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Improving Barley Productivity with Sustainable use of Agrochemicals and Managed Irrigation in Climate Change Scenario

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ABSTRACT: The ongoing climate change has severely altered the pattern of rainfall distribution spatially as well as temporally. The effect of climate change can be seen through the increased severity of torrential rains and the long interval between the two rains. In semi-arid and arid areas, where most of the agriculture is rainfall based with limited irrigation sources, long dry spells between the rains severely hampers the crop production. Late vegetative and reproductive water stress combined with high temperature stress, preferably in *rabi* crops (Wheat, Barley etc.) is highly disadvantageous for anthesis, fertilization, grain filling and grain development. Water availability at grain filling stage is quite crucial to avoid yield loss. Irrigation management and use of natural as well as synthetic agrochemicals in a sustainable manner is necessary. Irrigation timing as well as number should be planned in order to attain higher water use efficiency *i.e.*, more crop produced per drop of water. Natural agrochemicals such as herbal hydrogel "*Tragacanth katira*" holds water strongly and make it available to the crop slowly under high water tension in low soil moisture conditions. Plant bioregulators are well known to improve the physiology of the plant which increases stress tolerance. Salicylic acid and potassium nitrate are the plant bioregulators which improves the physiology of the plant giving stress endurance and reduces the extent of yield loss along with improvement in water use efficiency as well as quality of grains.

Keywords: Agrochemicals, water use efficiency, productivity, hydrogel, salicylic acid.

INTRODUCTION

Barley (*Hordeum vulgare* L.), an annual tall grass is fourth major cereal grain crop of the world. It is immensely potent from nutritional and medicinal point of view as barley grains contain 12.5 percent moisture, 11.5 percent albuminoids, 74 percent carbohydrates, 1.3 percent, fat, 3.9 percent crude fibre and 1.5 percent ash (Anderson *et al*., 1990; Dudi *et al*., 2019); and contain water soluble fibres (β glucans). About 70 percent of barley produced all over the world is used for feed, 21 percent in malting and processing industry and less than 6 percent is consumed for food purpose (Tricase *et al*., 2018). In India particularly, it is grown in the semi arid areas with less irrigation or completely rainfed. In respective of stress tolerance, barley is the hardiest crop and requires very less inputs and water for its high production as compared to wheat. Water shortage and drought stress are principal environmental factors reducing the productivity of crops in many arid and semi-arid areas among other abiotic stresses (Zargar *et al*., 2018) influenced by climate changes (Wassmann *et al*., 2009). Limitation and variation in soil moisture significantly influences yield and yield attributes of various barley genotypes (El- Shawy *et al*., 2017; Abdelaal *et al*., 2020). Under slight stress conditions either of heat or drought, plants tend to reduce transpiration by closing stomatal apertures due to reduction in relative leaf water content (Ghotbi-Ravandi *et al*., 2014), leading to less water loss without reducing the photosynthesis (Zhao *et al.,* 2020). This results in increased biomass production per unit of water consumed enhancing the water use efficiency. Under severe stress, photosynthesis is adversely affected (Hafez and Kobata, 2012) reducing crop yield.

Increased grain yield with relatively constant water use had increased water use efficiency over the time (Basso and Ritchie 2018) due to the adoption of navel varieties and hybrids by farmers. But increased water use efficiency of crops can be achieved only by two options: either by selection of new varieties and hybrids highly tolerant to stress conditions or by management practices (Hatfield and Dold 2019). Climate-Smart agrochemicals having economic viability and technical feasibility addresses the issues of food security, climate change, agricultural sustainability and productivity altogether. Hydrogels (hydrophilic cross-linked polymers) have become popular in recent years due to high water absorbing and holding property they possess. They can absorb more than 400 times its weight of water by binding the water molecules with hydrogen bonding and when surrounding dries out, release upto 95 percent of stored water. Synthetic hydrogels are expensive enough to be afforded by poor farmers but natural hydrogels like *Tragacanth katira* (gond-katira) gel are cheap and technically feasible. Application of hydrogels significantly reduces the required irrigation frequency in loamy and clay soils for a crop as available water content (AWC) is almost doubled (1.8-2.2 times) in the treatment where hydrogel is applied in comparison to the control (Abedi-Koupai *et al*., 2008).

Salicylic acid (SA, 2-hydroxybenzoic acid) is a phenolic phytohormone having important role in stomatal conductance and photosynthetic process (Khan *et al.*, 2003; Arfan *et al*., 2007) and signaling molecule for stress (Karlidag *et al*., 2009). Exogenous application of SA decreases oxidative stress and enhances stress tolerance (Gunes *et al*., 2007) by improving enzymatic (catalase, peroxidase etc.) and non-enzymatic antioxidant activity such as proline production (Mutlu *et al*., 2016). Potassium increases translocation of dry matter to grains (Kajla *et al*., 2015), essential for protein synthesis, activation of about 45 enzymes in plant cell and is indicative element for drought stress (Demidchik *et al*., 2014). Conventional practice followed by farmers generally focuses on use of nitrogenous fertilizers only which reduces crop yield as well as exhausts the soil fertility and in mid to late stages of crop growth, nutrients are not provided which also results in the yield decline. Application of potassium as foliar spray (as they easily get absorbed in the plant system) under stress conditions not only gave endurance to plants to withstand the stress but also enhances yield and water use efficiency (Mesbah, 2009). Two foliar applications of KNO_3 at 0.5% (one at booting and other at anthesis stage) significantly increased grain yield of wheat grown under late sown conditions in comparison to when no foliar spray is done or water spray is done at heading and anthesis stage (Chaurasiya *et al*., 2018).

Haryana and Punjab are less vulnerable to climate change for barley production (vulnerability index of 0.35 and 0.09, respectively) compared to states of central India (0.80-0.85). It suggests higher scope of increasing barley production herein present climate change scenario, when production from the major contributing states is supposed to decline (Sendhil *et al.,* 2017). In this review an attempt is made to study the impact of different irrigation levels and agrochemicals on barley growth and productivity.

Effect of irrigation levels and agrochemicals on Growth and Physiology of Barley. In an experiment conducted on barley at Dinajpur, Bangladesh with four irrigation levels (no irrigation, one at tillering, two at tillering and booting, three at tillering, booting and grain filling stage) having 30 mm water for each. Maximum dry matter and plant height 40 DAS onwards was recorded with three irrigations which was at par with two irrigations (Bahadur *et al*., 2013). Shirazi *et al*. (2014) in his study on wheat in Bangladesh reported that 300 mm irrigation (100 mm each at 30, 45 and 60 DAS) resulted in higher plant height compared to no irrigation, one and two irrigation. However, effect of one (at 30 DAS) and two irrigation (at 30 and 45 DAS) in was at par and higher than that of non-irrigated plants. Devi *et al.* (2017) reported that maximum significant increase in plant height (cm) of wheat plants was recorded with foliar spray of potassium nitrate at 3 percent but it was at par with 1.5, 2 and 2.5 percent. Leaf area index was significantly improved with increasing levels of irrigation at 30, 60 and 90 DAS in barley (Hingonia *et al*., 2018). Irrigation at 1.00 IW/CPE ratio reduced days to 50 percent flowering by 3 to 5 days compared to irrigation at either 0.75 or 0.50 IW/CPE ratio in groundnut grown at at Tindivanam, Tamilnadu (Hussainy and Vaidyanathan 2020). Similar results were also reported by Hussen *et al.* (2019) in mung bean and Ullah *et al*. (2002) in chickpea. Rehman and Khalil (2018) reported similar kind of findings of delaying physiological maturity with salicylic acid application in stress conditions.

Kumar *et al*. (2019) conducted a two-year study in Durgapur to study effect of different irrigation levels and hydrogel in wheat crop variety HD 2967. Two hydrogels, herbal hydrogel (Tragacanth *i.e*., gond-katira) at 400 ml/100 kg seed and Pusa hydrogel at 2.5 kg ha^{-1} were used for seed treatment and soil application respectively and control (no treatment) for comparison. Effect of herbal hydrogel was found at par with control (no seed treatment) for plant height, crop growth rate and dry matter accumulation in early stage of crop but near maturity, significant higher growth parameters were observed over control. Wairagade *et al.* (2020) also reported similar findings. Rathore *et al*. (2020) reported that RWC content was increased with the soil application of hydrogel compared to control in Indian mustard at 0.8, 0.6, 0.4 IW/CPE irrigations and in rainfed condition.

Rao *et al*. (2016) reported that foliar spray of 1 percent KNO_3 at flowering and pod initiation stage improves the RWC and chlorophyll content in both irrigated and unirrigated conditions in mung bean compared to water sprayed and control (no foliar application). Chaurasiya *et al*. (2018) reported that foliar spray of KNO_3 at 1, 1 and 0.5 percent in wheat at booting, anthesis and both (booting and anthesis) resulted into significant 5.63, 12.71 and 18.91 percent increase in total plant dry matter (g m^{-2}) over control, respectively. Bangar *et al*. (2019) conducted a study at College of Agriculture, Latur in soyabean to test the effect of foliar spray of agrochemicals. Total dry matter per plant (g) at harvest was increased from 17.08 (control) to 22.81 and 23.14 under one (30 DAS) and two (30 and 45 DAS) foliar application of KNO_3.

Hellal *et al*. (2020) from National Research Centre, Egypt observed that plant height of barley var. Giza 125 was significantly decreased under water stress compared to control. Application of foliar spray of potassium citrate, potassium nitrate and potassium silicate (each at 2%) at 40 and 60 DAS enhanced the plant height, RWC and chlorophyll under conditions of drought stress.Fayez and Bazaid (2013) reported that chlorophyll a and b in leaves of barley plants were decreased (when soil water content was reduced to

50%) compared to control and foliar application of KNO_3 at 10 mM at 50 percent SWC enhanced chl a and b. Arnold and Fletcher (1986) reported that potassium stimulates chlorophyll, grana and thylakoid synthesis in plants. Chlorophyll synthesis persists for a long time when stimulated by potassium and it requires a period of light for the two processes: cotyledon expansion and chlorophyll synthesis.

El-nasharty *et al*. (2019) carried out a research on wheat at Alexandria University, Egypt to check the alleviation effect of SA in mitigating stress and concluded that spray of SA at 400 ppm at tillering and booting initiation stage increased the plant height and dry matter per plant by 11 and 35.40 percent respectively over water spray. Similar findings for effect of SA were reported by Torun *et al*. (2020) and Torun *et al.* (2022) in barley for fresh and dry matter of plant. Anosheh *et al*. (2012) conducted field experiment on wheat and concluded that drought stress reduced chlorophyll a and b content by 55.65 and 73.34 per cent, while, foliar spray of SA @ 0.7 mM at double ridge stage increased chlorophyll a and b by 29.49 and 25.69 per cent. Similar results were also observed in seedlings of *Vigna radiata* (Asha *et al*., 2015). Moisture stress increases concentration of chlorophillase, peroxidase enzymes (Sepehri and Golparvar 2011) and reactive oxygen species (O_2^- and H_2O_2 increases) leads to lipid peroxidation which in turn reduces the chlorophyll content. Similar results of decreased chlorophyll content under withholding of irrigation were also reported by Mohseni Mohammadjanlou *et al.* (2021) and Seyed Sharifi (2020). Seed priming and SA foliar spray @ 10 mM was also observed effective in improving chlorophyll content by 18 and 24 percent under stressed conditions in wheat crop (Ilyas *et al*., 2017). Similar findings were reported by Ghani *et al.* (2021) in Brassica napus with application of 0.13 mM SA.

Abdelaal *et al*. (2020) reported that foliar spray of SA @ 0.5 mM at 21 DAS led to increased relative leaf water content by 20 to 30 per cent in water stressed plants of barley. Similar results were reported by Azmat *et al*., 2020 in wheat crop with 1 mM foliar spray. Relative leaf water content- an important index for water status in plants is closely related to the cell volume and it reflects the balance between water supply to the leaf and transpiration rate (Lugojan and Ciulca 2011). Abd El-Mageed *et al*. (2016); Nassef (2017) have also reported improved relative leaf water content in ample moisture conditions compared to stressed condition. SA helps in ion uptake regulation and integrity of membrane (Gunes *et al.,* 2007) and regulation of stomatal closure resulting in higher turgor in leaves.

Effect of irrigation levels and agrochemicals on Yield and yield attributes. Sharma and Verma (2010) undertook a study at Karnal in barley to evaluate the effect of irrigation. Irrigation levels used were one at 30 DAS, two at 30 and 60 DAS and three at 30, 60 and 90 DAS. Highest grain yield was recorded with three irrigation followed by two compared to one irrigation, however, no. of grains per spike and thousand grain weight were recorded maximum with two irrigations. Yield and yield attributes of barley were enhanced significantly when one or two irrigations were given compared to no irrigation (Hingonia *et al*. 2016). Grain, biological and protein yield of barley was found significantly maximum with irrigation at every 10 days after booting stage (7 irrigations total) followed by irrigation at every 15 (6 irrigations), 20 (5 irrigations) and 25 days (4 irrigations). Lowest yield was observed when no irrigation was given at all after booting stage. Only three irrigations were given before booting stage (Shrief and El-Mohsen, 2014). Safdari *et al*. (2018) conducted a study at Medicinal Plant Research Center of Shahed University, Iran and reported that yield and yield traits of barley showed a significant decrease when irrigation was given at maximum allowable depletion (MAD) of 90 percent of available soil moisture and highest values were observed when MAD equals to 30 percent of available soil moisture. Kumar *et al*. (2019) conducted a study at Kanpur, U.P. and observed that grain and straw yield of barley were increased with two irrigations (tillering and flag leaf stage) over one and no irrigation. However, maximum significant harvest index was achieved with no irrigation which was decreased by 4 to 6 per cent with two and one irrigation.

Foliar spray of SA improved grain yield and its attributes in wheat under conditions of stress (Yavas and Unay 2016; Kareem *et al*., 2019). Foliar spray of SA @ 0.2 mM L^{-1} at 45 and 60 DAS increased grain yield of barley by 15 per cent (Hafez and Seleiman, 2017). Abdelaal *et al*. (2020) reported that drought stress in barley decreased spike length and no. of grains per spike compared to control and foliar spray of 0.5 mM SA increased spike length and no. of grains per spike. However, significant difference was not observed in no. of grains per spike.

Suryavanshi and Buttar (2016) conducted a field experiment at Ludhiana to evaluate the efficacy of various osmoprotectants in mitigating terminal heat stress effects in wheat in North-west India. Treatments used were control (no spray), water spray, Thiourea at 20, 40 and 60 mM, KNO_3 at 1, 2 and 3 percent, SNP at 400, 800 and 1200 μg/ml. Foliar spray of 2 percent KNO_3 showed significantly higher response in grain, straw and biological yield than water spray and control. Chaurasiya *et al*. (2018) reported that 0.5 percent KNO_3 at booting and anthesis showed an increment of 10.99 percent and KNO_3 at 1 percent at anthesis showed 9.45 percent increment in grain yield of wheat compared to control. Total number of grains per spike and test weight were recorded significantly highest in KNO_3 sprayed at 0.5 percent. This treatment was found at par with 1 percent KNO_3 at anthesis stage.

Hellal *et al*. (2020) observed that yield, yield attributes and harvest index of Giza 125 variety of barley were decreased under conditions of water stress compared to control (no stress). Maximum significant increment in yield and yield attributes was observed with potassium citrate followed by potassium nitrate (2% twice at 40 and 60 DAS) and potassium silicate compared to drought stressed control (no foliar treatment).

Potassium, the most abundant cation in the phloem, along with amino-N compounds and sucrose affects the rate of translocation of photo-assimilates via phloem (Lalonde *et al*., 2003). Concentration of potassium within the cell sap is positively correlated to external supply as reported by Mengel and Haeder (1977). The gradient established by K^+ concentration, the so called "potassium battery" enables a plant to overcome the local shortage of ATP and; also maintains the efficiency in long distance transport system as reported by Dreyer *et al*. (2017). Enhanced translocation of photosynthates from source to sink increased yield attributes**.**

Lather *et al*. (2015) reported that yield and yield attributes of wheat was increased when seed priming was done with herbal *Tragacanth katira* gel at 100 g kg^{-1} seed compared to untreated seed when first irrigation was delayed by 35 DAS and 45 DAS respectively. Delayed first irrigation to 35 DAS significantly reduced grain yield and harvest index by 9.83 and 7.98 per cent which was increased by 8.04 and 6.27 per cent with seed coating of herbal hydrogel in late sown wheat. Kumar *et al*. (2019) reported that effective tillers and spike length were highest with Pusa hydrogel application compared with herbal hydrogel and control. But Pusa hydrogel and herbal hydrogel were found statistically at par for number of grains per spike and test weight, but higher over control. Herbal hydrogel statistically improved grain, straw and biological yield compared to control. However, maximum yields were recorded with Pusa hydrogel. Kumar and Singh (2020) conducted a study at CCSHAU, Hisar for two years to investigate the hydrogel effect on yield and profitability in wheat. Results showed that Pusa hydrogel at 2.5 kg ha^{-1} and herbal hydrogel application had no significant effect on yield and yield attributes compared with control.

Effect of irrigation levels and agrochemicals on Quality parameters and water use efficiency. Protein content (%) in grains of barley at Libya was enhanced and water use efficiency was decreased significantly when irrigation interval was increased from every 10 days after booting stage to 15, 20, 25 or no irrigation. Effect of irrigation at every 10 days or 15 days after booting was found at par. Before booting, three irrigations were given (Shrief and El-Mohsen 2014). Hingonia *et al*. (2016) reported that total protein content of grains of barley was significantly reduced by 1.9 to 7.5 per cent when two and one irrigation were replaced with no irrigation. Safdari *et al*., 2018 also observed that protein content in wheat was reduced with increment in severity of moisture stress. Kumar *et al*. (2019) reported that highest protein content (8.28%) and N content (1.31%) in barley grain was achieved under two irrigation (tillering + flag leaf stage) followed by one irrigation at tillering stage (8.19, 1.30) and; one irrigation at flag leaf stage (7.41, 1.18) compared to non-irrigated (6.93, 1.11) barley grains respectively.

Karimian *et al*. (2015) reported that spray of 1- or 2-mM SA in groundnut didn't show any significant increment in protein content of kernel over control in normal conditions but 3 mM SA spray showed significant response, while, under moderate drought stress, both 2 and 3 mM SA spray significantly increased protein content. In case of intense stress, even 1 mM SA spray showed significant increase. Nazar *et al*. (2015) conducted a pot culture experiment on mustard cultivar Pusa Jai Kisan and reported that drought stress (50% field capacity) reduced water use efficiency and 0.5 mM application of SA restricts the reduction.

Abrol *et al*. (2020) reported that foliar spray of KNO_3 at 0.5 percent significantly improved rain water use efficiency of wheat crop over water spray and control. Rain water use efficiency with water spray was recorded higher over control and maximum with 0.5% KNO_3 + 0.5% urea spray.

Water use efficiency in barley was decreased with stress and foliar applications of SA improved water use efficiency over control (Hellal *et al.,* 2020). Photosynthetic WUE was increased from 2.48 (mol^{-1} µmol CO_2) under control to 2.70 under drought stress in wheat with foliar application of SA at 0.5 mM (Khalvandi *et al*., 2021). Application of herbal hydrogel reduced the irrigation frequency and hereby, increasing water use efficiency in wheat and DSR rice (Lather *et al*., 2015; Lather, 2019). Application of hydrogel at 5 kg ha^{-1} with 200 ppm SA at flowering and siliqua formation stage resulted in maximum oil content and yield, protein content and water use efficiency of Indian mustard compared to control and other treatments in restricted irrigated conditions (Meena *et al*., 2020). Rathore *et al*. (2020) observed that water productivity and soil moisture content in Indian mustard was increased with the soil application of hydrogel in irrigated as well as rainfed conditions.

Effect of irrigation levels and agrochemicals on Economics

Barick *et al*. (2020) conducted a study on rapeseed and reported that highest cost of cultivation, net return and B:C ratio was observed with irrigation at IW/CPE of 1.0. Net return was observed negative for fully rainfed crop. Irrigation at 0.6 and 0.8 IW/CPE showed same cost of cultivation, but gross return, net return and B:C was higher with irrigation at 0.8 IW/CPE. Devi *et al.* (2017) reported that treatment having foliar application of KNO_3 at 2 percent showed maximum B: C ratio followed by KNO_3 at 1.5, 2.5, 1, 3 and 0.5 percent compared over control in wheat.

Pusa hydrogel at 2.5 kg ha^{-1} recorded higher cost of cultivation, gross and net returns in wheat compared to herbal hydrogel Tragacanth at 400 ml/100kg seed and control (no treatment). However, higher B:C was recorded with herbal hydrogel compared to Pusa hydrogel and control. An additional net return of Rs. 3514 ha^{-1} and Rs. 5689 ha^{-1} was achieved with seed treatment with *Tragacanth katira* gel and soil application of Pusa hydrogel (2.5 kg ha^{-1}) over control (no treatment or application) in wheat crop (Kumar *et al*., 2019). Lather, 2019 reported that novel herbal hydrogel technology significantly reduces cost of cultivation and use of fertilizers in DSR rice.

CONCLUSION

Water stress at critical stages certainly reduces the productivity and profitability of barley by adversely affecting the growth and physiology. But the extent of loss can be significantly reduced by the use of herbal hydrogel before sowing to mitigate early vegetative stress and foliar sprays of agrochemicals at late vegetative or reproductive stage. Being natural products, salicylic acid and hydrogel are not harmful for the environment, however KNO_3 is a chemical fertilizer and osmo-protectant, but the quantity used for foliar spray is quite low, thus helping in sustainable management of water stress.

FUTURE SCOPE

Sustainable use of agrochemicals is certainly helpful in improving the productivity and profitability in barley production in the scenario of climate change. There is high scope of agrochemicals in sustainable production of the crop which require further more studies on the type of agrochemicals that can be used, their doses and stage of application. The research will help in strengthening the barley productivity in adverse climatic conditions.

Conflict of Interest. None.

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