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Physiological and yield response of okra (*Abelmoschus esculentus* Moench.) to drought stress and organic mulching

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Abstract

A field experiment was carried out on okra by imposing water deficit and using organic mulches during spring-summer of 2009 and 2010 at Indian Institute of Vegetable Research, Varanasi, India. The treatments comprised of three levels of irrigation scheduling (5, 10 and 15 days intervals) and three level of mulch (pea straw, dry grass mulch at 7.0 t ha^{-1} and 'no mulch'). Significant differences on physiological and yield attributes were observed in various irrigation treatments and organic mulches. Organic mulching enhanced the stomatal conductance and photosynthesis by 127-154% and 50-59%, respectively over no mulch. Similarly, there was 16 and 33% reduction in photosynthesis, and 33 and 36% reduction in stomatal conductance in 15 days irrigation scheduled plant as comparison to 5 and 10 days schedule, respectively. The maximum photosynthesis and stomatal conductance was registered with irrigation at 10 days coupled with organic mulching. Similarly, irrigation at 5 or 10 days recorded 40.3 and 45.6% higher pod yield, respectively over longer intervals. Significantly higher yield was noticed in both organic mulches over no mulch. Maximum pod yields (103.55 and 116.73 q ha^{-1}) were recorded respectively, with irrigation at 10 days interval and mulching either with pea straw or dry grass. Mulched plants exhibited very proportional allocation of drymatter in various plant parts. The maximum water use efficiency of 351.60 kg $ha^{-1}cm^{-1}$ was recorded in treatment comprising irrigation scheduling at 10 days interval and mulching with dry grass.

Key words: Okra, *Abelmoschus esculentus*, drought stress, organic mulch, gas exchange, water use efficiency

Introduction

Agriculture is a major user of fresh water resources in many regions of the world including India. With increasing acridity and growing population, water will become scarce commodity in the near future (Chaves *et al.,* 2003). Okra (*Abelmoschus esculentus* Moench) in northern Indian plains if cultivated during spring-summer season requires about 320 mm of water (Bahadur *et al.*, 2007), and water deficit at flowering and pod-filling stages reduces pod yields to more than 70% (Mbagwu and Adesipe, 1987). Exposing the crop for a certain level of drought stress either during a specific period or throughout the growing season is one way of maximizing water use efficiency.

A better understanding of the effect of drought on plant physiological, biochemical and yield traits is vital for improved management practices to achieve higher production under limited water condition. Drought stress reduces plant growth by affecting various physiological and biochemical processes, such as photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism and growth promoters (Farooq *et al.*, 2009). Organic mulches on the other hand have potential benefits in soil structure formation, enhancing soil biodiversity, alleviating environmental stresses, buffering drastic changes in soil temperature and improving food quality and safety. The present study was undertaken to find out the effect of imposing mild to severe drought stress on plant growth, physiology, yield and water use efficiency of okra under organic mulched and non-mulched conditions.

Materials and methods

Field experiment was conducted at IIVR, Varanasi (25° 18′ N latitude and 83° 0′ E longitude) during 2009 and 2010 with three irrigation schedules [irrigation at 5, 10 and 15 days intervals designated as well watered (WW), moderate drought stress (MS)and severe drought stress (SS), respectively], and three levels of mulches [pea straw (PS), dry grass mulch (DG) at 7.0 t ha^{-1} and no mulch (M0)]. The experiment was laid in split-plot design with three replications in each treatment. The irrigation treatments were kept in main plots and mulch in sub-plots. The soil of experimental plot was sandy loam with pH 7.2, EC 0.32 dS m^{-1}, organic carbon 0.41% and available N, P and K was 258, 20.5 and 185 kg ha^{-1}, respectively. Moisture content (30 cm depth) at field capacity (-0.33 bars) and at wilting point (-15 bars) was 23.4 and 7.1%, respectively whereas; bulk density of soil was 1.38 g cm^{-3}. The average monthly pan evaporation was 6.4 and 6.7 cm in 2009 and 2010, respectively.

The crop was grown on 25-30 cm high ridges, and furrow of 30 cm wide, 25 cm deep and 9 m long with 0.25% slope along the side of ridge to supply water. The row-to-row spacing was kept 60 cm and plant-to-plant of 20 cm. 120 kg N, 60 kg each of P and K along with 15 tonnes of farmyard manure per hectare was applied to meet nutritional requirements of the crop. Dried pea straw and dry grass mulch at 7.0 t ha^{-1} was applied evenly in furrows, 25 days after seed sowing (DAS). A total of 7 pickings were undertaken at 3 days intervals starting from 50 DAS.

The photosynthetic rate (Pn), stomatal conductance (gs), transpiration rate (E) and leaf temperature was measured between 1000 to 1100 h using a Portable Photosynthesis System (LiCOR

6200, Lincoln, Nebraska, USA). During the measurement, the photoactive radiations (PAR) incident at the leaf cuvette ranged between 900 to 1250 μmol $m^{-2}s^{-1}$, and the external CO_2 varied between 285 to 360 μmol mol^{-1}. All physiological measurements were taken at active growth stage (45-50 DAS) in fully expanded leaves, just before release of stress. Soil water content (SWC) was determined by Gopher (Soil Moisture Technology, Queensland, Australia) to a depth of 30 cm in the middle of furrow just before release of stress. Water use efficiency (WUE) was calculated as pod yield divided by total water used. Total dry matter production and dry matter partitioning was measured by taking dry mass of roots, stems, leaves and pods.

Results and discussion

Physiological parameters: Physiological parameters showed significant variations in various treatments (Table 1). Maximum photosynthesis, Pn (15.54 μmol $m^{-2}s^{-1}$) was observed in MS plants followed by WW (12.32 μmol $m^{-2}s^{-1}$). There was about 16 and 33% reduction in photosynthesis rate in SS plant as compared to WW and MS, respectively. The interaction of irrigation scheduling and mulch were also found significant, and the maximum Pn was recorded with mild stress+ grass mulched (19.54 μmol $m^{-2}s^{-1}$) plant followed by moderate stress+pea straw (17.44 μmol $m^{-2}s^{-1}$). Stomatal conductance (gs) is an important physiological trait for abiotic stress, particularly for drought tolerance. In present study, the WW and MS plants exhibited significantly higher gs (49.7 and 57%, respectively) than the SS plants (0.575 mole m^{-2} s^{-1}). Similarly, both organic mulches registered higher gs (127 to 154%) than without mulch. I x M interactions showed significant variations, and the maximum gs (1.374 mol $m^{-2}s^{-1}$) was recorded in plants wherein irrigation was scheduled at 10 days intervals (MS) coupled with pea straw mulch (PS). Mild or severe stressed plant without mulch had the minimum gs (0.321 and 0.257 mol $m^{-2}s^{-1}$, respectively) as compared to the other interactions.

Leaf transpiration was significantly higher in WW (0.0167 mol $m^{-2}s^{-1}$) and PS mulch (0.0168 mol $m^{-2}s^{-1}$), however the interaction of irrigation scheduling and mulch was insignificant. The treatment effect on leaf temperature not significant. Similar to our findings, Bhatt and Rao (2005) also noticed 2.5 to 66% reduction in photosynthesis rate in different cultivars of okra due to water deficit. Ashraf *et al.* (2002) and Sankar *et al.* (2008) reported a decrease in biomass and yield, leaf area, cumulative water transpired, net assimilation rate, stomatal conductance and transpiration in okra due to drought stress. Water stress results in stomatal closure resulting reduced transpiration rate, decrease in LWP, photosynthesis and growth. Reduction in gs lowers Pn due to restriction of CO_2 availability at assimilation site (*e.g.* chloroplast) and lower internal CO_2 concentration inside the leaf (Lawlor and Cornic, 2002).

Yield parameters: Yield traits such as number of pods per plant and pod yields were significantly affected with imposing drought stress and applying organic mulches (Table 2). Significantly higher number of pods per plant was noticed under WW and MS (11 and 12.8, respectively). PS and DG mulches also recorded significantly higher number of pods per plant (12.7 and 12.6, respectively) over M0 (9.4). Pod yield (per plant or per ha) also showed similar trend as number of pods per plant. Irrigation at 5 days or 10 days recoded 40.3 and 45.6% higher pod yield, respectively over irrigation at 15 days. Earlier, Mbagwu and Adesipe (1987), Tiwari *et al.* (1998), Bahadur *et al.* (2007) also noticed reduction in okra yields due to imposing water deficits.

The interaction of irrigation and mulch was significant. Higher number of pods (14.7 and 14.3) and pod yields (205 and 215 g per plant, and 103.55 and 116.73 q ha^{-1}) were recorded with irrigation at 10 days interval and mulching with PS or DG, respectively. Plants under MS and DG mulch condition registered 43% and 117.5% higher pod yields, respectively over MSM0 and SSM0. Similar to our findings, Makus *et al.* (1994) and Tiwari *et al.* (1998) also noticed increase in yield traits of okra due to organic mulch application. A significant improvement in yield attributes with use of organic mulches may be due to conserved soil moisture, moderate plant water status, soil temperature and increased availability of plant nutrients (Tiwari *et al.,* 1998; Huang *et al.,* 2008). The positive effects of mulching might be due to maintaining a conducive soil environment in terms of better soil moisture, lowering of soil temperature and better supply of nutrients, which ultimately favoured better growth and vegetative biomass production (Ram *et al.,* 2003).

Table 1. Effect of drought stress and mulching on plant physiological traits in okra

Treatment	Photosynthesis (μ mol m^{-2} s^{-1})				Stomatal conductance (mol m^{-2} s^{-1})				Transpiration rate (mol m^{-2} s^{-1})				Leaf temperature (°C)			
	Irrigation intervals (days)				Irrigation intervals (days)				Irrigation intervals (days)				Irrigation intervals (days)			
	5	10	15	Mean	5	10	15	Mean	5	10	15	Mean	5	10	15	Mean
Pea straw	12.83	17.44	11.76	14.01	1.026	1.374	0.665	1.022	0.0198	0.0186	0.0121	0.0168	37.2	37.9	38.8	38.0
Dry grass	12.17	19.54	12.88	14.86	0.928	1.014	0.804	0.915	0.0167	0.0131	0.0134	0.0144	36.8	37.4	36.8	37.0
No mulch	11.97	9.63	6.35	9.32	0.629	0.321	0.257	0.402	0.0135	0.0109	0.0107	0.0117	37.1	37.7	38.1	37.6
Mean	12.32	15.54	10.33		0.861	0.903	0.575		0.0167	0.0142	0.0121		37.0	37.7	37.9	
LSD (*P*=0.05)	I = 1.78, M = 1.23, I x M = 2.23				I = 0.085, M = 0.117, I x M = 0.337				I = 0.0031, M = 0.0043, I x M = NS				I= NS, M = NS, I x M = NS			

Table 2. Effect of drought stress and mulching on yield parameters in okra

Treatment	Number of pods/plant				Pod yield (g/plant)				Pod yield (q/ha)				WUE (kg/ha-cm)			
	Irrigation intervals (days)				Irrigation intervals (days)				Irrigation intervals (days)				Irrigation intervals (days)			
	5	10	15	Mean	5	10	15	Mean	5	10	15	Mean	5	10	15	Mean
Pea straw	11.0	14.7	12.3	12.7	178.5	205.4	153.4	179.1	90.45	103.55	79.25	91.08	191.23	338.50	323.27	284.33
Dry grass	11.7	14.3	11.7	12.6	185.3	215.6	148.7	183.2	98.83	116.73	68.66	94.74	199.67	351.60	313.92	288.40
No mulch	10.7	9.3	8.3	9.4	167.2	143.8	117.7	142.9	93.63	81.45	53.66	73.58	152.00	221.33	197.43	190.25
Mean	11.1	12.8	10.8		177.0	188.3	139.9		94.30	97.91	67.19		180.97	303.81	278.21	
LSD (*P*=0.05)	I= NS, M= 2.3, I x M = NS				I= 10.3, M= 10.8, I x M = 12.4				I = 7.45, M= 6.63, I x M = 9.17							

Drymatter production and partitioning: Data recorded on dry matter production and partitioning pattern in various plant parts at 55 DAS are depicted in Fig. 1(a-d). Results indicated that biomass allocation in roots, leaves, steams and pods were very proportionate under PS and DG mulch, particularly with moderate moisture deficits. Overall, the maximum total dry matter production (TDM) was observed under PS, however under SS, the maximum TDM (65.48 g) was recorded with DG mulch as compared to PS (56.82 g) and M0 (46.82 g). Plants mulched with PS and DG allocated 25-40% of photosynthates in their economic part (pods), which resulted in higher yield under organic mulch system; whereas under M0, about 35-40% of the photosynthates were retained in leaves, and only 20-25% was translocated to the sink (pods). Similar to our findings, Bhatt and Rao (2005) and Sankar *et al.* (2008) also noticed 43-51% decrease in the plant biomass and dry weight in okra due to water deficit. The decrease in total dry matter may be due to the considerable decrease in plant growth, photosynthesis and imbalance in allocation of photosynthates in various plant parts. It may also be due to source limitation resulting from large carbon demands under water stress induce limitations on photosynthesis (Kumar *et al.,* 2002).

Water saving and water use efficiency: Water use efficiency (WUE) is the ability of the crop to produce biomass per unit of water transpired. The water applied under WW, MS and SS was 486, 300 and 228 mm, respectively; whereas under M0, PS and DG the water used pattern was 373, 312 and 328 mm, respectively. Thereby, about 38 and 53% water saving was registered under MS and SS as compared to WW. Similarly, PS and DG mulches have noticed 16.4 and 12% water savings, respectively over 'no mulch'. WUE was maximum in MS (303.81 kg ha^{-1}cm^{-1}), while WW recorded least WUE (180.97 kg ha^{-1}cm^{-1}). Both, pea straw and dry grass mulches have registered higher WUE over no mulch. As far as interaction was concerned, the maximum WUE was recorded in MS plants with PS (338.50 kg ha^{-1}cm^{-1}) or DG (351.60 kg ha^{-1} cm^{-1}) mulch. These two treatment combinations also recorded about 50 and 45% water savings, respectively over WWM0. Due to reduction of incoming solar energy, less water was evaporated from the mulched plots compared to the non-mulched plots. Furthermore due to longer irrigation intervals, less water was applied, and closure of stomata might reduce the loss of water and it caused decrease in CO_2 fixation. This indicates that the photosynthesis was increased at the cost of water loss resulting in lower WUE. These reasons have contributed higher WUE in limited water condition and organic mulching. In conformity to our findings, Sankar *et al.* (2008) also reported higher WUE in okra under water-limited conditions.

It is concluded that water deficit conditions and organic mulches influence the gas exchange and yield traits in okra as indicated by the differences in photosynthesis, stomatal conductance, transpiration, leaf temperatures, biomass partitioning and pod production. Irrigation scheduling at 5-day interval increased the gas exchange and yield. Both types of organic mulches had positive effect on gas exchange and pod yield, however the maximum gas exchange, pod yields, water use efficiency and an

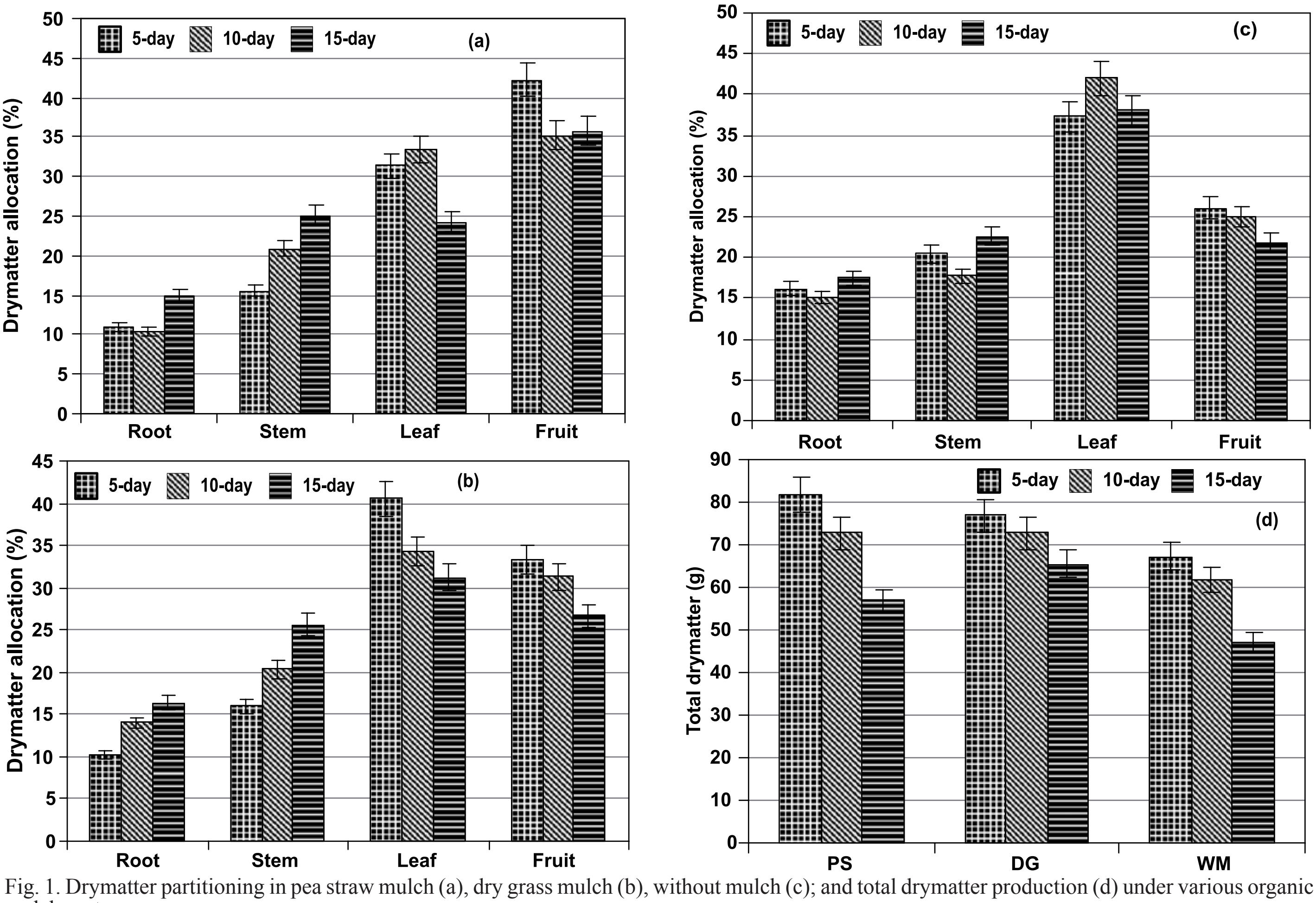

Fig. 1. Drymatter partitioning in pea straw mulch (a), dry grass mulch (b), without mulch (c); and total drymatter production (d) under various organic mulch systems

appropriated dry matter allocation was observed with irrigation at 10-day intervals and organic mulching, particularly with dry grass mulch.

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