obtained from meteorological observatory of the institute for calculation of CPE. The depth of irrigation water was kept 50 mm. Observations were recorded on plant growth and fodder yield. Green fodder yield was recorded and 100 g fresh samples were dried in hot air oven for dry matter estimation. Soil samples were collected from different depth at sowing and harvesting and before and after rainfall/irrigation. Water use and water use efficiency of fodder were calculated as under:

Water use (mm) = % water content × bulk density × 0.20

Water use efficiency (kg dry matter/ha/mm) = Dry matter yield (kg/ha)/water use (mm)

Table 1 Production practices followed in the experiment for raising different crops

Cropping season/ crops	Varieties	Sowing time	Seed rate (kg/ha)	Spacing (cm)	RDF (kg/ha) N : P	No. of cuts
Kharif						
Bajra	Raj-171	3rd Week July	12	30	60 : 40	Single
Cowpea	Bundel Lobia-2	3rd Week July	30	30	20 : 40	Single
C.ciliaris	CAZRI-358	3rd Week July	5	60	40 : 20	Six
Rabi						
Lucerne	A-2	1st Week Nov.	25	30	20 : 80	Six
Oat	Kent	1st Week Nov.	100	30	60 : 30	Two
Summer						
Bajra	Raj-171	1st Week April	12	30	60 : 40	Single
Sorghum	SSG-788	1st Week April	30	30	80 : 40	Single

The data on different parameters were statistically analysed by using statistical methods described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Plant height

Plant height of different crops was affected by intercropping and irrigation levels. During *kharif* season plant height of sole bajra was higher as compared to plants grown in bajra + cowpea intercropping system. However, plant height of cowpea was not affected due to intercropping. Plant growth of *rabi* crops was affected by different irrigation levels (Table 2). The height of all crops, i.e. lucerne, oat, *C. ciliaris* was higher at 50 mm CPE irrigation level as compared to 75 and 100 mm CPE levels. Similarly, plant growth of summer crops was also higher under 50 mm CPE level, except that of *C. ciliaris* where the plant height was at par under 50 and 75 mm CPE. The taller plant with 50 CPE irrigation level might be due to the fact that plants received adequate moisture to satisfy their physiological requirements which translated into more vigorous growth than the other treatments which received less amount of water under prevailing environmental conditions. Irrigation with full potential ET (100%) resulted in significantly taller plants than those of irrigated at 75% and 50% levels (Sani *et al.* 2008). Plant height of lucerne grown in association with *C. ciliaris* was lower as compared to the sole lucerne. This might be due to competition for soil moisture between lucerne and *C. ciliaris* crops.

Effect of cropping sequences on forage yield

Forage yield during kharif season: The maximum green and dry fodder yields was obtained solely from bajra that was significantly higher than other sequences in *kharif* 2008 (Table 3). During *kharif* 2009, maximum green fodder yield was obtained with bajra + cowpea intercropping at par with sole bajra, and significantly higher than sole cowpea and *C. ciliaris,* while dry fodder yield was maximum from sole bajra, which was at par with *C. ciliaris* and bajra + cowpea intercropping and significantly higher than sole cowpea. During *kharif* 2010, maximum green fodder yield was obtained from cowpea at par with *C. ciliaris* and significantly higher than sole bajra and bajra + cowpea intercropping. The dry matter production was at par with all the systems, except bajra + cowpea intercropping system. However, sole bajra had maximum dry matter followed by *C. ciliaris.* The mean data of all the three *kharif* season revealed that sole bajra had maximum green and dry fodder yields followed by bajra + cowpea intercropping system (Table 4). Patidar and Saxena (2005) recorded highest green and dry fodder yields from sorghum + cowpea followed by pearl millet + cowpea inter cropping system in *kharif* under sprinkler irrigation in drought year. Kumar *et al.* (2005) also reported beneficial effect of intercropping of maize and cowpea on green and dry fodder yields.

Forage yield during rabi season: During rabi 2008-09, oat was preceded by cowpea or bajra + cowpea intercropping produced significantly higher green fodder yield than sole lucerne but at par with *C. ciliaris* + lucerne system. Oat preceded by cowpea yielded significantly higher dry matter than *C. ciliaris* + lucerne and sole lucerne (Table 3). During *rabi* 2009-10, oat produced significantly higher green fodder yield either grown after cowpea or bajra + cowpea intercropping as compared to *C. ciliaris* + lucerne system and sole lucerne. Dry fodder yield with oat preceded by cowpea or bajra + cowpea intercropping and *C. ciliaris* + lucerne system was at par but significantly higher than sole lucerne. During *rabi* 2010-11, green and dry fodder yields were significantly higher from oat as compared to sole lucerne and *C. ciliaris* + lucerne system. Mean data of three years revealed that oat produced significantly higher forage yield either grown after cowpea or bajra + cowpea intercropping than sole lucerne and *C. ciliaris* + lucerne system during *rabi* season. The results clearly showed that oat is more suitable *rabi* fodder than other crops under prevailing soil and climatic condition.

Forage yield during summer season: During summer 2009, green fodder yield of sorghum, bajra and *C. ciliaris* + lucerne were at par with each other and significantly

Table 2 Plant height of forage crops of different crop sequences under limited irrigation (mean of three year)

Cropping system		Plant height (cm)								
		Kharif	*Rabi*				Summer			
			50 mm CPE	75 mm CPE	100 mm CPE	Mean	50 mm CPE	75 mm CPE	100 mm CPE	Mean
Sole Bajra– lucerne		167	66	59	49	58	72	67	46	62
Sole cowpea– oat–bajra		79	86	71	66	74	175	147	137	153
C. ciliaris – *C. ciliaris* + lucerne	*C. ciliaris*	91	83	74	61	73	59	61	56	59
	Lucerne		58	45	37	47	62	59	52	58
Bajra + cowpea (1:1)– oat– sorghum	Bajra	149	84	75	68	75	155	150	126	144
	Cowpea	77								

higher than that of sole lucerne while dry fodder yield was maximum with *C. ciliaris* + lucerne system and significantly higher than all other crops (Table 3). During summer 2010, green fodder yield was maximum with bajra being at par with *C. ciliaris* + lucerne system and significantly higher than that of sole lucerne and sorghum while dry fodder yield from *C. ciliaris* + lucerne system was significantly higher than all other crops. During summer 2011, maximum green fodder yield was recorded with bajra which was significantly higher than all crops while dry fodder yield was maximum with *C. ciliaris* +lucerne, statistically it was equal ($P < 0.05$) to all other crops. The mean data revealed (Table 4) that maximum green fodder yield was recorded with bajra which was at par with *C. ciliaris* + lucerne system while dry fodder yield was significantly higher from *C. ciliaris* +lucerne than all other crops. This showed that *C. ciliaris* +lucerne system produced higher forage yield during summer season. The higher dry forage yield with this treatment might be due to beneficial effect of intercropping and advantage of established stands.

Fodder production from different cropping sequences round the year

Yearly fodder production from different cropping sequences varied significantly (Table 3). Cowpea - oat - bajra and bajra + cowpea - oat - sorghum sequences produced more or less similar green fodder yield in all the three years. In first year (2008-09), bajra + cowpea - oat - sorghum produced maximum dry matter yield while in second (2009-10) and third (2010-11) years, cowpea - oat - bajra produced maximum green fodder yield. The mean data of three year revealed that maximum green fodder yield was obtained from cowpea– oat– bajra sequence however, it was at par with bajra + cowpea– oat– sorghum sequence and significantly higher ($P < 0.05$) than *C. ciliaris* +lucerne and bajra - lucerne sequences (Table 4). Dry forage yield of different cropping sequences also varied with years. In first and third years, cowpea - oat - bajra produced maximum dry matter yield followed by bajra + cowpea– oat– sorghum while *C. ciliaris* + lucerne system had maximum dry forage yield during second year. The mean data of three years revealed that all these three crop sequences produced more or less equal dry matter yield but significantly higher than bajra - lucerne sequence (Table 4). This showed that all these three sequences, i.e. cowpea-oat-bajra and bajra + cowpea – oat – sorghum and *C. ciliaris* + lucerne can be adopted for enhancing forage production round the year. The higher yield of these cropping systems may be attributed

Table 3 Green and dry fodder yield of different cropping sequences at various irrigation levels in different years

Treatment	Green fodder yield (t/ha)											
	2008-09				2009-10				2010-11			
	Kharif	*Rabi*	Summer	Total	*Kharif*	*Rabi*	Summer	Total	*Kharif*	*Rabi*	Summer	Total
Cropping sequences												
Bajra –lucerne	21.76	19.09	24.14	64.99	20.83	19.16	12.71	52.70	19.86	30.56	18.53	68.95
Cowpea-oat-bajra	11.10	35.72	35.45	82.27	17.47	44.39	20.02	81.88	28.06	41.44	27.77	97.27
Cenchrus+lucerne	5.90	30.79	35.81	72.50	16.19	34.96	18.11	69.26	23.95	24.35	20.26	68.56
Cowpea+bajra -oat-sorghum	17.95	35.22	37.03	90.20	23.93	44.30	10.21	78.44	19.67	45.62	22.38	87.67
CD (P=0.05)	3.56	8.32	6.70	11.35	3.65	6.60	3.94	8.68	4.76	6.72	4.67	8.79
Irrigation levels												
50 mm CPE	13.91	39.45	43.88	97.24	19.00	45.01	21.22	85.23	20.29	42.30	28.05	90.64
75 mm CPE	15.11	30.51	31.15	76.77	19.79	36.20	14.54	70.53	24.55	36.20	22.05	82.80
100 mm CPE	13.52	20.66	24.29	58.47	20.01	25.90	10.03	55.94	23.81	27.99	16.61	68.41
CD (P=0.05)	NS	13.18	12.04	21.23	NS	8.19	3.05	8.82	NS	6.07	6.27	14.25
	Dry matter yield (t/ha)											
Cropping sequences												
Bajra–lucerne	5.36	4.23	5.94	15.53	5.85	3.49	3.75	13.09	4.93	4.73	4.68	14.34
Cowpea-oat-bajra	2.79	9.89	6.47	19.15	2.64	7.44	4.08	14.16	4.35	6.87	5.12	16.34
Cenchrus+lucerne	1.53	6.7	8.69	16.92	5.30	7.37	5.44	18.11	4.86	4.2	5.56	14.62
Cowpea+bajra -oat-sorghum	4.43	7.95	6.36	18.74	4.90	7.39	2.43	14.72	3.65	7.4	5.07	16.12
CD (P=0.05)	0.9	2.77	1.48	3.15	1.23	1.02	0.89	1.71	1.17	1.17	NS	NS
Irrigation levels												
50 mm CPE	3.48	9.29	8.58	21.35	4.90	7.77	5.38	18.05	3.83	6.35	6.24	16.42
75 mm CPE	3.71	7.63	6.8	18.14	4.61	6.64	3.89	15.14	4.77	6.14	5.23	16.14
100 mm CPE	3.39	4.66	5.21	13.26	4.51	4.86	2.49	11.86	4.74	4.92	3.85	13.51
CD (P=0.05)	NS	4.27	2.71	4.80	NS	1.48	0.69	1.71	NS	1.31	1.44	2.8

to the better performance of cereal components and lower yield of bajra-lucerne system due to the poor performance of lucerne under arid climate. These results confirm the findings of Aulakh *et al.* (2012).

Effect of irrigation levels on forage yield

Analysis of data revealed that irrigation treatments affected the forage yield significantly (Table 3). Mean green fodder yields of all crops were significantly higher ($p < 0.05$) at 50 mm CPE than 75 mm and 100 mm levels during *rabi* season in all the three years except in the year 2008-09 in which the yield was at par with 75 mm CPE. The dry matter production was at par at 50 mm CPE and 75 mm CPE irrigation level but significantly higher than that of 100 CPE. During summer season, the green fodder yield was significantly more when the irrigations were applied at 50 mm CPE, except during third year where it was at par with 75 mm CPE. Similarly dry matter yield was also maximum with 50 mm CPE, significantly higher than 75 mm level in the second year, whereas in the first and third years it was at par with 75 and 100 mm CPE levels. The mean data of all seasons of the three years showed that green fodder yield at 50 mm CPE level was significantly greater than that of recorded at75 and 100 mm CPE levels. Application of irrigation at 50 mm CPE produced 18.7% and 49.4% higher green fodder over 75 and 100 mm CPE levels. The rate of increase in fodder yield was more from 100 mm to 75 mm CPE than 75 mm to 50 mm CPE level. Similarly, dry matter production which was recorded maximum at 50 mm irrigation regime was significantly greater than that recorded at 100 mm CPE level. The 75 mm CPE irrigation treatment yielded about 11.0% less dry fodder than 50 mm CPE treatment, however the difference was not statistically significant. The implication for this particular condition is more sustainable to apply irrigation at 75 CPE level than 50 mm CPE as yields are similar. The results indicate that plants subjected to water stress tend to produce less biomass than plants supplied with adequate water. This was probably caused by reduction in physiological activities of the plants under lower level of irrigation and subsequently resulted in lower

Table 4 Green and dry fodder yield of different cropping sequences at various irrigation levels (mean of three years)

Treatment	Green fodder yield (t/ha)												
	Kharif	*Rabi*				Summer				Total			
		50 CPE	75 CPE	100 CPE	Mean	50 CPE	75 CPE	100 CPE	Mean	50 CPE	75 CPE	100 CPE	Mean
Cropping sequences													
Bajra–lucerne	20.82	29.90	24.20	14.71	22.94	23.33	18.50	13.55	18.46	71.92	64.22	50.52	62.22
Cowpea-oat-bajra	18.88	46.96	42.80	31.79	40.52	35.66	25.51	22.08	27.75	99.76	87.74	73.93	87.14
Cenchrus+ lucerne	15.35	36.57	32.13	21.40	30.03	29.97	26.38	17.83	24.73	81.70	75.77	52.85	70.11
Cowpea+bajra-oat-sorghum	20.52	55.58	38.09	31.48	41.72	35.25	19.93	14.44	23.21	110.78	79.10	66.45	85.44
Mean	18.89	42.25	34.31	24.85		31.05	22.58	16.97		91.04	76.71	60.94	
CD (P=0.05)													
Cropping sequences(CS)	2.65	4.8				3.15				6.69			
Irrigation levels(I)	NS	7.4				4.95				14.01			
CS × I	NS	NS				5.5				11.59			
	Dry fodder yield (t/ha)												
Cropping sequences													
Bajra–lucerne -	5.38	4.92	5.07	2.46	4.15	5.97	4.88	3.51	4.79	16.03	15.33	11.59	14.31
Cowpea-oat-bajra	3.26	9.66	8.41	6.14	8.07	6.66	4.91	4.09	5.22	19.33	16.86	13.47	16.55
Cenchrus+ lucerne	3.90	7.02	6.80	4.45	6.09	7.89	7.05	4.74	6.56	18.78	18.08	12.77	16.54
Cowpea+bajra-oat-sorghum	4.33	9.61	6.94	6.19	7.58	6.42	4.39	3.05	4.62	20.29	15.65	13.65	16.53
Mean	4.22	7.80	6.80	4.81		6.73	5.31	3.85		18.61	16.48	12.87	
CD (P=0.05)													
Cropping sequences(CS)	0.82	1.0				1.3				1.39			
Irrigation levels(I)	NS	1.5				0.8				2.85			
CS × I	NS	NS				NS				2.40			

yield. This is in tandem with results obtained by Sani *et al.* (2008) and Rao *et al.* (2012). This showed that irrigation at 50 CPE level maximized the green fodder yield but irrigation at 75 CPE levels optimized dry fodder yield.

Interaction effects

Green and dry fodder yields varied due to interaction effect of cropping sequences and irrigation (Table 4). Interaction effect was not significant in all the seasons but some specific trends have been observed. During the *rabi* season, irrigation at 50 mm CPE recorded significantly higher green fodder yield of oat grown after bajra + cowpea inter cropping while irrigation at 75 and 100 mm CPE produced maximum green yield of oat grown after cowpea. Similarly, oatgrown after cowpea or bajra + cowpea inter cropping at 50 mm CPE produced significantly higher dry fodder yield than *C. ciliaris* + lucerne and sole lucerne while at 75 mm CPE level dry matter yield oat was at par with *C. ciliaris* +lucerne system. Maximum dry fodder yield was recorded from oat at 50 mm CPE which was at par with that of 75 mm CPE level. Fodder yield of *C. ciliaris* + lucerne was at par between 50 and 75 mm CPE but significantly higher than that of 100 mm CPE. Mean data of three year also revealed superiority of oat for green and dry fodder yield under 50 mm CPE irrigation while it was minimum with lucerne at 100 CPE Level.

During summer, mean data showed that bajra and sorghum produced significantly higher green fodder at 50 mm CPE level while at 75 mm CPE level *C. ciliaris* + lucerne produced maximum green fodder but it was statistically at par with bajra. Dry fodder yield was maximum from *C. ciliaris* + lucerne at all the levels of irrigation and it was significantly higher than other cropping sequences at 75 mm level only, however the interaction effect of cropping sequences and irrigation level on dry fodder yield was not significant. At 50 mm CPE level green and dry fodder yields of bajra, sorghum and lucerne were higher than that of 75 and 100 mm CPE. Forage yields of *C. ciliaris* +lucerne system at 50 and 75 mm CPE levels were at par. Thus irrigation at 75 mm CPE was best for *C. ciliaris* + lucerne intercropping system and 50 mm CPE for bajra, sorghum and lucerne for getting higher productivity during summer season. Further irrigation at 75 CPE level optimized dry fodder yield during *rabi* season and 50 mm CPE during summer season. Singh (2004) reported that growing sorghum during summer season with sprinkler irrigation gave maximum green fodder yield (14.8 tonnes/ha) followed by 13.6 tonnes/ha with pearl millet sole at CAZRI, Jodhpur. The mean of *rabi* and summer season revealed that irrigation at 50 mm CPE oat- sorghum and oat- bajra sequences produced more or less similar green and dry fodder yields that was significantly higher than *C. ciliaris* + lucerne and sole lucerne (Fig 1). At 75 mm CPE level, dry fodder yield was maximum from *C. ciliaris* + lucerne system which was at par with yield level at 50 mm CPE level and significantly higher than 100 mm CPE level. Thus irrigation at 75 mm CPE was best for *C. ciliaris* + lucerne intercropping system and 50 mm CPE for oat-bajra, and oat-sorghum and lucerne-lucerne sequences for getting higher productivity during *rabi* and summer season. Irrigation at 75 CPE levels optimized dry fodder yield during *rabi* season and 50 mm CPE during summer season.

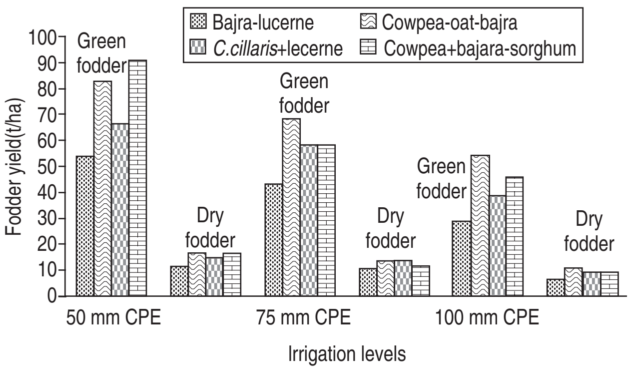

Fig 1 Green and dry fodder yields of different sequences under various irrigation levels during *rabi* and summer (mean of three years).

Mean data of all the seasons of three years (Table 4) showed that at 50 mm CPE irrigation level, green fodder yield was recorded maximum from cowpea + bajra – oat-sorghum at par with cowpea– oat-bajra sequence and was significantly higher than *C. ciliaris* + lucerne and bajra-lucerne sequences. However, at 75 mm CPE level green fodder yield was maximum with cowpea– oat-bajra sequence. Dry fodder yield at 50 mm CPE level was also recorded maximum with cowpea + bajra – oat-sorghum and at par with cowpea – oat-bajra and *C. ciliaris* +lucerne system. At 75 mm CPE irrigation level dry fodder yield was maximum with *C. ciliaris* +lucerne being at par with cowpea– oat-bajra sequence and significantly higher than cowpea + bajra – oat-sorghum and bajra- lucerne sequences. Green and dry fodder yields of cowpea + bajra – oat-sorghum and cowpea -oat-bajra sequence at 50 mm CPE level was significantly higher than that of 75 and 100 mm CPE. However, green and dry fodder yields from *C. ciliaris* + lucerneat 50 mm CPE level was at par with 75 mm CPE irrigation level. This showed irrigation at 75 mm CPE was best for *C. ciliaris* + lucerne intercropping system and 50 mm CPE for cowpea-oat – bajra and cowpea + bajra - oat -sorghum crop sequence for getting higher production of fodder round the year under arid conditions.

Water use and water use efficiency

Water use and water use efficiency (WUE) varied with different crops, cropping sequences and irrigation levels. Maximum water use was recorded in lucerne during *rabi* season and minimum in *C. ciliaris* in *kharif* season (Table 5). Water use was lower in bajra, *C. ciliaris* and oat than cowpea, lucerne and sorghum. Among cropping sequences bajra–lucerne used maximum water and *C. ciliaris* + lucerne system used minimum water. The variations were due to differences in growth habit of crops. The WUE has different trends. Maximum WUE was estimated in oat and minimum in lucerne during *rabi* season. Among cropping sequences, maximum WUE was under *C. ciliaris* + lucerne system followed by cowpea–oat–bajra sequence whereas, lowest was under bajra lucerne sequence. WUE was higher with bajra, *C. ciliaris* and oat as compared to cowpea, lucerne and sorghum. Patidar *et al.* (2008) reported that *C. ciliaris* had higher WUE than cowpea. In addition to forage species, the season of crop growth and quantity of available water also affected the WUE. It was higher in *rabi* crops than *kharif* and summer seasons. Among irrigation levels, the consumptive use of water was highest at 50 mm CPE level as compared to 75 and 100 mm CPE. The higher consumptive use with 50 mm irrigation level was due to more availability of soil moisture for plant growth. However, WUE was higher with lower level of irrigation and increased by 12.5% under 75 mm CPE and 14% under 100 mm CPE level over 50 mm CPE level. The higher WUE at lower level of irrigation was due to less use of water however dry matter production was higher by 45% under 50 mm CPE level and 28% under 75 mm CPE level as compared to 100 mm CPE. The rate of increase in WUE is 14.81 kg/ha/mm from 100 to 75 mm CPE and 7.32 kg/ha/mm from 75 to 50 mm CPE levels. The relationship between forage yield and total applied water is useful for optimising irrigation strategy. The response of forage yield to irrigation water was described using regression analysis. A highly significant polynomial relationship was observed between fodder yield and water applied ($R^2 = 1$). The curvilinear relationship of yield with irrigation level suggested that a policy for maximising yield under limited water resources conditions should be avoided and maximising water use efficiency is recommended for sustainable use of water resources in this region. Ramakrishna *et al.* (1990) reported that irrigation beyond 50% PET had no linear relationship with total biomass production in mustard under similar condition. Ali *et al.* (2007) suggested that high WUE for an irrigation scheduling should be associated with high yield particularly in water scares area. Based on the idea two curves for crop yield and WUE with irrigation level was used to determine optimum irrigation (Fig 2). The intersection point of two curves showed the optimum irrigation level that was for 75 mm CPE with 16 tonnes of dry fodder yield per ha/year. With this level 84% of the maximum fodder yield and 94% maximum WUE can be achieved. This showed that water use in fodder cropping sequences can be optimized by applying irrigation at 75 mm CPE under limited water availability condition in arid region of Rajasthan.

Water productivity

Water productivity varied with crops, cropping sequences and irrigation levels. Water productivity was maximum with bajra (1.85 kg/m^3), oat (1.88 kg/m^3) during *rabi* and *C. ciliaris* (1.86 kg/m^3) and minimum with cowpea (1.10 kg/m^3), lucerne (0.94 kg/m^3) and sorghum (1.21 kg/m^3). Among cropping sequences maximum water productivity was estimated with *C. ciliaris*+ lucerne system which was at par with cowpea-oat – bajra and bajra + cowpea – oat – sorghum sequences and higher with bajra – lucerne sequence (Table 6). The variation of water productivity may be due to differences in WUE of the crop species. Water productivity also varied with irrigation levels. Irrigation at 75 and 100 mm CPE levels produced higher water productivity as compared to 50 mm CPE level. Low water productivity with 50 mm CPE level was due to more use of water. Applying more water than required will not increase water productivity as the some water may be lost through unproductive soil evaporation (Geerts and Raes 2009).

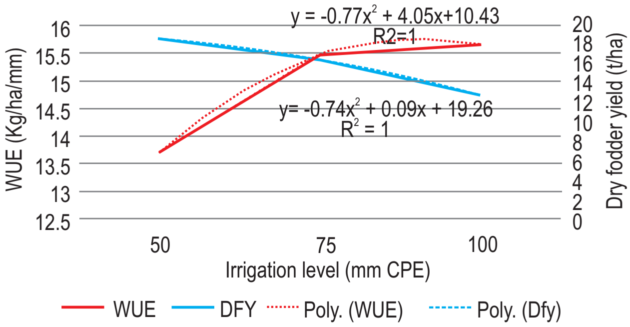

Fig 2 Releationship between fodder, water use efficiency and irrigation levels (mean of all cropping sequences).

Table 5 Water use and water use efficiency of different cropping sequences at various irrigation levels (mean of three years)

Treatment	Water use (cm)				Water use efficiency (kg/ha/mm)			
	Kharif	*Rabi*	Summer	Total	*Kharif*	*Rabi*	Summer	Mean
Cropping sequence								
Bajra –lucerne	29.08	44.30	37.60	110.98	18.50	9.36	12.73	12.90
Cowpea-oat-bajra	29.55	41.93	37.24	108.72	11.03	19.25	14.02	15.22
Cenchrus+lucerne	27.57	41.11	35.24	103.91	14.13	14.81	18.62	15.92
Cowpea+bajra -oat-sorghum	29.24	41.62	38.32	109.18	14.81	18.21	12.06	15.14
Mean	28.86	42.24	37.10	108.20	14.61	15.41	14.36	14.80
Irrigation levels								
50 mm CPE	28.96	56.56	50.17	135.70	14.05	13.79	13.42	13.71
75 mm CPE	28.85	42.22	35.57	106.63	15.13	16.12	14.93	15.45
100 mm CPE	28.77	27.95	25.55	82.26	14.64	17.21	15.07	15.65
Mean	28.86	42.24	37.10	108.20	14.61	15.71	14.47	14.94

Table 6 Water productivity of different cropping sequences at various irrigation levels (mean of three years)

Treatment	Water productivity (kg/m³)			
	Kharif	*Rabi*	Summer	Mean
Bajra–lucerne	1.85	0.94	1.28	1.36
Cowpea- oat- bajra	1.10	1.98	1.42	1.50
C. ciliaris- C.ciliaris + lucerne	1.41	1.52	1.92	1.62
Cowpea + bajra–oat-sorghum	1.48	1.89	1.21	1.52
Mean	1.46	1.58	1.46	1.50
Irrigation levels				
50 mm CPE	1.41	1.39	1.35	1.38
75 mm CPE	1.51	1.62	1.50	1.54
100 mm CPE	1.46	1.73	1.53	1.58
Mean	1.46	1.58	1.46	1.50

Table 7 Crude protein yield in different cropping sequences and irrigation level

Treatment	Protein yield (kg/ha)			
	2008-09	2009-10	2010-11	Mean
Bajra–lucerne	2464	1904	2366	2245
Cowpea- oat- bajra	2359	1826	1878	2021
C.ciliaris- C.ciliaris + lucerne	1873	1783	1764	1806
Cowpea + bajra-oat-sorghum	2155	1690	2024	1957
Mean	2213	1801	2008	2007
Irrigation levels				
50 mm CPE	2756	2210	2241	2402
75 mm CPE	2313	1839	2101	2084
100 mm CPE	1569	1354	1683	1535
Mean	2213	1801	2008	2007

Land use efficiency

Land use efficiency of different cropping sequences of forage production varied. Land use efficiency was the highest for *C. ciliaris*+ lucerne system followed by bajra-lucerne sequence. The higher land use efficiency of *C. ciliaris*+ lucerne system was due to perennial nature of Cenchrus grass which remained in field for longer duration. This sequence utilizes the land more efficiently. The other cropping sequences had more or less equal land use efficiency.

Protein yield

Protein content in fodder crops at the time of harvest varied with crop species and irrigation levels. Maximum protein content was found in lucerne (19.5%) followed by cowpea (18%). Protein content in lucerne and cowpea was higher as these were leguminous crops. Among cereals, quality of fodder in term of protein content was higher in oat (13.3%) followed by sorghum (9.2%), bajra (8.2%) and *C. ciliaris* (6.8%). Fodder crops grown during *rabi* and summer season had slightly higher protein content at 50 and 75 mm CPE irrigation levels as compared to 100 mm CPE level. Protein yield also varied with cropping sequences and irrigation levels and it was maximum from bajra – lucerne system followed by cowpea –oat – bajra while *C. ciliaris– C. ciliaris* + lucerne system had lowest protein yield being at par with bajra + cowpea –oat –sorghum sequence (Table 7). The differences in crude protein yield in cropping sequences were noticed mainly due to variation in dry matter yield and protein content of component crops. Krishna *et al*. (1998) also reported pronounced effect of intercropping of forage legumes with cereals on crude protein yield. Protein yield was higher with 50 mm CPE level as compared to 75 and 100 mm CPE in all cropping sequences. The higher protein with 50 mm irrigation level was due to higher forage yield.

It was concluded from the present study that the three sequences, ie cowpea– oat – bajra, bajra + cowpea – oat – sorghum and *C. ciliaris-C. ciliaris* + lucerne produced higher fodder yields with high water use efficiency. Though protein yield was maximum with bajra- lucerne but forage yield and water use efficiency was least as compared to other cropping sequences. Hence, crop sequences, i.e. cowpea - oat – bajra, bajra + cowpea – oat – sorghum and *C. ciliaris - C. ciliaris* + lucerne can be adopted for enhancing forage production round the year with limited irrigation under arid climate. For scheduling of irrigation, it is inferred that irrigation at 75 mm CPE level optimized fodder yield during *rabi* season and 50 mm CPE during summer season. It is also pertinent to conclude that irrigation at 75 mm CPE was best for *C. ciliaris - C. ciliaris* + lucerne intercropping system and 50 mm CPE for cowpea -oat – bajra and bajra + cowpea -oat –sorghum crop sequences for getting higher productivity of quality fodder under arid conditions. Water use efficiency and water productivity can be maximized with high land use efficiency by growing *C. ciliaris-C. ciliaris*+ lucerne with sprinkler irrigation under arid condition.

REFERENCES

Ali M H, Hoque M R, Hassan A A and Khair A. 2007. Effect of deficit irrigation on yield, water productivity and economic return of wheat. *Agricultural Water Management* **92**: 151–61.

Aulakh C S, Gill M S, Mahey R K, Walia S S and Singh Gurminder. 2012. Effect of nutrient sources on productivity of fodder cropping systems in Punjab. *Indian Journal of Agronomy* **57** (2): 200–5.

Balyan J S. 1997. Production potential and nitrogen uptake by succeeding wheat (*Triticum aestivum*) under different cropping sequences. *Indian Journal of Agronomy* **42** (2): 250–2.

Bandyopadhyay K K, Misra A K, Ghosh P K, Hati K M, Mandal K G and Moahnty M. 2010. Effect of irrigation and nitrogen application methods on input use efficiency of wheat under supply in a vertisol of Central India. *Irrigation Sciences* **28**: 285–99.

Geerts S and Raes D. 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agricultural Water Management* **96**: 1 275–84.

Gomez K A and Gomez A A. 1984. *Statistical Procedure for Agricultural Research*. 2nd Edn. pp 328–32. Wiley, New York.

Krishna A, Raikhelkar S V and Reddy A S. 1998. Effect of planting pattern and nitrogen on fodder maize intercropped with cowpea. *Indian Journal of Agronomy* **43** (2): 237–40.

Kumar S, Rawat C R and Melkania N P. 2005. Forage production potential and economics of maize (*Zea mays*) and cowpea (*Vigna unguiculata*) intercropping under rainfed conditions. *Indian Journal of Agronomy* **50** (3): 184–6.

Narain Pratap and Kar A. 2005. Drought in western Rajasthan impact, coping mechanism and management strategies, CAZRI, Jodhpur, p 45.

Pandey R K, Maranville J W and Chetima M M. 2001. Tropical wheat response to irrigation and nitrogen in a sahelien environment II biomass accumulation, nitrogen uptake and water extraction. *Europian Journal of Agronomy* **15**: 107–18.

Patidar M and Saxena Anurag. 2005. Production potential of forage cropping system with sprinkler irrigation under drought situation in arid region. (*In*) *National Symposium on Advances in Forage Research and Sustainable Animal Production* held at CCS, HAU, Hisar during August 29-30, p 63.

Patidar M, Mathur B K, Rajora M P and Mathur D. 2008. Effect of grass Legume strip cropping and fertility levels on yield and quality of fodder in silvipastoral system under hot arid condition. *Indian Journal of Agricultural Sciences* **78** (5): 394–8.

Ramakrishna YS, Rao AS, Singh RS and Joshi NL. 1990. Effect of irrigation on evapotranspiration, water and energy use efficiency of mustard crop. *Annals of Arid Zone* **29** (4): 259–64.

Rao S S, Regar P L, Tanwar S P S and Singh Y V. 2012. Wheat yield response to line source sprinkler irrigation and soil management practices on medium textured shallow soils of arid environment. *Irrigation Sciences* **31** (5): 1 185–97.

Sani B M, Oluwasemire K O and Mohammed H I. 2008. Effect of irrigation and plant density on the growth, yield and water use efficiency of early maize in the Nigerian Savanna. *Journal of Agricultural and Biological Sciences* **3** (2): 33–40.

Singh, Raj. 2004. Production potential and economics feasibility of summer forage crops in arid zone of Rajasthan. *Current Agriculture* **28** (1&2): 99–100.