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Productivity, water use efficiency and economics of furrow irrigation methods in rainfed vegetables under dryland condition

N. Sahoo[1], M.R. Panda[2], S.K. Behera[2,*] and A. Mishra[3]

[1]Department of Soil and Water Conservation Engineering, CAET, OUAT, Bhubaneswar, Odisha; [2]AICRP for Dryland Agriculture, OUAT, Phulbani, Kandhamal, Odisha; [3]AICRP on Potato, OUAT, Bhubaneswar, Odisha.

**Corresponding author:*
E-mail: subrat_behera@rediffmail.com (S.K. Behera)

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ABSTRACT

Rainfed agriculture encounters some major edaphic and climatic problems like land degradation, erratic rainfall pattern, moisture deficit or depletion due to uncertainty of monsoon and over-exploitation of natural resources. These problems pose a formidable challenge to the sustainability of rainfed crop production affecting the socio-economic status of the farming community. Conservation and proper utilization of rainwater at critical stages of the crop for optimum crop production is still a challenge to rainfed farmers. Adopting olericulture (vegetable production) on different furrow irrigation methods under rainfed condition is a suitable technology to minimize the above risk for stability in crop production. Considering the above facts, an experiment was undertaken in the research farm of the All India Coordinated Research Project for Dryland Agriculture (AICRPDA), Odisha University of Agriculture and Technology (OUAT), Phulbani during *kharif* seasons of 2012, 2013 and 2014. Four rainfed vegetables, *i.e.* radish (*cv.* Pusa Chetki hybrid), cauliflower (*cv.* Pearl White hybrid), yambean (*cv.* Rajendra Mishri Kanda-1) and Okra (*cv.* Supriya hybrid) were taken as Factor-A treatments and three irrigation methods *i.e.* continuous furrow irrigation (CFI), skip furrow irrigation (SFI), and no irrigation (NI) were taken as Factor-B treatments. It was found from the experiment that among furrow irrigation methods, CFI was the best recording the highest radish equivalent yield (REY, 22.13 t ha^{-1}) followed by SFI (19.1 t ha^{-1}) and NI (13.71 t ha^{-1}) and it exhibited 29.5, 46.7, 57.8 and 28.2% higher REY over NI in radish, cauliflower, yambean, and okra, respectively whereas it ranged from 7.9% in okra to 29.9% in cauliflower by SFI over NI on pooled analysis. Among rainfed vegetables, radish obtained the maximum vegetable yield (18.65 t ha^{-1}) followed by yambean (9.78 t ha^{-1}), okra (5.06 t ha^{-1}) and cauliflower (4.85 t ha^{-1}), whereas yambean recorded the maximum REY (24.52 t ha^{-1}) followed by radish (9.78 t ha^{-1}). The yambean under CFI also recorded the highest net income, B:C ratio and energy use efficiency (EUE), whereas radish recorded the highest crop water use efficiency (CWUE) and water productivity (WP) under the same treatment. The CFI irrigation method proved its effectiveness and efficiency during dryspell for high value-vegetable crops during the *kharif* season.

1. INTRODUCTION

In dryland agriculture, the distribution and pattern of the rainfall is more important than amount of rainfall (Behera *et al.,* 2012). The area receiving 1500 mm or more rainfall annually may also fall in the category of dryland agriculture because the annual potential evapo-transpiration (PET) is more than the annual rainfall. The erratic and uncertain rainfall pattern in dryland needs an assured *ex-situ* source of irrigation during occasional dry spell at the farmers' fields to neutralize the crop damaging effect at critical growth stages of crops. Annual evapo-transpiration (ET) by the crops exceeds precipitation (P) in the soil of dryland areas where the soil moisture balance is always on the deficit side. Thus, the average moisture deficit created is bound to affect crop production under dryland situation, ultimately leading to total or partial crop failure (Bastia *et al.,* 2019; Bastia *et al.,* 2020). Thus, any method of sustainable irrigation is now essential for adaptation and adoption in these rainfed areas where water resources are limited (Sarker *et al.,* 2016). So both the dryland and rainfed farming are now synonymous with each other. However, sometimes excess irrigation water increases surface runoff, deep percolation, water stagnant and decreases aeration and this excess water needs to be stored and utilized judiciously for optimum crop production (El-Halim, 2013).

Global climate change, environmental pollution and industrial wastewater are common phenomena that may limit water use for sustainable agriculture production in future (Stikic *et al.,* 2009). Accordingly the crop production under dryland condition is either fragile or extremely uncertain and unstable which are the real cruxes of problems. To overcome these chronic problems, short duration vegetable production in lieu of food crops in dryland condition by using *ex-situ* harvested water from farm ponds during *kharif* season, is a viable and attainable option in terms of economic returns, farm resilience, water productivity (WP) and sustainability of farming for the farmers and their preferences (Wani *et al.,* 2013).

Aberrant monsoon behavior under rainfed condition in red and lateritic soil of Odisha results in poor crop yields and makes crop production hyper or hypo-bolic. Lateritic soils are invariably low in organic matter and poor in N, P and K contents. These soils have low water holding capacity (WHC) and are highly susceptible to erosion. Retention and poor utilization of harvested rainwater through farm pond particularly during *kharif* season under the undulating topography, often result in poor crop production and profitability. For profitable cultivation in dryland, instead of cereals, some rainfed short duration vegetables requiring less water to complete their crop cycles but giving more profit, can be advocated for farm sustainability (Mishra *et al.,* 2017). These vegetables add tenacity and resilience to farm profitability within a short period of time, *i.e.* only *kharif* season and achieve more sustainable biological and economic productivity on a long term.

Water saving technologies and productivity per unit of water are becoming strategic importance for successful vegetable production. Two water saving strategies could be considered: Firstly, continuous furrow irrigation (CFI), where a certain depth of harvested water (*ex-situ*) is applied to the entire root-zone in every furrow. Secondly, partial root-zone *i.e.* skip furrow irrigation (SFI) technique, only one furrow of the root-zone is irrigated by water, while the remaining adjacent furrow is kept un-irrigated (Sarker *et al*., 2016). It is aimed to optimize the use of conserved water through farm pond judiciously through recycling, conserving of natural resources, internalizing the vegetable production, and reduces the risk. It also reduces the uncertainty of crop failure and maintains favourable soil moisture regime in field by recharging ground water table, and improves the soil WHC, physico-chemical and biological properties (Khan *et al.,* 2005).

The rainfed vegetables, instead of traditional cereal or pulses for this upland situation, are suitable for dryland farmers to augment the socio-economic condition (Saha *et al.,* 2014). Under the olericulture system, water saving vegetables can be grown successfully with *ex-situ* harvested water. The crop substitution system, *i.e.* field crops by horticultural crops, can be an economical and profitable proposition for marginal and small land holding farmers (Singh, 2013). It was also observed that the short duration, profit making vegetables like radish, cauliflower, yambean, and okra can substitute the cereal-pulses-vegetable cropping sequence by vegetable-pulses-cereal cropping sequence and sustain water and soil productivity in rainfed area. As the distribution of rainfall is highly erratic during *kharif* season, farmers never feel comfortable to grow vegetable crops in upland situations of Kandhamal district. When the farmers grow vegetable crop in their fields during *kharif* season, they solely depend on monsoon rainfall in which dryspell is a regular phenomenon. They neither apply any irrigation technique nor any mechanism to save their crops against critical dry spells / droughts. In view of the above context, a field experiment was conducted to test the soil and rainwater productivity, energy use efficiency (EUE), and economic viability of rainfed vegetables like radish, yambean, okra and cauliflower by utilizing *ex-situ* harvested and conserved water of farm pond through different methods of irrigation in time of the dryspell. The main objectives of the study were (i) to quantify the crop and water productivity and profitability through different furrow irrigation methods using *ex-situ* harvested water and (ii) to estimate the EUE and water use efficiency (WUE) of vegetable crops under different furrow irrigation methods to identify the most profitable and remunerative irrigation methods for rainfed vegetable/s suitable for the small and marginal farmers during *kharif* season, especially in red and lateritic soil of Odisha under rainfed condition.

2. MATERIAL AND METHODS

The experiment was conducted at the research farm of the AICRPDA, OUAT, Phulbani under Kandhamal district of Odisha during 2012, 2013 and 2014. The experimental site is located in the North Eastern Ghat Zone of Odisha at 20°28'9"N latitudes, 84°14'18"E longitudes and at an elevation of 518.0 m above mean sea level (amsl). It has a tropical sub-humid and monsoon-dependent climate with an average annual rainfall of 1407.3 mm, concentrated mostly from June to October. The onset of monsoon in 2012 was six days earlier than the normal date of 10th June but at the right time in 2013 and delayed by eight days in 2014 (Table 1). The total rainfall during 2012, 2013 and 2014 were found to be 17.4% more, 3.1% less and 11.5% more than normal, respectively. However, the pre-monsoon and post-monsoon rainfall in 2013 and 2014 were 70.6% and 13.8% less as compared to the normal, respectively whereas monsoon rainfall in 2012 was 17% more than the normal (Table 1). The total number of dryspells during crop seasons of 2012, 2013 and 2014 were found to be 2 (25 days), 8 (49 days) and 5 (38 days), respectively occurring at the early, mid and terminal stages of crop growth. The monsoon scenario of the experimental site during 2012-14 is given in Table 1 and monthly, weekly rainfall distribution during 2012-14 is given in Fig. 1a and 1b, respectively.

The soil of the experiment site is red lateritic (class - *alfisol*), granular in structure and sandy-loam to silty loam in texture with slightly acidic (pH-5.15), medium EC (0.45 dS m^{-1}), medium SOC (0.53%) and low (N, K) to high (P) in fertility status having FC (field capacity) at 14.6% (w/w) and PWP (permanent wilting point) at 7.4% (w/w). The available nitrogen (N), phosphorus (P) and potassium (K) in the soil layer of 0-15 cm were found to be 107.8 kg ha^{-1}, 66.8 kg ha^{-1} and 309.4 kg ha^{-1}, respectively. The experiment was conducted in factorial RBD with three furrow irrigation

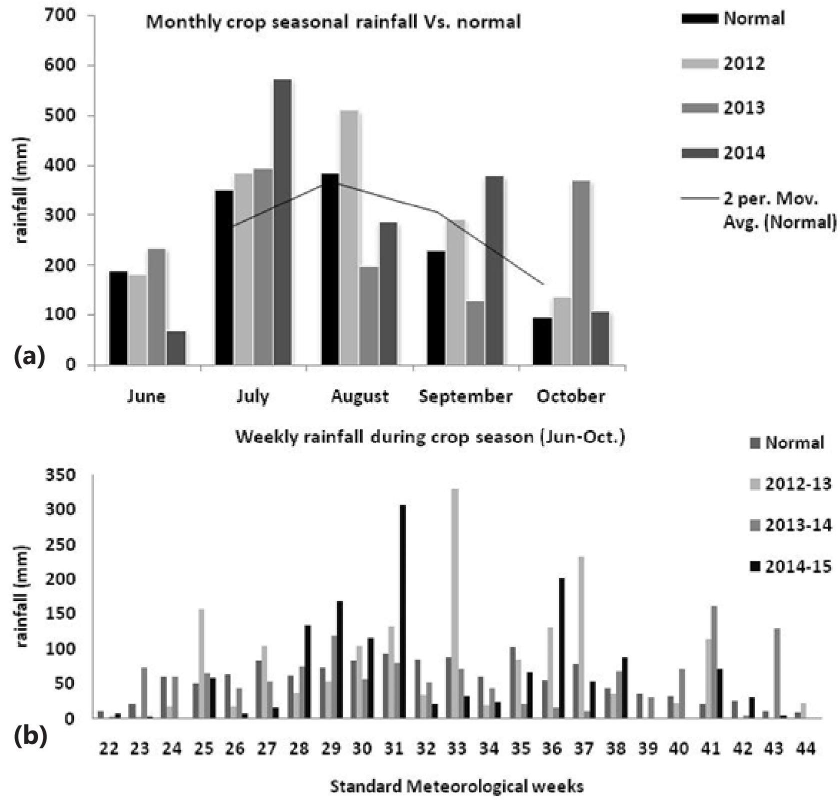

Fig. 1. Distribution of (a) monthly rainfall and (b) weekly rainfall during crop growing season from 2012 to 2014 at experimental site

Table: 1
Monsoon scenario of the research farm of All India Coordinated Research Project for Dryland Agriculture (AICRPDA), Phulbani during three crop seasons

Monsoon parameters	Normal	2012	2013	2014
Onset date of Monsoon	10th June	4th June	8th June	18th June
Pre monsoon (Jan.-May)	132.1	164.0	38.8	156.2
Monsoon (June-Sept.)	1150.5	1365.8	954.6	1305.7
Post monsoon (Oct.-Dec.)	124.7	165.8	370.0	107.4
Total rainfall (mm)	1407.3	1695.6	1363.4	1569.3
Dry spell period during crop season (June-Oct.)	-	2 no. on Sept. (24th-30th), and Oct. (14th-31st)	7 no. on Aug (14-18th, 22nd-26th), Sept. (30th Aug-8th Sept., 10th-14th, 23rd-27th) and Oct. (4th-11th, 15th-20th)	4 no. on Jun (10th-17th), July (28th-31st), Sept. (16th -19th), and Oct. (1st-11th)
Rainy days (No.)	65	76	70	66

methods *i.e.* CFI, SFI and NI as factor A and four rainfed vegetables *i.e.* radish (*cv.* Pusa Chetki), cauliflower (Pearl White), yambean (*cv.* Rajendra Mishri Kanda-1) and okra (*cv.* Supriya hybrid) as factor B with three replications. Before final land preparation, a uniform dose FYM of 10 t ha^{-1} was applied to all plots. All the vegetable crops were sown during 1st week to 2nd week of July, depending on the onset of monsoon after proper summer ploughing and land preparation every year and harvested during 2nd fortnight of September to 2nd fortnight of October for multiple times to catch the variable market price except radish which was harvested during 1st week of September. The planting was done in a net plot size of 34.96 m^2 (7.6 m × 4.6 m) in which spacing for each vegetables *i.e.* cauliflower - 60 cm × 45 cm, yam bean - 60 cm × 20 cm, radish - 45 cm × 5 cm, and okra - 60 cm × 30 cm were maintained between row to row and plant to plant, respectively with a seed rate of 0.5 kg ha^{-1} for cauliflower, 15.0 kg ha^{-1} for yambean, 10.0 kg ha^{-1} each for radish and okra in the same field over the years. The recommended fertilizer dose (RDF) (N-P-K) of 125:40:60 kg ha^{-1} for cauliflower, 80:60:80 kg ha^{-1} for yambean, 50:50:75 kg ha^{-1} for radish and 80:40:40 kg ha^{-1} for okra were applied in split doses (half of N + full P + full K as basal, rest half of N at flowering stage) to respective vegetables. Other standard agronomic package of practices were followed from sowing to harvesting including the application of pesticides (Chloropyrophos @ 2.5 ml l^{-1} for termite attack and soil borne pests, strike-505 @ 2 ml l^{-1} for pod and leaf borer, thrips and aphid in all vegetables except radish) during crop period. During critical dryspell, life-saving irrigation was provided to the vegetable crops through CFI, and SFI methods from the existing *ex-situ* lined farm pond. In CFI, water was applied in each furrow while in case of SFI; it was applied in alternate furrows during critical dryspell. In case of NI method, no water was applied to the crop during dryspells. One life saving irrigation of 5 cm depth was applied in CFI method in 2012 and 2014 whereas 3 nos of life-saving irrigation of 5 cm depth were applied in CFI method in 2013. One life-saving irrigation of 2.5 cm depth was applied in SFI method in 2012 and 2014 whereas 3 nos of life saving irrigation of 2.5 cm depth was applied in CFI method in 2013. Periodical observations on growth and yield parameter were recorded from time to time during the three *kharif* seasons of 2012, 2013 and 2014.

The crop yield (kg) has been calculated following the standard method by taking the entire net plot area (m^2), and then converted into kg ha^{-1} accordingly. The yield data were used for economic analysis and estimation of crop water use efficiency (CWUE) and WP. In order to compute the profitability of different crops under different irrigation methods, the net returns and B:C ratio were calculated. The net returns (₹ ha^{-1}) were computed as a difference of gross returns (₹ ha^{-1}) and cost of cultivation (₹ ha^{-1}). System profitability was calculated by using prevailing market price of inputs and outputs. The values of REY were computed by using the formula as follows (Behera *et al.,* 2012):

$$REY = \frac{(Y_i \times Pi)}{P_m} \quad ...(1)$$

Where, Y_i is yield of the concerned crop (kg ha^{-1}), P_i is price of concerned the crop (₹ kg^{-1}) and P_m is price of the radish (₹ kg^{-1}). Similarly, harvest index (HI) was calculated as suggested by Prakash *et al*. (2007).

$$HI = \frac{Ye}{Yb} \quad ...(2)$$

Where, *Ye* is the economic yield (kg ha^{-1}), and *Yb* is the biological yield of the crop (kg ha^{-1}).

CWUE indicates the yield per unit consumption of water by the crop according to Wani *et al*. (2013) and Ali *et al*. (2007). ET_{crop} under different irrigation methods (Table 2) was calculated using Penman-Monteith method (Allen *et al*., 1998). CWUE was determined as the ratio of yield and the water consumed by the crop during the growing season and is expressed as follows (Ali *et al*., 2007):

$$CWUE = \frac{Y}{CWU} \quad ...(3)$$

Where, CWUE is crop water use efficiency (kg ha^{-1} mm^{-1}); Y is crop yield (kg ha^{-1}), and CWU is consumptive water use by the crop, *i.e.* ET_{crop} (mm). WP was determined by dividing crop yield by total water applied to crop through rainfall and irrigation and is calculated as follows (Ali *et al*., 2007):

$$WP = \frac{Y}{W} \quad ...(4)$$

Where, WP is the water productivity expressed in kg $ha^{-1}mm^{-1}$, Y is yield in kg ha^{-1} and W is total water to the crop (rainwater + irrigation) expressed in mm. Energy use efficiency (EUE) of the system was calculated as per the estimation of different energy-equivalents of all agri-inputs and outputs including by-product, as suggested by Ghosh *et al*. (2007), Padhi and Panigrahi (2006) and Mishra *et al.* (2017).

$$EUE = \frac{E_o}{E_i} \quad ...(5)$$

Where, E_o is the energy output (MJ ha^{-1}) and E_i is the energy input (MJ ha^{-1}). Soil samples were collected from 0-15 cm depth from the experimental site which had FC of 14.6% and PWP of 7.4% on weight basis determined by gravimetric method. The soil moisture content (SMC) of soil was measured by the above method at different dates during crop season and also during dryspell periods depending on rainfall and crop growth stage every year

Table: 2
Yield, economics, energy use efficiency, crop water use efficiency and water productivity of vegetables under different irrigation methods from 2012 to 2014 (pooled data)

Vegetables (Factor-B)	Irrigation methods (Factor-A)	Vegetable yield (kg ha^{-1})	Harvest index (HI)	REY (kg ha^{-1})	Net income (₹ ha^{-1})	B:C	EUE	CWUE (kg ha^{-1}mm^{-1})	WP (kg ha^{-1}mm^{-1})
Radish	CFI	21612	0.31	21612	1,17,715	3.94	8.06	63.56	44.80
	SFI	19613	0.27	19613	1,06,158	3.87	7.70	61.29	44.33
	NI	14717	0.21	14717	73,988	3.18	4.40	54.51	37.51
Cauliflower	CFI	5964	0.32	20458	99,100	2.98	5.91	13.25	6.19
	SFI	5209	0.30	17859	83,230	2.77	5.08	12.11	5.64
	NI	3387	0.22	11525	40,686	1.93	3.12	8.68	3.88
Yambean	CFI	12310	0.33	30945	1,74,584	4.49	9.77	24.14	11.70
	SFI	10012	0.29	25221	1,35,869	3.89	8.85	20.43	9.99
	NI	7003	0.23	17400	82,850	2.88	5.01	15.56	7.28
Okra	CFI	5838	0.29	15506	71,614	2.71	4.50	12.16	5.94
	SFI	5188	0.28	13700	61,181	2.57	4.08	11.04	5.56
	NI	4160	0.23	11189	47,278	2.35	3.00	9.67	4.66
SE (+m)		-		617	-	-	-	0.19	0.16
CD (0.05)		-		1809	-	-	-	0.53	0.42

CFI: continuous furrow irrigation, SFI: skip furrow irrigation, NI: no irrigation; 70; Price of vegetables (₹ kg^{-1})- radish: 7, cauliflower: 25, yambean: 20, okra: 15; Average ET_{crop} of vegetables (mm ha^{-1}) under CFI - radish: 340, cauliflower: 450, yambean: 510, okra: 480; ET_{crop} under SFI- radish: 320, cauliflower: 430, yambean: 490, okra: 470; ET_{crop} under NI - radish: 270, cauliflower: 390, yambean: 450, okra: 430; Average crop seasonal rainfall (mm): radish: 392.4, cauliflower: 873.3, yambean: 962.1, okra: 892.7.

using the Kneer-Raczkowski box method (Sharma *et al.,* 2018).

$$SMC = \frac{Wm}{Wd} \times 100 \qquad ...(6)$$

Where, SMC is the soil moisture content (%, w/w), Wm is the weight of moisture per unit volume of soil (g) and Wd is the oven-dry weight of soil per unit volume (g). The crop seasonal rainfall for each crop was measured from the date of planting to the final date of harvesting of each crop to calculate the WP and CWUE of each factors. The data were subjected to paired "t" test analysis for determining the significance of the difference between the factors and to draw valid conclusions. The level of significance was at $p = 0.05$. Finally statistical analysis was done by following the "Analysis of Variance (ANOVA)" technique.

3. RESULTS AND DISCUSSION

Soil Moisture Variation in Different Irrigation Methods

The variation of soil moisture under different furrow irrigation methods at different intervals during crop growth stages in 2012, 2013, and 2014 are given in Fig. 2. During 2012 and 2014, the CFI and SFI methods at vegetative and harvesting stages of vegetables helped to retain more soil moisture (18.4% to 32.6%) than NI method during dryspells (Table 1) due to modification and alteration soil micro-climatic conditions at the crop root zone. However, more number of dryspells (7 no.) with lower amount of rainfall (1363.4 mm) during crop season in 2013 as compared to 2012 and 2014 actually projected a different weather graph (Table 1, Fig. 1a, 1b, 2b). As the vegetables are shallow rooted crops, favourable soil moisture regime created by both furrow irrigation methods in shallow soil profile implicitly saved the crops from yield reduction during water stress. However, soil moisture during other than dryspell remains at par with each other (Fig. 2a, 2b, 2c). Higher moisture retention through applied irrigation water prevents crop stress, reduce ET loss and increase infiltration of water during growing season. The CFI during dryspell performed better than SFI in saving soil water and providing better favorable soil moisture (Fig. 2). This can be correlated to its higher REY, CWUE and WP which reduce amount of water used (Table 1). In Fig. 2, it is clearly the visible impact of furrow irrigation methods on soil moisture storage in the top soil during the year of 2012, 2013 and 2014. There is no much difference in soil moisture storage in top layer of soil in all three irrigation methods. However, there is decrease in soil moisture storage in all the vegetable crops with SFI and NI than CFI during the dryspells which is clearly depicted by Fig. 2b during 2013. From these results, it is concluded that the CFI in rainfed vegetable crops, helps to overcome soil moisture stress significantly in the root zone and moderate the ultimate yield.

The overall performance of crops was better during 2012 and 2014 although dryspells occurred on fruiting and harvesting stage which was overcome by furrow irrigation of 5 cm depth for which harvesting of vegetables was prolonged up to mid October except for radish, but during 2013, seven numbers of dryspells at different critical periods of growth affected the yield of vegetables. However, its

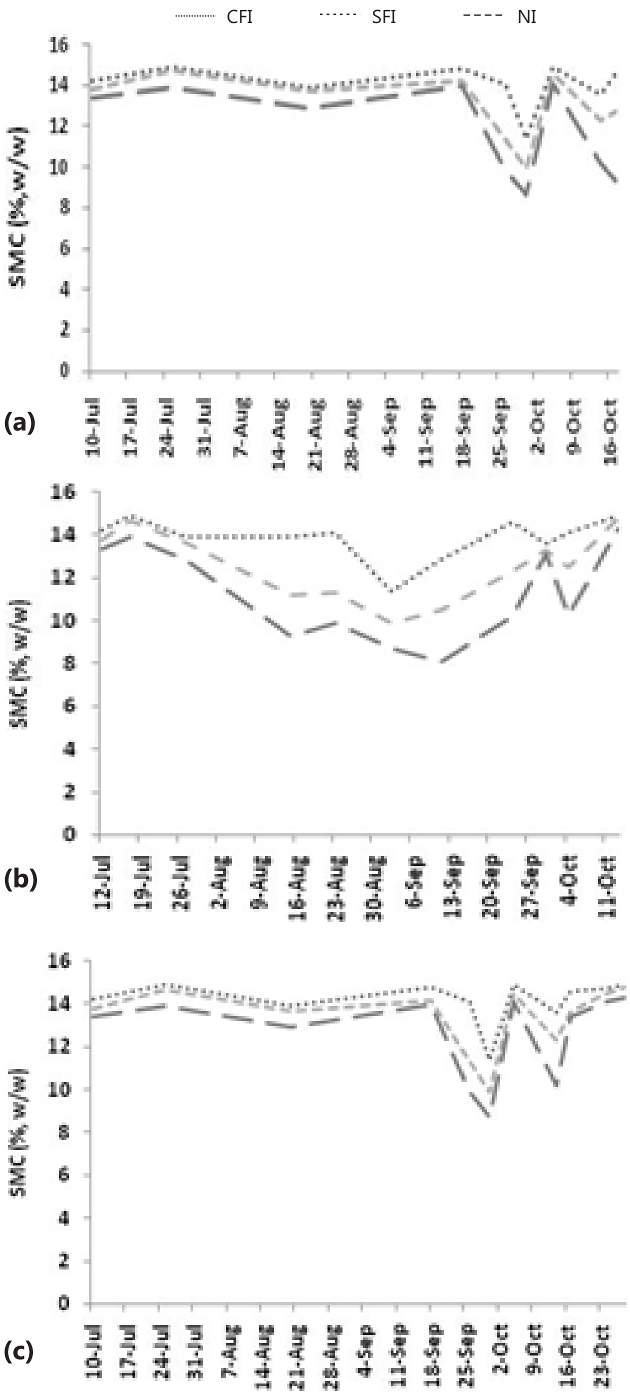

Fig. 2. Soil moisture variation under different furrow irrigation methods at different crop growth stages during (a) 2012, (b) 2013, and (c) 2014

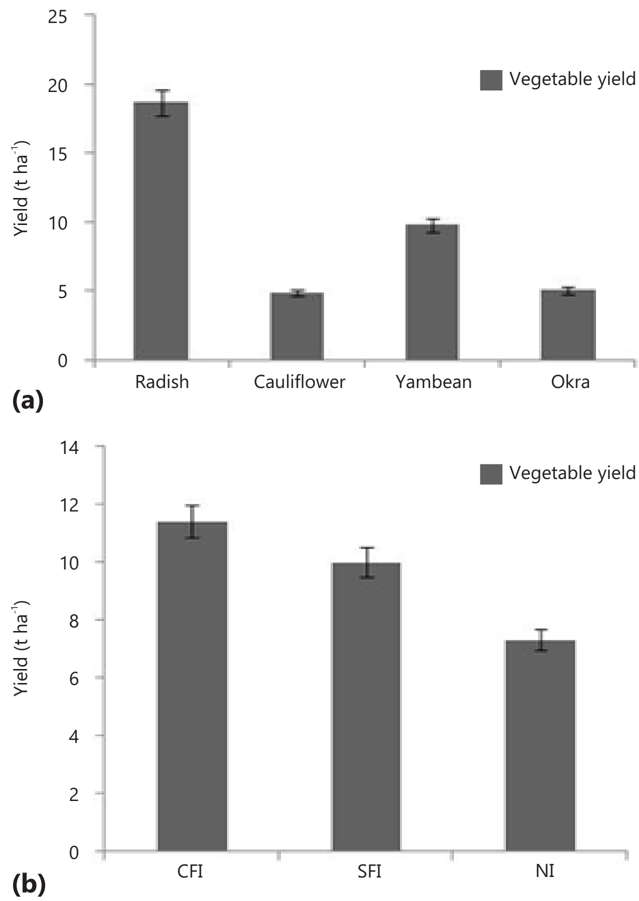

Fig. 3. (a) and (b) Vegetable yields by factorial treatments of (a) and (b) (pooled of three years); bars indicate standard error of means at 5% probability.

damaging effect on yield was neutralized by supplying three life-saving irrigations each on 14, 30 Aug and 23 Sept. Similarly heavy rainfall on 27 and 31 July in 2014 destroyed the vegetable foliage, but this was not coincided with the critical growth stage of vegetable crops and favorable weather at harvest, actually helped in prolonging harvesting phases for a couple of weeks beyond mid October.

System Productivity, Economics, Energy and Water Use Efficiency

Different furrow irrigation methods and different rainfed vegetables significantly influenced the vegetable yield and REY (Table 2). Among the vegetables crops, radish exhibited the highest vegetable yield of 18.65 t ha^{-1} while CFI recorded the highest vegetable yield of 11.43 t ha^{-1} among furrow irrigation methods (Fig. 2). The second highest vegetable yield of 9.78 t ha^{-1} was recorded by yambean but okra (5.06 t ha^{-1}) and cauliflower (4.85 t ha^{-1}) were lower than both radish and yambean vegetables but were at par with each other on pooled analysis. The CFI resulted the highest REY of 22.13 t ha^{-1} (60.7% over NI) in all four vegetables followed by SFI with 19.08 t ha^{-1} (39.7% over NI) (Fig. 3). The highest increase of 86.8% of REY under CFI over NI was during 2012 due to favourable rainfall pattern at post monsoon period and less no. of dryspells (2) occurring at harvest stage of vegetable. The lowest increase (20.3%) in REY under SFI over NI during 2014 was due to higher number of dryspells (4) at the critical crop growth stages coupled with heavy rainfall during the fruiting stage causing physiological damage to the crop, yet longer post monsoon period with supplemental furrow irrigation compensated the further yield loss (Table 1, Fig. 2) which clearly indicated the importance of life-saving irrigation during the dryspells to high-value vegetable crops in *kharif* season.

The economics of different vegetables under different irrigation methods indicated that the highest net income of ` 1,74,584 ha^{-1} and B:C ratio of 4.49 was recorded in case of yambean with CFI followed by the same crop under SFI (₹ 1,35,869 ha^{-1} and 3.89) which were significantly higher than the net income of radish with CFI (₹ 1,17,715 ha^{-1}) but higher B:C ratio (3.94) of it was due to lower cost of cultivation and market price of radish thus, lower REY as compared to yambean (Table 2).

In rainfed production systems, WP, EUE and CWUE are some of the important criteria to thrust upon. The highest CWUE of radish under CFI and SFI (63.56, 61.29 kg ha^{-1} mm^{-1}) were due to its maximum REY (30.95 t ha^{-1}, 25.22 t ha^{-1}). The highest EUE of yambean under CFI and SFI (9.77, 8.85) were due to its maximum REY and the higher HI (0.33, 0.31) than other vegetables closely followed by radish under CFI (8.06) which was significantly less than the former (Table 2). However, both furrow irrigation methods were significant enough to be adopted in time of occasional dryspell in rainfed condition as the WP (17.15, 16.38 kg $ha^{-1}mm^{-1}$) and CWUE (28.3, 26.2 kg $ha^{-1}mm^{-1}$) were 22% and 27% higher than NI (13.3 kg $ha^{-1}mm^{-1}$, 22.1 kg ha^{-1} mm^{-1}) in terms of REY (Table 2, Fig. 3b).This result was confirmed with the results obtained by Khan *et al.* (2005) and Li *et al.* (2007) for vegetables and maize respectively. Li *et al.* (2007) found that alternate partial root-zone (skip) and fixed partial root-zone irrigation (continuous) techniques led to a higher reduction of transpiration than photosynthesis and thus increased WUE in maize.

The EUE (9.77) was the highest in yambean with CFI but WP (42.2 kg $ha^{-1}mm^{-1}$) and CWUE (59.8 kg $ha^{-1}mm^{-1}$) were also the highest in radish in terms of REY on pooled data followed by SFI and NI which were statistically significant to each other in all vegetables as radish was the shortest duration crop but yielded the maximum vegetable production (Table 2, Fig. 4). The WP (17.15, 16.38 kg ha^{-1} mm^{-1}) and CWUE (28.3 kg $ha^{-1}mm^{-1}$, 26.2 kg $ha^{-1}mm^{-1}$) of CFI and SFI were 45.3% more efficient in yield and 25.6% more efficient in saving water than NI (13.33, 22.1 kg ha^{-1}

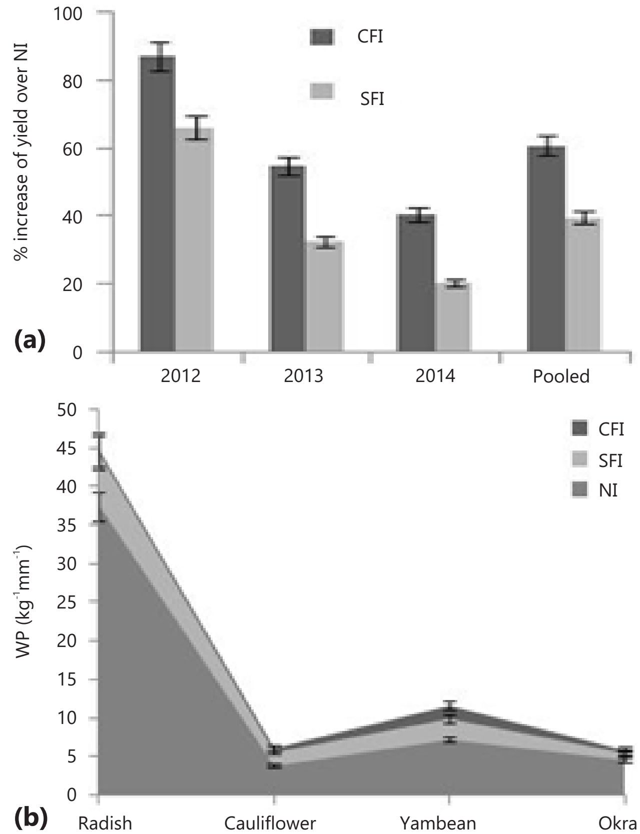

Fig. 4. Percent (%) increase of REY of vegetables by CFI, SFI over NI during three crop seasons (pooled) and water productivity (WP) of each vegetable (pooled) under different irrigation methods, bars indicate standard error of mean at 5% probability level

Table: 3
Interaction effects of different irrigation methods and vegetables on radish equivalent yield (REY) during 2012, 2013 and 2014

Crops	Irrigation methods											
	2012				2013				2014			
	CFI	SFI	NI	Mean	CFI	SFI	NI	Mean	CFI	SFI	NI	Mean
Radish	22595	21214	12143	18651	22944	20026	17103	20024	19297	17599	14906	17267
Cauliflower	21596	20408	11735	18580	20290	17681	10924	16298	17488	15489	11917	14965
Yambean	41429	34592	20238	32086	27749	22307	16971	22342	23656	18763	14992	19137
Okra	14388	13317	9260	12322	17055	15088	12547	14897	15075	12696	11759	13177
Mean	25502	22383	13344		22010	18776	14386		18879	16136	13394	
SE (+m)	C = 505	I = 437	C × I = 874		C = 204	I = 177	C × I = 354		C = 360	I = 311	C × I = 623	
C.D (0.05)	1480	1281	2563		599	519	1038		1055	913	1827	

C: Vegetables, I: Irrigation methods

mm^{-1}) during dryspell on pooled analysis (Table 2, Fig. 3). These facts are well supported by El-Sharkawy *et al*. (2006) and Sarker *et al*. (2016) in case of tomato and onion, respectively. Prakash *et al.* (2007) also reported higher system productivity in vegetable-based relay cropping system because of higher EUE and WUE while Padhi *et al*. (2006) and Mohapatra and Pradhan (1993) obtained maximum EUE in maize crop and vegetable cowpea-fodder rice bean sequence cropping under rainfed condition, respectively.

Interaction of Irrigation Methods and Vegetable on REY

The interaction effect of different furrow irrigation methods with different vegetables during 2012, 2013 and 2014 are given in Table 2. Significant differences in REY were found between irrigation methods irrespective of the short duration vegetables. The significant differences in REY were also found among vegetables under different irrigation methods during three crop seasons. Yambean was found to be the best performing vegetable crop with the significantly highest REY (32.08 t ha^{-1}, 22.34 t ha^{-1}, 19.14 t ha^{-1}, respectively) over the years irrespective of different irrigation methods followed by radish (18.65 t ha^{-1}, 20.02 t ha^{-1}, 17.23 t ha^{-1}, respectively. However, radish (18.65 t ha^{-1}), and cauliflower (18.58 t ha^{-1}) were at par in terms of REY during 2012 because of short duration of radish (45 days) which escaped from dryspell in September and also yield failure was mitigated during other growth stages by supplemental furrow irrigation but cauliflower experienced more no. of dryspells at its harvest stage due to longer crop duration (75 days) in other two seasons of 2013 and 2014 (7 no., 4 no.); thus, the yield of it was partially reduced in two seasons (16.3 t ha^{-1}, 14.96 t ha^{-1}) as compared to 2012 which only experienced 2 no. of dryspells (Table 1, 3; Fig. 2a).

During 2014, REY under SFI and NI were statistically insignificant due to the occurrence of dryspells at sowing and harvesting stage (5 nos) and heavy downpour at mid period of crop season, thus partially affecting biological and economic yield. However, REY under CFI was found to be significant as favorable moisture regime in effective root-zone of crop was maintained by both side furrows in red lateritic sandy-loam soil. In CFI and SFI methods, the water was supplied from the farm pond at critical stage of crop growth to save crops from water stress during the year which experienced 4 no. of dryspells (Table 1, Fig. 1).The higher REY in radish itself is attributed to maximum vegetable production (18.65 t ha^{-1}) by utilizing less rain water (392.4 mm ha^{-1}) at critical stage during dryspell with the same irrigation methods as compared to other vegetables although it had lower market price than the others (Table 2, Fig. 2). The Table 2 indicated that highest REY (41.43 t ha^{-1}) was obtained by yambean under CFI in 2012 while the lowest REY (9.26 t ha^{-1}) was found in okra under NI during the same year (Table 2). The above results clearly proved the importance and superiority of the continuous furrow irrigation method in rainfed vegetables. Ali *et al*. (2007), Padhi and Panigrahi (2006) confirmed the above result in wheat and maize, respectively. Uddin *et al*. (2009) also reported the same results in high-value vegetables intercropped with maize during the *kharif* season.

4. CONCLUSIONS

CFI with short-duration vegetables like radish, yambean, cauliflower and okra can be used as an efficient and profitable crop production system in dryland/rainfed areas where production depends heavily on uncertain and erratic monsoon rainfall. It could be concluded that furrow irrigation methods *i.e.* CFI and SFI at dryspells controlled and moderated the crop physiology and protected the crop from soil water stress with increased yield (60.7% under CFI to 39.7% under SFI) in comparison to NI.

Moreover, CFI increased the B:C ratio from 4.49 of yambean to 2.71 okra whereas the net return varied from ₹ 71,647 ha^{-1} of okra to ₹ 1,74,584 ha^{-1} of yambean. The WUE of cauliflower to radish varied from 10.96 to 59.8 kg ha^{-1} mm^{-1} with productivity from 5.24 to 42.21 kg $ha^{-1}mm^{-1}$ through the CFI method. The preference among rainfed vegetables depends on the quantum of water in relation to crop yield and prevailing market price. Though radish and yambean were superior in terms of yield, CWUE, EUE and WP yet, okra and cauliflower also had better B:C ratio and required less water to give more profit than any cereals in rainfed condition. It was observed that at the end of the *kharif* season, the volume of water available in the lined farm pond was one-fifth of the total storage capacity (75 m^3) and this water could be utilized for raising a short duration sequence crop like horse gram thus, sustaining and strengthening the farm productivity. The highest CWUE (28.3 kg $ha^{-1}mm^{-1}$) and highest WP (17.16 kg $ha^{-1}mm^{-1}$) in CFI method in all vegetables surpassed the other two methods, therefore it is recommended under the dryland condition. Moreover, it is advised that the small and marginal farmers should adopt short-duration vegetable crops instead of cereals crops for getting more return and the irrigation water available in the farm pond, should preferably be applied through the CFI method at the time of dryspell which will essentially be the best choice under rainfed upland and medium land situations in Odisha.

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