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EFFECT OF BIOCHAR ON YIELD, YIELD COMPONENTS, AND MACRONUTRIENTS OF RICE (*Oryza sativa* L.)

Alireza Nosrati Falahkar[1], Hamid Reza Doroudian[2*], Sirous Bidarigh[2], Seyyed Mostafa Sadeghi[2], Majid Ashouri[2]

[1]PhD student of Agronomy, Department of Agronomy and Plant Breeding, Lahijan branch,
Islamic Azad University, Lahijan, Iran

[2]Department of Agronomy and Plant Breeding, Lahijan branch, Islamic Azad University, Lahijan, Iran

[*]Corresponding author. E-mail: darya717@yahoo.com

ABSTRACT

Biochar has recently caught researchers' attention due to its potential of improving soil fertility and immobilizing pollutants and its emergence as a proper method of increasing crop yields. An experiment was conducted on the effect of chemical, ecological, and organic (biochar and compost) nutritional systems on yield and yield components of rice as a split-plot field experiment based on a randomized complete block design with three replications in two sites in Lahijan in 2018-2019. The experimental factors included nutrition at three levels (ecological, chemical, and control) as the main plot and the organic matter at four levels (urban waste compost, biochar, Azolla, and control) as the sub-plot. The combined application of chemical and organic fertilizers produced the highest grain yield, reflecting the positive effect of their combination on grain yield and yield components of rice cv. 'Hashemi'. The results showed that the highest grain yield of 3699 kg ha-1 was related to the treatment of chemical fertilizer and biochar and the lowest (2209 kg ha^{-1}, i.e., a 40% decline) to the control (no chemical or biological fertilizer application). The highest number of fertile tillers and panicles per plant was obtained from the application of chemical fertilizer and biochar, the highest number of filled grains per panicle (116 grains) was observed in the application of chemical fertilizer and biochar at the university farm, and the lowest (84 grains) from the control (unfertilized treatment) at the Kateshal farm. The nutrient uptake was significantly higher in the chemical and biochar treatment than in the other treatments. Organic systems had varying impacts on rice yield and reduced the application of chemical fertilizers. Biochar contributed to increasing the growth, yield, and nutrient uptake of rice plants.

Keywords: biochar, chemical fertilization, rice, yield.

INTRODUCTION

Rice is a staple and valuable grain that is the main source of food for over 50 percent of the world population after wheat (Jabran and Chauhan 2015; Lopez et al., 2019). Rice production should increase by over 50 percent by 2050, which can be realized by improving its cultivars and applying sound agronomic management practices (Esfahani et al., 2005; Asadi et al., 2016). Nitrogen (N) is a key macroelement that is decisive for plants, but it is deficient in most farms. N fertilizer is applied chemically, organically, and biologically (Moslehi et al. 2016). The nutrient limitation at vegetative growth reduces nutrient storage and finally decreases yields. Although the application of mineral fertilizers seems to be the fastest way of supplying soil fertility, concerns have been raised over the high costs of fertilizer application, as well as the pollution and degradation of the environment and water and soil resources, and even the loss of yields (Pampolino et al., 2007; Hassegawa et al., 2008; Divsalar et al., 2011). Lives in different parts of the world have been influenced by numerous hazards, e.g., climate change, food poverty due to the decline in agriculture production, lack of water, fertilizer scarcity, and social and political turmoil. Practical solutions for alleviating these hazards in agriculture require implementing regional programs and subsequently, developing global paradigms.

An effective approach to improving environmental sustainability and management is to use renewable energies

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for greater productivity and stability of the environment. In this regard, the production of biochar (biological charcoal) from the biomass found in nature and its application in the agricultural biome can be a good way to minimize pressure on our surrounding environment (Lehmann and Joseph, 2009). Most organic matter and wastes, e.g., farm effluents, agriculture factory effluents, urban waste, manures, aquatic algae, aquatic plants, and so on, can be raw materials for biochar production (Woolf et al., 2010). The use of biochar in agriculture as a soil amendment has a very long history. The natives in Amazon purposefully applied charcoal and its burnt residues to their lands in the last centuries, which created fertile lands, came to be known as black lands. The carbon released from the biochar buried in the soils of this region most probably dates back to 1000 years ago or even more (Saiee et al., 2010). Studies show that despite infertile soils, semi-intensive agriculture has been performed in these regions over centuries since the black lands are rich. Biochar is applied in environmental management for soil structure improvement, waste management, alleviation of the risk of climate change, and energy generation. These factors alone or in combination can have socio-economic benefits in each region (Steiner et al., 2010). Biochar is a solid product produced by the pyrolysis process in limited oxygen supply or oxygen-free conditions and can be used for various purposes, e.g., waste management, climate change mitigation, energy generation, soil improvement, improvement of the efficiency of chemical fertilizers, handling some environmental pollutions, and greenhouse gas reduction. The pyrolysis process can be a good way for the management of sewage sludge when compared to the current methods (Huang et al., 2003; Khadem et al., 2017). Biochar increases plant yields by partially supplying the nutrient requirement of plants (Khadem et al., 2017). Sewage sludge or bio-solids are a by product of the wastewater treatment process. Biochar can also prevent N loss by reducing leaching (Lehmann and Joseph, 2009). In addition, researchers have shown that biochar can increase the potential of using phosphorous (P) and potassium (K) fertilizers (Lehmann, 2019). The present study aimed to study the effect of chemical, ecological, and organic nutritional systems on yield, yield components, and macronutrients of rice cv. ‘Hashemi’.

MATERIAL AND METHODS

The research was conducted as a factorial experiment based on a randomized complete block design with three replications at two sites at the experimental farm of Islami Azad University of Lahijan (the village of Tustan) and Kateshal farm in 2018-2019. The study site [Lat. 36°55' N, Long. 45°20' E (first location) and Lat. 37°21' N, Long. 50°18' E (second location)] has a temperate and humid climate with a 10-year mean annual precipitation of 1150 mm (Guilan Meteorological Quarterly, 2019). Table 1 presents the meteorological data of the region during the experiment. Before the experiment, the physical and chemical characteristics of the soil at the study site were measured in the laboratory of Water and Soil Department of Rice Research Center (Table 2). The experimental factors included ecological, chemical fertilizer, and control as the three levels of the first factor and urban waste compost, biochar, Azolla, and control as the four levels of the second factor.

Table 1. Meteorological data of the study area (2018)

Data/Month	April	May	June	July	August	September
Monthly temperature	13.7	18.5	22.3	27.5	26.7	23.9
Total monthly rainfall	20.3	22.5	60.4	70.8	107.8	20.5
Minimum monthly temperature	12.1	12.4	16.7	22	22.3	19.3
Maximum monthly temperature	15.3	24.6	28	33.1	31.2	30.3
Monthly wind speed	38	54	40	36	28.8	36

Table 2. Physicochemical properties of the field soil

Location	N (%)	K (mg kg^{-1})	P (mg kg^{-1})	pH	Organic matter (%)	EC (dS.m^{-1})	Soil texture
Kateshal farm	0.9	205	12.2	6.1	2.2	0.7	Clay loam
University farm	0.86	213	13.8	6.2	2.1	0.6	

The research farm was plowed three times - first in February, second in early May when the nursery was built, and third (puddling) when the rice seedlings were transplanted. The seeds were sown in a nursery under a plastic cover and were selectively transferred at the age of 25 days to the farm where they were transplanted at a spacing of 20 × 20 cm at a rate of one seedling per hill to achieve a density of 25 plants per unit area. The experimental units were 9 m^2 (the main plots were 3 × 3 m, the sub-plots were 3 × 1 m, and the sub-sub-plots were 1 × 1 m). During the growth period of the rice, rice stem-borers were controlled with diazinon (granular 5%) and the weeds were controlled by hand twice (first 15-20 days after transplanting and second 20-35 days after transplanting), as well as the chemical herbicide Butachlor (Ec 60%) (N-butoxymethyl-2-chloro2,6-diethylacetanilide) at a rate of 3 L/ha applied four days after transplanting. The experimental plots were fertilized with N from the urea source (46% N), K from the potassium sulfate source, and P from the superphosphate triple source as per the results of soil analysis. All (4 tons per hectare) biochar (prepared from plant biomass and agricultural waste; combination of forest trees of northern Iran as a soil conditioner) was mixed with the soil at a depth of 20 cm before planting. The ecological treatment was composed of 600 ducks.

The plant height was measured at two stages, i.e., 70 days after transplanting and at the physiological maturity stage for this 10 plants were selected from each plot (except for two longitudinal marginal rows and one traverse row as the margin), and the plant height was measured from the soil surface to the tip of the longest pedicle excluding the awns. To determine the grain yield, the plots were harvested at the physiological maturity stage after eliminating the margins (two marginal rows), and the grain yield was determined based on 15% moisture. For yield components, 16 hills were randomly selected from each plot, cut from the surface by hand, and subjected to the measurement of traits like the number of pedicles per unit area, the number of filled grains per pedicle, and the 1000-grain weight. To measure the macronutrient contents, the grains were first husked with a rubber roll husker (Satake, Japan) and then were whitened with an abrasive rice whitening machine (Satake, Japan) for 1.5 hours (Latifi, 2011). The macronutrients were then measured with the dry ashing method for which 2 g of the ground white rice seeds were placed in a china crucible and burned in an electric furnace at 550°C. The samples were then added with 10 mL of 2N hydrochloric acid and put in a hot bath at 100°C for 10 minutes. Next, they were infiltrated through Whatman grade-2 filter paper, and their volume was adjusted to 100 mL. Eventually, the N, P, and K contents were measured with an atomic absorption device (Emami, 1996).

Bartlett's test was applied to the data before combined analysis to ensure their normality and the uniformity of the variance of the experimental error. The analysis of variance (ANOVA) and the statistical calculations were all performed with SAS (ver. 9.1), and the means of the studied traits were compared by the least significant difference (LSD) test at the $P < 0.05$ level.

RESULTS AND DISCUSSION

The number of panicles per plant

The results of ANOVA showed that the interactions effects of the chemical, biological, and organic nutritional systems were significant ($P < 0.01$) on the number of panicles per plant (Table 3). Based on the comparison of mean data in both experimental farms (Figure 1), the treatment of chemical fertilization + biochar produced the most number of panicles per plant (28 panicles) and the control (unfertilized) treatment produced the least number (16 panicles, i.e., 43% fewer). The treatments that were fertilized with chemical N fertilizer produced more panicles per plant than the treatments that weren't. Among the sub-plots, the highest number of panicles per plant was related to the biochar treatments under no-fertilization, ecological, and chemical conditions, and the lowest number to the control (unfertilized treatment).

The positive effect of N on increasing panicles was related to its impact on increasing the number of fertile tillers per plant, which might have caused the increase in the number of panicles per plant. This is consistent with Bagayoko's (2012) report that N fertilization at the recommended rate increased the number of panicles per unit area by increasing the number of tillers per unit area. Akita (1989) states that panicle formation is influenced by N uptake and carbohydrate availability during the reproductive stage and that the higher N content of plant tissues improves panicle differentiation and the supply of photosynthates required for minimizing panicle fall during the reproductive phase. The increase in crop yields with N application may be associated with the increase in panicle number in grains (Kamkar et al., 2011). Similar to our findings, Maleki et al. (2010) reported that the application of chemical N fertilizer along with azotobacter biofertilizer increased the number of spikes in grains (553 spikes). In a study on the integrated effects of N fertilizers and organic compost on rice yield in two growing seasons, Zayed et al. (2013) revealed that the highest number of panicles per hill was obtained from the application of 165 kg ha^{-1} N fertilizer in the first year (15 panicles) and from the integrated application of 5 t/ha composted rice straw and 110 kg ha^{-1} N fertilizer in the second year (14 panicles), whereas the lowest number was related to the control or unfertilized conditions. Furthermore, they expressed that the integrated application of N fertilizer and composted rice straw increased the number of panicles per hill by increasing P availability to plants, maintaining soil fertility, and improving soil characteristics. In our research, chemical fertilizer and biochar increased the number of rice panicles per plant.

Table 3. Variance analysis of parameters measured in nutritional conditions and organic matter of Hashemi variety rice in two locations

S.O.V	df	The number of panicles per plant	Biological yield	The number of filled grains per panicle	Plant height	Grain yield	Thousand-grain weight	N content	K content	P content
Location	1	86.68	1636542	308.3	88.2	1031048	0.533	0.285	0.0078	0.0589
Location (Place)	2	90.18	204512	368.2	496.5	297206	5.73	0.0288	0.00066	0.0104
Nutrition	2	156.72**	10908539**	586.6**	3721.5**	3743759**	5.67	0.433**	0.0314*	0.033*
Organic matter	3	135*	4477254*	1504**	188.12*	1483582**	2.12	0.315*	0.0132*	0.022*
Location × Nutrition	4	0.305	67571.5	0.292	57.73	2793.6	1.35	0.00058	0.000016	0.00007
Error 1	8	0.212	5435.1	0.222	60.68	4608.3	0.011	0.00031	0.000044	0.00051
Location × Organic matter	6	0.236	63947.5	0.291	0.146	7471.5	0.826	0.00055	0.0000709	0.00046
Nutrition × Organic matter	6	19.05*	1106059**	60.62**	166.79*	134107.8**	1.19	0.0634**	0.0043*	0.0013*
Location × Nutrition × Organic matter	12	0.277	54189	0.29	0.621	2812	0.827	0.00044	0.000071	0.00068
Error 2	27	0.264	5513.6	0.236	54.63	4097.2	0.012	0.00031	0.000034	0.00061
CV (%)		2.56	1.06	1.5	3.34	2.28	1.43	1.28	1.09	2.79

*,** are significant at the level of 1 and 5 percent, respectively.

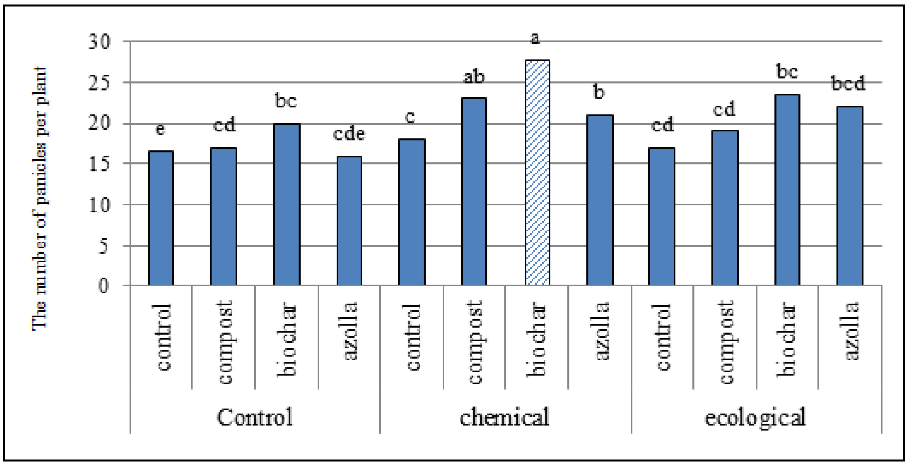

Figure 1. The interaction effect of nutrition systems and organic matter on the number of panicles per plant in two regions of Lahijan

Biological yield

As the results of ANOVA revealed, the biological yield was significantly ($P < 0.01$) influenced by the chemical, ecological, and organic nutritional systems (Table 3). Based on the comparison of means in both research farms (Figure 2), the highest biological yield was 8552 kg ha^{-1} obtained from the chemical fertilizer and biochar treatment and the lowest was 6201 kg ha^{-1} obtained from the control (unfertilized) treatment at the Kateshal farm. Indeed, the treatments that included chemical N fertilizer had the highest biological yield, and the inclusion of biochar in other treatments did not bring about any significant differences versus its non-application or the application of urban waste compost or Azolla.

It seems that when N is available to plants, their photosynthetic activities increase and their biological yield is escalated by vegetative growth (higher plant height, plant area, and tiller) and reproductive growth (higher grain yield). More N fertilizer application increases the total dry weight of the plant (Maleki et al., 2010). The higher N content of the straw in the treatments that received N fertilizer eventually increased the biological yield by increasing photosynthesis and shoot growth. Ashouri et al. (2012) reported that the highest biological yield was obtained from the integrated application of complete chemical fertilizer and organic supplements due to the increase in the number of tillers and plant height, which agrees with our results. In a study on the effects of manure and chemical fertilizers on rice yield, Gang et al. (2008) found that the total dry matter was significantly increased with the integrated application of complete chemical fertilizer and manure versus the application of either chemical fertilizers or manures.

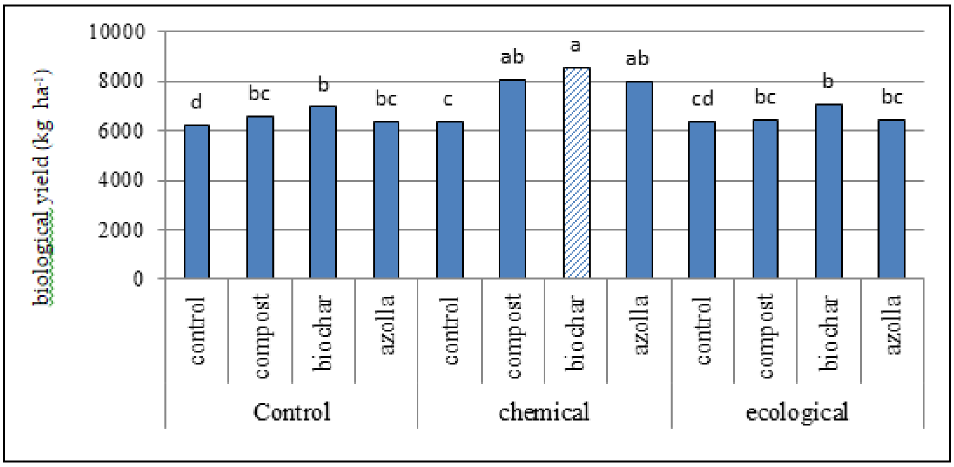

Figure 2. The interaction effect of nutrition systems and organic matter on biological yield in two regions of Lahijan

The number of filled grains per panicle

The results of ANOVA revealed that the interactions effects of chemical, ecological, and organic nutritional systems were significant ($P < 0.01$) on the number of filled grains per panicle (Table 3). The comparison of mean data in both research farms (Figure 3) showed that the highest number of filled grains per panicle (116 grains, on average) was obtained from the chemical fertilizer and biochar treatment and the lowest (84 grains) from the control (unfertilized). Among the sub-plots, the biochar treatment was the most effective and the control (unfertilized) was the least effective in this trait.

Liang and Xu Zhang (2013) state that as photosynthates decrease, the number of filled grains decreases and the process of grain filling is retarded. These researchers argue that the source capacity is the limiting factor of grain filling. It can, therefore, be said that post-flowering nutritional and photosynthesis conditions are of utmost importance for grain filling (Venkateswarlu, 1976). Maleki et al. (2010) reported that the concurrent application of N fertilizer and azotobacter increased the number of grains per spike significantly, which is consistent with our findings.

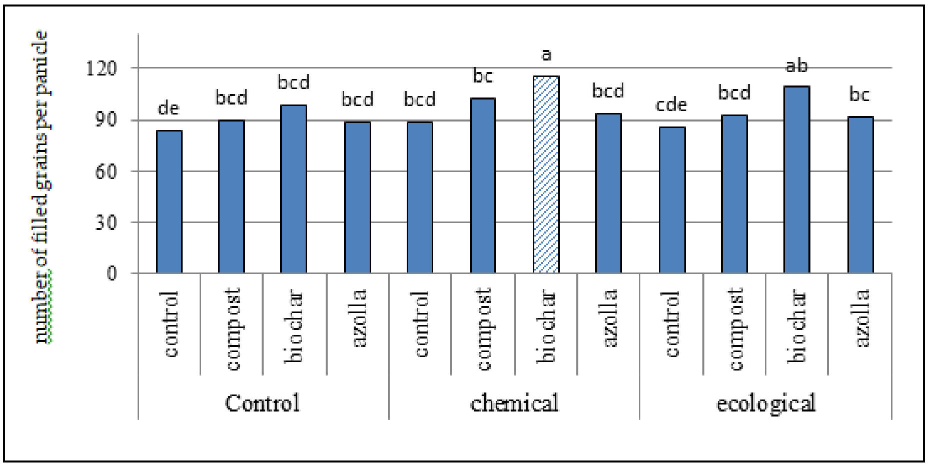

Figure 3. The interaction effect of nutrition systems and organic matter on number of filled grains per panicle in two regions of Lahijan

Plant height

The data on plant height at the physiological maturity stage showed that the effects of chemical and ecological systems were significant ($P < 0.01$) on plant height (Table 3). According to the comparison of mean data, the plant height was increased in the ecological and chemical fertilizer treatments. The plants treated chemically and ecologically in the presence of biochar were the tallest, growing to a height of 127 and 124 cm, respectively, whereas the lowest plant height was 108 cm related to the control (unfertilized plants). In fact, the chemical and ecological fertilizer treatments were related to taller plants than the treatments in which no ecological and/or chemical fertilizers were applied. The biochar treatment was the most and the control (unfertilized) treatment was the least effective sub-plots for the plant height.

The effect of chemical fertilizer on increasing the plant height can directly be related to the increase in N availability. Higher N availability increases plant height and crop growth rate (Fageria and Santos, 2008) whereas N deficiency results in the loss of plant height and tillering capacity in grains (Kamkar et al., 2011). The application of complete chemical fertilizer plus organic supplements increased the plant height of rice plants by improving the nutritional conditions and providing the nutrients required for plant growth (Ashoori et al., 2013). Organic fertilizer plays a special role in the synthesis and secretion of growth hormones, e.g., auxin and gibberellin, which improve plant growth and increase plant height along with N fixation (Kandil et al., 2004). Divasalar et al. (2011) reported that the highest plant height was obtained from the integrated application of organic fertilizer (Bio1555) and 100% chemical fertilizer in three rations. Other researchers (Yoseftabar, 2013; Tayefe et al. 2014) have reported that the plant height of rice plants was increased exponentially by increasing the N application level up to a certain level.

Grain yield

The simple effects of the chemical, ecological, and organic nutritional systems were found to be significant ($P < 0.01$) on grain yield (Table 3). Based on the comparison of data means for both research farms (Figure 4), the highest grain yield of, on average, 3699 kg ha^{-1}was obtained from the treatment of chemical fertilizer and biochar, and the lowest one of 2209 kg ha^{-1} (40% lower than its maximum counterpart) from the control (unfertilized) treatment.

When biochar was applied with chemical and/or ecological (duck) fertilizers, the plant yield was increased significantly, which was mainly related to the increase in the number of fertile tillers, the number of panicles per plant, the number of grains per panicle, and the number of filled grains per panicle. The application of complete chemical fertilizer with organic supplements increased photosynthesis activity and assimilate translocation from leaves to grains, thereby increasing final grain yield (Ashoori et al., 2013). In a study on the effect of manure and chemical fertilizers on rice growth and yield, Tilahun-Tadesse et al. (2013) reported that the highest grain yield (5.01 t ha^{-1}) was produced by the combined treatment of 15 t ha^{-1} manure, 120 kg ha^{-1} N fertilizer, and 100 kg ha^{-1} P fertilizer.

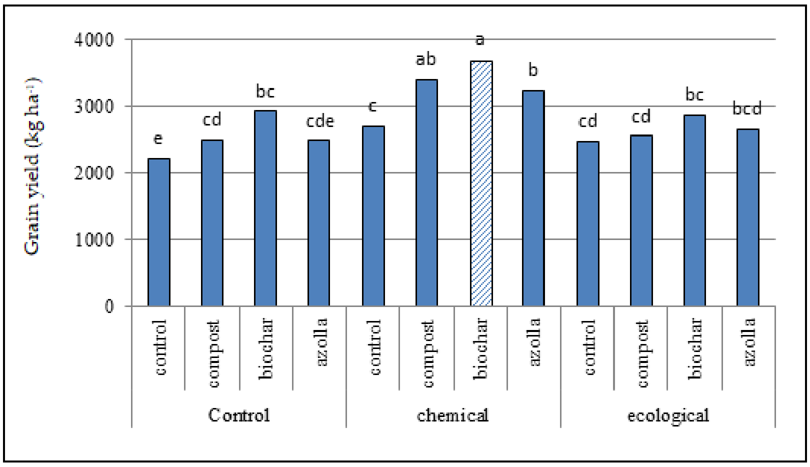

Figure 4. The interaction effect of nutrition systems and organic matter on grain yield in two regions of Lahijan

Thousand-grain weight

The results of variance analysis showed that the simple effect of chemical, ecological and organic nutritional systems on 1000-grain weight was not significant (Table 3). The highest 1000-grain weight (25.07 g) was observed in the treatment of chemical fertilizer and biochar and the lowest (23.83 g) in the control (unfertilized) treatment. Paramarik and Bera (2013) reported that the application of N fertilizer up to a certain level (150 kg ha^{-1} urea) increased the 1000-grain weight and subsequently, the grain yield of rice. Amoaghaei et al. (2003) stated that the application of two strains of *Azospirillum* bacteria increased 1000-grain weight versus the control or no bacteria application significantly.

Macronutrients

The results of ANOVA showed that the effects of chemical, ecological, and organic nutritional systems were significant ($P < 0.01$) on the N, P, and K contents (Table 3). According to the comparison of mean data for both research farms (Figure 5, 6 and 7), the highest N, P, and K contents of the grains (1.79, 0.377, and 0.265%, respectively) were observed in the treatment of chemical fertilizer and biochar and the lowest (1.18, 0.21, and 0.132%, respectively) in the control (unfertilized) treatment. Among the sub-plot, the application of biochar along with chemical and ecological fertilizers had the strongest impact on the N, P, and K contents.

Pedraza et al. (2009) stated that the highest grain N content was obtained from the seeds inoculated with *Azospirillum*. They attributed this increase to the increased availability of nutrients by *Azospirillum*. Amoaghaei et al. (2003) found that the application of *Azospirillum* strains increased grain N content versus the control. Similar results were reported by Yazdani Motlagh et al. (2013) and Turan et al. (2006) according to which the P concentration and uptake by rice grains were increased at higher P levels. The amount of P taken up by the grains was significantly influenced by the P level. The P uptake by grains was about 54% higher when rice was cultivated after *Trifolium alexandrinum* than when it was cultivated after fallow. The linear relationship between P consumption rate and P uptake by grains showed that the amount of P uptake was increased at the P level of 100 kg ha^{-1}. Esfahani et al. (2005) stated that the highest grain K content was obtained from the inoculation with K foliar application. These researchers ascribed this increase to more availability of nutrients in the foliar application. Likewise, Amoaghaei et al. (2003) found that when K solution was applied, the K content of the grains was increased versus the control. In recent years, the need for ensuring the safety of crops produced by different farming systems in terms of the presence of the residues of pesticides and chemicals and their impact on the health of humans and the environment has drawn attention to the production methods and inputs used during their application.

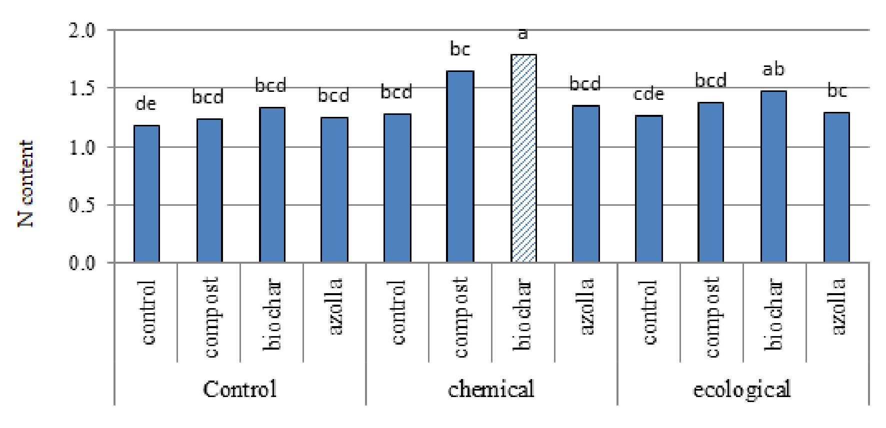

Figure 5. The interaction effect of nutrition systems and organic matter on N content in two regions of Lahijan

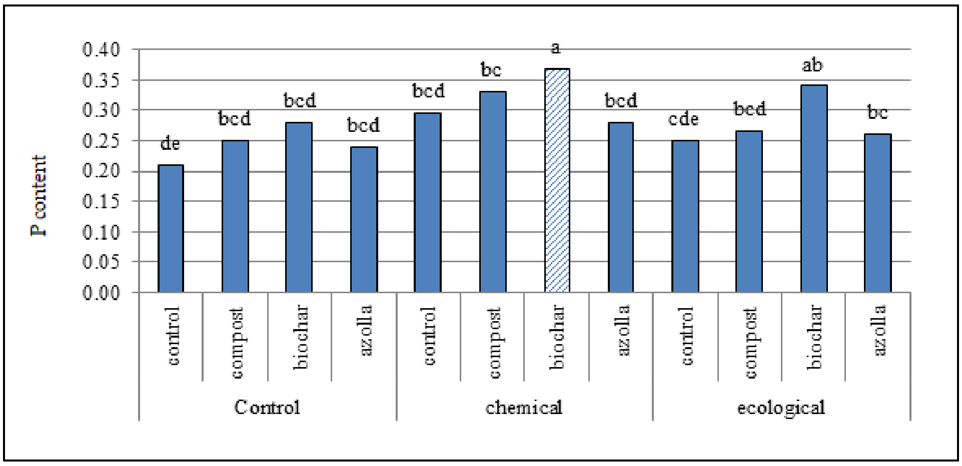

Figure 6. The interaction effect of nutrition systems and organic matter on P content in two regions of Lahijan

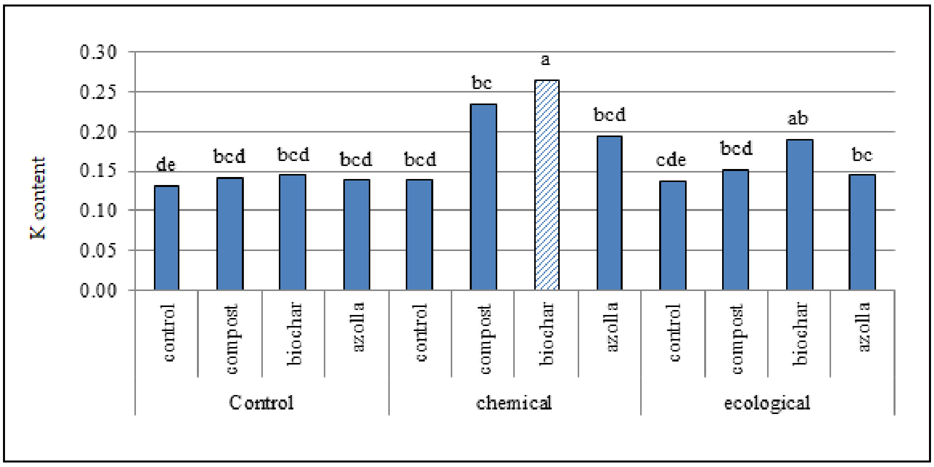

Figure 7. The interaction effect of nutrition systems and organic matter on K content in two regions of Lahijan

CONCLUSIONS

The use of organic fertilizers alone or in combination with chemical fertilizers, in addition to improving the quantitative and qualitative characteristics of rice, has a positive effect on the sustainability of production and preservation of the environment. Our results revealed that the application of the nitrogen fertilizer and biochar increased rice yield in addition to optimizing fertilizer application. It was found that the application of biochar increased grain yield-related traits. The role of biochar in significantly changing the studied traits of rice cv. ‘Hashemi’ was evident in the main treatments (control, ecological, and chemical). So, it is recommended to apply biochar along with chemical fertilizer to retain the yield, prevent biological pollution, and increase rice and soil fertility.

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