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Hydrogel applications for yield improvement of capsicum with deficit irrigation at cold desert Ladakh region

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Abstract

Aim : The study aimed to evaluate the effects of hydrogel application on growth, physiological responses and yield of capsicum under high altitude cold desert conditions with deficit irrigation of Ladakh region.

Methodology : Field experiment was conducted with five levels of hydrogel treatment (viz. 0, 5, 10, 15 and 20 kg ha⁻¹) at cold desert Ladakh region with two irrigation intervals (7 and 11 days) during 2014-15 cropping season. Plant growth characters, root morphology, physiological parameters and capsicum yield were analyzed according to standard methods during the experiments.

Results : Hydrogel application in deficit irrigation improved physiological parameters viz. leaf chlorophyll content, relative water content, membrane stability index and significant reduction in electrolyte leakage in capsicum plant. Significant improvement in root morphology was also recorded when hydrogel was applied @ 15 and 20 kg ha⁻¹. Improvement of yield attributing characters as influenced by hydrogel application @ 15 and 20 kg ha⁻¹ resulted in significant increase in capsicum yield with reduced water requirement.

Interpretation : Hydrogel has potential for growth of capsicum crop through improved root morphology and physiology of plant in deficit irrigation under arid and semi-arid regions where availability of water for irrigation is scarce or average rainfall is quite low.

Key words: Capsicum, Cold arid, Hydrogel, Physiological responses, Root morphology

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Introduction

Water deficit is one of the most common environmental limitations affecting crop at different growth stages and limits crop productivity and economic losses around the world (Hyman *et al.*, 2008). It has been estimated that about 28% of earth's land are too dry for plant production (IPCC, 2001). Approximately, one third of the cultivated area of the world suffers from inadequate water supplies (Massacci *et al.*, 2008). Prolonged drought stress, due to insufficient or scarcity of rainfall and irrigation water in arid and semi-arid areas, can be detrimental for plant growth and development (Huang and Gao, 1999; Wang *et al.*, 2003). Drought can significantly influence plant performance and survival and can lead to major constraints in plant functioning, including a series of morphological, physiological and metabolic changes (Ludlow and Muchow, 1990). In water stress conditions, plant physiological processes are adversely affected resulting in poor growth and yield. Vegetable crops are more sensitive to water stress and water scarcity may lead to considerable reduction in yield.

Capsicum (*Capsicum annuum* L.) commonly known as bell pepper or sweet pepper is one of the most popular and highly remunerative annual vegetable crops grown in subtropical and tropical areas. India contributes one fourth of the world's production of capsicum with an average annual production of 0.900 million tons from 0.885 million ha with a productivity of 1266 kg ha⁻¹ (Biwalkar *et al.*, 2015). It has been observed that capsicum production is confined to countries where water is often a limiting factor for production, necessitating the need to optimize water management (Dorji *et al.*, 2005). The crop is subjected to soil-moisture deficit in varying degree and duration, which occasionally result in substantial losses of yield. Capsicum has also been reported to be amongst the most susceptible vegetable to drought stress (Thomas, *et al.*, 2017) because of its wider range of transpiring leaf surface and high stomatal conductance (Alvino, *et al.*, 1994) and having a shallow root system (Dimitrov and Ovtcharow, 1995).

Super absorbent hydrogels (SAH) are compounds that absorb water and swell several times their original size and weight. They are lightly cross-linked networks of hydrophilic polymer chains. These networks swell in water and hold a large amount of water while maintaining the physical dimension structure (Mahdavinia *et al.*, 2004). Application of SAHs is seen as an important technology for agriculture production, especially in arid and semi-arid regions. SAHs have been successfully applied and found to significantly reduce water stress in crops like corn, barley, wheat, chick pea, lettuce, citrus, rapeseed, tomato etc. (Kalhapure *et al.*, 2016; Puoci *et al.*, 2008). Hydrogels in agriculture has shown encouraging results; they have been observed to reduce irrigation water consumption and enhance plants survival, improve fertilizer retention in soil and increase plant growth (Puoci *et al.*, 2008). Application of hydrogels in the water scanty, cold desert region in Ladakh, will help in maintaining optimum soil moisture for plant uptake and judicious use of water. Application of superabsorbent hydrogels on desert soils can

improve crop performance by increasing plant available water in soils; induce faster growth of plants under water deficit and help in prolong survival of plants under water stress condition. In view of the above, the objective of the present study was to evaluate potential effectiveness of hydrogel on growth, physiological responses and capsicum yield under water deficit conditions in cold desert region of Ladakh.

Materials and Methods

Experimental site : Ladakh is a high altitude cold desert under the rain shadow area of the Himalayas. Longer photoperiod (>12 hour), about 330 sunny days, very low relative humidity, high evapo-transpiration rates and only one cropping season in a year (span from May to October) are typical characteristics of this region. The average annual rainfall in this region is below 100 mm. Soil of Ladakh is taxonomically classified as typic cryorthids, physically thin, porous, with low water holding capacity and sandy in nature. This study was carried out at the experimental fields of Defence Institute of High Altitude Research (DIHAR), Ladakh in open field condition during 2014-2015 cropping seasons..

Experimental setup : Experiment was designed in a completely randomized block design (CRBD) with five levels of super absorbent hydrogel (SAH) (PUSA hydrogel which is commercially marketed as CUMI Gel by MURUGAPPA Group) @ 0, 5, 10, 15 and 20 kg ha⁻¹. Two irrigation intervals were followed viz., normal irrigation at an average interval of 7 days and deficit irrigation at an average interval of 11 days. The irrigation interval was decided on the basis of physical observation, feel method and weather conditions. Flood irrigation method was applied which is commonly used throughout Ladakh region and irrigation was done @ 40 l m⁻². The treatments are applied are as follows: T₀I_N = Control with normal irrigation; T₀I_D = Control with deficit irrigation; T₅I_D = SAH @ 5kg ha⁻¹ with deficit irrigation; T₁₀I_D = SAH @ 10kg ha⁻¹ with deficit irrigation; T₁₅I_D = SAH @ 15kg ha⁻¹ with deficit irrigation and T₂₀I_D = SAH @ 20kg ha⁻¹ with deficit irrigation.

Capsicum was planted on each plot (Plot size: 2 X 1 m²) with row spacing of 30 cm and interplant spacing of 40 cm in row. The SAH were applied surrounding the root zone of each seedling after transplanting, and the fields were irrigated on same day. Three plants were selected randomly from each plot to observe growth parameters and to evaluate plant physiological responses on different levels of SAH and irrigation interval. Irrigation as per treatments was applied two and three weeks after well establishment of seedlings.

Plant growth parameters and fruit yield : Growth parameters viz., plant height, number of leaves, number of branches and nodes per plant were measured before first harvesting at 93 and 98 DAT. During first flower formation stage, number of flowers per plant, as influenced by various treatments, was also recorded. Total capsicum fresh yield was measured with a digital weighing balance after consecutive harvest.

Estimation of physiological parameters : Leaf chlorophyll and anthocyanin content: Chlorophyll content index (CCI) and anthocyanin content index (ACI) were measured three times (40, 60 and 80 DAT) during the treatment period with portable leaf chlorophyll and anthocyanin meter (ADC Bioscience, UK). Membrane stability index (MSI) was calculated according to the method described by Sairam *et al.* (1997). Relative water content (RWC) was determined for detached capsicum leaves following the method of Mata and Lamattina (2001). In order to assess membrane permeability, electrolyte leakage (EL) was determined with a electrical conductivity meter as described by Lutts *et al.* (1996). Leaf water loss (LWL) was measured according to the method of Xing *et al.* (2004).

Root morphology : Root morphology of capsicum plant after harvesting was analyzed by an image analysis software (Biovis PSM, Expert Vision Labs Pvt. Ltd., India) specifically designed for root measurement in different forms (*viz.* projected area, total root length, number of root tips, number of forks, average root diameter). Before analyzing the root morphology, the plant roots were thoroughly washed under gentle tap water for removing soil and debris.

Statistical analyses : All experimental data were expressed as mean $\pm$ SD using statistical analysis with SPSS 16 (SPSS Corporation, Chicago, Illinois, USA), GraphPad PRISM version 5.01 software (San Diego, California, USA) and MS excel 2007. Difference between mean values were evaluated using one way analysis of variance (ANOVA). Significant difference level was set at P values < 0.05 for all statistical analysis.

Results and Discussion

Field experiment data showed significant improvements in plant growth characters *viz.* plant height, stem diameter, number of leaves, leaf area and number of branches under water stress condition with hydrogels treatments (Table 1). Except T₅I₀ and T₁₀I₀, all other hydrogel treatments showed significant increase ($p \leq 0.05$) in plant height, stem diameter, number of leaves per plant and leaf area as compared to T₅I₀. During the entire experiment period in normal irrigated plots, irrigations were applied 20 times whereas in hydrogel treated plots under deficit irrigation only 12 and 13 times irrigations were provided during 2014 and 2015 crop season, respectively. Hydrogels application help plants to survive in extended moisture stress by delaying the onset of permanent

Table 1: Growth characteristics in capsicum as influenced by super absorbent hydrogel treatments under deficit irrigation at DIHAR experimental field, Ladakh

Treatment	PH		SD		NL		LA		NB		NFL	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
T ₀ I _N	39.64 ^{ab}	34.38 ^{ba}	8.34 ^a	7.10 ^{ab}	35.00 ^a	31.89 ^a	25.07 ^a	20.98 ^a	4.67 ^a	4.34 ^a	10.67 ^{ab}	8.67 ^{ab}
T ₀ I ₀	36.02 ^a	32.83 ^a	8.32 ^a	6.62 ^a	31.22 ^a	31.11 ^a	24.42 ^a	20.76 ^a	4.45 ^a	3.44 ^a	9.44 ^a	7.6 ^a
T ₅ I ₀	42.30 ^c	38.44 ^{abc}	9.65 ^{ab}	10.17 ^{bc}	42.22 ^{ab}	34.33 ^a	34.87 ^b	26.14 ^{ab}	4.67 ^a	5.22 ^b	11.89 ^{ab}	9.67 ^{ab}
T ₁₀ I ₀	46.75 ^{cd}	42.53 ^{bc}	11.41 ^{ab}	11.34 ^c	44.56 ^{ab}	40.33 ^b	35.24 ^b	31.23 ^b	4.67 ^a	5.23 ^b	14.33 ^a	11.11 ^b
T ₁₅ I ₀	49.8 ^{cd}	42.80 ^c	11.77 ^b	11.40 ^c	46.44 ^{ab}	41.66 ^b	36.49 ^b	32.72 ^b	4.67 ^a	5.33 ^b	15.11 ^b	11.56 ^b
T ₂₀ I ₀	51.57 ^d	45.38 ^c	11.96 ^b	11.64 ^c	51.11 ^b	42.33 ^b	38.92 ^b	33.38 ^b	6.11 ^b	5.36 ^b	15.67 ^b	11.56 ^b

Where, PH = plant height (cm); SD = stem diameter (mm); NL= number of leaves per plant; LA=leaf area (cm²); NB=number of branch per plant; NFL=number of flowers. Mean values with different superscripts within a column differ significantly ($P < 0.05$) according to Tukey's Post Hoc Multiple

Table 2: Root development of capsicum as influenced by super absorbent hydrogel treatments under deficit irrigation at DIHAR experimental field, Ladakh

Treatment	EV		AD		NF		NR	
	2014	2015	2014	2015	2014	2015	2014	2015
T ₀ I _N	2225.78 ^a	2330.19 ^b	16.16 ^b	9.01 ^a	497.00 ^a	461.15 ^a	567.67 ^b	525.00 ^{bc}
T ₀ I ₀	1474.65 ^a	944.20 ^a	11.10 ^a	9.61 ^{ab}	391.22 ^a	398.28 ^a	440.89 ^a	401.44 ^a
T ₅ I ₀	1819.50 ^a	1019.17 ^a	11.34 ^a	11.19 ^{abc}	421.67 ^a	401.23 ^a	455.11 ^a	426.33 ^{ab}
T ₁₀ I ₀	2021.34 ^a	1281.72 ^a	12.24 ^{ab}	13.86 ^{bc}	457.11 ^a	470.21 ^a	507.33 ^{ab}	481.44 ^{abc}
T ₁₅ I ₀	2190.14 ^a	2047.36 ^b	14.92 ^{ab}	14.58 ^c	488.11 ^a	455.51 ^a	594.17 ^b	539.67 ^c
T ₂₀ I ₀	2211.31 ^a	2311.58 ^b	15.70 ^b	14.58 ^c	491.44 ^a	470.36 ^a	598.11 ^b	552.56 ^c

Where, EV=estimated root volume (mm³); AD=average root diameter (mm); NF=number of forks and NR=number of root tips. Mean values with different superscripts within a column differ significantly ($P < 0.05$) according to Tukey's Post Hoc Multiple comparisons

Fig. 1 : Values of (A) chlorophyll and (B) anthocyanin content of capsicum leaves as influenced by super absorbent hydrogel treatments under deficit irrigation at DIHAR experimental field, Ladakh. Mean values bearing same letter did not differ significantly ($P > 0.05$) according to Tukey's Post Hoc Multiple Comparisons.

Fig. 2 : Values of (A) relative water content and (B) leaf water loss of capsicum as influenced by super absorbent hydrogel treatments under deficit irrigation at DIHAR experimental field, Ladakh. Mean values bearing same letter did not differ significantly ($P > 0.05$) according to Tukey's Post Hoc Multiple Comparisons.

wilting point and reducing irrigation requirements of crops due to reduced water loss through evaporation. Water held in root zone and leaching of nutrients in soil is also reduced (Kalhapure *et al.* 2016) by hydrogel application. Flowering and fruiting behaviour of plants also showed positive improvement in flowering and number of fruiting in hydrogel treated plants. Number of fruits per plant also significantly improved with hydrogel treatments. In water stress conditions, photosynthesis and transpiration are adversely affected (Comic and Massacci, 1996), which directly influence crop growth and development (Aloni *et al.*, 1991). Plant physiological parameters in all treated and control plots were

recorded as influenced by hydrogel treatments in water stress condition. T_{0N} and T_{20D} showed significant increase in leaf chlorophyll content over control plots under deficit irrigation (T_{0D}) in 2014 crop season whereas in 2015 crop season only T_{20D} showed significant effect ($p \leq 0.05$) on leaf chlorophyll content (Fig. 1A). Similar to chlorophyll content, leaf anthocyanin content also showed considerable improvement with hydrogel application during 2014 cropping season. During 2015 cropping season T_{0N}, T_{15D} and T_{20D} significantly improved ($p < 0.05$) leaf anthocyanin content over T_{0D} (Fig. 1B).

Fig. 3 : Values of (A) Electrolyte Leakage (EL) and (B) Membrane Stability Index (MSI) of capsicum leaves as influenced by super absorbent hydrogel treatments under deficit irrigation at DIHAR experimental field, Ladakh. Mean values bearing same letter did not differ significantly ($P > 0.05$) according to Tukey's Post Hoc Multiple Comparisons.

Table 3: Capsicum yield as influenced by super absorbent hydrogel treatments under deficit irrigation at DIHAR experimental field, Ladakh

Treatment	No. of fruits plant ⁻¹		No. of fruits plot ⁻¹		Capsicum yield plot ⁻¹ (Kg)	
	2014	2015	2014	2015	2014	2015
T _{0N}	10.78 ^{bc}	11.95 ^{bc}	158.67 ^b	152.67 ^b	14.49 ^{cd}	11.95 ^{bc}
T _{0D}	6.33 ^a	4.38 ^a	93.33 ^a	89.33 ^a	5.52 ^a	4.38 ^a
T _{5D}	7.67 ^{ab}	6.47 ^{ab}	112.33 ^{ab}	113.67 ^{ab}	6.95 ^a	6.47 ^{ab}
T _{10D}	10.00 ^{bc}	8.82 ^{bc}	141.67 ^{ab}	135.67 ^{ab}	10.73 ^{bc}	8.82 ^{bc}
T _{15D}	10.55 ^{bc}	11.65 ^{bc}	151.67 ^{ab}	143.67 ^{ab}	14.10 ^{cd}	11.65 ^{bc}
T _{20D}	11.11 ^c	13.27 ^c	160.33 ^b	157.00 ^b	15.24 ^d	13.27 ^c

Mean values with different letters in each column are significantly different ($P \leq 0.05$) according to Tukey's Post Hoc Multiple Comparisons

In normal irrigation schedule, in control plants (T_{0N}) RWC was found 79.62 and 81.12% in 2014 and 2015 cropping season respectively whereas in T_{0D}, RWC was recorded only 54.87 and 52.92 % in 2014 and 2015 cropping season, respectively. One of the early symptoms of water deficiency in plant tissues is reduced RWC. Reduction of RWC in stressed plants may be associated with reduced moisture content in root zone and decrease in plant vigour and has been reported in many crop plants (Halder and Burrage 2003; Lopez *et al.* 2002). In all hydrogel treated plots, RWC was increased even in water stress condition and T_{15D} and T_{20D} showed significant improvement of RWC (Fig. 2A). Leaf water loss (LWL) in control plants under drought stress was much higher than plants under hydrogel treatments (Fig. 2B). Highest LWL was recorded in T_{0N} (24.39%) and lowest value was recorded in T_{20D} (15.41%) among all treatments in 2014 crop season, and the pattern of reduction of LWL was observed as T_{10D} > T_{15D} > T_{20D}. The same results were found during 2015 cropping season where LWL

was significantly reduced in hydrogel treated plants with deficit irrigation against normal irrigation (T_{0N}).

Minimum Electrolyte Leakage (EL) was recorded in T_{0N} as well as in hydrogel treated plants except T_{5D} whereas, T_{0D} in 2014 crop season showed highest EL (8.82%) (Fig.3A). In 2015 growing period almost similar trend was seen and significant lower EL ($p \leq 0.05$) was recorded in T_{0N}, T_{15D} and T_{20D} as compared to T_{0D}. Quan *et al.* (2004) also found higher EL% in drought stressed maize than in plants grown under control conditions. Similar results were also observed in rice plant by Guo *et al.* (2006). Khadem *et al.* (2010) showed that SAHs in drought stress conditions increased RWC of leaf, chlorophyll content and cytoplasm membrane stability in maize. Data obtained in the experiment indicated that impact of water stress on control plants was higher than on hydrogel treated plants. Membrane Stability Index (MSI) was found significantly higher in T_{15D} and T_{20D} over all

other treatments in both cropping seasons (Fig. 3B). Similar kinds of results were observed under water and salt stress by Gupta *et al.* (2000) in field crops and by Hajlaoui *et al.* (2009) in maize seedling, respectively.

Effects of hydrogel applications on capsicum root morphology under arid conditions are shown in Table 2. Estimated root volume of capsicum showed non-significant differences ($p \geq 0.05$) among all treatments particularly during 2014 but in 2015 cropping season significant improvement of root volume was observed except in $T_{15}I_0$ and $T_{10}I_0$, as compared to T_0I_0 which may be due to variability in weather and moisture content in root zone. It is clearly shown that scarcity of water significantly reduced overall capsicum root development in terms of root volume, its diameter and no of root tips in both cropping season, whereas soil application of hydrogel had positive effect on proper root development and growth of the plants. Phimchan *et al.* (2012) also observed that capsicum root growth as well as volume was significantly reduced under deficit water conditions. Nutrient movements from soil to plant through root water play a role of mediator which is directly connected with root growth (Worku *et al.*, 2012). Benjamin and Nielsen, (2006) also reported similar results where depth of root growth strongly increased under stress conditions in chickpea and field pea.

Significantly higher capsicum yield of 14.10 and 15.24 kg per plot and 11.65 and 13.27 kg per plot was achieved in $T_{15}I_0$ and $T_{20}I_0$, respectively, in 2014 and 2015 growing season, respectively when compared with T_0I_0 (Table 3). Whereas in T_0I_{10} , fresh capsicum yield of 14.49 and 11.95 kg plot⁻¹ was recorded in 2014 and 2015 respectively which are at par with $T_{15}I_0$. Lowest capsicum yield was observed in T_0I_0 (5.52 and 4.38 kg plot⁻¹ during the two seasons respectively). Besides reduced fruit number, smaller fruit size was also observed in T_0I_0 which resulted into lowest yield under water deficiency. In the present study, yield reduction with limited irrigation is in agreement with various studies on eggplant (Kırnak *et al.*, 2002), tomato (Topcu *et al.*, 2007) and also in capsicum (Sezen *et al.*, 2006). The results showed that hydrogel application significantly improved physiological processes and yield of capsicum at cold desert trans-Himalayan Ladakh region. Gencoglan, *et al.* (2006) also found that deficit irrigation significantly affected fruit numbers, fruit dry weight and dry yield of pepper. Under drought stress, plants physiological characteristics are affected such as photosynthesis and transpiration, which in turn affect plant growth and yield (Dorji *et al.*, 2005).

From the study, it can be concluded that super absorbent hydrogels (SAH) will provide significant yield benefits for small and marginal farmers in sandy soils of cold desert high altitude regions where water is limiting factor for crop production. SAH has potential to be used in agriculture for growing crops in irrigation deficit arid and semi-arid regions where water availability for irrigation is scarce or average rainfall is quite low.

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