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Physiological and yield response of okra (*Abelmoschus esculentus*) to irrigation scheduling and organic mulching*

ANANT BAHADUR[1], K P SINGH[2], ASHUTOSH RAI[3], AJAY VERMA[4] and MATHURA RAI[5]

Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh 221 305

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Scheduling irrigation is very critical to make the most efficient use of water, as excessive or inadequate irrigation reduces the yield. An optimum level of irrigation intervals is essential for judicious use of water. Exposing the crop for a certain level of water stress either during a specific period or throughout the growing season is one way of maximizing water-use efficiency. It is expected that any reduction in yield will be insignificant compared to the benefits gained through diverting the saved water to irrigate other crops.

Okra (*Abelmoschus esculentus* Moench), if cultivated during spring–summer season requires adequate moisture in the soil. Use of different types of soil covers or organic mulches, like straw, leaves, husk and crop residues have great potential to conserve moisture, control weeds, maintain soil temperature, microorganism population, soil structure and nutrient dynamics, which favourably affect the crop yield (Kar and Kumar 2007, Mulumba and Lal 2008). The present study was undertaken to find the effects of irrigation intervals and use of pea straw mulch on plant growth, physiology, weed growth and yield of spring-summer okra, and to work out an optimum water requirement under mulched and non-mulched conditions.

Field experiment was conducted at Varanasi (25° 182 N latitude and 83° 02 E longitude) during 2006 and 2007 with 4 levels of furrow irrigation (irrigation scheduled at 4, 7, 10 and 12 days intervals), and 2 levels of mulch (pea straw mulch at 12.5 tonnes/ha and no mulch). The irrigation treatments were kept in main plots and mulch and no mulch in sub-plots. The experiment was laid in split-plot design with 3 replications in each treatment. The soil was sandy loam, Typic Utochrept (Inceptisol) with *p*H 7.2, EC 0.32 dS/m, organic carbon 0.39% and available N, P and K was 258, 20.5 and 185 kg/ha respectively. Moisture content (0.30 m depth) at 0.33 bars (field capacity) and at 15 bars (wilting point) was 22.6% and 6.1%, respectively, whereas bulk density of soil was 1.38 g/cm^3. The average monthly maximum and minimum temperatures during experiment periods were 38.2°C and 21.8°C, respectively, in 2006 and 38.5°C and 24.9° C in 2007. The average monthly pan evaporation was 6.9 cm and 6.7 cm, respectively, in 2006 and 2007.

The crop was grown according to the ridge and furrow methods of planting with row-to-row spacing of 0.60 m and plant-to-plant of 0.25 m. Experimental furrows of 0.3 m wide, 0.20 m deep and 9 m long with 0.25% slope were made in respective plots. N 120 kg, 60 kg each of P and K along with 20 tonnes of farmyard manure/ha was applied to meet nutritional requirements of the crop. Pre-imbibed 'Kashi Pragati' okra seeds were sown over the ridges at seed-to-seed distance of 0.25 m. Dried pea straw mulch at 1.55 kg/m^2 (equivalent to 12.5 tonnes/ha) was applied evenly in furrows 25 days after seed sowing. A total of 10 pickings were undertaken at 3 days intervals starting from 45 DAS.

Leaf water potential was measured at the end of stress period during mid-day using Pressure Chamber. Photosynthetic rate (Pn), stomatal conductance (gs) and leaf temperature (T leaf) were measured between 1100 h and 1300 hr using a Portable Photosynthesis System. During the measurement, the photoactive radiations incident at the leaf cuvette ranged between 1 065 and 1 422 µmol/m^2/s^1, and the external CO_2 varied between 285 and 360 µmol/mol. Chlorophyll concentration index (CCI) of leaf was measured with the CCM-200 Portable Chlorophyll Meter (Opti-Sciences, Tyngsboro, MA) at the ratio of 655/940 nm. Soil water content was determined by Gopher (soil moisture technology, Queensland, Australia) to a depth of 0.30 m in the middle of furrow just before release of stress. Water-use efficiency was calculated as pod yield divided by total water used. All physiological measurements were taken on fully expanded leaves, fourth to fifth from the top, just before release

*Short note

[1]Scientist (e mail: singhab98@yahoo.co.in), [2]Principal Scientist (e mail: kps.iivr@gmail.com), [3]Senior Research Fellow (e mail: ashutoshraiiivr@gmail.com), [5]Director (e mail: mathura.rai@gmail.com)

[4]Senior Scientist, DWR, Karnal 132 001 (e mail: ajay.iivr@gmail.com)

Table 1 Effect of irrigation scheduling and pea-straw mulch on vegetative growth and yield of okra (pooled data for 2 years)

Treatment	Plant height (cm)	Nodes/ plant	Pods/ plant	Pod weight (g)	Yield/ plant (g)	Pod yield (tonnes/ ha)
Irrigation interval						
4-day	58.6[a*]	14.0[a]	14.7[a]	19.2[a]	221.1[a]	15.03[a]
7-day	54.4[b]	13.7[a]	10.6[b]	16.8[b]	185.8[b]	12.63[b]
10-day	49.8[c]	11.9[b]	8.7[c]	15.0[c]	165.6[b]	1.12[b]
12-day	49.7[c]	10.0[c]	7.2[c]	14.5[c]	111.3[c]	7.56[c]
CD ($P = 0.05$)	2.81	1.05	1.65	1.74	23.78	16.17
Mulch						
Pea-straw mulch	56.4[a]	13.4[a]	11.7[a]	17.4[a]	194.2[a]	13.20[a]
No mulch	49.8[b]	11.4[b]	9.0[b]	15.3[b]	147.8[b]	10.04[b]
CD ($P = 0.05$)	1.98	0.74	1.17	1.23	16.82	11.43

*Same superscripts indicate no significant difference at the 5% level.

Table 2 Effect of irrigation scheduling and pea-straw mulch on physiological attributes of okra

Treatment	CCI	LWP (MPa)	RWC (%)	T leaf (°C)	Pn (µmole $CO_2/m^2/s$)	gs (mmole $H_2O/m^2/s$)
Irrigation interval						
4-day	36.93[a*]	0.91[d]	83.0[a]	39.2[c]	14.10[a]	351.9[a]
7-day	34.58[a]	1.36[c]	78.6[b]	40.2[b]	12.35[b]	293.2[b]
10-day	23.66[b]	1.99[b]	73.5[c]	40.5[b]	9.41[c]	261.1[b]
12-day	16.86[c]	2.68[a]	66.1[d]	41.9[a]	5.69[d]	86.9[c]
CD ($P = 0.05$)	5.36	0.17	3.68	0.60	1.22	38.52
Mulch						
Pea-straw mulch	25.14[b]	1.58[b]	78.73[a]	40.33[a]	11.57[a]	279.5[a]
No mulch	30.88[a]	1.89[a]	71.87[b]	40.61[a]	9.2[b]	217.0[b]
CD ($P = 0.05$)	2.86	0.19	2.61	NS	0.86	27.24

CCI, Chlorophyll concentration index; LWP, leaf water potential; RWC, relative leaf water content; T leaf, leaf temperature; Pn, photosynthetic rate; gs, stomatal conductance

of stress at active growth stage 45–50 days after sowing. Weeds of 1 m × 1 m area in each replication were removed and oven-dried till constant weight to get dry weight of weeds.

Significant differences in plant height, number of nodes, number of pods/plant, pod weight and fresh pod yield were recorded in various irrigation treatments and mulching (Table 1). Maximum plant height, number of nodes, number of pods/plant, pod weight and fresh pod yield was recorded with irrigation schedule at 4-day interval (I_1). This treatment noticed an increase of 19%, 33.5% and 98.7% yields, respectively, over 7-day (I_2), 10-day (I_3) and 12-day (I_4) intervals. I_2 and I_3 showed significant variation in plant height, number of nodes/plant, number of pods/plant and pod weight, but the yield was at par to one another. Irrigation at 4-day interval offered optimum soil water content (15.7% at 0.30 m), relative water content (83%) and other physiological conditions that may have reflected as higher growth and yield. A significant reduction in growth and yield of okra was noticed when irrigation scheduled at longer intervals (10 or 12 days). Earlier Home *et al*. (2002) also reported reduction in yield of okra due to imposing water stress to 60% MAD.

A significant variation on plant growth and yield attributes of okra was observed with use of pea straw mulch. Mulch significantly enhanced the plant height, number of nodes/ plant, number of pods/plant, pod weight and fresh pod yield over no mulch. Mulched okra plant exhibited 31.4% higher pod yield over non-mulched plant. These results are in agreement to the findings of Tiwari *et al*. (1998) in okra and Kar and Kumar (2007) in potato *(Solanum tuberosum* L). Enhancement in growth and yield of okra under pea straw mulch may be attributed to conserved soil moisture, moderate plant water status, soil temperature, soil mechanical resistance and increased availability of plant nutrients (Kar and Kumar 2007, Mulumba and Lal 2008, Huang *et al*. 2008).

Results on physiological parameters indicated that furrow irrigation at 4-day interval had maximum leaf water potential (–0.91 MPa), relative water content (83%), photosynthetic rate (14.1 µmole $CO_2/m^2/s$), stomatal conductance (351.9 mmole $H_2O/m^2/s$) and lower T leaf (39.2°C) than the other irrigation treatments (Table 2). Irrigation at 10-day or 12-day intervals exhibited significantly lower CCI, leaf water potential, relative water content, soil water potential and photosynthetic rate than both I_1 and I_2. Sankar *et al*. (2008) also reported a decrease in biomass and yield, leaf area, cumulative water transpired, net assimilation rate, transpiration rate and harvest index in water stressed okra plants. Water stress results in stomatal closure and reduced transpiration rates, a decrease in leaf water potential, decrease in photosynthesis and growth inhibition. Reduction in stomatal conductance also lowers photosynthetic rate due to restriction of CO_2 availability at assimilation site (eg chloroplast) and lower internal CO_2 concentration inside the leaf (Lawlor and Cornic 2002).

Pea-straw mulch had significant effect on physiological traits of okra. An improvement in leaf water potential (–1.58 MPa), soil water content (13%), relative water content (78.7%), photosynthetic rate (11.57 µmole $CO_2/m^2/s$) and stomatal conductance (279.5 mmole/m^2/s), and a significant reduction in CCI were recorded under pea-straw mulch, however mulch did not affect the leaf temperature. Significantly higher soil water content was registered with irrigation at 4-day interval coupled with pea-straw mulch (I_1M_1) (Fig 1). An optimum soil moisture and hydrothermal regime of soil with higher relative water content and leaf water potential under mulched condition may have contributed for improved photosynthetic rate, stomatal conductance and other physiological attributes of plant. Similar findings with use of organic mulches have also been reported by Huang *et al*. (2008).

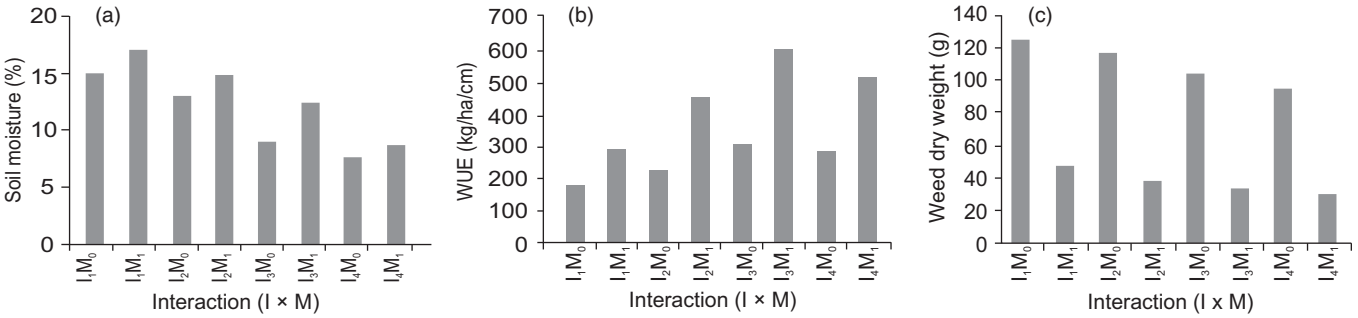


Fig. 1 Variations in soil-water content (a) water-use efficiency, (b) weed dry weight, (c) for 8 combinations of irrigation scheduling (I) and pea-straw mulch (M)

Water-use efficiency is the ratio of total pod yield and total water applied to the crop. The total water applied under I_1, I_2, I_3 and I_4 were 628, 375, 255 and 180 mm respectively. In mulched plot, the estimated total water applied was 278 mm, and 395 mm in 'no mulch'. The maximum water-use efficiency was recorded under I_3 (455.72 kg/ha/cm) with 59.4% water saving over I_1. Mulched plant exhibited remarkably higher water-use efficiency (474.56 kg/ha/cm) and water saving (29.6%) than 'no mulch' (253.86 kg/ha/cm). The interactive effect of irrigation scheduling and mulch was highly significant, and the highest water-use efficiency was noticed under I_3M_1 (602.73 kg/ha/cm), followed by I_4M_1 (551.21 kg/ha/cm) (Fig 1). At longer irrigation intervals, less water and subsequent closure of stomata might reduce the loss of water than it caused decrease in CO_2 fixation. This indicates that the photosynthesis was increased at the cost of water loss resulting in lower water-use efficiency. In conformity to our findings, Sankar *et al.* (2008) also reported higher water-use efficiency in okra under water-limited conditions.

Frequent irrigations (4 or 7-day intervals) encouraged higher weed growth over longer intervals. The plots irrigated at 4-day intervals (I_1) registered about 8%, 25.7 and 37% higher weed growth, respectively over I_2, I_3 and I_4. Lowest weed dry weight was observed with irrigation at 12-day coupled with pea-straw mulch (I_4M_1) (Fig 1). Organic mulch drastically reduced the weeds (65.4%) compared to that of non-mulched plots. Organic mulches have been reported to control weeds by inhibiting weed germination, and also acting as a physical barrier to weed growth. Similar to our findings, Tiwari *et al*. (1998) also noticed considerable reduction in weed growth in okra with use of organic mulch.

SUMMARY

A field experiment was carried out during spring-summer of 2006 and 2007 at Indian Institute of Vegetable Research, Varanasi. The treatments comprised 4 levels of surface irrigation (4, 7, 10 and 12 days intervals) and 2 level of mulch (pea straw mulch at 12.5 tonnes/ha and 'no mulch'). Significant differences on morpho-physiological and yield attributes were observed in various irrigation treatments and organic mulches. Irrigation scheduled at 4-day interval exhibited maximum fresh pod yield of okra (15.03 tonnes/ha) with higher leaf water potential, (0.91 MPa), relative water content in leaves (83%), photosynthetic rate (14.10µmole $CO_2/m^2/s^1$) and stomatal conductance (351.9 mmol $H_2O/m^2/s^1$). Higher chlorophyll concentration index was recorded in 4 or 7-day irrigation intervals. Pea-straw mulch significantly enhanced the plant height, number of nodes/plant, number of pods/plant, pod weight and fresh pod yield over non-mulched. Significant improvement was observed in plant physiological parameters and soil water content under pea straw mulch. Irrigation at 10-day interval along with pea-straw mulch exhibited maximum water-use efficiency (455.72 kg/ha-cm). Significant reduction in weed population (65.4%) and considerable water savings (29.6%) was recorded with use of pea-straw mulch over no mulch.

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