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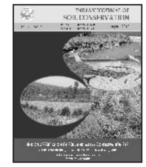

Impact of land configuration and irrigation management on crop growth, yield and water use efficiency of okra under rice ecosystem

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ABSTRACT

A field experiment was carried out at Central Research Farm, Gayeshpur, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal to assess the impact of raised-sunken bed (RSB) system on the water saving, crop growth and yield of okra (*Abelmoschus esculentus* [L.] Moench) under irrigated situation during 2012 and 2013. Treatments comprised of three RSB)ratios *viz.*, 1:3, 2:3, 3:3 and two irrigation schedules like continuous standing water (CSW$\pm$5 cm) and alternate wetting and drying (AWD at 5 days interval) for rice in sunken bed. The growth parameters *viz.*, plant height, leaf number, dry matter (DM) accumulation, leaf area index (LAI) and crop growth rate (CGR) of okra were significantly influenced by RSB land configuration as well as CSW and AWD irrigation. The highest okra yield (14.08 t ha^{-1} and 15.43 t ha^{-1} during 2012 and 2013, respectively) was noted with 1:3 RSB system which was statistically at par with 3:3 bed width ratio under AWD, whereas, the lowest yield (9.42 t ha^{-1} and 10.70 t ha^{-1}) was recorded in CSW 1:3 RSB system. Okra yield in RSB with 1:3 bed width ratio under AWD was 50% and 44% higher than the crop grown with 1:3 bed width ratios under CSW during 2012 and 2013, respectively. RSB land configuration of 3:3 width ratios saved about 24-33% and 18-26% of irrigation water over other two bed width ratio *i.e.* 2:3 and 1:3 during 2012 and 2013, respectively. AWD irrigation schedule with RSB 3:3 system was found more profitable with B:C of 2.58 than others.

1. INTRODUCTION

Okra (*Abelmoschus esculentus* [L.] Moench) or bhindi also known as 'lady's finger' is an important vegetable crop being native of tropical Africa. It is widely cultivated within tropical and sub-tropical regions, including the Mediterranean Basin for its immature pods, which are consumed either fresh or after processing as dried, canned or frozen (Doymaz, 2005). The immature fruits and leaves of *Abelmoschus esculentus* are used in soup as a thickener because it is a rich source of vitamins and minerals (Awodoyin and Olubode, 2009). It has been found to be a rich source of vitamin A and C, calcium, thiamine and riboflavin. Okra has a great scope in world trade. The crop is grown year round under varied soil and climatic conditions of India. The coastal belt of eastern India is one of the major okra growing regions of the country. India is the world's topmost country, producing 4.18 million tones (mt) of okra annually, which is around 70% of global okra production (FAO, 2008). The underground water and water storage reservoirs are rapidly depleting due to a nominal recharging by the rainfalls and continuous silting in the dams making water a scarce resource for irrigation. This shortage of water for irrigation is one of the most crucial factors limiting growth and production of almost all the crops worldwide including okra. Panigrahi *et al.* (2011) stated that the financial return per every drop of irrigation water should be enhanced while considering the best water use efficiency (WUE) associated with any crop. Declining ground water table is more pronounced in tube well commands of lower Indo-Gangetic plain region of West Bengal. In order to face the calamity it is necessary to take some effective strategies that may improve WUE. In this context, adoption of RSB system is a viable alternative technology in increasing productivity and income (Singh *et al.*, 2005). The soil water is managed effectively under RSB land configuration, which improves productivity of crops and WUE (Saha, 2011). Experiment conducted at mid-altitude of Meghalaya proved that with the adoption of RSB land configuration, three crops in succession can be grown on raised beds and at least two crops in sunken beds in a single year as against mono-cropping of rice in lowland (Das *et al.*, 2013). Again, inclusion of vegetables in the rice culture can be one of the alternative land use systems for higher crop water productivity (Goswami and Sarkar, 2007). Keeping this in view, present study aims at growing of arable vegetable crop okra and wet crop rice in raised and sunken bed respectively to save aquifer water in the tube well commands.

2. MATERIALS AND METHODS

The field experiment was carried out at Central Research Farm, Bidhan Chandra Krishi Viswavidyalaya, West Bengal (22°58′N latitudes and 88°30′E longitudes with 9.75 m above mean sea level (amsl) to study the impact of RSB system on the water saving, crop growth and yield of okra under irrigated situation during 2012 and 2013. The experimental site belongs to sub-tropical humid climate. The maximum and minimum mean monthly temperature, maximum and minimum RH, bright sunshine hour and daily class-A pan evaporation rate varied in the range 23.54-37.90 and 13.21-29.05°C, 87.37-95.58 and 36.74-60.81%, 4.90-8.74 and 1.06-4.82 mm, respectively during 2012 whereas the values ranged between 25.11-37.59 and 9.97-26.41°C, 87.97-94.07 and 34.19-78.63%, 4.74-8.41 and 1.14-4.53 mm, respectively during 2013. The amount of effective rainfall received by the crop was 141.3 and 151.4 mm during 2012 and 2013, respectively. Three RSB ratios *viz.*, 1:3, 2:3, 3:3 and two irrigation schedules likely I_1 - CSW with standing water of $\pm$5 cm and I_2-AWD at 5 days interval for rice in sunken bed were tested. The length and height of each bed in RSB system was 6 m and 20 cm, respectively. The field experiment was laid out in randomized block design (RBD) with three replication consisting seven combinations of RSB with irrigation scheduling as: $T_1 = I_1\,RSB_1$ (1:3) - CSW in 3 m sunken rice bed with 1 m raised okra bed; $T_2 = I_1\,RSB_2$ (2:3) - CSW in 3 m sunken rice bed with 2 m raised okra bed; $T_3 = I_1\,RSB_3$ (3:3) - CSW in 3 m sunken rice bed with 3 m raised okra bed; $T_4 = I_2\,RSB_1$ (1:3) - AWD in 3 m sunken rice bed with 1 m raised okra bed; $T_5 = I_2\,RSB_2$ (2:3) - AWD in 3 m sunken rice bed with 2 m raised okra bed; $T_6 = I_2\,RSB_3$ (3:3) - AWD in 3 m sunken rice bed with 3 m raised okra bed and T_7 = sole okra with irrigation at IW/CPE = 1.0. Okra was grown on raised bed of 6 m length and 20 cm elevation following land configuration model (Fig. 1) with the planting geometry of 50 x 30 cm row-plant spacing. Irrigation water applied in sunken bed gets transmitted to the raised bed through seepage. Depth of irrigation was 5 cm. Land configuration was made by 'Bull' tractor in the 1st cropping season and the lay out was maintained for the next season. The soil of the experimental site was sandy loam in texture with soil pH 6.8 and organic carbon 0.55%, nitrogen 0.59%, available P_2O_5 - 30 kg ha^{-1} and available K_2O - 145 kg ha^{-1}. Bulk density value was of 1.47 Mg m^{-3}. Rice *cv.* IET 4786 was transplanted on 1st week of February, 2012 and 2013 and okra *cv.* Hybrid-152 (Syngenta) was sown 10 days early of rice transplanting so as to get smooth germination of crop. Crops were raised with standard agronomy practices in RSB. Rice was harvested in the 1st week of May and okra was harvested in 15 occasions starting from 2nd week of

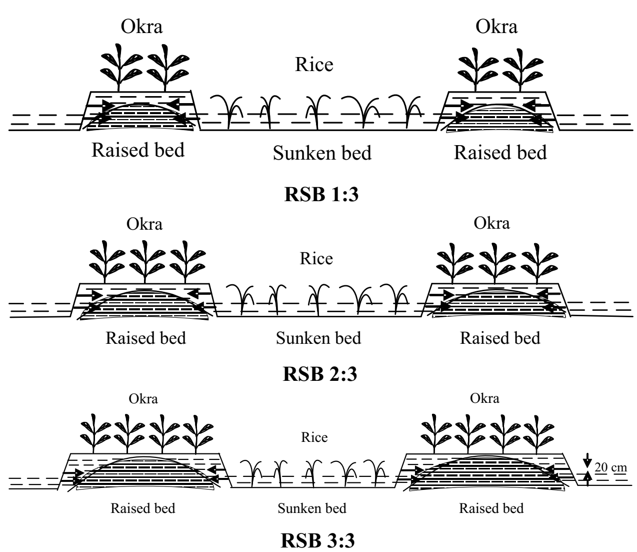

Fig. 1. Hydraulics of soil water movement in raised bed from sunken bed (RSB) having different raised bed width ratios

March to end of May. Observations were taken on crop growth, yield performance, soil moisture movement from sunken bed to raised bed as the wet zone (border of bed which got more water) and dry zone (middle part which got less seepage water), irrigation water use in sunken bed and crop productivity. Statistical significance of different treatments was calculated following least square difference (LSD, P = 0.05) test using analysis of variance in RBD.

3. RESULTS AND DISCUSSION

Crop Growth Parameters

Crop growth parameters of okra in terms of plant height, branches/plant, leaf number, above ground DM accumulation, LAI and CGR were significantly influenced by CSW and AWD irrigation in rice and soil moisture availability in okra (Table 1). Okra grown in raised plots with 3:3 bed width ratios under AWD recorded maximum plant height (79.2 cm) as compared to okra grown in other two raised bed width ratios *i.e.* 1:3 and 2:3. AWD recorded 13-23% higher plant height over CSW which might be attributed better aeration in the root zone which resulted more growth of plant. Panigrahi *et al*. (2011) also reported that alternate partial root zone irrigation like as AWD produced the higher plant height (0.5-0.7 m) of okra over full root zone irrigation through CSW. The highest value of number of leaves per plant (43.2) was recorded under sole okra which was statistically at par with 3:3 bed width ratios under AWD water regimes. Okra crop grown in raised bed under CSW irrigation recorded 15-19% less number of leaves per plant as compared to AWD irrigation. Number of branches/plant was generally high in the raised bed of okra under AWD irrigation scheduling as compared to CSW irrigation in rice. This might be attributed to higher moisture content in the root zone of okra plant under CSW irrigation scheduling which affects the metabolic activity of the plants. The 3:3 bed width ratio with AWD irrigation recorded highest number of branches/plant (*i.e.* 3.83). The highest value of aerial DM accumulation (392.1 g m^{-2}) of okra was obtained with 3:3 bed width ratios under AWD which was significantly different from okra crop grown in other two bed width ratio *i.e*. 1:3 and 2:3. The dry weight of vegetative as well as reproductive part of okra crop was also less under CSW irrigation scheduling as compared to AWD due to less number of leaves and branches/plant. On the other hand, roots are in direct contact with soil and the first to be affected by the water logging in CSW. Thus growth of okra plant is not faster under CSW irrigation scheduling which ultimately hampered the DM production. This result is in line with findings of Rauf and Sadaqat (2007); Jayapiratha *et al.* (2010); Panigrahi and Sahu (2013). The same trend was also observed for the LAI and CGR of okra. The maximum LAI value of 1.34 was obtained with 3:3 bed width ratios under AWD and was significantly higher than what was observed with okra grown in other two bed width ratios *i.e.* 1:3 and 2:3. On the other hand, the CGR value increased with the increasing bed width ratio and the maximum value (5.99 g $m^{-2}day^{-1}$) was observed with 3:3 bed width ratios under AWD water regimes.

Table: 1
Growth and yield attributes of raised bed okra as influenced by raised bed width and water regimes (Pooled data of 2012 and 2013)

Treatment	Plant height (cm)	Leaves /plant	Branches /plant	ADM (g m^{-2})	LAI	CGR (g $m^{-2}day^{-2}$)	Fruits /plant	Av. fruit length (cm)	Av. fruit weight (g)
I_1RSB_1 (1:3)	60.5	33.5	2.63	336.2	0.98	3.53	20.9	9.97	9.42
I_1RSB_2 (2:3)	66.9	33.1	2.93	341.3	1.03	4.32	21.9	9.99	9.53
I_1RSB_3 (3:3)	68.6	34.4	3.13	349.1	1.08	4.66	25.3	10.09	10.06
I_2RSB_1 (1:3)	77.7	39.9	3.07	359.1	1.14	4.99	30.7	10.18	10.70
I_2RSB_2 (2:3)	77.6	36.1	3.67	378.5	1.21	5.39	25.5	10.47	10.60
I_2RSB_3 (3:3)	79.2	40.8	3.83	392.1	1.34	5.99	24.9	11.20	11.03
Sole okra	77.8	43.2	3.37	375.6	1.17	5.60	21.2	10.51	10.83
S.Em (±)	2.35	1.71	0.09	2.19	0.02	0.06	0.53	0.11	0.14
CD (*P* = 0.05)	6.85	4.98	0.26	6.59	0.06	0.19	1.55	0.31	0.41

I_1 RSB_1 (1:3) - CSW in 3 m sunken rice bed with 1 m raised okra bed; I_1 RSB_2 (2:3) - CSW in 3 m sunken rice bed with 2 m raised okra bed; I_1RSB_3 (3:3) - CSW in 3 m sunken rice bed with 3 m raised okra bed; I_2 RSB_1 (1:3) - AWD in 3 m sunken rice bed with 1 m raised okra bed; I_2 RSB_2 (2:3) - AWD in 3 m sunken rice bed with 2 m raised okra bed; I_2 RSB_3 (3:3) - AWD in 3 m sunken rice bed with 3m raised okra bed and sole okra; ADM - Aerial Dry Matter; LAI - Leaf Area Index at 60 DAS; CGR - Crop Growth Rate at 60-90 DAS.

Yield Attributes

Yield parameters of okra like fruit number, fruit length, fruit weight were significantly influenced by CSW and AWD irrigation in rice and soil moisture availability in okra (Table 1). The maximum number of fruits per plant (30.7) was recorded with 1:3 bed width ratios under AWD irrigation scheduling as compared to okra grown in other two bed width ratio *i.e*. 2:3 and 3:3 during both the years of experimentation. It was significantly higher than the values recorded with other treatments. The highest value of fruit length of 11.20 cm and average fruit weight of 11.03 g was observed with 3:3 bed width ratios under AWD irrigation scheduling. AWD irrigation scheduling recorded higher values of average fruit length as well as average fruit weight than CSW irrigation regimes. The higher fruit length recorded under AWD was probably due to higher nutrients assimilation supported by the availability of more nutrients in the soil solution under favorable soil moisture and temperature within the plant rhizosphere and the minor weed cover.

Green Fruit Yield

Okra *cv.* Hybrid 152 (Syngenta) grown in 3:3 RSB system recorded the fruit yield of 12.16 and 14.05 t ha^{-1} with CSW irrigation scheduling in rice but okra grown in 1:3 RSB system recorded the highest fruit yield of 14.08 t ha^{-1} and 15.43 t ha^{-1} with AWD irrigation scheduling in rice during 2012 and 2013, respectively (Table 2). It was statistically at par with 3:3 bed width ratios under AWD irrigation scheduling. AWD irrigation scheduling recorded about 13-33% and 9-30% yield advantage over CSW irrigation scheduling during 2012 and 2013, respectively. This yield variation might be attributed to the variation in the soil water availability to the root zone of okra (Sharma, 2003). In AWD irrigation regime, narrow bed (1 m width) gets more water than wider beds (2 and 3 m). On the contrary, in CSW irrigation okra grown in wider beds (3 and 2 m) responded better than 1 m bed as okra was susceptible to water logging or more water in the root zone. Partial root zone irrigation through AWD in rice has been found potential irrigation technique over full root zone irrigation through CSW without affecting the yield and yield attributes of various crop in water scarce environments (Liu *et al.*, 2006; Patanea *et al.*, 2011).

System Yield and Economics

Irrigation given following CSW and AWD in rice under RSB system had diverse impact on the system yield (REY) *i.e.* rice equivalent yield (Table 3). CSW irrigation treatment recorded increased yields of rice but decreased the okra yield as the crop could not tolerate much water in the root zone, whereas, AWD irrigation in rice decreased the rice yield by 8.14-13.30% but it increased the okra yield by 8.22-49.57% irrespective of land configurations. Impact of land configuration was very much conspicuous in system yield advantage compared to sole cropping irrespective of irrigation regime. CSW irrigation scheduling failed to record high B:C ratio due to high

Table: 2
Fruit yield, water supply and WUE of raised bed okra as influenced by raised bed width and water regimes

Treatment	Fruit yield (t ha^{-1})		Water Use (mm)		WUE (kg $ha^{-1}mm^{-1}$)	
	2012	2013	2012	2013	2012	2013
I_1 RSB_1 (1:3)	9.42	10.70	337	331	27.96	32.35
I_1 RSB_2 (2:3)	9.44	11.15	297	299	31.79	37.30
I_1 RSB_3 (3:3)	12.16	14.05	280	290	43.44	48.47
I_2 RSB_1 (1:3)	14.08	15.43	256	267	55.02	57.80
I_2 RSB_2 (2:3)	13.32	14.52	223	241	59.75	60.27
I_2 RSB_3 (3:3)	13.62	14.49	170	197	80.15	73.57
Sole okra	10.42	10.40	341	351	30.57	29.64
S.Em (±)	0.35	0.27	-	-	1.35	1.01
CD (P = 0.05)	1.09	0.83	-	-	4.15	3.09

I_1 RSB_1 (1:3) - CSW in 3 m sunken rice bed with 1 m raised okra bed; I_1 RSB_2 (2:3) - CSW in 3 m sunken rice bed with 2 m raised okra bed; I_1RSB_3 (3:3) - CSW in 3 m sunken rice bed with 3 m raised okra bed; I_2 RSB_1 (1:3) - AWD in 3 m sunken rice bed with 1 m raised okra bed; I_2 RSB_2(2:3) - AWD in 3 m sunken rice bed with 2 m raised okra bed; I_2 RSB_3 (3:3) - AWD in 3 m sunken rice bed with 3 m raised okra bed and sole okra

Table: 3
System yield and economics as influenced by land configuration and water management practices

Treatment	Crop yield (t ha^{-1})						B:C
	Okra		Rice		REY		
	2012	2013	2012	2013	2012	2013	
I_1RSB_1 (1:3)	9.42	10.70	4.36	4.89	5.67	6.39	2.19
I_1RSB_2 (2:3)	9.44	11.15	3.92	4.22	6.02	6.72	2.26
I_1RSB_3 (3:3)	12.16	14.05	3.43	3.56	6.82	7.49	2.53
I_2RSB_1(1:3)	14.09	15.43	3.78	3.95	5.74	6.11	1.82
I_2RSB_2 (2:3)	13.32	14.52	3.34	3.50	6.30	6.75	2.38
I_2RSB_3 (3:3)	13.62	14.49	3.12	3.27	6.91	7.33	2.58
I_1Sole rice	-	-	4.23	4.24	4.23	4.24	1.52
I_2Sole rice	-	-	3.46	3.63	3.46	3.63	1.34
Sole okra	10.42	10.40	-	-	5.79	5.78	2.58
CD (P=0.05)	1.087	0.828	0.159	0.484	3.71	4.04	-

REY- Rice equivalent yield was calculated on sale price of okra and rice ₹ 10 and 18 kg^{-1}, respectively; Benefit Cost (B:C) ratio water cost, whereas, AWD irrigation schedule with RSB (3:3) system gave high B:C ratio of 2.58 due to less irrigation water charges and high system productivity. Land configuration RSB 3:3 was more economical than RSB 1:3. Sole rice recorded the least B:C ratio of 1.34 and 1.52 under AWD and CSW irrigation regimes, respectively.

Water Supply and Water Use Efficiency (WUE)

Water supply to raised bed okra crop and its WUE value were significantly influenced by the irrigation scheduling like CSW and AWD in rice and land configuration of raised bed for okra (Table 4). As there was no irrigation to the raised bed okra the total water supply was measured considering the effective rainfall during the cropping period and the water gained through seepage from the adjacent sunken bed of rice. The total amount of effective rainfall was 141.3 and 151.4 mm for the two consecutive cropping periods. Okra crop grown in the narrow bed (1 m) gained more amount of irrigation water through seepage than the crop grown in broader bed (2 and 3 m) under both AWD and CSW irrigation scheduling. AWD irrigation scheduling with 3:3 RSB treatment recorded the least water supply of 170 and 197 mm gained through seepage having WUE value of 80.15 and 73.57 kg ha^{-1} mm^{-1} during 2012 and 2013, respectively. Results revealed that the WUE and yield of raised bed okra was significantly correlated with each other (Fig. 2). Raised bed land configuration of 3:3 width ratio saved about 5-17% and 3-12% of irrigation water under CSW and 24-33% and 18-26% of irrigation water under AWD over other two bed width ratio *i.e.* 2:3 and 1:3 during 2012 and 2013, respectively. The relationship of crop water demand (PET) was very much corresponding to reference evapotranspiration (ET_c) of okra in lower Indo-Gangetic plains (Fig. 3).

Moisture Availability

Moisture availability at different soil depth of the wet zone (part of the raised bed adjacent to the sunken

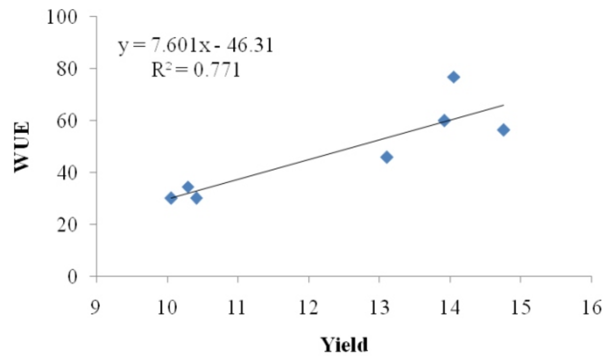

Fig. 2. Relation between Water use efficiency (kg ha^{-1}mm^{-1}) and yield of okra (t ha^{-1})

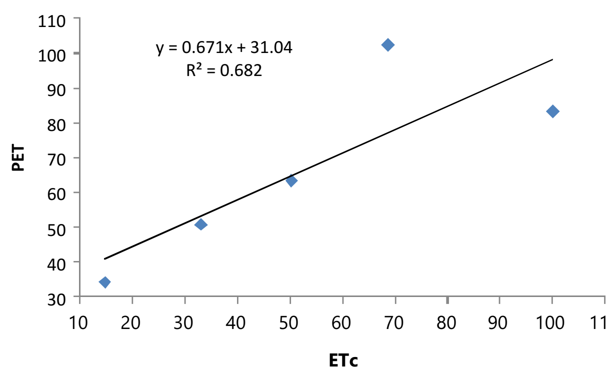

Fig. 3. Relation between Potential Evapotranspiration (PET, mm) and Crop Evapotranspiration (ET_c, mm)

Table: 4

Soil moisture availability (SMA) to wet and dry zone of raised bed okra at different depth (cm) as influenced by raised bed width and water regimes

Treatment	SMA (mm) in 2012						SMA (mm) in 2013					
	Wet zone			Dry zone			Wet zone			Dry zone		
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
I_1RSB_1 (1:3)	16.0	17.6	19.2	14.4	14.4	15.5	13.6	15.5	16.5	11.7	12.5	12.9
I_1RSB_2 (2:3)	14.4	14.3	15.3	12.1	12.7	12.9	12.6	13.6	14.5	10.4	11.4	12.1
I_1RSB_3 (3:3)	13.1	14.0	13.7	10.9	11.1	12.3	11.9	13.8	13.9	10.2	11.2	12.0
I_2RSB_1 (1:3)	11.6	12.5	13.1	10.2	10.3	11.5	10.4	12.6	12.9	10.1	10.7	10.9
I_2RSB_2 (2:3)	11.4	11.9	12.6	9.4	9.8	10.3	10.3	12.2	12.4	9.1	9.9	10.4
I_2RSB_3 (3:3)	9.3	11.0	11.4	8.0	9.5	9.7	10.1	10.9	11.2	8.8	9.2	9.8
Sole okra	44.8	46.9	49.3	36.8	38.9	41.8	49.1	52.0	53.6	37.6	39.3	41.6

I_1RSB_1 (1:3) - CSW in 3 m sunken rice bed with 1 m raised okra bed; I_1RSB_2 (2:3) - CSW in 3 m sunken rice bed with 2 m raised okra bed; I_1RSB_3 (3:3) - CSW in 3 m sunken rice bed with 3 m raised okra bed; I_2RSB_1 (1:3) - AWD in 3 m sunken rice bed with 1 m raised okra bed; I_2RSB_2 (2:3) - AWD in 3 m sunken rice bed with 2 m raised okra bed; I_2RSB_3 (3:3) - AWD in 3 m sunken rice bed with 3m raised okra bed and sole okra; Wet Zone- two border sides of raised bed adjacent to sunken bed; Dry zone- middle part of raised bed away from sunken bed

bed) and dry zone (the middle part of raised bed) of raised bed okra was significantly influenced by the bed width ratio and irrigation scheduling in rice (Table 3). It was observed that the moisture availability of the raised bed generally higher under CSW irrigation as compared to AWD irrigation and the value was decreased with the increased bed width ratio of raised bed okra. This may be due to the continuous supply of water to the adjacent sunken bed of rice which gets transmitted through seepage to the okra plot grown under CSW irrigation. The crop grown as sole recorded the highest amount of available soil moisture (341 and 351 mm) during both the year of 2012 and 2013 as the sole okra plot received 4 number of irrigation throughout its crop growing period.

4. CONCLUSIONS

RSB system of 3:3 bed ratio recorded the high fruit yield (14.05 t ha^{-1}) of okra with maximum WUE (76.86 kg ha^{-1} mm^{-1}) and saved about 35% irrigation water. CSW irrigation treatment recorded increased yields of rice but decreased the okra yield, whereas, AWD irrigation in rice decreased the rice yield by 8.14-13.30% but it increased the okra yield by 8.22-49.57% irrespective of land configurations. AWD irrigation schedule with RSB (3:3) system gave high system productivity having B:C ratio of 2.58. Land configuration RSB 3:3 was more economical than RSB 1:3. Sole rice recorded the least B:C ratio of 1.34 and 1.52 under AWD and CSW irrigation regimes, respectively. On the basis of the results, in summer rice cultivation (January to April), inclusion of RSB system may be advocated for okra cultivation with less amount of water in sandy loam soil of Eastern India, particularly in the lower Indo-Gangetic plains and it will help the farmers to increase the crop water productivity.

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