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Evaluating partial root-zone irrigation and mulching in okra (*Abelmoschus esculentus* L.) under a sub-humid tropical climate

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Abstract

The field experiments were conducted to compare the alternate partial root-zone irrigation (APRI) with and without black plastic mulch (BPM) with full root-zone irrigation (FRI) in furrow-irrigated okra (*Abelmoschus esculentus* L. Moench) at Bhubaneswar, India. APRI means that one of the two neighboring furrows was alternately irrigated during consecutive watering. FRI was the conventional method where every furrow was irrigated during each watering. The used irrigation levels were 25 % available soil moisture depletion (ASMD), 50 % ASMD, and 75 % ASMD. The plant growth and yield parameters were observed to be significantly ($p < 0.05$) higher with frequent irrigation (at 25 % ASMD) under all irrigation strategies. However, APRI + BPM produced the maximum plant growth and yield using 22 % and 56 % less water over APRI without BPM and FRI, respectively. The highest pod yield (10025 kg ha $^{-1}$) was produced under APRI at 25 % ASMD + BPM, which was statistically at par with the pod yield under APRI at 50 % ASMD + BPM. Irrigation water use efficiency (IWUE), which indicates the pod yield per unit quantity of irrigation water, was estimated to be highest (12.3 kg m $^{-3}$) under APRI at 50 % ASMD + BPM, followed by APRI at 25 % ASMD + BPM. Moreover, the treatment APRI at 50 % ASMD + BPM was found economically superior to other treatments, generating more net return (US $ 952 ha $^{-1}$) with higher benefit–cost ratio (1.70).

Keywords: okra, partial root-zone irrigation, irrigation water use efficiency, yield, production economics

1 Introduction

In almost all regions of the world, water supply is the major constraint to crop production due to water demand for rapid industrialization and high population growth. The further scarcity of irrigation water for crop production should be checked for sustaining the food supply through efficient water conservation and management practices even in high rainfall areas (Panda *et al.*, 2004). Moreover, the financial return per every drop of irrigation water should be enhanced while considering the best water use efficiency (WUE) associated with any crop.

Okra (*Abelmoschus esculentus* L.) or Lady's finger is one of the important vegetables grown throughout the tropics and subtropics. India is the topmost country, producing 4.18 million tonnes of okra annually, which is around 70 % of global okra production (FAO, 2008). The nutritional value of 100 g of edible portion of okra contains 1.9 g protein, 0.2 g fat, 6.4 g carbohydrate, 0.7 g minerals and 1.2 g fiber (Gopalan *et al.*, 1989). 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, one of the major okra growing region of the country, is characterized by a long dry season with an amount of 1000 to 1200 mm average

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annual rainfall concentrated mainly (> 85 %) in three to four months (July – October) of the year. Paddy rice is the leading rainy season (August-November) field crop and is cultivated on an area of 12 million ha in eastern India, which is constrained with a high percent (70 %) of marginal lands (< 1ha.) in total cultivated area (Srivastava *et al.*, 2004). Sowing of okra seeds in the residual soil moisture of rice fallow in the month of December-January is a common agricultural practice of this region. After germination of seeds, short supply of soil moisture at any stage of growth reduces the productivity of the crop. Moreover, limited fresh water availability due to the regional saline aquifer restricts irrigation water supply for the crop in the post rainy season. It is therefore essential to develop an efficient, feasible and economically viable irrigation management strategy to sustain the productivity of crop as well as to irrigate more land area with existing water resources in this water scarce region.

Irrigation scheduling is considered as a vital component of water management to produce higher irrigation efficiency under any irrigation system, as excessive or sub-optimum irrigation both have detrimental effects on productivity parameters of okra (Aiyelaagbe & Ogbonnaya, 1996). Moreover, scheduling irrigation is influenced by many complex factors such as soil, crop, environment, water supply and cultivation practices. Thus, it is essential to develop an efficient irrigation scheduling under prevailing local conditions. Various methods based on estimated crop evapotranspiration rate (Jaikumaran & Nandini, 2001), ratio of irrigation water to cumulative pan evaporation (Aiyelaagbe & Ogbonnaya, 1996; Batra *et al.*, 2000), open pan evaporation rate (Singh, 1987; Manjunath *et al.*, 1994) and soil moisture depletion (Home *et al.*, 2000) are widely used for scheduling irrigation in okra. The soil moisture based irrigation scheduling is found to be a more reliable tool for determining the water requirement in various vegetable crops, as this method integrates the effect of variables such as soil, crop and climate.

Furrow is the widely adopted method of irrigation in okra grown on rice fallow of coastal areas of eastern India. After 20 to 25 days of germination of the seeds, ridge formation and supplying irrigation water through closed end shallow furrows between each row is a general irrigation method practiced in this region. Ground water or harvested rainwater is the prime source of irrigation for the crop. Excess irrigation and deep percolation of the irrigation water in the local sandy loam soil causes low water use efficiency and water shortage in critical growth period of the crop. Alternate furrow irrigation is the proved water conservation technique over every-furrow irrigation in different crops without any detrimental effect on yield (Samadi & Sepaskhah, 1984; Prabhakar & Srinivas, 1995; Ramalan & Nwokeocha, 2000; Singh & Murthy, 2001). Moreover, besides yield enhancement, the beneficial effects of plastic mulch on moisture conservation, weed control and temperature modulation within the effective root zone of the plants is well documented under various agro-climatic conditions in okra (Gupta & Gupta, 1987; Al Masoum & El Gharib, 1996; Saikia *et al.*, 1997; Brown & Channell Butcher, 1999; Damato, 2000; Jaikumaran & Nandini, 2001). But, the knowledge of the alternate partial root-zone irrigation (APRI) scheduling with and without plastic mulch in okra is still scarce.

A field experiment was conducted to study the effects of APRI with and without black plastic mulch and full root-zone irrigation (FRI) on crop morphology, pod yield and irrigation water use efficiency (IWUE) in furrow-irrigated okra on a rice fallow under sub-humid subtropical climate of coastal Orissa in eastern India. In addition, an economic evaluation of different irrigation techniques was carried out.

2 Materials and methods

The experiment was carried out in rain-fed rice fallow at the Central Research Station of Orissa University of Agriculture and Technology, Bhubaneswar, Orissa, India (20° 15’ N latitude, 85° 52’ E longitude and 25.9 m above mean sea level) during the months of December – March for two seasons (1997/98 and 1998/99). The region has a mean annual precipitation of 1400 mm, out of which 90 % fall in between July and October. The data observed at meteorological station located at about 1 km away from experimental site indicated the maximum air temperature, minimum temperature, and pan evaporation during the crop season varied in the range 24.8–29.7 °C, 14.9 - 23.2 °C and 1.0 to 5.2 mm, respectively. The experimental soil has sandy loam texture (74.8 % sand, 10.4 % silt and 14.8 % clay) with bulk density 1.7 g cm^{-3} and pH 7.3. The soil water content at field capacity (–0.33 bar) and permanent wilt point (–15.0 bar) of the soil is 12.8 % and 3.6 %, respectively, on weight basis. Groundwater level remained at a depth of about 60 m below ground surface during the study. Both the soil and irrigation water were free from salinity and alkalinity.

The experimental field (43.5 m × 21 m) was divided into three plots, each with a size of 43.5 m × 6 m. Each plot was divided into nine subplots with a size of $3.5\,m \times 6\,m$ (in total 27 plots). Between each plot, one and half metre wide buffer strip was provided to minimize moisture movement from one treatment to another. The experiment was conducted within complete randomized block design and was replicated three times with three treatments: (1) alternate partial root-zone irrigation (APRI), (2) alternate partial root-zone irrigation + black plastic mulch (APRI + BPM) and (3) full root-zone irrigation (FRI). Alternate partial root-zone irrigation (APRI) means that one of the two neighbouring furrows was alternately irrigated during consecutive watering and FRI was the conventional method where every furrow was irrigated during each watering. In addition, each treatment was carried out at three different irrigation levels: at 25 % available soil moisture depletion (ASMD) (I_1), at 50 % ASMD (I_2) and at 75 % ASMD (I_3). The used okra cultivar was "Vijaya", an Indo-American hybrid. A standard seed rate of 20 kg ha^{-1} was used. The seeds were sown at a row spacing of 0.50 m and a plant spacing of 0.25 m in each plot. A standard fertilizer dose consisting of 100 kg N, 50 kg P_2O_5 and 50 kg K_2O ha^{-1} was applied uniformly in all treatments. Out of the total fertilizer quantity applied, 50 kg N, 50 kg P_2O_5 and 50 kg K_2O ha^{-1} were applied prior to seed sowing, and additionally 50 kg N ha^{-1} were applied in two equal splits after 20 and 40 days of seed germination. To establish the seedlings during the initial stages, by hand watering a water layer with a height of 2 cm was applied uniformly to all treatments. Shallow furrows with a top width of 0.40 m, a bottom width of 0.10 m and a depth of 0.25 m with 0.4 % slope were opened between each row after twenty days of sowing. Afterwards plastic mulch was applied at the 50 % height of the ridge by two pieces of plastic sheet with a size of $0.20\,m \times 6.0\,m$ on each row and stapled through pins on the top of the ridges to prevent sliding. The used mulch was black linear low-density polyethylene (LLDPE) with 15 micron (60 gauge) thickness.

The daily soil moisture data at 0.30 m depth was measured by a neutron moisture meter near the central plant of the plots and irrigation was applied as soon as the soil attended the required soil moisture contents under different treatments. Water quantity applied for irrigation under different irrigation regimes was computed using the equation: $V = (F.C. - R.S.M.) \times d \times A$, where V is the volume of irrigation water (m^3), $F.C.$ the field capacity (v/v, %), $R.S.M.$ is the required soil moisture level (v/v, %), d is depth of effective root zone (0.30 m) and A constitute the area that has to be irrigated. This area was further determined by the formula: A = number of wetted furrows × width of each ridge × row length. The number of irrigated furrows under APRI was half of that under FRI treatment. The measured quantities of irrigation water (water meter) were applied through flexible pipes directly to the experimental plots under different treatments. The total quantities of irrigation water which were applied under the different treatments were recorded. No rainfall was observed during the experimental periods. The vegetative growth (plant height, number of branches, number of leaves) and yield parameters (pod number, pod length, weight per pod, pod yield) of ten randomly pegged plants in each plot were recorded. The total pod yield per hectare was estimated considering the mean yield obtained from the replicated plots under the treatments. Irrigation water use efficiency (IWUE) was the ratio of total pod yield to total seasonal irrigation water applied per hectare.

Cost–benefit analysis was carried out to determine the economic feasibility of adopting APRI with and without plastic mulch against conventional FRI in furrow-irrigated okra. The seasonal cost of production under different irrigation treatments includes expanses that incurred on field preparation, seeds, fertilizers, pesticides, pumping (energy cost) and labour cost (sowing, irrigation, fertilizer application, spraying, weeding, harvesting). The seasonal cost of the plastic film was calculated based on the prevailing price of Rs 80,000 t^{-1} (US \$ 2200 t^{-1}) with a bank interest rate of 5 %, and the spreading, folding and lifting labour charges. The quantity of plastic film required for mulching was 80 kg ha^{-1} and the economic life-time of the plastic film was assumed to be 3 seasons (3 years). The gross income from the produce was estimated using the prevailing average wholesale market price of Rs. 5500 t^{-1} (US \$ 150 t^{-1}). The net seasonal income was estimated by subtracting the seasonal cost of production from the gross income of the produce. The cost–benefit ratio was calculated as the ratio of net income to total production cost. Data generated for all the parameters were statistically subjected to analysis of variance (ANOVA) and Least Significant Difference at 5 % probability level ($LSD_{0.05}$) was obtained according to the methods described by Gomez & Gomez (1984).

3 Results

3.1 Irrigation applied

The imposed irrigation treatments influenced the quantity of water applied to varying proportions (Table 1). The volume of irrigation water applied under APRI + BPM was 21–22 % lower than APRI alone. The mean seasonal water required for the APRI treatments (1044–1102 m^3 ha^{-1}) was more than 50 % of that required for

Table 1: *Water supply, vegetative growth and yield parameters of okra under different irrigation treatments and plastic mulch.*

Treatment	*Water quantity applied ($m^3 ha^{-1}$)*	*Vegetative growth parameters*			*Yield parameters*				*Irrigation water use efficiency ($kg\,m^{-3}$)*
		Plant height (m)	*Leaf number $plant^{-1}$*	*Branch number $plant^{-1}$*	*Pod number $plant^{-1}$*	*Pod length (mm)*	*Weight pod^{-1} (g)*	*Pod yield ($kg\,ha^{-1}$)*	
APRI_1 *	1102.28	0.69	25.26	3.72	8.35	187.21	17.72	8255	7.49
APRI_2	1044.16	0.56	20.14	3.25	6.73	164.16	15.25	7304	6.99
APRI_3	1043.63	0.47	19.67	3.06	5.45	144.51	12.81	5103	4.89
APRI_1+BPM †	870.28	0.71	32.22	3.92	8.92	192.04	18.47	10025	11.52
APRI_2+BPM	812.77	0.60	23.63	3.47	7.27	170.22	15.85	9997	12.30
APRI_3+BPM	810.09	0.49	20.33	3.13	5.92	149.16	13.44	6200	7.65
FRI_1 ‡	1856.41	0.67	20.71	3.43	7.94	179.65	16.83	8040	4.33
FRI_2	1855.17	0.52	19.64	3.14	6.37	153.32	14.37	6560	3.53
FRI_3	1740.22	0.43	18.92	2.83	5.08	131.01	11.82	4410	2.53
$LSD_{0.05}$	–	1.21	ns	0.08	0.32	7.52	0.85	205.73	0.52

* APR is alternate partial root-zone; † BPM is plastic mulch; ‡ FR is full root-zone

I_1: Irrigation at 25 % available soil moisture depletion (ASMD); I_2: Irrigation at 50 % ASMD; I_3: Irrigation at 75 % ASMD

$LSD_{0.05}$ is Least Significant Difference at 5 % level of significance, ns is not significant

FRI treatments (1740.22–1856.41 $m^3\,ha^{-1}$) in spite of half the number of irrigated furrows under the former treatment in comparison to latter one.

3.2 *Vegetative growth response*

The effect of different irrigation treatments on vegetative growth parameters (plant height, number of leaves and branches per plant) were observed for two growing seasons and the mean values were analysed statistically (Table 1). The plant height and number of branches per plant were significantly ($p < 0.05$) higher under APRI + BPM over APRI alone and FRI, in corresponding irrigation regimes. However, APRI produced the higher plant height (0.5–0.7 m) and number of branches per plant (3.1–3.7) over FRI (0.4–0.7 m and 2.8–3.4, respectively). However, the highest plant height (0.71 m) and maximum number of branches (3.9 $plant^{-1}$) were observed under APRI at 25 % ASMD + BPM, followed by APRI at 25 % ASMD. Leaf number per plant was not affected by irrigation and mulching.

3.3 *Marketable yield parameters and irrigation water use efficiency*

The numbers of pods per plant and pod quality (pod length and weight per pod) were significantly ($p < 0.05$) influenced by irrigation treatments and BPM (Table 1). Results indicated that the number of pods per plant was higher under APRI + BPM (6–9) as compared to APRI (5–8) and FRI (5–8). However, APRI at 25 % ASMD + BPM produced the highest number of pod per plant, while the lowest number of pod was registered with FRI at 75 % ASMD. The maximum length (139–192 mm) and weight (13.4–18.5 g) per pod was recorded under APRI + BPM, which was similar with pod size that was produced under the APRI treatment. The FRI treatment resulted in 4–9 % and 5–8 % reduction in pod length and pod weight, respectively, over that under APRI.

Irrigation at lower level of soil moisture depletion (25 % ASMD) resulted in significantly ($p < 0.05$) higher yield under both APRI and FRI (Table 1). Mulching resulted in significantly higher yield compared to non-mulched treatment under APRI treatment. Based on analysis of the two years of pooled yield data, the per cent increase in the yield due to BPM were 21.4, 36.9 and 21.5 % for the irrigation regime at 25 % ASMD, 50 % ASMD, 75 % ASMD, respectively, under APRI. Moreover, APRI without BPM resulted in 2.7–15.7 % higher yield as compared to FRI even with 40–41 % deficit irrigation water supply under the former treatment. It can be seen that the highest pod yield (10025 $kg\,ha^{-1}$) produced under APRI at 25 % ASMD + BPM was statistically at par with pod yield (9997 $kg\,ha^{-1}$) under APRI at 50 % ASMD + BPM. The irrigation at lower soil moisture depletion (25 % ASMD) produced higher pod yield, irrespective of furrow treatment and mulch.

The significantly higher IWUE was obtained from APRI + BPM over APRI alone and FRI, in corresponding level of irrigation (Table 1). However, APRI produced higher IWUE over FRI. The pooled average IWUE was highest under APRI at 50 % ASMD + BPM (12.3 $kg\,m^{-3}$) followed by APRI at 25 % ASMD + BPM (11.5 $kg\,m^{-3}$).

Table 2: *Economic analysis for different irrigation treatments in okra.*

Treatment	*Total seasonal cost of production (US \$ ha^{-1})*	*Gross seasonal return (US \$ ha^{-1})*	*Net seasonal return (US \$ ha^{-1})*	Benefit : Cost ratio
APRI_1 *	468.40	1246.56	778.16	1.66
APRI_2	458.79	1103.02	644.23	1.40
APRI_3	439.55	770.60	331.05	0.75
APRI_1 + BPM †	576.92	1513.83	936.91	1.62
APRI_2 + BPM	557.69	1509.60	951.91	1.70
APRI_3 + BPM	535.71	936.81	401.09	0.74
FRI_1 ‡	542.58	1214.80	672.25	1.23
FRI_2	520.60	991.20	470.60	0.90
FRI_3	498.62	666.34	167.71	0.33

* APR is alternate partial root-zone; † BPM is plastic mulch; ‡ FR is full root-zone

I_1: Irrigation at 25 % available soil moisture depletion (ASMD)
I_2: Irrigation at 50 % ASMD
I_3: Irrigation at 75 % ASMD

3.4 *Economics*

Cost – benefit analysis was carried out to determine the economic feasibility of APRI with and without BPM over traditional FRI scheduling (Table 2). The seasonal cost of BPM was estimated to be US \$ 65 ha^{-1} considering the life period of it as 3 seasons (3 years). The maximum seasonal cost of production (US \$ 540–580 ha^{-1}) with highest gross return (US \$ 940–1510 ha^{-1}) was associated with APRI + BPM. However, the cost of production in FRI (US \$ 500–540 ha^{-1}) was higher than APRI (US \$ 440–470 ha^{-1}), whereas APRI produced higher gross return (US \$ 770–1250 ha^{-1}) as compared to FRI (US \$ 670–1210 ha^{-1}). The estimate shows that APRI at 50 % ASMD + BPM gave the highest net seasonal return of US \$ 950 ha^{-1}, followed by APRI at 25 % ASMD + BPM (US \$ 940 ha^{-1}). The results also indicate that APRI at 50 % ASMD + BPM produced the highest benefit : cost ratio (1.70) among the treatments.

4 Discussion

This study could show that the amount of irrigation water consumed under APRI + BPM was lower than that used under APRI and FRI. The reduced irrigation under APRI + BPM is attributed to less frequency of water supply caused by lower evaporation losses from soil surface under BPM. Earlier studies demonstrated a reduction of water consumption of okra up to 25–30 % in Italy (Damato, 2000), 50 % in Nigeria (Aiyelaagbe & Ogbonnaya, 1996) and 15 % in United Arab Emirates (Al Masoum & El Gharib, 1996) under BPM compared to bare soil. The variations of water consumption of okra are due to the nature of cultivars studied under different soil-climates, thickness of the used plastic mulch and methods adopted in scheduling irrigation for okra.

A reduced water application, as it was implemented under APRI treatment (50 % water quantity of FRI), leads to a reduction in evaporation and percolation losses. Although the area wetted under APRI in each irrigation event was half of that under FRI, the total seasonal water requirements under APRI were more than 50 % of that under FRI treatments. This was due to a more frequent irrigation under APRI, caused by higher rate of water uptake by okra plants from lower wetted soil volume.

The higher plant height and the higher number of branches per plant that were recorded for APRI + BPM in comparison to APRI and FRI were resulted in the better metabolic activity of the plants probably caused by consistent supply of optimum soil moisture in root-zone coupled with effective rooting (fibrous roots) of the plants under BPM (Wien *et al.*, 1993; Al Masoum & El Gharib, 1996). A more frequent irrigation resulted in significantly higher vegetative growth of the plants under both APRI and FRI, indicating the need of higher soil moisture for okra plant growth. A positive effect of frequent irrigation on plant growth could be also described for sweet pepper (Hegde, 1989) and sugarbeet (Sepaskhah & Kamgar Haghighi, 1997).

The significant higher number of pods per plant and pod quality (length and weight per pod) under APRI + BPM and APRI is explained by the positive relationship between number of branches per plant and plant height. The higher pod length and pod weight recorded under APRI + BPM and APRI was probably due to higher nutrients assimilation supported by the availability of more nutrients in the soil solution under favourable soil moisture and temperature within the plant rhizosphere and the minor weed cover (Islam *et al.*, 1990; Damato, 2000; Kumar, 2001). An increase in yield under APRI at optimum irrigation level could be also verified for sugarbeet (Sepaskhah & Kamgar Haghighi, 1997), cauliflower (Prabhakar & Srinivas, 1995) and for sweet pepper (Hegde, 1989). A possible explanation for higher yield of the plants with less irrigation water use under APRI compared to FRI could be the reduction of leaf transpiration and stomatal conductance coupled with higher photosynthesis and dry matter accumulation under the APRI treatment (Kang *et al.*, 2000). If plants are rooted partly in dry soil, a significant amount of abscisic acid (ABA) is produced in the roots and transported to the shoot where stomatal opening is regulated. Photosynthesis is less affected by such partial stomatal closure because photosynthesis and stomatal opening have a saturation relationship (Kang *et al.*, 2000). Maximum stomatal opening does not necessarily lead to maximum photosynthesis. However, better nutrients availability in leafs with partially-irrigated plants probably caused higher photosynthesis rate of plants. Mulched treatments produced higher yield than non-mulched treatments. The beneficial effect of BPM on yield of different vegetables was also reported by Islam *et al.* (1990), Damato (2000) and Kumar (2001).

Due to the lower number of furrows that have to be irrigated, cost–benefit analysis could verify a considerable saving of labour under APRI management. Additionally the costs of energy for pumping and conveying irrigation water to the field under APRI management were almost half of the FRI management. Despite higher seasonal production costs, the net seasonal income from APRI + BPM was highest. This was due to higher gross seasonal return obtained from the higher pod yield. The higher net seasonal return obtained under APRI at 50 % ASMD + BPM in comparison to APRI at 25 % ASMD + BPM was due to the lower cost of production and lower labour charges. Despite savings in labour costs for weeding and irrigation at the BPM treatments, this cultivation was more expensive due to the initial cost of the plastic sheet.

5 Conclusions

The alternate partial root-zone irrigation either alone or in combination with black plastic mulch (15 μM thickness) is found as a productive and potential water saving technique for okra cultivation in coastal Orissa, India. Both plant vegetative growth and yield parameters of okra showed a need for higher soil moisture content (25 % available soil moisture depletion). However, the maximum irrigation water use efficiency was obtained from irrigation at 50 % available soil moisture depletion under alternate partial root-zone irrigation with black plastic mulch. It also generated the highest financial benefit with maximum return per unit investment due to higher productivity and savings of labour. We conclude that adoption of alternate partial root-zone irrigation at optimum irrigation regime (50 % available soil moisture depletion) with black plastic mulch is a viable option against traditional full root-zone irrigation for okra cultivation under furrow method in sandy loam soils under similar agro-climatic conditions such as those found in coastal Orissa, India.

References

Aiyelaagbe, I. O. O. & Ogbonnaya, F. C. (1996). Growth, fruit production and seed yield of okra (*Abelmoschus esculentus* L) in response to irrigation and mulching. Research Bulletin, No. 18. National Horticultural Research Institute, Ibadan. 13 pp.

Al Masoum, A. A. & El Gharib, I. M. (1996). Plastic mulches for winter okra production. *Egyptian Journal of Horticulture*, 23 (2), 211–219.

Batra, B. R., Inder, M., Arora, S. K. & Mohan, I. (2000). Effect of irrigation and nitrogen levels on dry matter production by okra (*Abelmoschus esculentus* L. Moench). *Haryana Journal of Horticultural Science*, 29 (3-4), 239–241.

Brown, J. E. & Channell Butcher, C. (1999). Effect of three row covers and black plastic mulch on the growth and yield of 'Clemson Spineless' okra. *Journal of Vegetable Crop Production*, 5 (2), 67–71.

Damato, G. (2000). Effects of two sowing dates and plastic mulch on okra production. *Acta Horticulture*, 533, 329–336.

FAO (2008). FAOSTAT Production. Food and Agriculture Organization of the United Nations (FAO), Rome. URL `http://faostat.fao.org/site/339/default.aspx` (last accessed 15 April 2011).

Gomez, K. A. & Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research, 2nd Edition*. Wiley, New York.

Gopalan, C., Rama-Sastri, B. V. & Balasubramanian, S. C. (1989). Nutritive value of Indian foods. National institute of Nutrition, ICMR, Hyderabad, India.

Gupta, J. P. & Gupta, G. N. (1987). Response of tomato and okra crops to irrigation and mulch in an arid region of India. *Agrochimica*, 31 (3), 193–202.

Hegde, D. M. (1989). Effect of method and volume of irrigation on yield and water use of sweet pepper (*Capsicum annuum* L.). *Indian Journal of Horticulture*, 46 (2), 225–229.

Home, P. G., Kar, S. & Panda, R. K. (2000). Effect of irrigation scheduling on water and nitrogen balances in the crop root zone. *Zeitschrift für Bewasserungswirtschaft*, 35 (2), 223–235.

Islam, T., Sarkar, H. & Alam, J. (1990). Water use and yield relationships of irrigated potato. *Agricultural Water Management*, 18, 173–179.

Jaikumaran, U. & Nandini, K. (2001). Development of mulch cum drip irrigation for vegetables. *South Indian Horticulture*, 49, 373–375.

Kang, S., Liang, Z., Pan, Y., Shi, P. & Zhang, J. (2000). Alternate furrow irrigation for maize production in an arid area. *Agricultural Water Management*, 45, 267–274.

Kumar, A. (2001). Effect of mulch and sowing method on pod yield at vegetable pea in Garhwal Himalaya. *Indian Journal of Soil Conservation*, 29, 84–85.

Manjunath, B. L., Mishra, P. K., Rao, J. V. & Reddy, G. S. (1994). Water requirement of vegetables in a dryland watershed. *Indian Journal of Agricultural Sciences*, 64 (12), 845–846.

Panda, R. K., Behera, S. K. & Kashyap, P. S. (2004). Effective management of irrigation water for maize under stressed conditions. *Agricultural Water Management*, 66, 181–203.

Prabhakar, M. & Srinivas, K. (1995). Effect of soil matric potential and irrigation methods on plant water relations, yield and water use of cauliflower. *Journal of Maharashtra Agricultural University*, 20 (2), 229–233.

Ramalan, A. A. & Nwokeocha, C. U. (2000). Effects of furrow irrigation methods, mulching and soil water suction on the growth, yield and water use efficiency of tomato in the Nigerian Savanna. *Agricultural Water Management*, 45 (3), 317–330. doi: 10.1016/S0378-3774(99)00104-3.

Saikia, S., Saikia, A., Shadeque, A. & Gogoi, S. (1997). Field performance of okra as influenced by low density plastic mulches. *Annals of Biology*, 13 (2), 253–257.

Samadi, A. & Sepaskhah, A. R. (1984). Effects of alternate furrow irrigation on yield and water use efficiency of dry beans. *Iran Agricultural Research*, 3 (2), 95–115.

Sepaskhah, A. R. & Kamgar Haghighi, A. A. (1997). Water use and yields of sugarbeet grown under every other furrow irrigation with different irrigation intervals. *Agricultural Water Management*, 34, 71–79.

Singh, B. P. (1987). Effect of irrigation on the growth and yield of okra. *HortScience*, 22, 879–880.

Singh, S. D. S. & Murthy, V. R. K. (2001). Water use pattern and its efficiency in brinjal under different irrigation management practices. *Crop Research*, 21 (1), 101–104.

Srivastava, R. C., Singhandhupe, R. B. & Mohanty, R. K. (2004). Integrated farming approach for runoff recycling systems in humid plateau areas of eastern India. *Agricultural Water Management*, 64, 197–212.

Wien, H. C., Mirotti, P. C. & Grubinger, V. P. (1993). Polyethylene mulch stimulates early root growth and nutrient uptake of transplanted tomatoes. *Journal of the American Society for Horticultural Science*, 118, 207–211.