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EFFECT OF PLANT DENSITY, HUMIC ACID AND WEED MANAGEMENTS ON YIELD, YIELD COMPONENTS AND WATER USE EFFICIENCY IN DIRECT-SEEDED RICE (*Oryza Sativa*) PRODUCTION

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ABSTRACT

Rice is the most important crop after wheat in Iran. Since direct seeded rice cultivation has recently started in Golestan province and complete information about the effect of weed management, plant density and humic acid on rice grain yield and yield components as well as water use efficiency is not available, these issues have been investigated in this study. Therefore a study was carried out on direct-seeded rice cultivation (cv. Tarom Hashemi) in the cropping years 2018 and 2019 in Gonbad Agricultural Research Station as a split-factorial experiment based on randomized complete block design with three replications. Plant density (plant distance on row) was considered as the main factor (5, 10, 15 and 20 cm), and combination of humic acid consumption (consumption of humic acid, non-consumption of humic acid) and weeds management (control, chemical management and weeding) were considered as sub plots. The results showed that the effect of year on panicle length, number of seeds per panicle, paddy protein and water use efficiency was significant. Also, the effect of humic acid, plant distance on row and type of weeds management on all studied traits including plant height, panicle length, number of fertile tillers per hill, number of grains per panicle, paddy yield, biological yield, harvest index, paddy protein and water use efficiency were significant. Also, the highest paddy yield, biological yield, harvest index and water use efficiency were obtained from plant distance on row 5 cm under humic acid consumption or chemical management and weeding, but the amount of paddy protein was higher in the plant distance on row 10 cm.

Keywords: biological yield, direct-seeded rice, number of grains per panicle, paddy protein, paddy yield.

INTRODUCTION

Rice (*Oryza sativa* L.) can undoubtedly be named the most important crop in the world if the human population of the planet is considered as an indicator of the degree of dependence on a crop to supply their food. The International Rice Research Institute (IRRI) claims that one-third of the world's population obtains about half of their daily energy from rice consumption (Zimdahl, 2004). Rice is the most important crop after wheat in Iran. The transition from transplanting rice to direct-seeded rice production in Iran, especially Golestan province, has done in a short time. On the one hand, water reserves reduction and shortages of water for irrigation, and on the other hand, increasing labor costs have encouraged farmers to produce direct-seeded rice. Despite the emphasis of many researchers on the advantages of direct-seeded rice cultivation, it has not yet gained public acceptance (Farooq et al., 2011). In direct seeded rice cultivation, weed intensity is higher than transplanted-flooded rice cultivation because the weeds emerge at the same time as the rice and the required water level to control the weeds is not the same as transplanted-flooded rice cultivation method

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and there is a risk for rice grain yield reduction very serious due to weeds competition (Chauhan and Johnson, 2010). Thus, weeds should be considered as a major obstacle to the success of direct seeded rice cultivation (Singh et al., 2008). Annual application of Pendimethalin herbicide at the rate of 750-1000 g/ha effectively reduced the density and dry matter (82-86%) of all weeds in direct seeded rice cultivation (Jat et al., 2019). Mahajan and Chauhan (2013) also reported that continuous application of Pendimethalin at a rate of 1000 g/ha as herbicide before emergence, and 25-30 g/ha of the active ingredient bispyribac-sodium (Nominee herbicide) after emergence effectively controlled various types of weeds in direct seeded rice cultivation. Walia et al. (2008) also reported that the application of 750 g/ha Pendimethalin herbicide as the herbicide before emergence and bispyribac-sodium 25 g of the active substance after emergence of weeds effectively controlled the weeds, and rice grain yield increased up to 307% compared to conditions without weed controls in direct seeded rice cultivation.

Selecting the appropriate density plays an important role in increasing crop yields. At low densities, plants tend to deliver most of the produced biomass to reproductive organs (Kleunen et al., 2001; Weiner, 2004), whereas at high densities plants tend to transfer more nutrients to vegetative organs (Weiner, 2004). In one hand, relative access to resources such as water, space, and nutrients decreases as plant density increases, leading to reduced biomass and grain yield of single plant (Li-chao et al., 2018). On the other hand, increasing the number of plants per square meter increases the number of panicles per square meter and very little affects the number of seeds per panicle (Qun et al., 2020). Therefore, Houa et al. (2019) by studying the optimum density in transplanted-flooded rice reported that the density of 210000 to 270000 hills per hectare significantly increased rice grain yield under normal conditions of nitrogen consumption, which is one of the main reasons was increasing the leaf area index, followed by an increase in radation absorption coefficient. Also, increasing the density to 270000 hills per hectare along with 165 kg N/ha due to increasing radiation absorption coefficient and nitrogen use efficiency, had the highest rice grain yield. Higher density induces fewer tillers per plant and eventually fewer seeds per panicle, but seed weight remains unchanged, so that from a density of 5 to 100 plants per square meter, grain yield is mainly increases and increasing the density to more than 100 plants per square meter has no significant effect on increasing rice grain yield (Nakano et al., 2012). Clerget et al. (2016) by investigation the effect of plant density on rice grain yield found that the average grain yield ranged from 6.7-6.8 t/ha at 6 to 10 cm plant distance on row, and grain yield decreased significantly (5.9 t/ha) at 20 cm plant distance on row, because panicle density decreased by up to 20% compared to closer distances. This decrease in panicle density was due to a decrease in the number of tillers/m^2. In one study, it was reported that 20 cm plant distance on row had a higher grain yield than 30 cm, which seems to be depend on the type of cultivar, climatic and soil conditions and the flora of weeds. Be different (Chauhan et al., 2011). Quang et al. (2004) by studying the interaction between crop density and herbicide showed that herbicide use efficiency increased due to proper crop density.

Humic acid (HA) as a type of biostimulants plays an important role in increasing plant growth. Various studies have shown that external consumption of humic acid increases the weight of shoots and roots (Rose et al., 2014), improves plant resistance to stress (Cimrin et al., 2010), cell membrane stability, maintaining the moisture absorption under osmotic stress conditions, potassium uptake, proteins and hormones synthesis, and elongation of root cells (Calvo et al., 2014; Aslam et al., 2016). Therefore, Liu et al. (2019) by examining the use of humic acid on grain maize yield in semi-saline areas found that the application of humic acid significantly increased the nitrogen, potassium and phosphorus uptake in maize roots and had a positive effect on the nitrogen concentration, available phosphorus and exchangeable potassium in the soil. It was also reported that humic acid had a very important role in maintaining the nutrient balance in maize roots by increasing the availability of nutrients in the soil, which can reduce the negative effects of semi-saline soils. In another study, Sebahattin and Necdet (2005) found that a concentration of 50 mg/l humic acid increased stem length from 20.9 to 51.5 cm. The use of humic acid promotes the shoot growth due to the enhance absorption of nitrogen, calcium, phosphorus, potassium, manganese, iron, zinc and copper elements (Harper et al., 2000).

Since direct seeded rice cultivation has recently started in Golestan province and complete information about the effect of weed management, plant density and humic acid on rice grain yield and yield components as well as water use efficiency is not available, these issues have been investigated in this study.

MATERIAL AND METHODS

Site description

This experiment was performed in Gonbad Agricultural Research Station during the months of May to September in 2018 and 2019. The research site was located at 37°16' N, 55°12' E, which is 45 m above sea level. Soil sampling was performed at several points from 0 to 30 cm depth of farm soil to determine the soil physical and chemical characteristics before and after the experiment. Then a composite sample was prepared by mixing the samples. Soil analysis was done in a soil science laboratory and is presented in Table 1. The most important characteristics of climate such as temperature, rainfall and relative humidity during 2018 and 2019 were presented in Table 2.

Table 1. Physico-chemical characteristics of the soil (0-30 cm)

Characteristics	Unit	2018	2019
EC	dS/m	1.19	1.21
pH	-	7.9	7.9
Total carbon	%	0.68	0.76
Total nitrogen	%	0.117	0.112
P	ppm	13.4	16.2
K	ppm	356	370
Clay	%	15	25
Loam	%	64	60
Sand	%	21	15

Table 2. Climatically data at Agricultural Research Station of Gonbad during the years 2018 and 2019

Month	Precipitation (mm)		Mean of maximum temperature (°C)		Mean of minimum temperature (°C)	
Year	2018	2019	2018	2019	2018	2019
20 April-20 May	23.5	41.5	27.1	28.2	14.1	13.5
21 May-20 June	10.5	6.3	31.8	36.3	19.7	20.1
21 June-21 July	0.2	7.1	41.2	36.9	24.6	24.6
22 July-21 August	7.1	8.3	37.8	36	25.1	23
22 Agusut-21 September	2	12	35.1	33.1	20.4	19.7

Characteristics of design and experimental treatments

The experiment was conducted as a split plot-factorial in the form of a randomized complete block design with three replications, each replication consisting of 20 experimental plots. The selected cultivar was Tarom Hashemi. Plant density (plant distance on row) as the main factor with 4 levels (5, 10, 15 and 20 cm), combination of humic acid treatments at 2 levels (humic acid consumption, humic acid non-consumption) and weed managements at 3 levels (control, chemical management and weeding) were considered as sub-factors. Humic acid with a concentration of 250 ml/ha was added in three stages: 1: tillering (4-6 leaves); 2: stem elongation (20-30 days after tillering); 3: Before panicle initiation: 50% of the field had panicles. Herbicides also include bispyribac-sodium (Nominee herbicide) at a rate of 250 ml/ha and Pendimethalin at a rate of 3-4.5 l/ha which was used as a post-emergence and pre-emergence, respectively.

The soil was prepared by disking once prior to planting. Sowing was done manually in late May, so that first the furrow was created and the seeds were planted inside the furrows. The desired densities were created after the seedling emergence. The first irrigation was done after planting and irrigation was done during the growing season depending on the needs of the plant, other crop managements, such as fertilizers consumption was applied based on the soil testing and fertilizer recommendations, as well as control of pests and diseases according to common methods in the region. In this experiment, each subplot consisted of 8 rows with a spacing of 30 cm and a row length of 5 m.

At harvest time, 10 plants were randomly harvested from 2 middle rows to measure traits such as plant height, panicle length, number of fertile tillers, number of seeds per spike, 1000-grain weight, grain yield, biological yield and harvest index.

In order to determine the amount of grain protein, a Micro Kjeldahl device was used. In the next step, the percentage of nitrogen obtained was multiplied by 6.25 and the percentage of protein was obtained.

To evaluate water use efficiency, the amount of water consumed was first measured by water flow during the growing season. After that, using the following formula, the water use efficiency was calculated separately for each experimental plot.

Water use efficiency = grain yield/volume of water consumption.

In which the paddy yield of is terms of in kilograms per hectare and volume of water consumption is in terms of cubic meters per hectare (Kiani, 2015).

Data analysis

The obtained data were analyzed after field and laboratory experiments. Data were first entered into Excel spread sheet and then analyzed using SAS software (SAS Institute, 2007). Mean comparisons were performed based on LSD test at 5% level. Graphs were also drawn using Excel spread sheet.

RESULTS AND DISCUSSION

Plant height and panicle length

Based on the results, plant height was statistically affected by plant distance on row, humic acid and weed management types, but the effect of year was not significant. The interactions of plant distance on row × humic acid, year × plant distance on row and year × plant distance on row × humic acid were also significant (Table 3). The results of mean comparisons showed that the plant height in 5, 10 and 15 cm plant distance on row was 8.86, 10.68 and 9.45% higher than 20 cm plant distance on row, respectively, and was statistically significant. Also, humic acid consumption increased the plant height 4% in compared to not using it. Also, lack of weed managements (control treatment) caused a significant reduction in plant height with 6 and 4% compared to chemical management and weeding treatments (Table 3). The results of interactions of plant spacing on row × humic acid show that plant spacing on rows 5, 10 and 15 cm with humic acid consumption showed the highest plant height compared to other treatments (Table 4). Also, only 20 cm plant distance on row compared to other plant distance on row treatments had the lowest plant height at the first and second year (Table 4). There are several reports that increase the plant density increases rice height (Bozorgi et al., 2011; Mobasser et al., 2007; Ahmad et al., 2005; Maske et al., 1997). Vanitha and Mohandass (2014) found that by adding humic acid to direct seeded rice, plant height increased by 9%. They stated that humic acid can be absorbed by the roots and transported to the shoots, which in turn will increase plant growth. Sani (2014) also found that by adding humic acid in the stages of stem elongation, flowering and silique formation, canola stem height increased by 30% compared to humic acid non-consumption. Khang (2011) obtained similar results.

The results confirm that the effect of year on panicle length was significant so that panicle length in the second year was 14% higher than the first year (Table 4). Also, 5 and 15 cm plant distance on rows had longer panicle length than 10 and 20 cm (Table 4). Consumption of humic acid compared to non-consumption caused 4% increase in the panicle length, which was statistically significant (Table 4). On the other hand, weeds chemical management treatment had the highest and control treatment had the lowest panicle length (Table 4). As can be seen from Table 6, the highest panicle height was obtained in the treatment of humic acid consumption with weeds chemical management, which showed a significant difference with other treatments.

Table 3. Biennial analysis of variance (mean squares) effects of plant distance on row, type of weed managements and humic acid consumption on grain yield and yield components

	df	Plant height	Panicle length	No. of fertile tillers per plant	No. of grain per panicle	1000-grain weight	Paddy yield	Biological yield	Harvest index	Paddy protein (%)	Water use efficiency
Year (Y)	1	60.22ns	448.27**	41.95**	2140.21**	1.76ns	286388ns	1446623ns	0.30ns	0.97**	0.005**
Replication	4	40.78ns	1.44ns	2.91ns	17.54ns	1.57ns	44133ns	309676ns	1.40ns	0.007ns	0.0009ns
Plant distance on row (A)	3	678.18**	17.65**	89.26**	4077.67**	41.21**	16894561**	83466614**	52.58**	12.88**	0.297**
Humic acid (B)	1	444.65**	32.73**	22.30**	4937.05**	21.39**	15074524**	68219667**	49.21**	6.86**	0.267**
Weed control (C)	2	271.79**	258.81**	109.74**	412**	82.31**	21416805**	134914234**	102.82**	0.48**	0.046**
A×B	3	123.81**	0.13ns	0.22ns	75.18**	1.05ns	191894ns	189720ns	8.52**	2.95**	0.503**
A×C	6	9.22ns	3.59ns	1.12ns	4.39ns	2.34ns	460774**	2156999**	0.38ns	0.07ns	0.008**
B×C	2	61.28ns	15.99*	0.11ns	54.78*	10.06**	1437958**	5476153**	8.09**	0.1ns	0.02**
Y×A	3	80.57*	7.67ns	0.83ns	803.32**	3.39ns	28238ns	351027ns	1.77ns	0.313	0.003ns
Y×B	1	33.56ns	92.53ns	0.81ns	0.55ns	0.77ns	135317ns	1168020ns	0.75ns	0.12ns	0.002ns
Y×C	2	11.29ns	21.34ns	0.19ns	2.59ns	2.55ns	17938ns	102320ns	0.03ns	0.06ns	0.0004ns
Y×B×C	2	23.27ns	2.72ns	0.59ns	6.07ns	0.68ns	10833ns	45522ns	0.07ns	0.005ns	0.0002ns
Y×A×C	6	9.35ns	3.48ns	0.16ns	7.39ns	0.17ns	25698ns	300207ns	0.89ns	0.9ns	0.0004ns
Y×A×B	3	81.2*	9.09*	0.70ns	107.36**	0.72ns	6680ns	19198ns	1.2ns	0.06ns	0.0001ns
Y×A×B×C	12	14.73ns	1.29ns	0.43ns	5.49ns	0.38ns	58781ns	392255ns	0.44ns	0.177ns	0.001ns
Error	-	22.01	3.32	1.40	11.97	2.01	36825	275308	1.36	0.075	0.0006
CV (%)	-	5.46	7.90	10.60	3.32	8.21	5.51	5.29	2.95	4.02	5.64

Table 4. Comparisons of biennial mean effects of plant distance on row, type of weed managements and humic acid consumption on grain yield and yield components

Treatments	Plant height (cm)	Panicle length (cm)	No. of fertile tillers per plant	No. of grain per panicle	1000-grain weight (gr)	Paddy yield (kg/ha)	Biological yield (kg/ha)	Harvest index	Paddy protein (%)	Water use efficiency (kg/m^3)
Year										
First	85.28a	21.27b	10.63b	100.09b	17.41a	3437a	8834a	38.58a	6.90a	0.46a
Second	86.52a	24.79a	11.71a	107.81a	17.19a	3526a	9034a	38.66a	6.72b	0.47a
Plant distance on row										
5	87.25a	23.71a	9.46d	89.19d	16.43c	4030a	10035a	39.89a	7.06b	0.54a
10	89.03a	22.84bc	10.64d	107.95b	17.94b	3750b	9443b	38.97b	7.54a	0.52b
15	87.94a	23.44ab	11.34b	114.23a	18.73a	3479c	8995c	38.51c	6.19d	0.46c
20	79.52b	22.13b	13.23a	104.39b	16.52c	2516d	6762d	37.01d	6.45c	0.35d
Humic acid										
Consumption	87.69a	23.51a	11.56a	109.80	17.68a	3805a	9622a	39.19a	7.02a	0.51a
Non-consumption	84.81b	22.56b	10.58b	98.09b	16.91b	3158b	8246b	38.03b	6.60b	0.42b
Weed management type										
Chemical	88.04a	24.98a	12.25a	105.71a	18.27a	3939a	9934a	39.69a	6.80a	0.52a
Weeding	86.37a	23.82b	11.82a	105.56a	17.82a	3912a	9869a	39.19b	6.90a	0.52a
Control	83.42b	20.46c	9.44b	100.56b	15.81b	2593b	6998b	36.94c	6.8a	0.34b

In each column and for each treatment, numbers with similar letters do not differ significantly at the 5% level based on the LSD test.

Number of fertile tillers per hill

According to the findings, the effect of the year on the number of fertile tillers per hill was significant, so that it increased by 9% in the second year. The highest number of fertile tillers per hill was obtained in 20 cm plant distance on row (22.13), which reduced with decreasing plant distance on row, so that 14.28, 19.57 and 28.49% were reduced in 15, 10 and 5 cm plant distance on row treatments compared to 20 cm, respectively (Table 4). Consumption of humic acid also significantly reduced the number of fertile tillers per plant by 8.47% compared to not consuming it. The results also revealed that weeds chemical management and weeding treatments did not differ significantly in terms of the number of fertile tillers per hill, but the control treatment had a lower number of fertile tillers (12.25 and 11.82 vs. 9.44) than the two mentioned treatments (Table 4). Grain yield in cereals depends on the number of fertile tillers per unit area, which is one of the most important morpho-physiological traits in rice grain yield (Tao et al., 2006). In a study on direct seeded rice, the number of tillers per plant increased from 8 to 10.3 and 19.2, by increasing the plant distance on row from 6 to 10 and 20 cm, respectively (Clerget et al., 2016). Some researchers have stated that the radiation use efficiency is increased and also the time to reach 50% of pollination is delayed by reducing plant density per square meter due to creating more space and higher nitrogen content in shoots. Also, the time to reach 50% of pollination is delayed and increases the light absorption period before pollination, which in turn increases the number of fertile tillers (Whaley et al., 2000; Fischer et al., 2019). Feng et al. (2000) also found that the number of fertile tillers increased with increasing rice density. The results of the present study showed that the number of fertile tillers in the second year was higher than the first year, which can be attributed to better conditions for rice seedling emergence and also higher leaf area durability in the second year than the first year, which leads to greater tillers survival.

Yield and yield components of rice paddy

The results showed that the effect of year on number of seeds per panicle was significant, so that it was greater 7.16% in the second year compared to the first year (Table 4). The highest and lowest number of seeds per panicle were obtained in 15 and 5 cm plant distance on rows, which showed a significant difference with other treatments (Table 4). Consumption of humic acid also caused 10.66% increase in the number of seeds per panicle (Table 4). The findings also indicated that weeding or use of chemical pesticides on the number of seeds per panicle was not significant but showed a significant difference with the control treatment (Table 4). The mean comparison interactions revealed that the highest number of seeds per panicle was obtained in the combination of humic acid consumption × 15 cm plant distance on row, second year × 15 cm plant distance on row and second year × humic acid consumption × 15 cm plant distance on row that they showed a significant difference with other treatments (Tables 5, 6, 7, 8). The results showed that the 1000-grain weight was not affected by the effect of the year. The highest 1000-grain weight was obtained at 15 cm plant distance on row, which showed a statistically significant difference with other treatments. After that, 10 cm plant distance on row was observed. 5 and 20 cm plant distance on row also showed the lowest 1000-seed weight, which were included in a statistical group. Consumption of humic acid also caused 5% and significant increase in 1000-grain weight of rice (Table 4). The results of mean comparisons indicate that the highest 1000-grain weight was obtained in the combination of humic acid consumption and weeds chemical management treatments, which showed a significant difference with other treatments (Table 6). The results indicated that the effect of year on paddy yield, biological yield and harvest index was not significant (Table 3). Also, the highest amount of paddy yield, biological yield and harvest index were obtained at 5 cm plant distance on row, which showed a significant difference with other treatments (Table 4). The results showed that the paddy yield of rice decreased significantly by increasing the plant distance on row from 5 to 20 cm, so that the paddy yield of rice in 10, 15 and 20 cm plant distance on row, 7, 14 and 37% reduced compared to 5 cm plant distance on row, respectively (Table 4). This trend was also observed for biological yield and harvest index, so that, biological yield decreased by 6, 10 and 32% by increasing the plant distance on row from 5 to 10 and 20 cm, respectively. Therefore, the harvest index decreased by 2.3, 3.45, and 7.21%, respectively (Table 4). Mean comparison interactions indicated that the highest harvest index was obtained in the treatment combinations of humic acid consumption × 5 cm plant distance on row (Table 5). Also, the highest amount of rice paddy yield, biological yield and harvest index were observed in the treatment combinations of humic acid × chemical management and humic acid × weeding, which indicated a significant difference with other treatment combinations (Table 6). Weeding or chemical management along with 5 and 10 cm plant distance on row had the highest rice paddy yield and biological yield, which showed a significant difference with other combinations of treatments (Table 7). Xian-qing et al. (2009) stated that increasing plant density in hybrid rice caused to decrease in grain yield. In the present study, despite the higher number of fertile tillers per plant in 20 cm plant distance on row, the yield was significantly different from other plant distance on row treatments. One of the reasons is the lack of compensation for paddy yield due to the reduction in the number of grains per panicle in more row distances, which was also confirmed by Clerget et al. (2016). They found that grain yield at 6 and 10 cm plant distance on row compared to 20 cm showed a significant decrease due to the lower number of grains per panicle. In another study some researchers found that increasing rice density decreased tiller number and 1000-grain weight but increased biological yield and number of panicles, resulting in reduced rice paddy yield (Amin et al., 2004). Humic acid contains cytokines and its consumption leads to increased levels of cytokines and external auxin, which ultimately increases crop yields (Osman et al., 2013). This could explain the increase in paddy yield by consuming humic acid compared to humic acid non-consumption in the present study. In this regard, it has been reported that the use of humic acid in rice cultivation increased rice yield by 16.12% compared to its non-consumption (Mehdiniya Afra et al., 2017). On the other hand, with the addition of humic acid, the rate of biological yield and grain yield of corn showed a significant increase, so that grain setting and grain filling are very important stages that depend on the size of the source and sink of plants (Tsimba et al., 2013). Humic acid affects the number of root branches and root length, which in turn increases shoot growth and biological yield (Fahramand et al., 2014). In a study using humic acid, wheat yield increased by 24% compared to non-consumption. However, the use of humic acid without the use of any chemical fertilizers, especially nitrogen fertilizers, will not lead to good grain yield (Delfine et al., 2005).

Table 5. Comparisons of biennial mean interactions of plant distance on row and humic acid consumption on number of grains per spike, harvest index, grain protein and WUE

Humic acid	Plant distance on row	Plant height (cm)	No. of grain per panicle	Harvest index	Paddy protein (%)	Water use efficiency (kg/m^3)
Consumption	5	90.59a	94.28e	41.04a	7.14c	0.59a
	10	91.49a	115.11b	39.30b	7.39b	0.56b
	15	90.08a	121.21a	38.62bc	6.67e	0.49c
	20	78.60d	109.59c	37.82bc	6.89e	0.37f
Non-consumption	5	83.91bc	84.10f	38.72bc	6.98cd	0.48cd
	10	86.57b	100.81d	38.8bc	7.63a	0.47d
	15	85.79b	107.26c	38.38bc	5.71g	0.43e
	20	80.43cd	100.19d	36.2d	6.02f	0.29g

In each column and for each treatment, numbers with similar letters do not differ significantly at the 5% level based on the LSD test.

Table 6. Comparisons of biennial mean interactions of humic acid and type of weed management on grain yield and yield components

Humic acid	Weed management type	Panicle length (cm)	No. of grain per panicle	1000-grain weight (gr)	Paddy yield (kg/ha)	Biological yield (kg/ha)	Harvest index	Water use efficiency (kg/m^3)
Consumption	Chemical	26.11a	112.79a	19.14a	4387a	10746a	40.37a	0.58a
	Weeding	23.87b	110.8ab	17.78b	4309a	10824a	39.69a	0.57a
	Control	20.68c	105.8bc	16.12c	2719c	7297c	37.18c	0.46b
Non-consumption	Chemical	23.84b	98.62d	17.39b	3491b	8993b	38.66c	0.46b
	Weeding	23.58b	100.32cd	17.85b	3515b	9044b	38.71c	0.47b
	Control	20.25c	95.32d	15.49c	2467c	6700c	37.72d	0.33c

In each column and for each treatment, numbers with similar letters do not differ significantly at the 5% level based on the LSD test.

Table 7. Comparisons of biennial mean interactions of humic acid and plant distance on row on grain yield, biological yield and WUE

Weed management type	Plant distance on row	Paddy yield (kg/ha)	Biological yield (kg/ha)	WUE (kg/m^3)
Chemical	5	4506a	10932a	0.59a
	10	4444a	1112a	0.59a
	15	3984b	10042b	0.53c
	20	2823cd	7391c	0.37de
Weeding	5	4626a	11430a	0.61a
	10	4376a	11040a	0.58b
	15	3850b	9819b	0.51c
	20	2797cd	7746c	0.37e
Control	5	2958c	7745c	0.39d
	10	2881cd	7679c	0.38de
	15	2605d	7125c	0.35f
	20	1929e	5446d	0.26g

In each column and for each treatment, numbers with similar letters do not differ significantly at the 5% level based on the LSD test.

Table 8. Comparisons of biennial average interactions of plant distance on row and year on plant height, number of grains per grain and paddy protein

Year	Plant distance on row	Plant height (cm)	No. of grain per panicle	Paddy protein (%)
First	5	88.44ab	90.35e	7.09b
	10	88.91ab	105.8bc	7.49a
	15	85.74b	104.16cd	6.36c
	20	78.05c	100.05d	6.60c
Second	5	86.06b	88.03e	7.03b
	10	89.15ab	110.12b	7.54a
	15	90.13a	124.31a	6.01e
	20	80.98c	108.73bc	6.30cd

In each column and for each treatment, numbers with similar letters do not differ significantly at the 5% level based on the LSD test.

Paddy protein

The results showed that the percentage of paddy protein was affected by the year so that the first year showed a higher percentage of paddy protein than the second year (6.9 vs. 6.72). The highest percentage of paddy protein was obtained in the row spacing of 10 cm, followed by 5, 20 and 15 cm plant distance on row, which were significantly different from each other (Table 4).

Consumption of humic acid also caused a significant 6% increase in paddy protein (Table 4), but weed management types had no significant effect on increasing or decreasing the percentage of paddy protein (Table 4). The results of mean comparison interactions showed that the highest percentage of paddy protein was obtained in the treatment combinations of non-consumption of humic acid × 10 cm plant distance on row (Table 5). On the other hand, 10 cm plant distance on row indicated the highest percentage of paddy protein, which was significantly different from other treatment combinations in both years (Table 8). Research on humic acid consumption in maize has shown that the higher protein yield by humic acid consumption may have been due to increased access to minerals. Also, wheat grain protein content and protein yield can be increased by replacing organic nutritional sources with chemical sources (Sarwar et al., 2009). In another study, the effect of humic acid on the yield protein of chickpea was shown to have a significant effect (Nakhzari Moghadam et al., 2013).

Water use efficiency (WUE)

The results showed that the effect of WUE was not significant in both years (Table 3). Also, 5 cm and humic acid consumption increased WUE, which showed a significant difference with other treatments, so that by increasing 5 to 10, 15 and 20 cm plant distance on row, the WUE decreased by 4, 14.81, and 35.18%, respectively. Also, consumption of humic acid increased WUE by 17.64% (Table 4). The results of mean comparisons indicated that the humic acid consumption along with 5 cm plant distance on row had the highest WUE, which showed a significant difference with other treatment combinations. Also, the lowest WUE was observed with no consumption of humic acid along with 20 cm plant distance on row (Table 5). The interactions results of humic acid × type of weed management showed that chemical control with and 5 and 10 cm plant distance on row, and weeding with 5 cm plant distance on row had the highest WUE (Table 6). In the studies of Mehdinyia Afra et al. (2019) reported that the consumption of humic acid can be effective in increasing the WUE by increasing the access of plants to nutrients.

CONCLUSIONS

Increasing the plant distance on row increased the number of fertile tillers per hill and the number of grains per panicle, but did not increase paddy yield. Because these traits could not compensate the fewer number of plants per square meter. Although 5 cm plant distance on row had the lowest number of fertile tillers per hill and the number of grains per panicle, but the higher density and number of plants per square meter could compensate these traits and the highest yield of paddy, followed by biological yield, Harvest index and water use efficiency. The results also indicated that the humic acid consumption increased the paddy yield.

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