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Management of moisture stress in okra under tropical island ecosystem

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Abstract
In Andaman and Nicobar islands, vegetables crops are cultivated during post monsoon period (Nov – May) and experience severe water stress during reproductive stages. Under this context, the field experiments were conducted to study the effect of moisture stress management practices on growth, yield attributes and yield of Okra (Arka Nikita) during dry periods (Feb-May) of 2021 and 2022. The experiment was conducted in strip plot design with three horizontal treatments (Surface irrigation + residue mulch, Drip + plastic mulch, Sub-surface drip irrigation) and four vertical treatments (Hydrogel, hydrogel + K spray, hydrogel + Ca spray, hydrogel + K & Ca spray) in three replications. The irrigation was given through drip, subsurface drip and surface irrigation. Pusa hydrogel was applied through seedling dipping. The fertilizer was given as per the recommended dose (100: 60:50 NPK kg/ha). Potassium Nitrate and Calcium Nitrate were applied as foliar spray at flowering and 15 days after the first spray. In Okra, drip irrigation with plastic mulching recorded maximum fruit length (15.0 cm), no. of fruits (14.9), fruit weight (20.4 g) which resulted in higher yield (303 g/plant, 9.68 t/ha) followed by sub-surface drip irrigation. Application of hydrogel + K & Ca foliar spray recorded maximum fruit length (15.0 cm), no. of fruits (14.5), fruit weight (19.6 g) which resulted in higher yield (286 g/plant, 9.15 t/ha) and at par with hydrogel + K spray. Maximum relative leaf water content (53.8%), Maximum membrane stability index (71.0), total chlorophyll (1.8 mg g^{-1}) and lesser proline content (27.8 mg g^{-1}) were recorded in drip irrigation + plastic mulching. Similarly, maximum RLWC (53.4%), membrane stability index (67.3), total chlorophyll content (1.65 mg g^{-1}) and minimum proline (24.5 mg g^{-1}) were recorded in hydrogel + foliar spray of K & Ca. Higher water use efficiency (327 kg/ha-cm) was observed in drip irrigation + plastic mulch. The maximum net return (₹ 2,31,200) was recorded in drip irrigation + plastic mulch which was followed by sub-surface drip irrigation. Similarly, maximum net return (₹2,26,333) was recorded in the treatments which received hydrogel + foliar spray of K & Ca. Hence, it can be concluded that drip irrigation + mulching, hydrogel and foliar spray of K and Ca is best option to mitigate the moisture stress in okra under island condition.

Keywords: Moisture stress, okra, drip irrigation, mulching, hydrogel, K and Ca spray

Introduction
In Andaman and Nicobar islands, vegetables crops viz., okra, brinjal, cowpea, french beans, field beans, gourds and leafy vegetables are cultivated during post monsoon period (Nov – April) and experience water stress (Agricultural drought) as the rainfall and soil moisture are inadequate to meet the crop water requirement. During flowering stage of vegetables, water scarcity leads to flower shedding and during fruit setting, plants with small sized fruits are produced. Okra is a high water consuming crop despite having considerable drought resistance. For obtaining high yield in Okra, an adequate water supply is required during the total growing period. Water supply reduction during the growing period has an adverse effect on yield (Al-Harbi *et al.*, 2008) [2]. Further, traditional flood irrigation methods (irrigation with hose pipe) are being used to irrigate the crops. This method not only consume more water and but also leads to loss of water through evaporation from the surface. These losses can be managed by efficient water management practices (Dahiya *et al.*, 2005) [8]. In Andaman and Nicobar Islands, though various attempts were made to promote drip irrigation in the islands, its adoption is in nascent stage due to high initial cost, its maintenance and lack of skills. However, suitability and performance of subsurface drip irrigation system for island condition are also to be studied. Mulching is efficient method to reduce evaporation and conserve soil moisture. Further, use of agricultural hydrogel will be a productive option for increasing agricultural production. Hydrogels can absorb water and help to reduce percolation losses. Agricultural hydrogels are eco-friendly and do not leave any toxic residue in the soil and plants.

It is normally being used in extremely dry regions. Its efficiency under tropical climatic condition is also needs to be studied for adoption during prolonged drought in the islands. Potassium fertilizer is widely reported to improve drought tolerance when used as foliar spray under drought condition. Further, uptake of Calcium (Ca^{2+}) which is essential for photosynthesis is severely affected under drought stress. So, it is imperative to standardize the effect of foliar application of K and Ca on growth and yield of vegetables in the islands. Keeping the importance and lack of moisture stress management practices for vegetables in the islands, the experiments were carried out in Okra.

Materials and Methods

The field experiments were conducted to assess the effect of moisture stress management practices on growth and yield of Okra during dry months (Feb- May) of 2021 and 2022 at Garacharma, ICAR-Central Island Agricultural Research Institute, Port Blair. The experiment was laid out in strip plot design with three horizontal treatments (surface irrigation + residue mulch, drip + plastic mulch, Sub-surface drip irrigation) and four vertical treatments (hydrogel, hydrogel + K spray, hydrogel + Ca spray, hydrogel + K & Ca spray) in three replications. Pusa hydrogel was used for the study. Okra (Variety – Arka Nikita) was sown at 50 × 50 cm in paired row drip system. The crop water requirement was estimated for Okra at study area as 370 mm during dry period at different growing stages of Okra using CROPWAT8.0 model (Smith, 1992) [14] based on the climate, rainfall, crop, cropping pattern and soil data. For inducing moisture stress, deficit irrigation was given at 80% crop water requirement (296 mm or 2960 m^3/ha). Irrigation schedules were prepared using CROPWAT model considering there is no rainfall during the crop period. The drip irrigation operation time for the different treatments was calculated and operated in alternate days. For the surface irrigation treatment (control), the same 80% crop water requirement was provided. Pusa hydrogel was applied @ 4 kg/ha through soil application at the time of sowing. The fertilizer was given as per the recommended dose (100: 60:50 NPK kg/ha). Foliar spray of Potassium Nitrate (N-13% & K-45%), Calcium Nitrate (N-13.5 & Ca-18.5%) was done at flowering and 15 days after the first spray. Growth, yield attributes and yield of okra were recorded, physiological parameters were estimated, economics and water use efficiency were worked out. The data were analyzed statistically as per the procedures suggested by Gomez and Gomez (1984) [9].

Results and Discussion

Growth attributes

The growth of okra was significantly influenced by different methods of irrigation, hydrogel and foliar spray of nutrients under moisture stress condition (Table 1). Among the irrigation methods, drip irrigation with plastic mulching recorded higher plant height (80 cm) and at par with subsurface drip irrigation. Similarly, maximum plant height was recorded by application of hydrogel + foliar spray of K & Ca (79.2 cm) and at par with hydrogel+ foliar spray of K.The higher plant height with hydrogel might be due to water availability and indirect nutrients provided by hydrogel. Abha Nutan Kujur *et al.* (2022) [1] reported similar results in Okra. Among the treatments, early flowering (47 days) was observed in sub-surface drip irrigation and hydrogel+ foliar spray of K & Ca. Higher root length (25.6 cm) was recorded in drip irrigation and at par with subsurface drip irrigation. This is in confirmatory with the findings of Jayapiratha *et al.* (2010) [11]. The root length was not significantly influenced by foliar sprays. However, dry matter production was highly influenced by irrigation treatments, hydrogel and foliar sprays. Maximum dry matter production (1672 kg/ha) was recorded in drip irrigation + plastic mulch and at par with sub-surface drip irrigation as compared to surface irrigation. Similarly, higher DMP (1654 kg/ha) was recorded in hydrogel + foliar spray of K and Ca. The interaction of irrigation methods, hydrogel and foliar spray of nutrients showed non – significant effect on all growth attributes. The better growth of plants under drip irrigation + mulching might be due to favourable moisture content and aeration in the root zone. The results are in line with findings of Choudhary *et al.* (2012) [6] and Haris *et al.* (2014) [10].

Table 1: Growth attributes of Okra as influenced by irrigation methods, hydrogel and foliar spray under moisture stress condition.

Treatments	Plant height (cm)	Days to 50% flowering	Root length (cm)	Dry matter production (kg/ha)
Horizontal treatments (I)				
I_1-Surface irrigation+ residue mulch	69.6	50.9	22.4	1471
I_2- Drip+plastic mulch	80.1	48.4	24.7	1672
I_3- Sub-surface drip irrigation	76.0	47.3	25.6	1609
SEm	1.1	0.28	0.28	24
CD (5%)	4.3	1.1	1.0	93
Vertical treatments (S)				
S_1-Hydrogel	71.5	48.4	25.7	1524
S_2-Hydrogel +K	77.1	48.5	26.4	1606
S_3-Hydrogel +Ca	73.1	50.2	25.3	1549
S_4-Hydro +K & Ca	79.2	48.2	26.5	1654
SEm	1.1	0.42	0.5	28
CD (5%)	3.2	NS	NS	93

Yield attributes

Irrigation methods, hydrogel and foliar spray of nutrients showed significant difference on yield attributes of Okra during moisture stress condition under island ecosystem (Table 2). The drip irrigation with plastic mulching recorded higher fruit length (15 cm) which was at par with subsurface drip irrigation. Lowest fruit length (13.6 cm) was recorded by surface irrigation + residue mulching. Similarly, application of hydrogel and foliar spray of K and Ca recorded higher fruit length (15.3 cm) and at par with hydrogel + K spray. Lowest fruit length (13.6 cm) was recorded in hydrogel alone. The maximum fruit weight (204) per plant was recorded in drip irrigation + plastic mulch which was followed by sub-surface drip irrigation. The lowest fruit weight (16.9 g) was recorded

by surface irrigation + residue mulching. The higher fruit weight (19.6 g) was recorded in soil application of hydrogel + foliar spray of K & Ca and at par with hydrogel + K spray. Similarly, the maximum number of fruits (14.9) per plant was recorded in drip irrigation + plastic mulch which was at par with sub-surface drip irrigation. Highest fruits per plant was recorded in soil application of hydrogel + foliar spray of K & Ca. The interaction of irrigation methods, hydrogel and foliar spray of nutrients showed non –significant effect on all yield attributing characters. Optimum moisture supplied by drip irrigation under mulched conditions compared to the surface irrigation enhances yield attributes and yield of Okra. Chandra and Singh (2019) recorded highest yield in okra under drip irrigation with mulch. Higher yield of Okra with hydrogel application was probably due to increase in water holding capacity of soil. Similar findings were also observed by Abha Nutan Kujur *et al.* (2022) [1].

Table 2: Yield attributes and yields of Okra as influenced by irrigation methods, hydrogel and foliar spray of nutrients under moisture stress condition

Treatments	Fruit length (cm)	Fruit weight (g)	No of fruits/plant	Yield/plant (g)	Yield (t/ha)
Horizontal treatments (I)					
I_1-Surface irrigation	13.6	16.9	12.2	207	6.63
I_2- Drip + plastic mulch	15.0	20.4	14.9	303	9.68
I_3- Sub-surface drip irrigation	14.6	18.7	13.7	256	8.18
SEm	0.16	0.22	0.35	8.2	0.25
CD (5%)	0.63	0.87	1.34	31.6	1.0
Vertical treatments (S)					
S_1-Hydrogel	13.6	17.4	12.8	224	7.16
S_2-Hydrogel +K spray	14.8	19.3	13.7	266	8.51
S_3-Hydrogel +Ca spray	14.3	18.4	13.2	244	7.82
S_4-Hydro +K & Ca spray	15.0	19.6	14.5	286	9.15
SEm	0.22	0.39	0.33	7.0	0.23
CD (5%)	0.66	1.15	0.98	21.0	0.67

Yield

Irrigation methods, hydrogel and foliar spray of nutrients showed significant difference on yield of Okra during moisture stress condition under island ecosystem. The maximum fruit yield (303 g/ plant and 9.68 t/ha) was recorded in drip irrigation + plastic mulch which was followed by sub-surface drip irrigation. The lowest yield (207 g/plant and 6.63 t/ha) was recorded by surface irrigation+ crop residue mulch. The increased yield under drip +plastic mulching might have resulted from better water utilization, reduced evaporation, higher uptake of nutrients and better soil-water-plant relationship. Besides, drip + plastic mulching reduced water loss through deep percolation and increased water use from root zone soil. The higher yield under combined effect of drip and mulch were also reported by Chandra and Singh (2019) [5] in Okra and Biswas *et al.* (2015) [4] in tomato. Similarly, maximum fruit yield (286 g/ plant and 9.15 t/ha) was recorded in the treatments which received hydrogel + foliar spray of K & Ca. This was at par with hydrogel + foliar spray of K. Under drought stress conditions, K regulates stomatal opening and helps the plants to adapt water stress. Similarly, Calcium Nitrate fertilizer also helps in water regulation in plant tissues, improvement and enhancement in photosynthesis, and also protecting the plants from biochemical stresses. Similar results were also reported by Amrit raj and Mallick, 2017 [3]. However, there is no significant interaction between irrigation methods, hydrogel and foliar spray of K and Ca.

Physiological parameters

Relative leaf water content

Under moisture stress condition, as the water stress increased the relative leaf water content (RLWC) significantly decreased (Table. 3). Among water stress management practices, maximum RLWC (53.8%) was recorded in drip irrigation +plastic mulching followed by subsurface drip irrigation (52.4%). The lowest RLWC (50.0%) was recorded in surface irrigation+ residue mulch. Similarly, maximum RLWC (53.4%) was recorded in the treatments which received hydrogel + foliar spray of K & Ca which was at par with hydrogel + foliar spray of K. The reduction of relative water content under moisture stress condition is probably an oxidative injury at the cellular level under water stress has high lipid peroxidation which decreases the stability of cell membrane and led to lose more water from cells (Clarke and Caig, 1982) [7].

Membrane Stability Index

Among different moisture stress management practices, as the water stress increased the membrane stability index declined significantly. Maximum membrane stability index (71.0) was recorded in drip irrigation + plastic mulch, while sub-surface drip irrigation and surface irrigation+ residue mulching showed significantly less membrane stability index. Similarly, higher membrane stability index (67.3and 66.1) was observed in hydrogel + foliar spray of K & Ca and hydrogel + foliar spray of K, whereas, hydrogel alone recorded significantly less membrane stability index.

Proline content

As the water stress increases, the proline content also increases significantly. Maximum proline content (27.8 mg g^{-1}) was recorded in surface irrigation+ residue mulching, while drip irrigation + plastic mulch and sub-surface drip irrigation showed significantly less proline content. Similarly, less proline content (24.5 mg g^{-1}) was recorded in hydrogel + foliar spray of K & Ca which was at par with hydrogel + foliar spray of K. Proline is a major osmoregulant, it is produced in larger amount under stress conditions. The results of our study are in accordance with the findings of Prabhakar *et al.* (2018) [12].

Total chlorophyll content

Total chlorophyll content was decreased significantly under water stress condition. Drip irrigation recorded significantly

more total chlorophyll (1.8 mg g^{-1}), followed by subsurface drip irrigation (1.60 mg g^{-1}). Similarly, maximum total chlorophyll content (1.65 mg g^{-1})was recorded in hydrogel + foliar spray of K & Ca, which was at par with hydrogel + foliar spray of K. Decrease in chlorophyll content under moisture stress conditions could be related reduced photosynthetic process in plants. The results were in line with the findings of Ranjitha *et al*. (2021) [13].

Table 3: Physiological parameters of Okra as influenced by irrigation methods, hydrogel and foliar spray of nutrients

Treatments	Relative Leaf Water Content (%)	Membrane Stability Index	Proline content (umol/g. fw)	Total Chlorophyll content (mg/g.fw)
Horizontal treatments (I)				
I_1-Surface irrigation	50.0	60.7	4.00	1.31
I_2- Drip + plastic mulch	53.8	71.0	3.60	1.80
I_3- Sub-surface drip irrigation	52.4	66.6	3.75	1.60
SEm	0.32	0.42	0.06	0.03
CD (5%)	1.24	1.60	0.21	0.11
Vertical treatments (S)				
S_1-Hydrogel	50.7	64.2	3.87	1.50
S_2-Hydrogel +K	51.6	66.1	3.70	1.58
S_3-Hydrogel +Ca	52.5	64.6	3.83	1.54
S_4-Hydro +K & Ca	53.4	67.3	3.72	1.65
SEm	0.40	0.85	0.05	0.03
CD (5%)	1.18	2.6	NS	0.09

Water use efficiency (WUE) and economics

Irrigation methods, hydrogel and foliar spray of nutrients showed significant difference on WUE and economics of Okra under island ecosystem. Higher water use efficiency (327 kg/ha-cm) was observed in drip irrigation + plastic mulch. The maximum net return (₹2,31,200) was recorded in drip irrigation + plastic mulch which was followed by sub-surface drip irrigation. The lowest net return (₹1,59,200) was recorded by surface irrigation+ residue mulch. However, drip + plastic mulch and surface irrigation recorded higher B; C ratio than the subsurface drip irrigation. Similarly, maximum net return (₹2,26,333) was recorded in the treatments which received hydrogel + foliar spray of K & Ca. This was at par with hydrogel + foliar spray of K.

Table 4: WUE and economics of moisture stress management practices in Okra

Treatments	Water use efficiency (kg/ha-cm)	Cost of cultivation	Gross income	Net income	B: C ratio
Horizontal treatments (I)					
I_1-Surface irrigation	224	1,06,000	2,65,200	1,59,200	2.50
I_2- Drip + plastic mulch	327	1,56,000	3,87,200	2,31,200	2.48
I_3- Sub-surface drip irrigation	276	1,36,000	3,27,200	1,91,200	2.41
Vertical treatments (S)					
S_1-Hydrogel	242	1,27,667	2,86,400	1,58,733	2.24
S_2-Hydrogel +K	288	1,31,667	3,40,400	2,08,733	2.59
S_3-Hydrogel +Ca	264	1,31,667	3,12,800	1,81,133	2.38
S_4-Hydro +K & Ca	309	1,39,667	3,66,000	2,26,333	2.62

Conclusions

Maximum okra yield of 9.7 t/ha was obtained in drip irrigation with plastic mulching under moisture stress condition which is 18% higher than the sub-surface drip irrigation and 46% more than the surface irrigation +residue mulch. In Okra, drip irrigation with plastic mulching recorded maximum fruit length (15.0 cm), no. of fruits (14.9), fruit weight (20.4 g) which resulted in higher yield (303 g/plant, 9.68 t/ha) followed by sub-surface drip irrigation. Application of hydrogel + K & Ca foliar spray recorded maximum fruit length (15.0 cm), no. of fruits (14.5), fruit weight (19.6 g) which resulted in higher yield (286 g/plant, 9.15 t/ha) and at par with hydrogel + K spray. Maximum relative leaf water content (53.8%), Maximum membrane stability index (71.0), total chlorophyll (1.8 mg g^{-1}) and lesser proline content (27.8 mg g^{-1}) were recorded in drip irrigation +plastic mulching. Similarly, maximum RLWC (53.4%), membrane stability index (67.3),total chlorophyll content (1.65 mg g^{-1}) and minimum proline (24.5 mg g^{-1}) were recorded in hydrogel + foliar spray of K & Ca. Higher water use efficiency (327 kg/ha-cm) and net return (₹2,31,200) was recorded in drip irrigation + plastic mulch which was followed by sub-surface drip irrigation. Similarly, maximum net return (₹2,26,333) was recorded in the treatments which received hydrogel + foliar spray of K & Ca. Hence, it can be concluded that drip irrigation + mulching, application of hydrogel and foliar spray of K and Ca is best option to mitigate the moisture stress and get higher yield and net return in okra under island eco system.

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