International Journal of Plant & Soil Science

Volume 36, Issue 2, Page 9-27, 2024; Article no.IJPSS.111404
ISSN: 2320-7035

Impact of Hydrogel Polymer on Water Productivity, Weed Control Efficiency and Yield of Broadcast-Seeded Rice

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2024/v36i24359

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/111404

Original Research Article

Received: 12/11/2023
Accepted: 15/01/2024
Published: 22/01/2024

ABSTRACT

A field study was investigated at the Experimental Farm of Rice Research Department, Sakha Agricultural Research Station, Kafrelsheikh, Egypt during summer seasons of 2020 and 2021 to study the capability of hydrogel polymer application under different irrigation intervals and chemical weed control on water conservation and weed control under Egyptian broadcast-seeded rice (Giza 179 cv). A strip spit design with three replicates was used during the study. Three irrigation intervals (irrigation every 5 days (I_1), 10 days (I_2) and every 15 days (I_3) were randomly devoted in horizontal plots, hydrogel polymer at rate of 20 kg ha^{-1} as compared to normal soil (zero hydrogel) were assigned in vertical plots, while three weed control treatments (thiobencarb at 2.38 kg ai ha^{-1} at 9 days after sowing (DAS) followed by (fb) bispyribac-sodium at 0.038 kg ai ha^{-1} + halosulfuron-methyl at 0.036 Kg ha^{-1} applied at 25 DAS (W_1), Thiobencarb at 2.38 kg ai ha^{-1} fb cyhalofop-butyl at 0.286

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Kg ai ha^{-1} + halosulfuron-methyl at 0.036 Kg ha^{-1} applied at 25 DAS (W_2) as compared to un-treated weedy check plots (W_3) were allocated in endo/sub-sub plots. Results showed that irrigation every 10 and 15 days saved about 26.4% and 35.8% of applied water, respectively, while the yield reduced by 31.8% and 56.1% respectively compared to irrigation every 5-days as average of the two seasons. The lowest dry weights of grasses and total weeds were recorded of I_1, while *C. difformis* weed was absent under I_3 during 2020 and 2021 seasons. Hydrogel polymer application conserved about 14.8% of applied water and improved rice grain yield by 16.5% as well as increased water productivity to be 0.48 kg m^{-3} compared to 0.32 kg m^{-3} for without hydrogel treatment. Hydrogel encouraged *C. difformis* appearance while decreased grasses and total weeds compared to without hydrogel. Sequential herbicides application W_1 recorded the best weed control against grasses, *C. difformis* and total weeds in addition to higher WCE (91.9%) against total weeds consequently produced the highest values of rice dry matter, yield and its attributes during both seasons of study. The interaction of I_1 x hydrogel x W_1 achieved the highest grain yield (10.11 t ha^{-1}) with same significance for I_1 x without hydrogel x W_1 (9.75 t ha^{-1}), while I_2 x hydrogel x W_1 recorded the highest water productivity (0.78 kg m^{-3}) and produced 7.63 t ha^{-1} of rice grain yield by increasing of 20.7% than I_2 x without hydrogel x W_1 as average for 2020 and 2021 seasons.

Keywords: Rice; broadcast; hydrogel; weed control; irrigation intervals; water productivity.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the main crops in the world agricultural systems and essential in the diet for the majority of world's populations. It is annual production should increase by 8-10 million tons over the next 20 years in order to meet the forecasted needs [1]. In the past, rice was classified as one of the most irrigation water consumer crop in Egypt. Rice Research & Training Center (RRTC) had a future vision and created a special branch for rice breeding against water scarcity and high temperature in nineteenth at the last century and worked before to breed short and medium duration rice cultivars, Giza 177 as a short duration rice cultivar was the first (120 days) which saved about 20% of irrigation water when compared to ancient long duration rice cultivars [2], then released many short duration cultivars such as Sakha 102, Sakha 103, Sakha 105, Giza 179. Moreover, RRTC released Sakha 107 in 2016 as water scarcity tolerant cultivar.

Agriculture is a vital sector that plays a crucial role in providing food, fiber, and other essential resources for human populations. However, various challenges such as water scarcity, nutrient deficiency, and environmental degradation pose significant obstacles to sustainable agricultural production. Irrigation water becomes scarce and the world is looking for water-efficient agriculture. Increasing food demand and declining water resources are challenges for food security [3], In Egypt, water is very limited, so it must be keep every water drop and well-use in agriculture, industry and human consumption. Introduce water save substances in agriculture as new approach becomes a necessary to maximize water advantage in agricultural system. Hydrogel technology has emerged as a promising solution to address these challenges and improve agriculture.

Water deficit is considered one of the most severe environmental stresses affecting rice productivity [4]. Furthermore, it is anticipated that 15 – 20 million hectares of irrigated rice will suffer from water scarcity by 2025 due to increasing population growth and associated water demands of urban and industrial use [5]. Increasing water scarcity has the potential to farther exacerbate confects on water resources over the coming decades. Moreover, both the poor quantity and quality of water resources threatens not only economic development and quality of life but it is also exerting a negative impact on food security. The water crises nowadays are prioritized as one of the top five global risks [6].

Hydrogel is a synthetic polymer, which is able to absorb and hold 80–180 times its volume of water for a long time [7]. Hydrogel acts as a reservoir to store and release a steady stream of water and nutrients which plants need to grow. Plant roots are able to absorb water from the crystal bead of hydrogel. Mikkelsen [8] classified hydrogel in to three cantores (1) natural (2) semi-artificial (3) artificial hydrogel. Artificial hydrogel are divided in to three types (2) starch polymers (2) Polyvinyl alcohol polymers (3) cross-linked polyacrylamides. Several previous studies showed that these are very useful under limited water conditions to the cope with plant water needs [9,10,7]. Johnson [11] reported that addition of hydrogel at the rate of 2 g/kg improved the water holding capacity of sand from 171% to 402%. Application of hydrogel decreases the irrigation requirements of several crops by improving water holding capacity resulting in delay and onset of permanent wilting percentages under intense evaporation. The role of hydrogel in improving agriculture is supported by a growing body of scientific research. Numerous studies have investigated the effects of hydrogel application on plant growth, water retention, nutrient availability and herbicide efficacy in agricultural systems. These studies have provided valuable insights into the potential benefits of hydrogel technology for sustainable agricultural practices. The addition of gel-polymers was effective to improve soil moisture availability and root development, thus increased plant establishment, vegetative growth, and rice yield [12,13]. Application of soil polymers is a promising on-farm practice in drought condition to conserve irrigation water and enhance crop productivity and water use efficiency through. It keeps its wetting over a longer period, maintaining its high water swelling and releasing capacity against soil pressure. Consequently, deep percolation, evaporation and nutrient leaching can be avoided in the effective root zone [14].

The rice straw-based and acrylamide hydrogels improved soil moisture content, moisture retention curve, bulk density, particle density, total _porosity, pores diameters, organic matter, total count of bacteria in sandy and calcareous soils [15].

Weeds is the main limiting factor in rice production system because of many problems which it cause such as competition on growth demands for rice, high yield losses (93 % in drill-seeded rice in Egypt as reported by Abd El-Naby and El Ghandor [16] while in aerobic direct seeded rice ranged from 50-91% as cited by Rao et al. [17], difficulties in mechanical harvest, bad seed quality, damage seed production system by increase moisture content of stored rice seeds, moreover increasing production cost and playing as a host for many insects and diseases which attack rice plants. Reddy et al. [18] stated that weed flora under direct seeded rice conditions included grasses, sedges and broad leaf weeds.

Chemical weed control in direct seeded rice especially under water scarcity is the main defines line and best choice to avoid high yield losses caused by weeds because of herbicides as selective chemical substances kill weeds early, keep optimum conditions for rice growth, moreover less labor. Sequential application as well as herbicide mixtures (more than one active ingredient differ in mode of action on weeds) increases the efficacy of weed control and wide spectrum in one time which reduced weed-competition to the minimum limits and delay appearance of resistant weeds against the used herbicides [16]. In this research, it will be detected how hydrogels can enhance water use and improve herbicide efficiency in broadcast-seeded rice.

2. MATERIALS AND METHODS

During 2020 and 2021 summer seasons, two field experiments were carried out at The Experimental Farm of Sakha Agricultural Research Station, Kafrelsheikh, Egypt to study the effect of irrigation intervals, hydrogel polymer and weed management on rice and weeds under broadcast-seeded rice.

Data of weather was obtained from the nearby agro-meteorological Station of Sakha as illustrated in Table 1.

Soil samples were taken from the experiment area before cultivation, physical properties i.e., bulk density, total porosity, particle-size distribution, permanent wilting point in addition to field capacity were determined as described by Klute [19] as demonstrated in Table 2. Soil pH in addition to electrical conductivity (EC) were determined according to Page et al. [20].

Giza 179 rice cultivar (cv) was planted on 20 and 25th of May in 2020 and 2021 seasons, respectively and seeding rate was 150 kg ha^{-1}, rice seeds were soaked in fresh water for 48 hours (h) and incubated for another 48 h. Manual broadcasting of seed was done in presence water after puddling plots. Water was kept at 3-5 cm for about 5 days after sowing, and then field drained for 2-3 days, then water was given as needed. All rest cultural practices were applied as recommended in broadcast-seeded rice according to RRTC recommendations.

Table 1. The agro-meteorological parameters of Sakha (31° 07' N Latitude, 30° 57' E Longitude)

Seasons	Parameters		May	June	July	August	September	October
2020	Temperature	Max. (ºC)	31.90	31.10	33.70	34.60	34.60	31.50
		Min. (ºC)	23.80	25.20	27.30	28.20	27.10	24.60
		Mean (ºC)	27.85	28.15	30.50	31.40	30.85	28.05
	Relative humidity	Max. (%)	68.90	78.00	84.20	85.30	86.70	84.80
		Min. (%)	38.40	42.60	51.10	49.60	47.70	47.10
		Mean (%)	53.65	60.30	67.65	67.45	67.20	65.95
	Wind speed	Mean (km d^{-1})	114.40	111.80	101.70	92.40	93.30	72.70
	Pan evaporation	Mean (mm d^{-1})	7.70	8.44	8.79	8.03	6.24	4.12
	Rain	(mm)	0.00	0.00	0.00	0.00	0.00	0.00
2021	Temperature	Max. (ºC)	32.54	32.04	34.69	35.66	32.51	28.50
		Min. (ºC)	24.72	25.52	27.00	27.99	25.10	22.3
		Mean (ºC)	28.63	28.78	30.85	31.83	28.81	25.4
	Relative humidity	Max. (%)	74.18	80.27	84.77	85.32	83.97	76.50
		Min. (%)	42.64	50.23	50.62	46.72	49.5	61.20
		Mean (%)	58.41	65.25	67.70	66.02	66.74	68.85
	Wind speed	Mean (km d^{-1})	81.1	106.7	99.2	83.18	96.70	80.49
	Pan evaporation	Mean (mm d^{-1})	8.63	8.92	8.60	7.53	7.58	5.03
	Rain	(mm)	0.00	0.00	0.00	0.00	0.00	0.00

Table 2. Mean values of soil properties at the experiment location in 2020 and 2021 seasons

Soil depth (cm)	EC_e (dS m^{-1})	pH	Particle-size distribution			Texture class	Field capacity (%)	Wilting point (%)	Bulk density (g cm^{-3})	Total porosity (%)
			Sand (%)	Silt (%)	Clay (%)					
0-15	2.19	7.78	18.54	23.81	57.65	Clayey	44.88	24.32	1.19	55.09
15-30	2.83	7.95	19.84	24.92	55.24	Clayey	41.72	20.11	1.33	49.81
30-45	3.01	8.34	20.05	24.33	55.62	Clayey	40.06	19.92	1.38	47.92
45-60	3.33	8.61	20.83	24.62	54.55	Clayey	39.42	18.64	1.42	46.42
Mean	2.84		19.81	24.42	55.77	Clay	41.52	20.75	1.33	49.81

A strip split-plot design with three replications was used in both seasons. Three irrigation intervals were randomly devoted the horizontal plots. Vertical plots were assigned to two hydrogel treatments, while weed management were randomly distributed in sub-plots during both seasons. Plot area was 16 m^2 (4 x 4 m) in both seasons. The studies factors were as following:

A-Irrigation intervals:

Three irrigation intervals were studied as follow:

1- Irrigation every five days (I_1).
2- Irrigation every ten days (I_2).
3- Irrigation every fifteen days (I_3).

B-Hydrogel polymer:

One rate of hydrogel was compared to normal conditions as follow:

1- Hydrogel at 20 kg ha^{-1}.
2- Without hydrogel.

Chemical and physical properties of hydrogel polymer used in this study are presented in Table 3.

Table 3. Hydrogel polymer industrial information, physical and chemical properties, stability and reactivity

Product Name	Agriculture Super Absorbent Polymer	
Company Identification	SHANDONG HIKING GROUP	
Composition/Information on Ingredients	**Composition**	Salts acrylate + Bentonite + Other additives .etc
Physical and Chemical Properties	Appearance	Powder particle.
	Particle Sizes	Fine, Powder, Granular, 2.0-4.75mm, 1.0-2.0mm, 0.2-1.0mm, <0.2mm
	Color	Gray
	Specific gravity	0.87
	pH	6- 8
	Solubility	Insoluble, swelling in water
	Odor	Imperceptible
Stability and Reactivity	Stability	Stable
	Conditions to avoid	Fire, Water
	Hazardous polymerization	None
	Decomposition products	Carbon monoxide, carbon dioxide


Fig. 1. Hydrogel polymer before and after water absorbation

C-Weed control treatments

Three weed control treatments were applied as follow

1- Thiobencarb at 2.38 kg ai ha^{-1} (Saturn 50% EC) applied at 9 days after sowing (DAS) followed by (fb) bispyribac-sodium at 0.038 g. ai ha^{-1}. (Nominee 2% SL) + halosulfuron-methyl at 0.036 Kg ha^{-1} (Inpul 75% WG) applied at 25 DAS (W_1).
2- Thiobencarb at 2.38 kg ai ha^{-1} fb cyhalofop-butyl at 0.286 Kg ai ha^{-1} (Bazooka 10% EC) + halosulfuron-methyl at 0.036 Kg ha^{-1} (Inpul 75% WG) applied at 25 DAS (W_2).
3- Un-weeded (Weedy check) (W_3).

Thiobencarb as pre-emergence herbicide was applied at 9 DAS mixed with sand on flooded land then, kept field flooded for 4 days after herbicidal application. Bispyribac-sodium and cyhalofop-butyl mixed with halosulfuron-methyl as post-emergence treatments were applied at 25 DAS. Nominee or Bazooka plus Inpul were sprayed using Gloria sprayer as 5 liters capacity with rate of water as 300 liter ha^{-1} on dry land then, irrigation was introduced after 24 h from herbicidal application.

3.1 Sampling, Data Recorded and Calculations

A-Weed data:

At 60 DAS, weeds were hand pulled from 50 x 50 cm quadrate replicated four times for each plot. Weeds were cleaned, classified into species, and were air dried for two days, then dried in the

Table 4. Studied herbicides trade name, active ingredient, chemical group, mode of action, target weeds and active ingredient per hectare

Herbicide Character	Herbicide trade name			
	Saturn 50% EC	**Nominee 2% SL**	**Bazooka 10% EC**	**Inbul 75% WG**
Active ingredient	thiobencarb	bispyribac-sodium	cyhalofop-butyl	halosulfuron-methyl
Chemical group	Thiocarbamate	Pyrimidinyloxybenzoic acid	Aryloxy phenoxy propionate	pyrimidinyl sulfonylurea
Mode of action	systemic-photosynthesis inhibitors	Systemic-ALS inhibitors	Systemic-ACCase inhibitors	Systemic – ALS inhibitors
Target weeds	Grassy + sedges	Grassy + sedges	Grassy	Broad leaves + sedges
Rate (Kg ai ha^{-1})	2.38	0.0381	0.286	0.0357

Lit.= litter, ha= hectare, g= gram, ALS= Aceto Lactate Synthase, ACCase = Acetyl-Coenzyme A Carboxylase

oven at 70 ˚C for 48 hours to constant weight, and dry weight as g m^{-2} was determined. Weed control efficiency (WCE %) was calculated with the following formula [21]:

$$WCE\ (\%) = \frac{DMC - DMT}{DMC} \times 100$$

Where:

DMC = Weed dry matter in un-weeded treatment.
DMT = Weed dry matter in weed control treatment.

B-Rice data:

Rice dry weight at 60 DAS also, was measured by the same method of sampling for weeds. After rice maturity, panicles were counted in two random quadrate of 50 x 50 cm and number of panicles per square meter was calculated as a mean. Before harvest, ten panicles of rice were randomly taken from every plot to estimate panicle weight and filled grains per panicle and their average was recorded. Rice grain yield as ton ha^{-1} was recorded by manually harvesting of the central 8 m^2 from each plot then, air dried, threshed and cleaned then adjusted at 14% moisture content.

C- Applied water and water productivity

By the use of a fixed rectangular weir, the applied water was measured for irrigation interval every irrigation time, the following equation was also used:

$$Q = 1.84LH^{1.5}$$

Where,

Q =discharge rate, m^3/min.,
L = weir length edge, cm
H = Height of water column above weir edge, cm

The seasonal applied water was calculated through the assumption of the applied quantity in all irrigation during the season. Water productivity in kg grain per m^3 was calculated as said by Ali et al. [22], as follows:

Water productivity (kg m^{-3}) = Grain yield (kg/ ha) / Applied water (m^3 / ha)

3.2 Statistical Analysis

Experiment data was subjected to proper statistical analysis of variance, according to Snedecor and Cochran [23]. Weed data were statistically analyzed by MSTATC program after transformed according to square-root transformation ($\sqrt{[x+0.5]}$). Rice data were directly analyzed by MSTATC program, and then means of studied traits for both weeds and rice were compared by using Duncan´s Multiple Range Test [24].

3. RESULTS AND DISCUSSION

3.1 Water Measurements

3.1.1 Applied water

Data in Fig. 2 presents the seasonal applied water in 2020 and 2021 seasons, respectively, as influenced by irrigation intervals and soil conditioner treatments. The amount of applied water was decreased by 26.4% and 35.8%

respectively compared to irrigation intervals every 5 days as average of 2020 and 2021 seasons. These results match with those gained by Ashouri [25], who found that water use decreased by 18% under 8 days interval compared to continuous flooding. Irrigation intervals and alternative wetting and drying can markedly decrease applied irrigation when comparing to continuous flooding [26]. Hydrogel polymer treatment has a significant effect to reduce the amount of applied water compared to without application of hydrogel under all irrigation intervals treatments. Hydrogel treatment reduced applied water by 14.8% compared without hydrogel treatment, this may be due to the importance of hydrogel polymers to improve soil moisture content, moisture retention, keeps its wetting over a longer period, maintaining its high water swelling and releasing capacity against soil pressure [14,27,15]. The highest amount of applied water was obtained when the irrigation interval every 5 days x without hydrogel treatment, while the lowest values were obtained when irrigation every 15 days x hydrogel application for both studied seasons.

3.2 Main Effect on Weed Parameters

3.2.1 Effect of irrigation intervals

Data on dry weight (g/m^2) of *C. difformis*, Grasses and total weeds as influenced by irrigation intervals, hydrogel application and weed control treatments are presented in Table 5. It is clear that dry weight of *C. difformis*, grassy weeds and total weeds was significantly affected by irrigation intervals during the two seasons of study. *C. difformis* recorded the highest value of dry weight under five days irrigation, while the lowest one was observed under fifteen days irrigation interval during 2020 and 2021 seasons. These results may explain that more moisture available in the soil is a favorite condition for *C. difformis* germination and growth. Dry weight of grassy weeds was clearly influenced by the presence of irrigation water. The plots irrigated every fifteen days exhibited the heaviest dry weight of grassy weeds while those irrigated every five days recorded the lowest values in this respect. This trend was obtained during the two seasons of study. The reduction of grassy weeds under more soil moisture means that more flooding reduces germination and growth of grassy weed species. Similar findings were observed by Abou El-Darag et al. [29].

It is clear from results in Table 5 that, dry weight of total weeds was considerably affected by irrigation intervals. Delaying irrigation period to 15 days resulted in the highest dry weight to total weeds while irrigation every 5 days recorded the lowest values, the same trend was obtained during two seasons. The reduction of total weeds under five days irrigation period may be related to the reduction of germination of some weed species especially grassy weeds under flooding conditions [16]. While the high biomass of grassy weeds under irrigation interval every 15 days as aerobic conditions may be due to encourage of such weeds to germinate and have strong growth and high competitiveness ability against rice plants.

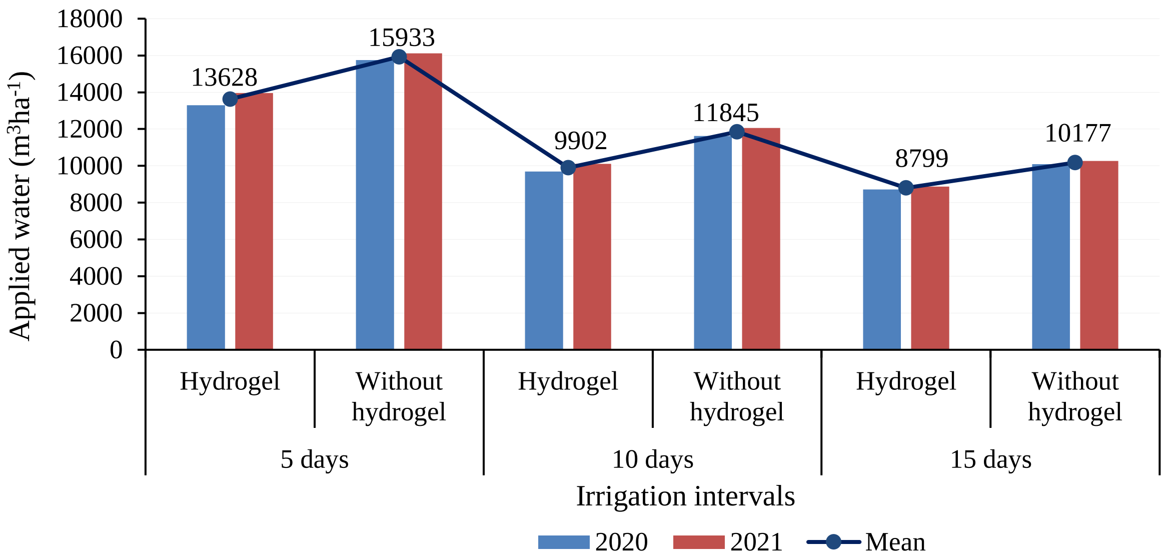

Fig. 2. Applied water as affected by irrigation intervals and conditioner

Table 5. Effect of irrigation intervals, hydrogel polymer and weed control on dry weights of *C. difformis*, grasses, total weeds and weed control efficiency (%) during 2020 and 2021 seasons

Factors	***C. difformis***		**Grassy weeds**		**Total weeds**		**Weed control efficiency (%)**	
A-Irrigation intervals	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Five days	55.6 (6.0 a)	36.3 (4.9 a)	120.3 (9.3 c)	87.9 (7.8 c)	175.9 (11.0 c)	124.2 (9.2 c)	-	-
Ten days	21.4 (4.0 b)	16.6 (3.4 b)	240.4 (13.7 b)	183.9 (11.9 b)	261.8 (14.3 b)	200.5 (12.4 b)	-	-
Fifty days	0.0 (0.71 c)	0.0 (0.7 c)	407.8 (18.3 a)	367.9 (17.4 a)	407.8 (18.3 a)	367.9 (17.4 a)	-	-
F test	**	**	**	**	**	**	-	-
B- Hydrogel								
Without hydrogel	23.1 (3.5 b)	15.5 (2.9 b)	287.2 (14.8 a)	245.1 (14.5 a)	310.3 (15.5 a)	260.5 (14.0 a)	-	-
Hydrogel	28.3 (3.7 a)	19.8 (3.1 a)	225.1 (12.7 b)	181.5 (11.2 b)	253.4 (13.6 b)	201.3 (11.9 b)	-	-
F test	**	**	**	**	**	**	-	-
C- Weed control								
Saturn fb Nomee.+ Inp.	2.6 (1.6 c)	1.6 (1.4 c)	52.9 (6.7 c)	38.5 (5.6 c)	55.5 (7.0 c)	40.1 (5.8 c)	91.4	92.4
Saturn fb Bazooka + Inp**.**	6.9 (2.4 b)	4.1 (1.9 b)	135.8 (11.1 b)	121.8 (10.3 b)	142.6 (11.5 b)	125.9 (10.6 b)	78.0	76.1
Weedy check	67.7 (6.7 a)	47.2 (5.7 a)	579.8 (23.5 a)	479.5 (21.2 a)	647.4 (25.2 a)	526.7 (22.5 a)	0.0	0.0
F test	**	**	**	**	**	**	-	-
Interaction							-	-
A x B	Ns	Ns	**	**	**	Ns	-	-
Ax C	**	**	**	**	**	**	-	-
B x C	**	Ns	NS	NS	Ns	Ns	-	-
Ax B x C	**	**	**	**	*	*	-	-

*** indicates P< 0.01, NS=not significant. Transformed values are shown in parentheses. In a column, means of transformed data followed by the same letter are not significantly different at 5% level, using Duncan's Multiple Range Test. DAS = days after sowing*

3.2.2 Effect of hydrogel

Data represented in Table 5 revealed that dry weight of *C. difformis*, grassy weeds and total weeds were significantly influenced by hydrogel treatment. Under adding of hydrogel polymer, grassy weeds and total weeds dry weights were greatly reduced while *C. difformis* dry weight was markedly increased. On the other hand, in case of hydrogel absence, grassy weeds and total weeds recorded the heaviest dry weights. The same trends were true during the two seasons of study. The different behavior of weed species under the presence or absence of hydrogel may referred to hydrogel ability to keep and release more moisture in the soil, basically influences the germination and growth of different weed species according to their behaviors. Huttermann et al. [30] found that adding hydrogel to the soil increase moisture content, consequently increase germination percentage of plants. Narjary et al. [28] reported that using hydrogel polymer in agriculture is a magic option to save irrigation water in addition to improve chemical and biological properties of the soil.

3.2.3 Effect of weed control

Data in Table 5 clarify that *C. difformis*, grassy weeds and total weeds dry weights were significantly affected by weed control treatments. The application of Saturn followed by Nominee + Inpul or by Bazooka + Inpul at recommended doses greatly reduced dry weights of all mentioned weed species and total weeds as compared to the weedy check plots which produced the highest dry biomass of studied weeds during the study. Using Saturn 50% followed by Nominee 2% + Inpul 75% resulted in the lowest dry weight of *C. difformis*, grassy weeds and total weeds and highest weed control efficiency (more than 90%). The same trends were true during the two seasons of study. The considerable reduction in weed dry weights under the application of chemical control may reflect the prevention of germination and the reduction of weed growth due to such treatments. Singh et al., [31] 2016 found that sequential application of pendimethalin as pre-emergence herbicide followed by post-emergence application of bispyribac-sodium surpassed the application of pre or post-emergence herbicides alone in weed control. These results are in harmony with those obtained by Abd El-Naby and El-Ghandor [16].

3.3 Effect Interaction on Weed Parameters

3.3.1 Effect of irrigation intervals x hydrogel application on *C. difformis*

Data cited in Table 6 showed that dry weight of *C. difformis*, grassy weeds and total weeds was greatly influenced by irrigation intervals x hydrogel application interaction. Dry weight of *C. difformis* showed the highest values under five days irrigation interval with hydrogel presence or absence while under ten days irrigation interval, hydrogel application increased dry weight of *C. difformis* as compared to without hydrogel application. On the other hand under fifteen days irrigation interval *C. difformis* weed was absent under both hydrogel presence and absence. The same trends were true during 2021 and 2022 seasons. The increased values of *C. difformis* dry weight under 5 and 10 days irrigation interval with hydrogel application means that hydrogel provided the soil with more moisture [32], consequently enhanced *C. difformis* germination and growth. For grasses and total weeds. Irrigation every 5-days x hydrogel polymer application recorded the lowest figures of both grasses and total weeds during 2020 and 2021 seasons. On the other hand, the highest dry biomass of abovementioned weeds was recorded by I_3 x without hydrogel adding in both seasons of study.

3.3.2 Effect of irrigation intervals x weed control treatments

Data in Table 7 revealed that dry weights of *C. difformis*, grasses and total weeds were significantly affected by interaction between irrigation intervals and weed control treatments. Both chemical weed control treatments clearly reduced dry weight of the three weed categories as compared to weedy check plots during the two seasons of study. In addition, sequential application of Saturn followed by Nominee + Inpul at recommended doses with irrigation interval every 5-days recorded the lowest dry weights of grassy weeds and total weeds during both seasons of the trail. For *C. difformis*, the lowest dry weights were obtained by the plots irrigated every 10- days treated with Saturn followed by Nominee + Inpul, moreover it was absent under irrigation interval every 15-days during the study. On the other hand, under untreated check plots, with interval irrigation of five days, *C. difformis* recorded the highest dry weight wile under fifteen days intervals it was absent. Moreover, grassy weeds and total weeds exhibited their dominancy under weedy check plots followed by fifteen days irrigation intervals. The same trend was obtained during the two seasons of study. These results show the superiority of sequential application of pre-emergence followed by post-emergence herbicides in weed control under short, medium and long irrigation intervals in direct seeding as a result of high efficiency of such combination to reduce weeds in rice fields during the critical period of weed competition [33, 34].

3.3.3 Effect of irrigation intervals x hydrogel application x weed control treatments

Results cited in Table 8 revealed that dry weights of *C. difformis*, grassy weeds and total weeds were significant influenced by the interaction among irrigation intervals x hydrogel application x weed control treatments during 2020 and 2021 seasons. Dry weigh of *C. difformis* exhibited the highest values under five days irrigation treatment with the presence of hydrogel polymer in weedy check plots. In addition, under the same treatment of hydrogel, the herbicidal treated plots with Saturn of Nominee +Inpul recorded lowest values of *C. difformis* dry weight than under the absence of hydrogel. On the other hand, irrigation every 15- days interval under both the treated or untreated plots with hydrogel, no *C. difformis* plants were observed under such conditions. The same trend was observed during the two seasons of the study. The absence of *C. difformis* under delayed irrigation conditions my referred to the low moisture conditions in the soil which prevents germination of *C. difformis*.

It is clear from data in Table 8 that dry weight of grassy weeds and total weeds recorded the highest values under the delayed irrigation intervals (15 days) in case of hydrogel absence in weedy check plots. On the other side, under five days interval of irrigation, sequential application of Saturn *fb* Nominee +Inpul achieved the lowest dry weights of grassy weeds and total weeds during 2020 and 2021 seasons. The dominance of grassy weeds in case of delayed irrigation and the absence of hydrogel could reflects the favorable aerobic conditions for germination and growth of grassy weeds, consequently increased total weeds in such conditions [35].

3.4 Main Effect on Rice Crop

3.4.1 Irrigation intervals effect

Data presented in Table 9 showed that dry weight, panicle weight, number of panicles /m^2 and grain yield of rice crop were considerably influenced by irrigation intervals during the two seasons of study. The highest values of all abovementioned traits were recorded under the irrigation every five days followed by ten days interval whereas delaying irrigation to fifteen days produced the lowest values of the studied traits. The same trends were true during the two

Table 6. Effect of interaction between irrigation intervals and hydrogel polymer on dry weights of *C. difformis*, grasses and total weeds during 2020 and 2021 seasons

Irrigation intervals	Dry weight					
	C. difformis		Grassy weeds		Total weeds	
	Without	Hydrogel	Without	Hydrogel	Without	Hydrogel
	2020					
I_1	52.60 (6.05 a)	58.72 (5.97 a)	129.30 (9.77 e)	111.33 (8.74 f)	181.90 (11.47 e)	170.05 (10.57 e)
I_2	16.58 (3.71 c)	26.26 (4.31 b)	278.94 (15.00 c)	201.77 (12.45 d)	295.52 (15.43 c)	228.02 (13.16 d)
I_3	0.00 (0.71 d)	0.00 (0.71 d)	453.39 (19.60 a)	362.18 (17.01 b)	453.39 (19.60 a)	362.18 (17.01 b)
			2021			
I_1	33.44 (4.80 a)	39.16 (4.93 a)	102.28 (8.55 e)	73.57 (7.10 f)	135.72 (9.78 e)	112.73 (8.61 f)
I_2	13.01 (3.17 c)	20.17 (3.67 d)	226.08 (13.28 c)	141.63 (10.45 d)	239.09 (13.65 c)	161.80 (11.07 d)
I_3	0.00 (0.71 d)	0.00 (0.71 d)	406.71 (18.60 a)	329.25 (16.12 b)	406.71 (18.60 a)	329.25 (16.12 b)

Means fb a common letter within a season for every weed are not significantly differed at 5% level, using DMRT. Values within parentheses are transformed

Table 7. Effect of interaction between irrigation intervals and weed control on dry weights of *C. difformis*, grasses and total weeds during 2020 and 2021 seasons

Irrigation interval	Weed control treatments					
	W_1	W_2	W_3	W_1	W_2	W_3
	C. difformis					
	2020			2021		
I_1	5.22 (2.34 d)	11.21 (3.41 c)	150.54 (12.28 a)	2.97 (1.82 de)	7.77 (2.87 c)	98.16 (9.90 a)
I_2	2.47 (1.71 e)	9.37 (3.14 c)	52.41 (7.19 b)	1.82 (1.51 e)	4.59 (2.21 d)	43.37 (6.54 b)
I_3	0.00 (0.71 f)	0.00 (0.71 f)	0.00 (0.71 f)	0.00 (0.71 f)	0.00 (0.71 f)	0.00 (0.71 f)
	Grassy weeds					
	2020			2021		
I_1	14.38 (3.81 h)	42.19 (6.51 g)	304.39 (17.45 c)	7.88 (2.87 g)	32.34 (5.68 f)	223.58 (14.93 c)
I_2	39.89 (6.29 g)	136.47 (11.58 e)	544.71 (23.29 b)	25.55 (5.06 f)	106.19 (10.17 d)	419.83 (20.37 b)
I_3	104.55 (9.99 f)	228.63 (15.12 d)	890.17 (29.81 a)	82.11 (8.85 e)	226.82 (15.04 c)	795.01 (28.18 a)
	Total weeds					
	2020			2021		
I_1	19.60 (4.41 h)	53.41 (7.32 g)	454.93 (21.34 c)	10.83 (3.33 i)	40.11 (6.33 g)	321.74 (17.93 c)
I_2	42.37 (6.49 g)	145.83 (11.99 e)	597.12 (24.41 b)	27.37 (5.24 h)	110.78 (10.39 e)	463.19 (21.44 b)
I_3	104.55 (9.99 f)	228.63 (15.12 d)	890.17 (29.81 a)	82.11 (8.84 f)	226.82 (15.04 c)	795.01 (28.18 a)

Means fb a common letter within a season for every weed are not significantly differed at 5% level, using DMRT. Values within parentheses are transformed

seasons of the study. The reduction of growth, dry matter accumulation, yield and its components of rice under dry conditions may referred to the high pressure of water shortage and dominance of grassy weeds resulting in shortage of moisture and nutrients which adversely affected crop growth, tillering ability and yield. These results are similar to those cited by Bagavathiannan et al. [36] and Abou El-Darag et al. [29].

3.4.2 Hydrogel polymer effect

Referring results in Table 9, dry weight, panicle weight, number of panicles / m^2 and grain yield of rice were significantly increased by the hydrogel application. The same behavior was obtained during 2020 and 2021 growing seasons. The positive response of rice growth and yield under the presence of hydrogel may reflects the ability of such polymer to work as water reservoir and release more water in zone of plant roots when needed, consequently enhances growth conditions of rice plants. Hydrogel as a synthetic polymer is able to absorb and hold 80–180 times its volume of water for a long time [7,14,27,15] then work as a reservoir to store and release water and nutrients depending on plant requirements. Singh and Raghav [37] stated that hydrogel polymer increase seed germination and growth of plant roots in addition to plant density and improve crop yield. Hydrogel application enhances rice grain yield and its components as compared to without hydrogel [38,39].

3.4.3 Weed control effect

It could be observed from data in Table 9 that weed control treatments clearly affected dry weight, panicle weight, number of panicles / m^2 and grain yield of rice crop during the two seasons of study. The application of the two chemical weed control treatments greatly increased the abovementioned rice traits as compared to the untreated check plots. Moreover, sequential application of Saturn followed by Nominee 2% + Inpul 75% at recommended doses showed its superiority in dry mater accumulation, panicle weight, number of panicles/m^2 and grain yield of rice than using Saturn followed by Bazooka 10% + Inpul 75% at recommended doses. The same trend of results was true during the two seasons of study. The considerable increase of rice growth and yield and its components in case of using sequential application of Saturn followed by Nominee 2% + Inpul 75% reflex the high efficiency of such treatment in controlling weeds and enhancing more favorable conditions of moisture, nutrients, sun light and space for rice crop. These results are in harmony with those found by Abd El-Naby et al. [40] and Abd El-Naby and El-Ghandor [16].

Table 8. Effect of interaction among irrigation intervals, hydrogel polymer and weed control on dry weights of *C. difformis*, grasses and total weeds during 2020 and 2021 seasons

Irrigation interval	Hydrogel	Weed control treatments					
		W_1	W_2	W_3	W_1	W_2	W_3
		C. difformis					
		2020			**2021**		
I_1	Without	7.10 (2.74 g)	12.83 (3.65 e)	137.88 (11.76 b)	3.96 (2.07 gh)	8.02 (2.92 e)	88.33 (9.41 b)
	Hydrogel	3.34 (1.95 h)	9.61 (3.17 f)	163.20 (12.79 a)	1.98 (1.57 gh)	7.52 (2.82 ef)	107.99 (10.39 a)
I_2	Without	2.97 (1.86 h)	9.31 (3.1 fg)	37.65 (6.17 d)	2.11 (1.61 gh)	4.46 (2.19 fg)	32.47 (5.71 d)
	Hydrogel	1.99 (1.56 h)	9.60 (3.18 f)	67.18 (8.20 c)	1.52 (1.41 h)	4.72 (2.23 fg)	54.27 (7.36 c)
I_3	Without	0.00 (0.71 i)	0.00 (0.71 i)	0.00 (0.71 i)	0.00 (0.71 i)	0.00 (0.71 i)	0.00 (0.71 i)
	Hydrogel	0.00 (0.71 i)	0.00 (0.71 i)	0.00 (0.71 i)	0.00 (0.71 i)	0.00 (0.71 i)	0.00 (0.71 i)
		Grassy weeds					
		2020			**2021**		
I_1	Without	19.04 (4.41 l)	48.29 (7.0 0 ij)	320.58 (17.92 e)	9.87 (3.22 l)	40.52 (6.40 ij)	256.45 (16.03 e)
	Hydrogel	9.71 (3.19 m)	36.09 (6.04 jk)	288.19 (17.00 e)	5.84 (2.51 l)	24.15 (4.96 k)	190.71 (13.82 f)
I_2	Without	50.14 (7.11 ij)	170.52 (13.06 g)	616.16 (24.83 c)	30.73 (5.57jk)	136.35 (11.66 g)	511.15 (22.62 c)
	Hydrogel	29.63 (5.47 kl)	102.41 (10.10 h)	473.26 (21.76 d)	20.37 (4.55 k)	76.03 (8.67 h)	328.50 (18.13 d)
I_3	Without	145.69 (12.02 g)	242.67 (15.58 f)	971.80 (31.18 a)	115.12 (10.68 g)	253.46 (15.93 e)	851.56 (29.18 a)
	Hydrogel	63.40 (7.95.i)	214.60 (14.65 f)	808.53 (28.44 b)	49.10 (7.02 i)	200.18 (14.15 f)	738.47 (27.18 b)
		Total weeds					
		2020			**2021**		
I_1	Without	26.14 (5.15 l)	61.11 (7.84 j)	458.46 (21.42 e)	13.83 (3.78 mn)	48.54 (7.00 k)	3.44.78 (18.57 d)
	Hydrogel	13.05 (3.68 m)	45.70 (6.79 jk)	451.40 (21.25 e)	7.82 (2.88 n)	31.67 (5.66 l)	298.7 (17.29 e)
I_2	Without	53.11 (7.32 j)	179.65 (13.41 g)	653.81 (25.57 c)	32.84 (5.76 l)	140.82 (11.85 h)	543.62 (23.32 c)
	Hydrogel	31.62 (5.66 kl)	112.01 (10.57 i)	540.44 (23.25 d)	21.89 (4.72 lm)	80.75 (8.93 j)	382.76 (19.56 d)
I_3	Without	145.69 (12.02 h)	242.67 (15.58 f)	971.80 (31.18 a)	115.12 (10.68 i)	253.46 (15.93 f)	851.56 (29.18 a)
	Hydrogel	63.40 (7.95 j)	214.60 (14.65 f)	808.54 (8.44 b)	49.10 (7.02 k)	200.18 (14.15 g)	738.47 (27.18 b)

Means fb a common letter within a season for every weed are not significantly differed at 5% level, using DMRT. Values within parentheses are transformed

Table 9. Effect of irrigation intervals, hydrogel polymer and weed control on dry weight, number of panicles m^{-2}, panicle weight, number of filled grains per panicle and grain yield of rice during 2020 and 2021 seasons

Factors	Rice dry weight (gm^{-2})		Panicle weight (g)		Number of field grain per panicle		Number of panicle m^{-2}		Grain yield (t ha^{-1})	
A-Irrigation intervals	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Every 5 days	836.4 a	959.6 a	1.62 a	1.71 a	82.6 a	88.6 a	387.6 a	424.9 a	6.526 a	6.923 a
Every 10 days	592.8 b	711.4 b	1.27 b	1.36 b	64.7 b	70.3 b	274.7 b	302.2 b	4.315 b	4.852 b
Every 15 days	332.5 c	382.8 c	0.97 c	1.04 c	49.9 c	55.4 c	222.2 c	249.8 c	2.852 c	3.055 c
F. test	**	**	**	**	**	**	**	**	**	**
B- Hydrogel										
Without	541.9 b	639.2 b	1.29 b	1.29 b	62.2 b	67.4 b	274.9 b	306.9 b	4.170 b	4.479 b
Hydrogel (20 kg/ha^{-1})	632.5 a	729.9 a	1.37 a	1.45 a	69.3 a	75.5 a	314.7 a	344.3 a	4.959 a	5.408 a
F. test	**	**	**	**	*	*	**	**	**	**
C-Weed control treatment										
Saturn fb Nomee.+ Inp.	872.2 a	998.6 a	1.84 a	1.92 a	89.6 a	92.9 a	408.9 a	443.6 a	6.818 a	7.342 a
Saturn fb Bazooka + Inp**.**	708.7 b	819.3 b	1.59 b	1.63 b	76.7 b	81.8 b	353.8 b	392.9 b	5.936 b	6.299 b
Weedy check	180.9 c	235.9 c	0.43 c	0.56 c	30.8 c	39.7 c	121.8 c	140.4 c	0.939 c	1.190 c
F. test	*	*	*	*	*	*	**	**	**	**
Interaction:										
A x B	NS	NS	NS	NS	NS	NS	NS	NS	*	*
A x C	**	**	**	**	**	**	**	**	**	**
B x C	**	**	NS	NS	NS	NS	NS	NS	**	**
A x B x C	**	*	NS	NS	NS	NS	*	*	*	*

*** indicates P< 0.01. Means of each factor within each column, values fb the same letters are not significantly differed at 5% level, using DMRT*

3.5 Effect Interaction on Rice Crop

3.5.1 Irrigation intervals x weed control treatments

Data on dry weight, panicle weight, number of panicles / m^2 and grain yield as influenced by irrigation intervals x weed control are presented in Table 10.

It is clear that highest values of all abovementioned traits were achieved by irrigation every five days x sequential application of Saturn 50% followed by Nominee 2% + Inpul 75%, while Saturn 50% followed by Bazooka 10% + Inpul 75% ranked second under the same irrigation interval in 2020 and 2021 seasons. On the opposite, weedy check plots x fifteen days irrigation interval produced the lowest values of dry weight, panicle weight, number of panicles / m^2 and grain yield of rice. The same trend of results was obtained during first and second season of the study. Abd El-Naby and Mahmoud [35] found that sequential application of pre followed by post-emergence herbicides under irrigation every 4 and 8 days provided the best weed control resulting in improving rice vegetative growth, dry matter and enhanced rice grain yield and its attributes.

3.5.2 Hydrogel application x weed control treatments

Data allocated in Table 11 revealed that dry weight and grain yield of rice crop were significantly influenced by interaction between hydrogel application and weed control treatments during the two seasons of study. The greatest

Table 10. Effect of interaction between irrigation intervals and weed control on dry weight, number of panicles m^{-2}, panicle weight and grain yield of rice during 2020 and 2021 seasons

Irrigation interval	Weed control treatments					
	W_1	W_2	W_3	W_1	W_2	W_3
	Rice dry weight					
	2020			**2021**		
I_1	1276.2 a	854.2 c	486.2 e	1428.2 a	1006.2 c	561.5 e
I_2	992.9 b	743.4 d	389.6 f	1144.9 b	895.4 d	417.5 f
I_3	240.2 g	180.7 h	121.7 i	305.8 g	232.7 h	169.4 i
	Panicle weight					
	2020			**2021**		
I_1	2.22 a	1.85 c	1.45 d	2.34 a	1.92 b	1.50 c
I_2	1.99 b	1.56 d	1.21 e	2.00 b	1.61 c	1.29 d
I_3	0.67 f	0.39 g	0.25 h	0.79 e	0.54 f	0.34 g
	Number of field grain per panicle					
	2020			**2021**		
I_1	113.2 a	86.7 c	69.0 e	116.8 a	88.7 c	73.2 e
I_2	93.8 b	75.5 d	60.8 f	98.0 b	80.3 d	67.2 f
I_3	40.7 g	31.8 h	20.0 i	51.0 g	42.0 h	26.0 i
	Number of panicle m^{-2}					
	2020			**2021**		
I_1	528.0 a	381.3 c	317.3 d	565.3 a	416.0 c	349.3 d
I_2	464.0 b	322.7 d	274.7 e	512.0 b	360.0 d	306.7 e
I_3	170.7 f	120.0 g	74.7 h	197.3 f	130.7 g	93.3 h
	Grain yield					
	2020			**2021**		
I_1	9.700 a	6.415 c	4.340 e	10.162 a	7.270 c	4.593 e
I_2	8.487 b	5.627 d	3.695 f	8.868 b	6.172 d	3.857 f
I_3	1.392 g	0.903 h	0.522 i	1.740 g	1.115 h	0.715 i

Means fb a common letter within a season for every trait are not significantly differed at 5% level, using DMRT

Table 11. Effect of interaction between hydrogel polymer and weed control on dry weight and grain yield of rice during 2020 and 2021 seasons

Hydrogel	Weed control treatments					
	W_1	W_2	W_3	W_1	W_2	W_3
	Rice dry weight					
		2020			**2021**	
Without	814.7 b	651.6 d	159.6 f	949.5 b	758.6 d	209.6 f
Hydrogel	929.7 a	765.7 c	202.1 e	1047.8 a	879.9 c	262.3 e
	Grain yield					
		2020			**2021**	
Without	6.328 b	5.457.c	0.726 e	6.877 b	5.617 c	0.944 e
Hydrogel	7.309 a	6.416 b	1.152 d	7.807 a	6.981 b	1.436 d

Means fb a common letter within a season for every trait are not significantly differed at 5% level, using DMRT

values of both rice characteristics were achieved by the application of hydrogel polymer at rate of 20 kg ha^{-1} with the treatment of Saturn 50% followed by Nominee 2% + Inpul 75%, while the lowest figures were recorded under the absence of hydrogel with untreated weedy check plots. The great outputs of sequential application of Saturn 50% *fb* Nominee 2% + Inpul 75% at recommended doses under the presence of hydrogel polymer may clarified the positive action of hydrogel in providing more moisture in the soil, basically improved herbicide efficacy for weed control and improved crop growth and grain yield of rice. Narjary et al. [39] found that hydrogel polymer improved physical and chemical properties of the soil which save soil moisture content, these conditions encourage all chemical compounds.

3.5.3 Irrigation intervals x hydrogel application x weed control treatments

It is clear from data in Table 12 that dry weight, number of panicle / m^2 and grain yield of rice were greatly affected by the interaction of irrigation interval x Hydrogel application x weed control treatments during both seasons of the study. The highest values of all abovementioned characteristics were achieved when rice was irrigated every five days under hydrogel application in plots received sequential application of Saturn50% *fb* Nominee 2% + Inpul 75% at recommended doses for weed control during both seasons of study.

Weedy check plots under without hydrogel application and irrigated every fifteen days produced the lowest values of dry weight, number of panicles /m^2 and grain yield of rice. The sane trends were true during the two seasons of the study. The superiority of rice plots irrigated every 5-days, received hydrogel and treated by sequential application of Saturn 50% *fb* Nominee 2% + Inpul 75% in producing more dry weight, higher number of panicles and grain yield of rice could be attributed with the presence of more water and the hydrogel ability to increase soil moisture enhances the weed control efficacy against weeds consequently, improved growth and yield of rice.

3.6 Water Productivity

As shown in able (13), significant differences were obtained between irrigation intervals, hydrogel and weed control treatments and the interaction among them. The highest values of water productivity were found with 5-days interval, while the lowest values were obtained with 15-day interval in both seasons. Water productivity values were reduced by 5.8% and 44.4% for irrigation intervals every 5 and 10 days respectively compared to irrigation every 15 days as an average of 2020 and 2021 seasons. The values of water productivity of weed control treatments were taken the descending order: W_1 > W_2 > W_3 for both studied seasons. Hydrogel polymer significantly enhanced water productivity by 43.9% compared to without addition of hydrogel polymer.

The peak values of water productivity were obtained of 10-days × hydrogel ×W_1, while the lowest values of applied water were found with 15-days × without hydrogel × W_3 in the two seasons compared to the others treatments as shown in Table 13.

Table 12. Effect of interaction among irrigation intervals, hydrogel polymer and weed control on dry weight, number of panicles m^{-2} and grain yield of rice during 2020 and 2021 seasons

Irrigation interval	Hydrogel	Weed control treatments					
		W_1	W_2	W_3	W_1	W_2	W_3
		Rice dry weight					
			2020			**2021**	
I_1	Without	1243.2 b	917.4 d	218.9 k	1395.2 b	1069.4 d	293.4 kl
	Hydrogel	1309.1 a	1068.3 c	261.5 j	1461.1 a	1220.3 c	318.1 k
I_2	Without	790.4 e	675.5 f	163.7 l	942.4 e	827.5 f	217.5 m
	Hydrogel	917.9 d	811.4 e	197.7 kl	1069.9 d	963.4 e	247.8 lm
I_3	Without	410.5 h	361.9 i	96.2 n	510.8 h	378.8 j	117.9 n
	Hydrogel	561.9 g	417.3 h	147.1 m	612.2 g	456.3 i	220.8 m
		Number of panicles					
			2020			**2021**	
I_1	Without	517.3 ab	432.0 c	160.0 h	554.7 ab	485.3 c	181.3 i
	Hydrogel	538.7 a	496.0 b	181.3 h	576.0 a	538.7 b	213.3 h
I_2	Without	346.7 d	320.0 def	96.0 i	384.0 e	357.3 e	112.0 k
	Hydrogel	416.0 c	325.3 def	144.0 h	448.0 d	362.7 e	149.3 j
I_3	Without	298.7 ef	256.0 g	48.0 j	330.7 f	288.0 g	69.3 l
	Hydrogel	336.0 de	293.3 f	101.3 i	368.0 e	325.3 f	117.3 k
		Grain yield					
			2020			**2021**	
I_1	Without	9.517 a	8.260 c	1.117.k	9.990 a	8.507 c	1.390 l
	Hydrogel	9.883 a	8.713 b	1.667 j	10.333 a	9.230 b	2.090 k
I_2	Without	5.583 f	4.920 g	0.730 kl	6.523 f	5.330 g	0.940 lm
	Hydrogel	7.247 d	6.333 e	1.077 k	8.017 d	7.013 e	1.290 l
I_3	Without	3.883 h	3.190 i	0.330 l	4.117 i	3.013 j	0.503 m
	Hydrogel	4.797 g	4.200 h	0.713 kl	5.070 gh	4.700 h	0.927 lm

Means fb a common letter within a season for every trait are not significantly differed at 5% level, using DMRT

Table 13. Water productivity (kg / m^3) as influenced by irrigation intervals, soil conditioners and weed control treatments

Irrigation intervals	5 Days		10 Days		15 Days		Mean
conditioner	Hydrogel	Without hydrogel	Hydrogel	Without hydrogel	Hydrogel	Without hydrogel	
Weed treatments	**2020**						
W_1	0.74 a	0.60 c	0.75 a	0.48 e	0.55 d	0.39 f	0.59 a
W_2	0.65 b	0.52 de	0.65 b	0.42 f	0.48 e	0.32 g	0.51 b
W_3	0.12 h	0.08 hi	0.11 hi	0.07 ij	0.08hi	0.03 j	0.08 c
Mean	**I_1 = 0.45 a**		**I_2= 0.41 b**		**I_3 =0.31 c**		
	Hydrogel = 0.46 a			**Without hydrogel = 0.32 b**			
	2021						
W_1	0.74 b	0.62 d	0.80 a	0.54 ef	0.57 e	0.40 h	0.61 a
W_2	0.66 c	0.53 f	0.69 c	0.44g	0.53 f	0.29 i	0.52 b
W_3	0.15 j	0.09 klm	0.13 jk	0.08 lm	0.11 kl	0.05 m	0.10 c
Mean	**I_1 = 0.46 a**		**I_2= 0.45 b**		**I_3 = 0.32 c**		
	Hydrogel = 0.49 a			**Without hydrogel = 0.34 b**			

Means fb a common letter within a season are not significantly differed at 5% level, using DMRT

4. CONCLUSION

Irrigation every 5-days (I_1) x application of hydrogel polymer at rate of 20 kg ha^{-1} x sequential application of thiobencarb 50% *fb* bispyribac-sodium 2% + halosulfuron-methyl 75% at recommended doses (W_1) recorded the best weed control and produced highest grain yield (10.108 t ha^{-1}). Under water deficit, irrigation water productivity could be improved by irrigation every 10-days (I_2) with adding hydrogel polymer and treated with treated with sequential application of W_1 produced the highest irrigation water productivity of rice (0.78 kg m^{-3}) and increased rice grain yield by 20.7% under the same conditions without hydrogel as mean of the two growing season.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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