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Sustainable water consumption of rice (Oryza sativa L.) as influenced by superabsorbent polymer in water stressed conditions

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Abstract

Sustainability in irrigation and agriculture has received widespread attention among researchers across the globe in the recent decade. To ensure food security and to protect water resources, agricultural and irrigation practices need to be amended with innovative technology that conserves water and increases productivity. The application of SAP or hydrogel as soil conditioners was identified as a possible solution to increase water use efficiency in irrigation. This study aimed to evaluate the swelling properties of hydrogel and its effects of hydrogel application to the soil on plant. Paddy was chosen for plant growth assessment due to its large water footprint. Laboratory scale experiments were carried out in growth bags for control group (TC1) supplied with excess water and treatment groups (20% - TC2, 40% - TC3, and 60% - TC4 deficit supply of water) amended with hydrogel under drip irrigation. Hydrogel exhibited an equilibrium swelling of 513.3 (TH1 - deionized water), 188.8 (TH2 - groundwater) and 121.9 (TH3 - 0.5 % saline water) times its dry weight respectively. The water retention time in hydrogel was maximum for saline water, followed by groundwater, and deionized water. Seed treatment of paddy showed the optimum dosage of hydrogel to be 1.25% by weight of seeds. The plant height at 2 weeks after sowing showed significant trend of increasing plant height in the order of TC1 (17 cm) > TC2 (23 cm) > TC3 (24 cm) > TC4 (28 cm). The results support the hypothesis that hydrogel can be advantageously used in soil conditioning as an effective way to protect irrigation water resources and to ensure food security.

Keywords: Hydrogel, Irrigation, Paddy, Water Consumption, Sustainability.

I.INTRODUCTION

Water is the most consumed resource on earth and irrigation has a major share of consumption in agriculture. Almost three-fourth of potable water is used for irrigation alone across the world (ICAR, 2019). The prevalence of water stress in arid and semi-arid regions calls for the protection of water resources. Moreover, climate change studies project uncertain and erratic rainfall and extreme weather conditions (ECOSOC, 2019; Jha et al., 2016; Piao et al., 2010) adversely affecting crop cultivation, which in turn affects the food security (Roy et al., 2019). To protect water as a resource and to ensure food security, sustainable irrigation practices become necessary. Sustainability in irrigation can be brought by engineering the conveyance and application of water in the agricultural fields, and enhancing the water use efficiency of plants. Water influences photosynthesis, absorption, respiration and other internal processes for any crop. By increasing the root zone soil water retention, the living conditions of crops would be enhanced, and the water use efficiency effectively increases (Jacoby et al., 2017).

Establishment of a fertile land in big proportion always have had constraints such as lack of financial resources, appropriate land, fertile soils and stable water sources (Shooshtarian et al., 2012). In India, land and water availability are limiting factors for large-scale production for actual food demand. Irrigated areas account for nearly 48.8 % of the cultivated area and the remaining 51.2 % are rainfed in the country. The major problem of the rainfed cultivations is that the crop production is only about half that of the irrigated area (CWC, GoI, 2019). In densely populated arid and semi-arid regions, high water stress compels a shift towards unconventional methods to attain sustainability in agriculture, to meet required food production levels within the available water resource levels.

Paddy is a premier food crop in Asian countries. Almost 90% of the world's rice is produced and consumed in Asian countries alone, China being the primary producer, followed by India (FAO STAT, 2019-20). Requiring almost 5000 litres of water for 1 kg rice grain production using traditional methods, globally rice production consumes 40% of freshwater (Parthasarathy et al, 2018). Enhancing the irrigation efficiency for paddy would play a significant impact in protecting water resources.

The application efficiency can be enhanced by use of drip irrigation (Jha et al., 2016). Aerobic cultivation is shown to produce more yield in paddy than conventional methods (Parthasarathy et al., 2018). Further, soil conditioners are known to enhance the water use efficiency. Superabsorbent polymers are widely used soil conditioners (SAP). The term SAP is alternatively used with the term hydrogel. Hydrogel is defined as a three-dimensional polymeric network that can retain a significant amount of water within its structure and swell without dissolving in water (Jamnongkan & Kaewpirom, 2010; Guilherme et al., 2015). Figure 1 shows swollen hydrogel particles. The particles when in soil, act as water reservoirs from which roots of the plants can absorb water. (Agaba et al. 2011) demonstrated an increase in water use efficiency while the roots of plants formed a complex with soil and hydrogel. Similar studies on paddy are necessary to assess and contribute to sustainability. To that end, the effect of hydrogel on the water use of paddy is the object of study in this paper.

Figure 1: Swollen hydrogel particles in 200 ml beaker.

The scope of the present study includes experiments on swelling properties of hydrogel and small-scale comparative investigation of growth of paddy in loamy soil under the influence of said soil conditioner. A randomized control method was adopted to account for exposure to wind, sunlight, humidity, and temperature. The crop growth was monitored only for the first stage (tillering) due to COVID-19 restrictions. The following sections elaborate on the methods, materials, results, discussions and conclusions drawn from the study.

II. MATERIALS AND METHODS

Materials

Experimental site and soil characteristics: This study was conducted at CHRIST (deemed to be university), School of Engineering and Technology, Bengaluru. Karnataka, India during January - March, 2020. Loamy soil was used for the study. The details of the soil used are tabulated in table 1.

Hydrogel: The hydrogel used for the study was purchased from Agrionics India and the hydrogel is sold under the brand name "Magic hydrogel" (acuro), which is a slow-release potassium polyacrylate-based SAP with a swelling ratio of 500. The filter used for swelling test was "Atoz prime 1Mx1M Nylon Filtration Sheet Water oil industrial filter cloth 200 mesh". Water used for testing included deionized water, saline water (0.5% w/w NaCl), and groundwater (electrical conductivity 1346 µS/cm and pH 7.5).

Crop growth: The fertilizers used for the study were urea - 46% nitrogen, diammonium phosphate (DAP) - 46% phosphorus, and muriate of potash (MOP) - 60% potassium. Farmyard manure used was an organic nutrient rich mix obtained from composting. The paddy seeds used were of hybrid variety Ankur 13555.

Table 1: Characteristics of soil for experimental study

Characteristics	value
Texture	Loam Soil
Sand (%)	40
Silt (%)	35
Clay (%)	25
Colour	Black
Zn (zinc)	0.27(deficiency)
Fe (Iron)	8.14
Cu (copper)	5.132
B (Boron)	0.43 (deficiency)
S (sulphur)	31 (HIGH)
Ca (calcium)	0
N (Nitrogen)	268.09 kg/ha
P (Phosphorus)	27.47 kg/ha
K (Potassium)	305.98 kg/ha

Methods

Soil tests: The index properties of soil were found out using sieve analysis and pycnometer specific gravity test as per the code of Indian standards (IS 2720: 1983). The specific gravity was found out to be 2.34.

Seed Treatment: seed treatment with hydrogel was done under laboratory conditions. The method was as described in detail by (Chandana S S 2019). This test was conducted to determine the optimal dosage of the hydrogel for germination. The seeds were placed in petri dishes and different doses of hydrogel were administered (0.5 %, 0.75 %, 1 % and 1.25 % by weight of seeds). One control group was left without hydrogel. 10 ml of water was added to each dish and left in a dark chamber for 10 days for paddy seeds. The radicle length was measured for each seed and the average germination index was calculated by the equation 1 (Francesco *et al.*, 2015):

$$GI = \left(\frac{G}{G_0}\right) \times \left(\frac{L}{L_0}\right) \times 100 \qquad \text{… (Eq 1)}$$

Where *GI* is the germination index, *G* and *L* are the number of germinations and average radicle length respectively under hydrogel treatment; G_0 and L_0 are the number of germinations and average radicle length of control group.

Hydrogel swelling: The swelling was studied according to methods adopted in similar research studies (Cannazza et al., 2014; Guilherme et al., 2015). The swelling of hydrogel for increasing time intervals of immersion in deionized water (TH1), groundwater (TH2), and saline water 0.5 w/w g of NaCl (TH3) was respectively calculated using equation 2:

$$Swelling\ ratio = \frac{W_s - W_d}{W_d} \qquad \text{… (Eq 2)}$$

Where W_s is the weight of swollen hydrogel and W_d is the dry weight of hydrogel.

Water retention: The test determines the amount of water released by the hydrogel under various temperature conditions over time. The test was done according to method adopted by (Zhang, Yong et al. 2014). A measured amount of hydrogel was soaked in the solution and kept at 25 ^{0}C for 24h with three types of solution - deionized, groundwater and saline (0.5 % w/w) water were used. The soaked hydrogel was removed from the solutions, filtered with the 180 µm and wiped with tissues gently to remove surface water. The surface dried soaked hydrogel is weighed and placed in the incubator at 35 ^{0}C The equilibrium swelling was recorded at regular time intervals, up to 24 h.

Table 2: Treatment groups and respective representations

Representation	Treatment	Water supply (ml/day-plant)
TC1	Control group without hydrogel	144 ± 14
TC2	With hydrogel	115 ± 14
TC3	With hydrogel	87 ± 14
TC4	Treated with hydrogel	58 ± 14

Comparative assessment of plant growth: Paddy seeds were soaked in water for 12 hours before being sown in separate growth bags at a depth of 3 cm from soil surface. 0.75% hydrogel by weight of seeds was carefully placed along the seeds. 3 such groups were prepared with 20 %, 40 %, and 60 % deficit water supply respectively from the average supply of 144 ml per day per plant. A 4th control group was prepared with no hydrogel applied, and allowed to water log (table 3). surface drip irrigation was used for water supply. A set up similar to that used by (Cannazza et al. 2014) was adopted. The total water supplied for each bag was deduced from evapotranspiration values as per (Tyagi N K et al., 2000). The test was carried out for the first stage of crop growth. The plant height at the end of 3 weeks was recorded for comparative study. ANOVA on the data was carried out based on (David J Weiss 2006) and reported with a significance greater than 95 %.

III. RESULTS AND DISCUSSIONS

Hydrogel Assessment

The results of hydrogel swelling ratio were plotted as graphs of time vs. equilibrium swelling (figure 2). The maximum swelling attained significantly differed for all three cases (TH1, TH2, and TH3) with values of 513.3 (30 min), 188.8 (20 min), and 121.9 (60 min) for TH1, TH2, and TH3 respectively. Initial absorption rate for hydrogel in TH1 was observed to be similar to the sample in TH2. TH3 showed a relatively linear variation in initial stages. After peak swelling, the graph shows a slow decrease of swelling rate. The retention property (figure 3) of hydrogel was represented through a graph of time vs. percentage moisture content with respect to swollen hydrogel. TH1, TH2, TH3 represent deionized water (circle), groundwater (square), and saline water (triangle) respectively.

Table 3: Average plant height (cm) for different groups at 2 weeks after sowing.

Groups	Average plant height (cm)	Number of samples
TC1	17	8
TC2	24	5
TC3	23	9
TC4	28	13

The three cases showed no significant differences in the moisture retained till 8 hours. The retention showed a diverging at 24 hours with retention percentages 63.56%, 66.94%, and 70.73% for case I, II, and III respectively. The retention is low for deionized water and increases with increasing ionic content of water.

Crop growth assessment

Seed treatment: The maximum radicle length observed for paddy seeds was for the seeds amended with 1.25 % of hydrogel. It is imperative that the trials show a Germination Index value upwards of 60% as that is the first test to check for signs of phytotoxicity (Francesco et al., 2015). The values obtained conformed to such and consistently stayed upwards of 80%. These values are also in concordance with other similar tests done by (Francesco et al. 2015).

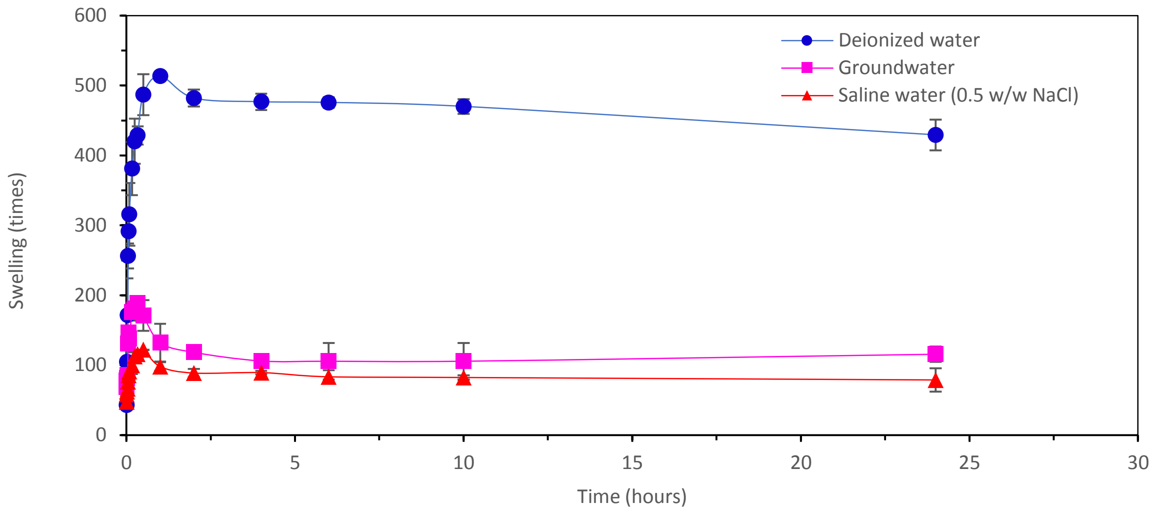

Fig 2: Swelling ratio of hydrogel in deionized water (circle), groundwater (square), and 0.5 % w/w saline water (triangle) reported as a mean of three data points with error bars representing standard deviation.

Crop water requirement comparative study: Table 2 shows the average plant height obtained at 2 weeks after sowing for corresponding number of samples. A gradual trend of increase in plant growth was seen with decreasing water supply and application of hydrogel (figure 4). The least plant height corresponded to the control group (17 cm) and the highest plant height corresponded to treatment group with 60% deficit water supply (28 cm). These effects in paddy can be attributed to several factors - improved root zone moisture retention, improved access to oxygen to plant root as a result of increase in porosity of soil surrounding the roots, and reduced leaching of nutrients from soil through runoff and infiltration. Moreover, deficit irrigation for paddy benefits in more than just saving water.

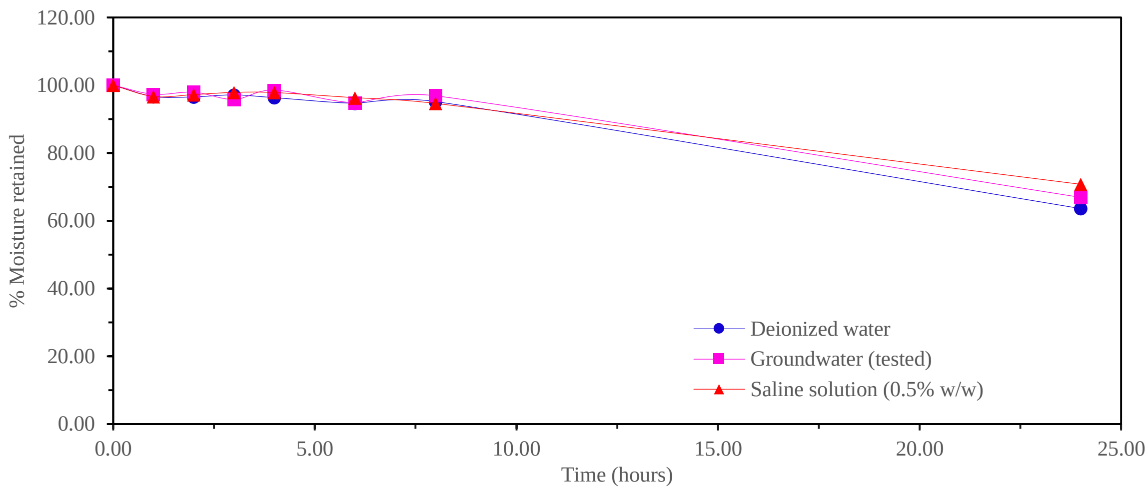

Fig 3: Percentage moisture content in swollen hydrogel in deionized water (circle), groundwater (square), and 0.5 % w/w saline water (triangle) reported as a mean of 3 data points over 24 hours while exposed to 35 ^{0}C

A study in West Bengal by (Sarkar et. al., 2012) showed that deficit irrigation can reduce the uptake of arsenic in paddy. The results of the present study are consistent with growth patterns reported in various studies.

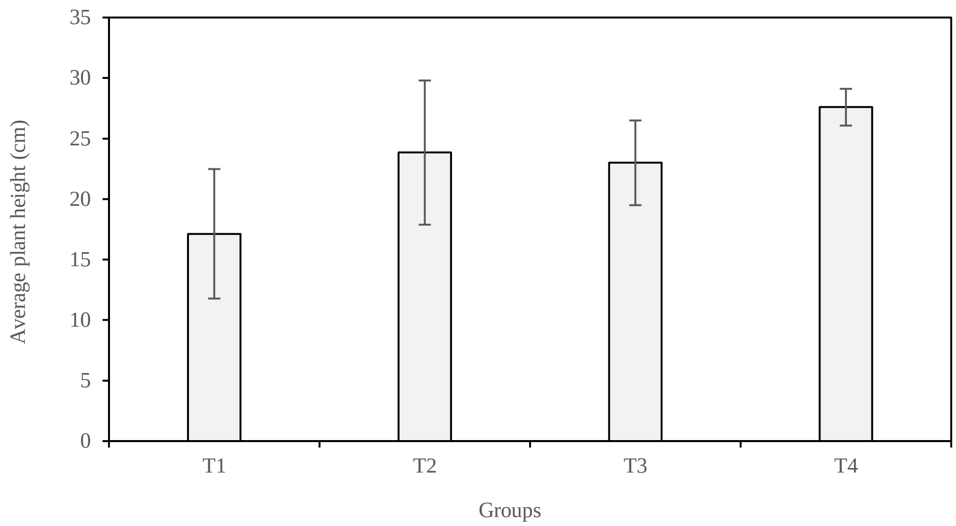

Fig 4: Average plant height of paddy recorded at 3 weeks after sowing for different groups - control excess corresponding to group without hydrogel application; t-20 deficit, t-40 deficit, and t-60 deficit corresponding to groups treated with hydrogel with 20%, 40%, and 60% deficit water supply respectively. The error bars represent standard deviation.

(Parthasarathy et al.2018) showed that aerobic irrigation for paddy gave better yields compared to conventional irrigation methods. (Rehman A et al. 2011) investigated the use of hydrogel for aerobic irrigation of paddy and showed that the yield increased relative to conventional methods. Though plant height cannot be a direct indicator of grain yield, A study by (Ronghua L et al.2019) showed a significant correlation between plant height and grain yield for indica hybrid variety of paddy for a large dataset ranging from 1978 to 2017. Thus, it could be validated that the results of the current study would indicate towards a greater yield in paddy treated with hydrogel for aerobic irrigation method. There has however been indication that the effect of the hydrogel on the rate of growth of the plant in its final stage is close to negligible, possibly due to the fact that water requirement at this stage is relatively less, and thus the amelioration with the hydrogel becomes optional (Francesco et al., 2015). However, there is a need to study this phenomenon further in water stressed areas and of soil types with poor water retention. In this regard, cultivated lands, known to have contamination can use the application of hydrogel as a remedial measure for the improvement of yield during deficit irrigation.

IV. CONCLUSIONS

Water uptake is the functional part of any crop. Once the seed is sowed in the soil the immediate requirement is a favourable condition with sufficient moisture content in the soil. Through hydrogel this was achieved even with deficit water intake. Increased amount of water availability to the seed at the crucial stages of its growth capacitated a high number of germinations and also faster and healthy growth of the plant. Inclusion of hydrogel showed a positive impact on the plant and have shown a greater rate of growth. In paddy with 60% deficit water, the highest plant growth was seen and this surprising trend of increased growth with decreased supply of water, is an interesting find and should warrant more investigation.

Studies on the properties of hydrogel showed that the commercially available hydrogel developed based on potassium polyacrylate is a brilliant candidate for improving the agricultural water use efficiency and consequently the irrigation efficiency. Shocks during dry spells can be prevented with hydrogel. As hydrogel enables deficit irrigation by a large margin, bioaccumulation can be prevented in contaminated cultivable lands. Though this study indicates towards a probable higher yield, validation of the water requirement must be done through field level experiments. There is also a need to experiment on porous soil with less clay content which is more prevalent in arid and semi-arid regions.

The study supports that the use of hydrogel could protect water resources and ensure sustainability in terms of water and food security. Though studies have pointed towards no negative environmental impact of hydrogel in agriculture, the long-term effects need to be addressed in future studies. This again requires a field level substance flow investigation for effects of hydrogel especially in arid and semi-arid regions.

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VI.AUTHOR CONTRIBUTIONS

Surya designed methodology, literature review and writing-original draft. Sriram performed data analysis, interpretation and writing-original draft. Girinath contributed in conceptualization. Ankush and Aditya performed experiments and investigation. Shibu and Geetha contributed in supervision and reviewing the analysis in the manuscript.

VII.CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the author.

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