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SELECTING A SMART CROPPING SYSTEM: FIELD TRIAL EVIDENCES OF RICE CULTIVARS IN NORTHERN IRAN

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ABSTRACT

The plant growth and productivity are associated with the interaction between the genetic potential and environmental factors. But, in recent decades most of the agricultural researches have focused on modifying the genetic potential of the cultivars and, less attention has been paid to the cultivation practices and production systems. The benefits of this strategy have diminished by increasing the economic costs and environmental damage arising from the chemical input-dependent approach. Therefore, the present study was aimed to determine the optimum condition in crop growing environment by increasing the productivity and reducing the chemical input application in rice production. Hence, this experiment was conducted to evaluate the cropping systems used for local rice cultivars in Iran in 2017 and 2018. Planting systems including and the cultivars were chosen as the first and second factors, respectively. Results revealed that grain NPK content, NPK harvest index and NPK use efficiency are positively associated with the paddy yield. Hence, the high-input and conventional systems resulted in an increase in the quantitative yield, but the organic and transition to organic systems led to higher WUE over both years than other systems. Also, WP was higher in the conventional system than other systems.

Keywords: growth phenology, nutrient use efficiency, organic system, water productivity.

INTRODUCTION

To ensure the food security for the growing population, there is a need for expansion of the rice-cropped area, as well as the continuous intensification of the rice cultivation to increase the rice production. In contrast, rice cropping is facing with the major challenges regarding the provision of the nutritious food and delivering sufficient amount of product to meet the demands of the growing population, and overcoming issues such as soil fertility depletion, irrigation water and water scarcity, deterioration of soil health and decline in productivity level, which are considered as serious concerns (Tivet and Boulakia, 2017). In addition, soil fertility depletion, loss of biodiversity and water scarcity all are taken into account as major constraints (Tivet and Boulakia, 2017). Hence, the modified cropping systems are appropriate conservation tools that can be used to increase the nutrient use efficiencies, mine nitrates from groundwater, reducing the nitrate leaching, improving the soil and water quality, and also contributing to the atmospheric carbon sequestration. Therefore, alternative management techniques are required to reduce the environmental challenges related to the rice planting without causing hazard for rice production, commoditization and global food security (Tivet and Boulakia, 2017).

Rice (*Oryza sativa* L.) is the earliest stable food crops with the global cultivation area of 165 million ha, accounting for more than one tenth of the worldwide-cultivated area (Tivet and Boulakia, 2017). According to the report published in 2017, in Iran, the paddy field cultivation area is about 630,000 million ha, from which a product with a volume of 2.5 million tons is obtained (Ministry of Jihad-e-Agriculture of Iran, 2017). Mazandaran Province

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in northern Iran is the largest rice producing area in Iran with 230,000 ha cultivation area, accounting for 38% of the total rice cultivation and production area in Iran (Ministry of Jihad-e-Agriculture of Iran, 2017).

Thakur et al. (2018) reported that the modified rice production system compared to the conventional system significantly enhanced grain yield to 58%, and saved the irrigation water to about 16%, and also an increased water productivity was found as a result of improving the plant root growth, Leaf Area Index (LAI), interception of light by canopy, and the photosynthesis rate at grain filling stage. Dass et al. (2017) found that improvement of the rice cultivating systems compared to the conventional system increased the rice grain yield, grain nutrient content and, uptake of the grain nutrients such as S, ZN, Fe, Mn and Cu to 36%, 32%, 28%, 32% and 63%, respectively. In addition, wider planting arrangement (20×20 cm^2) significantly enhanced the grain yield, as well as the grain nutrient content and grain nutrient uptake (Dass et al., 2017). Thakur et al. (2016) in a study on rice cropping systems reported that, compared to the conventional planting system SRI significantly enhanced the light interception by the canopy, chlorophyll content of the leaves, photosynthesis rates during flowering, morphological and physiological parameters, plant height, number of tiller per hill, number of leaves and root systems, resulting in an increase in the grain yield and water productivity. Other researchers reported that, SRI caused an increase in the rice grain yield by reducing irrigation water, modifying the organic matter, providing the wide transplanting space, transplanting the single seedling and transplanting the young seedling per hill (Jain et al., 2014). But, other researches showed no significant effect in favor of SRI on the rice grain yield. This result might be due to the transplanting a single seedling per hill and, the reduction of plant population per m^2 (Jain et al., 2014).

In the current situation, the uncontrolled use of the chemical fertilizers is no longer economically and environmentally viable or justified. Following this global trend, Iran, has also started paying attention to the economics of fertility with regard to the health of the soil, production, and its citizens, thus a serious consideration has been given to the use of the organic manures (Ministry of Jihad-e-Agriculture of Iran, 2017). Hence, modifying the conventional rice cropping systems and creating innovative cropping techniques might be considered as a way to increase the grain yield, saving the irrigation water, reducing the environmental pollutants and, enhancing the productivity. Therefore, the current study was conducted to (i) assess the effects of the rice cropping systems on the rice crop yield parameters and irrigation water indices, (ii) comparing the Iranian rice cultivars in terms of the grain yield and nutrient uptakes, and (iii) selecting better cropping systems for a sustainable rice production in northern Iran.

MATERIAL AND METHODS

Description of the experimental site

Field trials were conducted in Babol (in the central part of Mazandaran province), Sari (in the central part of Mazandaran province) and Neka (in the eastern part of Mazandaran province) regions located in north of Iran between the Alborz Mountains and the Caspian Sea during the periods of 2016-17 and 2017-18.

Description of the experiment

In this research, five cropping systems were studied for three local rice cultivars (‘Tarom Hashemi’, ‘Tarom Mahalli’ and ‘Sang Tarom’). Organic cropping system was carried out in the Babol region; the transition to organic system was conducted in the Neka region; and three cropping systems (conventional, low-input and high-input) were conducted in the Sari region. The paddy fields were selected for the conventional, low-input and high-input systems based on the soil characteristics analysis done in each region. But, the paddy fields were selected for the organic and transition to organic systems according to the IFOAM protocols under the supervision and control of the experts and the inspector of IFOAM. There was no option for selecting the organic and transition to organic systems in another region. In fact, only two farmers had organic and transition to organic rice farms in all cities of the Mazandaran province. Each cropping system was selected according to all social, economic, environmental and agricultural issues. The experiment was carried out as a Randomized Complete Blocks Design (RCBD) with three replications, in which three local cultivars were considered as treatment. The size of each plot was 5×10 m^2. After collecting the data, the data was analyzed by a factorial experiment based on RCBD with three replications. Five cropping systems (conventional, low-input, high-input, organic and transition to organic) were used as main plots and three rice cultivars ('Tarom Hashemi', 'Tarom Mahalli' and 'Sang Tarom') were used as a sub plots, respectively. Details of each cropping system are described in the below:

High-Input (Intensive) System: seedlings were prepared by the traditional method (furrow and basin); transplanting (spacing of 20×20 cm^2 equals 25 seedlings per m^2) was done by four semi-matured seedlings per hill with 5-6 leaves (30 days old). Flooding irrigation was done with one step drainage during the maximum of tillering (initial heading stage) in the growing season period. Chemical fertilizers were used from urea sources (250 kg ha^{-1}) for nitrogen; followed by using the triple super phosphate (100 kg ha^{-1}) for phosphorous; and potassium sulfate (150 kg ha^{-1}) for potassium. Total phosphorus fertilizer containing 50% of the nitrogen and 50% of the potassium fertilizers was used as basal application in the paddy field preparation stage. 25% of the nitrogen and 25% of potassium fertilizers were used as top-dressing in panicle initiation. In addition, 25% of nitrogen was consumed in full heading stage. To control weed, weedicide was applied once pre-emergence and, hand weeding was done at third steps (28, 40 and 50 days after transplanting). Pesticides were used to control the pests and diseases.

Conventional System: seedlings were prepared by the traditional method (furrow and basin); transplanting was done based on the random and irregular planting arrangement by more than four matured seedlings per hill with 6-7 leaves (35 days old). Flooding irrigation was done during growing season period without drainage and periodic irrigation. Chemical fertilizers were used from urea sources (200 kg ha^{-1}); followed by using the triple super phosphate (100 kg ha^{-1}); and potassium sulfate (100 kg ha^{-1}). Total phosphorus fertilizer containing 75% of the nitrogen and 75% of the potassium fertilizers was consumed as basal (before transplanting). Remained nitrogen and potassium (25%) were used as top-dressing in panicle initiation (30 days after transplanting). Weeds control was done by hand in two steps (28 and 40 days after transplanting). All farming practices were done traditionally by hand.

Transition to Organic System: according to the IFOAM protocol, poison (pesticides and weedicides) and chemical residue amounts in the organic product should be at the allowed rate. Therefore, to achieve the safe and organic crop production in the transition to organic system, the poisons and chemicals should be omitted over the years to take the first step of crop production in the transition to organic protocols. Accordingly, transition to organic system was conducted in a paddy field with a background of organic protocol cultivation for 4 years (called as the transition to organic III). Transplanting practices (spacing of 25×25 cm^2 equals 16 seedlings per m^2) were done by three young seedlings per hill with 4-5 leaves (25 days old). Flooding + periodic irrigation was done in the growing season period. Before paddy field preparation, vermi-compost was used at a level of 15 tons per hectare. In order to supply the NPK, the bio-fertilizers (Phosphate Barvar, *Azotobarvar* and Potash Barvar) amounting 300 g were used through foliar application in two stages including transplanting to main land and after first weeding (28 days after transplanting). Fighting the rice stem borer (*Chilo suppressalis* Walker) was done by pheromone traps, trichogramma bee and bio-insecticide Bt (*Bacillus thuringiensis*) solution. Weeds control was done by hand in three steps including 28, 40 and 50 days after transplanting.

Organic System: the control of this system is based on the minimum utilization of off-farm inputs as well as management measures to rebuild the maintenance and enhancement of the ecological balance according to the IFOAM protocol without using the chemical inputs during a 15-year period with continuous rice-based system. Transplanting practices (spacing of 25×25 cm^2 equals 16 seedlings per m^2) were done by three young seedlings per hill with 4-5 leaves (25 days old). Flooding + periodic irrigation was done in the growing season period. Before paddy field preparation, vermi-compost was used at a level of 10 tons per hectare. In order to supply the NPK, the bio-fertilizers (Phosphate Barvar, *Azotobarvar* and Potash Barvar) amounting 300 g were used through foliar application in two stages including transplanting to main land and after first weeding (28 days after transplanting). Fighting the rice stem borer (*Chilo suppressalis* Walker) was done by pheromone traps, trichogramma bee, Bt. spray and the bio-insecticide (*Bacillus thuringiensis*) solution and, the contaminated plants were removed. Weeds control was done by hand in three steps including 28, 40 and 50 days after transplanting, as well as duck release in the paddy field (40 days after transplanting) and, through managing the irrigation water depth in each plot.

Low-Input (Conservation) System: low-input planting system was conducted based on the low application of inputs such as seed, chemical fertilizers, chemical pesticides and other inputs in the field. All agronomic operations were done based on the minimum inputs. Seedlings were prepared by the traditional method (furrow and basin); transplanting (spacing of 30×30 cm^2) was done by three young seedlings per hill with 3-4 leaves (20 days old). Flooding irrigation was started from transplanting stage and, continued until two weeks after transplanting. Periodic irrigation started two weeks after transplanting and continued until harvesting. 10 tons of rotted manure was used along with the chemical fertilizers including urea (100 kg ha^{-1}); triple super phosphate (50 kg ha^{-1}); and potassium sulfate (50 kg ha^{-1}). Total phosphorus fertilizer was used containing 50% of the nitrogen and 50% of the potassium fertilizers as basal. 50% of the nitrogen and 50% of potassium fertilizers were used as top-dressing in panicle initiation stage (30 days after transplanting). To control weed, herbicide was applied once pre-emergence and, as well as two steps of hand weeding (28 and 5 days after transplanting). Control of rice stem borer (*Chilo suppressalis* Walker) was done by trichogramma bee.

In all cropping systems, nylon plastic covers were placed at the borders up to a depth of 30 cm in order to prevent the weeds growth and the water-fertilizer mixing in each plot. Other agricultural and paddy field management practices were done according to the Standard Evaluation System (SES) of the International Rice Research Institute (IRRI).

Measurement

During the growth period, after the removal of marginal effect, traits were randomly measured according to the Standard Evaluation System (SES) of the International Rice Research Institute (IRRI). Thus, 10 tillers per hill were randomly selected from each experimental plot and, their average was analyzed. Measurement protocol of each trait is described in the supplementary file.

Statistical analysis

All statistical analyses were performed using the SAS software. LSD test was used to compare the differences between the treatment means at a 5% of probability level.

RESULTS AND DISCUSSION

Quantitative traits, paddy yield and harvest index

According to the findings, the number of panicle per m^2 was highest during both years in the high-input system (359 and 344 panicles), and the conventional system ranked next during both years. Transition to organic and organic systems ranked third and fourth, respectively. The lowest number of panicle per m^2 was achieved in the low-input system (228 and 273 panicles). The maximum number of tiller per hill, number of spikelet per panicle, and 1000-grain weight were observed in the high-input and conventional systems, but the highest number of fertile tiller per hill (11.71 and 11.60 tillers) was achieved in the conventional and transition to organic systems. The lowest number of total tiller and fertile tiller per hill was obtained in the low-input system. Filled spikelet percentage was highest in the high-input, conventional and transition to organic systems. But, the maximum number of blank spikelet per panicle (25.29 spikelets) was observed in the low-input system. The lowest number of total and fertile tiller per hill, number of spikelet per panicle, filled spikelet percentage and 1000-grain weight was achieved in the low-input system (Table 1). Therefore, these traits were found to cause the enhancement of the paddy yield in the high-input and conventional systems (4122 and 4088 kg ha^{-1}, respectively). Transition to organic and organic systems with 3254 and 3223 kg of paddy yield per hectare ranked next, respectively. The paddy yield of low-input system (3038 kg ha^{-1}) was 26.3%, 25.68%, 6.64% and 5.74% less than the high-input, conventional, transition to organic and organic systems, respectively. In addition, paddy yield of the organic system was 21.81%, 11.16% and 0.95% less than high-input, conventional and transition to organic systems. But, paddy yield of the high-input system was 0.83% higher than the conventional system. The maximum straw yield (8158 and 8001 kg ha^{-1}, respectively) was obtained in the conventional and organic systems, as the high-input and transition to organic systems ranked next. The minimum straw yield (7473 kg ha^{-1}) was obtained in the low-input system. According to the findings related to the paddy and straw yields, the highest harvest index (34.88%) was obtained in the high-input system, as the conventional and transition to organic systems (33.46% and 30.96%) ranked next, respectively. The minimum harvest index (29.01%) was observed in the low-input system (Table 1).

Mean comparison of these traits in the cultivar level revealed that, ‘Sang Tarom’ cultivar showed the most panicle per m^2 in both years (313 and 323 panicles), as ‘Tarom Hashemi’ and ‘Tarom Mahalli’ cultivars ranked next, respectively (Table 1). Number of tiller per hill in Sang Tarom cultivar (14.67 tillers) was 5.09% and 10.08% higher than the ‘Tarom Hasheni’ and ‘Tarom Mahalli’ cultivars. In addition, number of spikelet per panicle (120.81 spikelets) in ‘Sang Tarom’ cultivar was 3.72% and 3.72% more than the ‘Tarom Hashemi’ and ‘Tarom Mahalli’ cultivars, as the filled spikelet percentage in ‘Sang Tarom’ cultivar (87.22%) was 5.98% and 11.96% greater than the ‘Tarom Hashemi’ and ‘Tarom Mahalli’ cultivars. But, ‘Tarom Mahalli’ cultivar (28.31 gr) compared to ‘Sang Tarom’ and ‘Tarom Hashemi’ cultivars had 12.88% and 6.03% higher 1000-grain weight (Table 1).

Table 1. Mean comparison of yield components and quantitative yield of rice cultivars in different cropping systems

Treatment	No. of tiller per hill	No. of fertile tiller per hill	No. of panicle per m^2 First year (2017)	No. of panicle per m^2 Second year (2018)	No. of spikelet per panicle	Filled spikelet percentage	No. of blank spikelet per panicle	100-grain weight (gr)	Paddy yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)
Planting system											
High-input	15.94 a	10.08 bc	359 a	344 a	125.00 a	83.38 a	20.83 bc	28.12 a	4122 a	7686 b	34.88 a
Conventional	16.13 a	11.71 a	316 ab	307 b	122.25 a	82.93 a	21.36 bc	27.67 a	4088 a	8158 a	33.46 b
Organic	13.76 b	11.60 a	281 bc	273 d	117.21 b	83.67 a	19.74 c	26.68 b	3254 b	7293 c	30.92 c
Transition to organic	12.52 c	10.89 ab	260 cd	286 c	109.92 c	79.59 b	22.49 b	25.80 c	3223 b	8001 a	28.89 d
Low-input	11.44 c	9.71 c	228 d	334 ab	108.03 c	76.63 c	25.29 a	25.21 c	3038 c	7473 bc	29.01 d
LSD 0.05	1.12	1.05	44.95	10.82	3.69	1.91	1.77	0.63	176.13	284.09	1.16
Cultivar											
Tarom Mahalli	13.24 b	10.47 a	313 a	323 a	112.15 c	75.26 c	29.63 a	28.31 a	3728 a	7083 c	34.44 a
Sang Trom	14.67 a	11.13 a	282 ab	309 b	120.81 a	87.22 a	14.25 c	25.08 c	3545 b	7722 b	31.34 b
Tarom Hashemi	13.96 ab	10.80 a	270 b	295 c	116.48 b	81.24 b	21.94 b	26.70 b	3362 c	8362 a	28.52 c
LSD 0.05	0.86	0.81	8.06	22.25	2.86	1.48	1.37	0.49	136.43	220.06	0.90

*: Values within a column followed by same letter(s) are not significantly different according to the LSD test (*P = 0.05*).

Irrigation water indices and weed traits

Based on the findings of the cropping system, the weed height was highest for high-input system over both years, as conventional system ranked second. In terms of weed height and weed density, transition to organic and organic systems ranked third and fourth, respectively and, low-input system showed least weed height and density (Table 2). Consumed water was higher in the high-input and conventional systems than other systems as low-input system showed least consumed water. In addition, water requirement was greater in the high-input and conventional systems than other systems as organic and low-input systems showed lowest water requirement. In contrast, WUE was higher in the organic system over both years than other systems, as low-input and transition to organic systems ranked next, respectively. The least WUE for both years was observed in the high-input system (1.25 kg m^{-3}). In contrast, WP was higher in the conventional system (0.51 kg m^{-1}) than other systems as high-input and transition to organic systems ranked next, respectively. The least WP was observed in the low-input and organic systems. In addition, weed day matter was found to be higher in high-input system than other systems as transition to organic, organic and low-input systems statistically got same ranks. Mean comparison of the cultivars showed that, the consumed water and water requirement was significantly greater in 'Sang Tarom' cultivar over both years than 'Tarom Hashemi' and 'Tarom Mahalli' cultivars. In contrast, WUE was higher in 'Tarom Mahalli' cultivar during both years (1.58 and 1.56 kg m^{-3}) than 'Tarom Hashemi' and 'Sang Tarom' cultivars (Table 2).

Table 2. Mean comparison of weed parameters and irrigation water indices of rice cultivars in different cropping systems

Treatment	Weed dry matter (gr)	Water productivity (kg m^3)	Weed height (cm)		Weed density (no m^2)		Consumed water (m^3)		Water use efficiency (kg m^3)		Water requirement (m^3 kg^{-1})	
	Combined analysis	Combined analysis	First year (2017)	Second year (2018)	First year (2017)	Second year (2018)	First year (2017)	Second year (2018)	First year (2017)	Second year (2018)	First year (2017)	Second year (2018)
Planting system												
High-input	169.25 b	0.47 b	56.67 a	53.33 ab	41.33 a	40.00 b	8527 a	8471 a	1.25 c	1.25 c	0.81 a	0.81 a
Conventional	169.17 b	0.51 a	54.67 ab	54.00 a	36.50 bc	41.17 a	9054 a	8652 a	1.33 bc	1.37 b	0.77 ab	0.73 b
Transition to organic	168.67 b	0.50 b	52.17 c	49.50 c	36.83 bc	35.67 d	8265 a	8230 ab	1.36 abc	1.41 a	0.76 ab	0.72 b
Organic	172.00 b	0.40 c	54.33 abc	51.00 bc	34.17 c	38.50 c	8430 a	7892 b	1.51 a	1.55 a	0.69 b	0.65 c
Low-input	176.33 a	0.36 d	52.67 bc	51.67 abc	37.50 b	34.33 e	7055 b	7116 c	1.50 ab	1.50 a	0.67 b	0.68 c
LSD 0.05	3.52	0.03	2.40	2.94	2.87	1.16	1041	525.4	0.18	0.08	0.10	0.04
Cultivar												
Sang Tarom	170.77 a	0.43 a	53.40 a	50.80 a	37.73 a	37.73 a	9030 a	8600 a	1.21 c	1.27 c	0.84 a	0.79 a
Tarom Mahalli	171.08 a	0.44 a	54.80 a	53.00 a	36.80 a	38.13 a	7502 b	7544 c	1.58 a	1.56 a	0.64 c	0.64 c
Tarom Hashemi	171.40 a	0.45 a	54.10 a	51.90 a	37.27 a	37.93 a	8266 ab	8072 b	1.38 b	1.41 b	0.74 b	0.72 b
LSD 0.05	2.73	0.03	1.86	2.28	2.22	0.90	806.02	406.98	0.14	0.07	0.08	0.03

*: Values within a column followed by same letter(s) are not significantly different according to the LSD test (*P = 0.05*).

Nutrient (NPK) uptake indices

Mean comparison of cropping system for NHI, NUE, grain P content and grain K content over both years showed that, NHI and grain P content were highest in the high-input and conventional systems during both years (Tables 3, 4 and 5). NUE of organic system showed the highest amount (82.10 and 63.87 kg kg^{-1}) over both years compared to other systems, as other systems statistically ranked next. Grain K content was higher in the high-input, conventional and transition to organic systems than the organic and low-input systems during both years. Mean comparison of cultivar for N-related parameters showed that NHI and NUE were significantly higher in the 'Tarom Mahalli' cultivar than other two cultivars as 'Sang Tarom' and 'Tarom Hashemi' cultivars ranked second and third, respectively. But, grain P and K content were higher in the 'Sang Tarom' cultivar than other cultivars as 'Tarom Hashemi' and 'Tarom Mahalli' cultivars ranked next, respectively (Tables 3, 4 and 5).

According to the findings of mean comparison for the nutrient-related parameters under the cropping system effect, grain and straw N content, grain and straw N uptake and protein yield (365.93 kg ha^{-1}) were statistically higher in the conventional system than other systems, as the high-input, transition to organic and organic systems ranked next, respectively. The lowest mount of these traits was observed in the low-input system. Mean comparison findings of the phosphorous-related parameters were different from those of the N-related parameters. Hence, only the grain P uptake and P harvest index were higher in the high-input and conventional systems than other systems, as for P harvest index, transition to organic, organic and low-input systems ranked next, respectively. Straw P content of was higher in the organic system than other systems. But, straw P uptake was higher in the organic and low-input systems than other systems. P use efficiency was significantly greater in the high-input, conventional and transition to organic systems than the organic and low-input systems. Furthermore, mean comparison of the cropping systems for the K-related parameters revealed that, the straw K content was significantly higher in the high-input, conventional and transition to organic systems than the organic and low-input systems. Straw K uptake and K harvest index were statistically greater in the high-input and conventional systems than other systems, as organic and low-input systems showed lower amounts of these parameters. But, K use efficiency was significantly more in the high-input and organic systems than other systems (Tables 3, 4 and 5).

Mean comparison of the cultivars for the nutrient-related parameters demonstrated that, all the investigated traits were significantly higher (grain and straw N content, grain and straw N uptake and protein yield) in the 'Sang Tarom' cultivar than other two cultivars, as 'Tarom Hashemi' and 'Tarom Mahalli' cultivars ranked next, respectively. Mean comparison of the cultivars for P-related parameters demonstrated that, the grain and straw P uptakes were higher in the 'Sang Tarom' cultivar than 'Tarom Hashemi' and 'Tarom Mahalli' cultivars. But, P use efficiency in the 'Tarom Mahalli' cultivar (180.05 kg kg^{-1}) was 12.11% and 24.16% higher than 'Tarom Hashemi' and 'Sang Tarom' cultivars, respectively. Mean comparison of the cultivars for K-related parameters showed that, the grain and stem K content in the 'Sang Tarom' cultivar was higher than other two cultivars, as 'Tarom Hashemi' and 'Tarom Mahalli' cultivars ranked next, respectively. But, K harvest index in the 'Tarom Mahalli' and 'Tarom Hashemi' cultivars were 13.82% and 7.43% greater than the 'Sang Tarom' cultivar, respectively. In contrast, K use efficiency in the 'Tarom Mahalli' cultivar was 21.69% and 45.08% more than the 'Tarom Hashemi' and 'Sang Tarom' cultivars, respectively (Tables 3, 4 and 5).

Table 3. Mean comparison of N-related parameters of rice cultivars in different cropping systems

Treatment	Grain N content (%)	Straw N content (%)	Plant N content (kg ha^{-1})	Grain N uptake (kg ha^{-1})	Straw N uptake (kg ha^{-1})	Plant N uptake (kg ha^{-1})	Nitrogen harvest index (%)		Nitrogen utilization efficiency (kg ha^{-1})		Protein content (%)	Protein yield (kg ha^{-1})
							First year (2017)	Second year 2018)	First year (2017)	Second year 2018)		
Planting system												
High-input	1.30 b	0.47 a	1.78 b	52.68 b	36.40 b	89.08 b	56.64 a	60.76 a	51.02 b	44.34 b	7.75 b	313.47 b
Conventional	1.51 a	0.51 a	2.01 a	61.50 a	41.71 a	103.21 a	58.57 a	61.10 a	38.94 b	43.04 b	8.97 a	365.93 a
Transition to organic	1.33 ab	0.50 a	1.84 ab	42.04 c	36.80 b	78.82 c	47.00 bc	57.04 b	48.38 b	40.15 b	7.92 ab	250.12 c
Organic	1.11 c	0.39 b	1.50 c	35.82 d	30.95 c	66.77 d	42.47 c	52.59 c	82.10 a	63.87 a	6.60 c	213.15 d
Low-input	0.78 d	0.32 c	1.11 d	22.87 e	24.22 d	47.09 e	53.45 ab	53.81 c	48.88 b	55.78 a	4.67 d	136.06 e
LSD 0.05	0.19	0.05	0.23	6.02	4.44	9.08	8.66	2.65	14.53	9.55	1.13	35.85
Cultivar												
Sang Tarom	1.32 a	0.48 a	1.80 a	44.59 a	40.29 a	84.87 a	47.29 b	53.90 c	46.54 b	42.62 b	7.86 a	265.30 a
Tarom Hashemi	1.21 ab	0.44 b	1.65 ab	43.16 a	33.82 b	76.98 b	51.76 ab	57.09 b	53.05 ab	48.27 b	7.18 ab	256.81 a
Tarom Mahalli	1.09 b	0.39 c	1.49 b	41.20 a	27.93 c	69.12 c	55.83 a	60.19 a	62.00 a	57.42 a	6.51 b	245.13 a
LSD 0.05	0.15	0.04	0.18	4.67	3.44	7.03	6.71	2.05	11.26	7.40	0.88	27.77

*: Values within a column followed by same letter(s) are not significantly different according to the LSD test (*P = 0.05*).

Table 4. Mean comparison of P-related parameters of rice cultivars in different cropping systems

Treatment	Grain P content (%)		Straw P content (%)	Plant P content (%)		Grain P uptake (kg ha^{-1})	Straw P uptake (kg ha^{-1})	Plant P uptake (kg ha^{-1})	P harvest index (%)	P utilization efficiency (kg ha^{-1})
	First year (2017)	Second year (2018)		First year (2017)	Second year (2018)					
Planting system										
High-input	0.21 a	0.21 a	0.19 c	0.40 a	0.40 a	8.43 a	14.79 b	23.22 a	36.53 a	179.19 a
Conventional	0.20 a	0.20 a	0.18 c	0.39 ab	0.38 a	8.30 a	14.88 b	23.18 a	35.83 a	177.20 a
Transition to organic	0.18 b	0.18 ab	0.19 c	0.37 c	0.37 a	5.75 b	13.96 b	19.70 b	29.23 b	169.70 a
Organic	0.16 c	0.15 b	0.24 a	0.38 bc	0.40 a	4.66 c	17.60 a	22.26 a	21.01 c	138.06 b
Low-input	0.17 b	0.16 b	0.21 b	0.39 ab	0.36 a	5.27 bc	17.07 a	22.34 a	23.95 c	145.28 b
LSD 0.05	0.01	0.04	0.01	0.02	0.05	0.73	1.41	1.52	3.12	11.66
Cultivar										
Sang Tarom	0.20 a	0.20 a	0.20 a	0.39 a	0.40 a	6.81 a	16.58 a	23.39 a	28.99 a	145.01 c
Tarom Hashemi	0.18 b	0.18 ab	0.20 a	0.38 ab	0.38 a	6.50 ab	15.68 ab	22.18 b	29.30 a	160.60 b
Tarom Mahalli	0.17 c	0.16 b	0.21 a	0.37 b	0.37 a	6.13 b	14.71 b	20.85 c	29.65 a	180.05 a
LSD 0.05	0.01	0.03	0.01	0.01	0.04	0.57	1.09	1.17	2.42	9.03

*: Values within a column followed by same letter(s) are not significantly different according to the LSD test (*P = 0.05*).

Table 5. Mean comparison of K-related parameters of rice cultivars in different cropping systems

Treatment	Grain potassium content (%)		Straw K content (%)	Plant K content (%)	Grain K uptake (kg ha^{-1})	Straw K uptake (kg ha^{-1})	Plant K uptake (kg ha^{-1})	K harvest index (%)	K utilization efficiency (kg ha^{-1})
	First year (2017)	Second year (2018)							
Planting system									
High-input	0.37 a	0.37 a	2.39 a	2.76 a	15.16 a	183.95 b	199.11 b	7.60 a	20.93 a
Conventional	0.40 a	0.40 a	2.51 a	2.91 a	16.31 a	205.47 a	221.78 a	7.34 a	18.99 b
Transition to organic	0.41 a	0.39 a	2.50 a	2.90 a	13.01 b	182.22 bc	195.22 b	6.62 b	17.07 c
Organic	0.21 c	0.23 b	1.90 c	2.12 c	6.51 d	142.94 d	149.45 d	4.34 d	21.18 a
Low-input	0.32 b	0.25 b	2.11 b	2.39 b	9.17 c	168.95 c	178.13 c	5.10 c	18.79 b
LSD 0.05	0.05	0.09	0.15	0.19	1.62	13.66	14.99	0.54	1.53
Cultivar									
Tarom Mahalli	0.38 a	0.37 a	2.16 c	2.45 c	11.12 b	152.74 c	163.86 c	6.59 a	23.17 a
Sang Tarom	0.34 ab	0.33 ab	2.41 a	2.78 a	12.90 a	201.21 a	214.12 a	5.79 b	15.97 c
Tarom Hashemi	0.30 b	0.29 b	2.28 b	2.62 b	12.08 ab	176.16 b	188.24 b	6.22 a	19.04 b
LSD 0.05	0.04	0.07	0.11	0.15	1.26	10.58	11.61	0.42	1.19

*: Values within a column followed by same letter(s) are not significantly different according to the LSD test (*P = 0.05*).

Yield components are influenced by the management practices, genotypes, and environmental factors and, are often used to justify the cause of yield reduction or increment (Dastan et al., 2019). In addition, incorrect crop management, water usage, nutrition, temperature, light, and other inappropriate environmental factors can reduce one or more components of the yield components (Dastan et al., 2019). Mean comparison demonstrated that, the highest number of panicle per m^2, number of tiller per hill, number of spikelet per panicle, and 1000-grain weight were observed in the high-input system and, the conventional system ranked next, but the most number of fertile tiller per hill was achieved in the conventional and transition to organic systems. Therefore, these findings were found to cause the enhancement of the paddy yield in the high-input and conventional systems. The paddy yield of the low-input system (3038 kg ha^{-1}) was 26.3%, 25.68%, 6.64% and 5.74% less than the high-input, conventional, transition to organic and organic systems, respectively. In addition, paddy yield of the organic system was 21.81%, 11.16% and 0.95% less than the high-input, conventional and transition to organic systems. But, paddy yield of the high-input system was 0.83% higher than the conventional system.

In another study, it has been demonstrated that the number of tiller per hill was lower in the intensive system following transplanting the young seedlings (10-days old) and applying the planting arrangement of 25×25 cm^2 area than the conventional system in which, 20-day old seedlings were transplanted and the planting arrangement was of 20×15 cm. Due to transplanting the 20-days old seedlings the leaf area index and photosynthesis increased, which in turn influenced the rice crop tillering (Anitha and Chellappan, 2011). The number of panicle per m^2 was more in the high-input system than other systems, which was due to the increase in the fertile tiller per hill. The same findings have been obtained in other studies (Hameed et al., 2011; Thakur et al., 2011). In addition, as a result of increasing the panicle length in the high-input system compared to other systems, highest number of spikelet per panicle and filled spikelet percentage were obtained. Other researchers reported the same findings in this regard (Thakur et al., 2011). In contrast, the percentage of blank spikelet per panicle was 25% less in the intensive system than the conventional system, which could be due to the shading, inter-competition and intra-competition between the bushes in higher densities and the lower nutrient absorption by the main plant (Hameed et al., 2011). Several studies found a significant increase in the 1000-grain weight in the intensive system compared to the conventional system (Thakur et al., 2011).

The maximum paddy yield was achieved in the high-input and conventional systems, mainly attributed to the increase in the panicle length, flag leaf length, the number of fertile tiller per hill, the number of panicle per m^2, the number of spikelet per panicle, and filled spikelet percentage compared to other cropping systems. The highest paddy yield was achieved as a result of providing the optimal growth conditions for the plant in the high-input and conventional systems. The lowest paddy yield was obtained in the low-input system due to the lower input (NPK) application leading to a decrease in the panicle length, flag leaf length, the number of fertile tiller per hill, the number of panicle per m^2, the number of spikelet per panicle, and filled spikelet percentage compared to other cropping systems. Other researchers demonstrated the enhancement of the paddy yield in the intensive system compared to conventional system, mainly due to the improvement of morphological, physiological and agronomic traits along with improvement of the growth and activity of root for water and nutrient uptake leading to a delay in leaf aging as well as the improvement of the photosynthesis rate (Hameed et al., 2011; Thakur et al., 2011). Additionally, they reported that the desirable plant density and aerobic conditions of soil cause the increase in the paddy yield in the intensive system. Barison (2003) reported that, the use of compost and organic fertilizer resources increased the number of panicle per m^2, and the number of spikelet per panicle and paddy yield by increasing the root volume and absorption of soil nutrients due to the periodic irrigation, occurring as a result of gradual and continuous supply of the nutrients, especially during the period of grain filling. Other researchers also revealed an increase in the grain yield in the intensive system caused by the combined effect of periodic irrigation management, using young seedlings with 3-4 leaves, quadrangle transplanting pattern by one seedling with more distances and, using the organic fertilizers (Uphoff, 2006). These findings are in line with the results of other studies in the different countries (Zhao et al., 2010).

Irrigation water indices and weed traits

Analyzing the cropping system demonstrated that, the weed height was highest for both years in the high-input system, as conventional system ranked second. In terms of weed height and weed density, transition to organic and organic systems ranked third and fourth, respectively and, low-input system showed least weed height and density. Consumed water was higher in the high-input and conventional systems than other systems as low-input system showed least consumed water. In addition, water requirement was greater in the high-input and conventional systems than other systems as organic and low-input systems showed lowest water requirement. In contrast, WUE was higher in the organic system than other systems over both years, as low-input and transition to organic systems ranked next, respectively. The least WUE for both years was observed in the high-input system (1.25 kg m^{-3}). In contrast, WP was higher in the conventional system (0.51 kg m^{-1}) than other systems as high-input and transition to organic systems ranked next, respectively. The least WP was observed in the low-input and organic systems. In addition, weed dry matter was statistically higher in the high-input system than other systems as transition to organic, organic and low-input systems statistically got same ranks. Mean comparison of the cultivars showed that, the consumed water and water requirement was significantly greater in 'Sang Tarom' cultivar during both years than 'Tarom Hashemi' and 'Tarom Mahalli' cultivars. In contrast, WUE was higher in 'Tarom Mahalli' cultivar during both years (1.58 and 1.56 kg m^{-3}) than 'Tarom Hashemi' and 'Sang Tarom' cultivars (Table 3).

The transfer of young seedlings and lower number of seedlings to the experimental paddy field, as well as periodic irrigation, led to a decrease in the amount of water consumed in the organic and low-input systems. In another study, the irrigation regime in the intensive system was based on the soil moisture reduction, which led to a reduction in the water application by 22%. As a result, water productivity significantly increased compared to conventional planting system (Thakur et al., 2011). In another study conducted over a 3-year period, a significant increase was reported in the WUE in the intensive system compared to the conventional system (Zhao et al., 2010).

Weed species were sampled according to their relative density and height at the end of the growing season. Weed flora has been identified in the experimental paddy field, including species of *Cyperus*, *Echinocloa crus galli*, *Veronica persica*, *Paspalum distichum*, and *Alisma plantago aquatic*. The most important and common weeds were *Cyperus* and *Echinocloa crus galli*. Because the relative share of weed density and height were much higher for *Cyperus* and *Echinocloa crus galli* than other weeds and, they occupied higher ecological niches on the field. The proper leaf arrangement and favorable structure of rice canopy in intensive system resulted in the more exposure of the plant to the light and, the efficiency of light use also increased, attributing to the shallow planting and desirable compaction in the intensive system compared to conventional system (Thakur et al., 2011). Consequently, the growing area for weeds decreased; therefore, it competed with the rice plant. Weeds are the main cause of decline in the paddy yield in the rice fields, requiring more labor costs (Chang, 2008). In fact, weed competition reduced through the weed control for the experimental plots and, and more nutritional space was provided to the rice plant.

Nutrient (NPK) uptake indices

According to the findings, grain and straw N content, grain and straw N uptake and protein yield (365.93 kg ha^{-1}) were statistically higher in the conventional system than other systems. But, phosphorous-related parameters were different from N-related parameters. Hence, only grain P uptake and P harvest index were higher in the high-input and conventional systems than other systems. P use efficiency was significantly higher in the high-input, conventional and transition to organic systems than the organic and low-input systems. Furthermore, the results of K-related parameters revealed that, the K harvest index was greater in the high-input and conventional systems than other systems. But, K use efficiency was significantly more in the high-input and organic systems than other systems.

In this context, it has been found that, the nutrient translocation from root to shoots through xylem at the pre-maturity stage was significantly higher in the intensive system than the conventional system (Thakur et al., 2011). In addition, it has been reported that, the rice varieties had the highest light absorption in the intensive system, due to the optimum cover of canopy structure and the increased leaf area index, moreover the plant had a better root growth and higher material transfer through the phloem during the maturity stage, resulting in providing more chlorophyll content for lower leaves, as well as an increase in the photosynthesis rate and the nutrient uptake.

In addition, higher nutrient (NPK) uptake in the intensive system compared to conventional system can be due to the drainage and ventilation in the soil and, using the young seedlings with more root activity resulting in an increase in the nutrient uptake and potential yield (Zhao et al., 2011). In a study, it was reported that using 120 kg ha^{-1} of nitrogen provided the highest rice grain yield whereas using 100 kg ha^{-1} of nitrogen caused a 40% decrease in yield, which led to a decline in leaf area index and chlorophyll index (Dehpouri et al., 2022). In a research, with increase of 90 and 130 kg N ha^{-1} compared to 50 kg N ha^{-1}, rice grain yield and harvest index were significantly enhanced. In contrast, Nitrogen use efficiency were significantly decreased (Jafari Kelarijani et al., 2021). In another study, it was found that the consumption of 60 kg.ha^{-1} of P_2O_5 increased chickpea grain yield, which was significantly different from 30 kg.ha^{-1} of P_2O_5 (Uyeturk et al., 2023).

In addition, the application of compost and organic fertilizer resulted in the gradual and continuous release of the nutrients during the period of grain filling by increasing the root volume and absorption of soil nutrients in the intensive system compared to conventional system (Barison, 2003; Zhao et al., 2011). Moreover, in the intensive system, the efficiency of assimilation, agronomic efficiency, and nutrient physiological efficiency significantly increased. Hence, the nutrient utilization efficiency and removal of the nitrogen accumulation in soil were higher in the intensive system than other systems. Other studies revealed that, the intensive system increased the nutrient use efficiency compared to the traditional system due to increasing the grain yield and higher nutrient uptake (Barison and Uphoff, 2011).

CONCLUSIONS

According to the findings, growing period of the rice cultivars was more in the high-input cropping system than other systems. In fact, increasing the input (NPK) application and transplanting the mature seedlings led to the longer vegetative and reproductive growing period in the high-input and conventional systems. Therefore, in the case of the delayed rice cultivation, younger seedlings should be used. Hence, semi-young and young seedlings were transplanted in the transition to organic and organic systems.

The maximum paddy yield was obtained in the high-input and conventional systems, mainly attributed to the increase in the panicle length, flag leaf length, the number of fertile tiller per hill, the number of panicle per m^2, the number of spikelet per panicle, and filled spikelet percentage compared to other cropping systems. The highest paddy yield was achieved as a result of providing the optimal growth conditions for the plant in the high-input and conventional systems. Consumed water and crop water requirement were higher in the high-input and conventional systems than other systems. In contrast, WUE was higher in the organic system over both years than other systems. But, WP was higher in the conventional system than other systems.

The excessive use of irrigation water, chemical fertilizers and pesticides not only leads to the increased production costs, but also reduces the income and economic productivity, resulting in the long-term degradation of resources in the environment. Accordingly, it can be concluded that, the reduction of economic productivity in an agro-system is due to the excessive application of inputs, imposing serious risks if the cultivation of this strategic product is neglected for a long time.

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