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YIELD GAP AND MORPHOPHYSIOLOGICAL TRAITS OF RICE CULTIVARS: THE AFFECT OF SEEDLING AGE

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ABSTRACT

Understanding yield-limiting traits can help researchers reduce rice yield gap, a key step in increasing yield and sustainability. This research therefore involved two steps: (i) monitoring 100 paddy fields of farmers to identify the most important variables to enter into a CPA model (comparative performance analysis) for the yield gap in the Sari region of northern Iran in 2015 to 2016, and (ii) investigating the effect of seedling age on local and improved cultivars in this region (Mazandaran province) in 2016 and 2017. The field experiment was conducted in a factorial experiment based on a randomized complete block design (RCBD) with three replications. The three seedling ages were 20, 27 and 34 days old for six Iranian rice cultivars (three local cultivars: Tarom Hashemi, Tarom Mahalli and Sang Tarom; and three improved rice cultivars: Fajr, Neda and Shiroodi). Of the 150 variables studied in the first experiment, eight independent variables were chosen for the final model. In the yield model, the average and maximum yields were 4437 and 6690 kg ha^{-1}, respectively, with an estimated yield gap of 2253 kg ha^{-1}. This yield gap was related to seedling age, transplanting date and seedling number per hill. Those factors were responsible for 104, 224 and 534 kg ha^{-1}, i.e. 5, 10 and 24 percent, respectively. The results of the second experiment demonstrated that all investigated traits were significantly affected by seedling age. Twenty-day-old seedlings yielded the greatest panicle length, flag leaf length, number of panicles per m^2, filled spikelet percentage, grain yield, harvest index, protein content, protein yield, nitrogen harvest index. Accordingly, the model's precision is good and can be applied both to estimate the quantity of yield gap and to determine the portion of each constraint in the yield variables. Importantly, as the calculated yield potential is reached based on actual data in each paddy field, the yield potential is attainable. A seedling age of 20 days created better conditions for growth and yield for both local and improved cultivars.

Keywords: cultivar, documentation, lodging index, *Oryza sativa* L., seedling age, yield gap.

INTRODUCTION

Sustainable food security is the ultimate goal of agricultural production systems. The global human population is predicted to grow substantially through 2050, necessitating enormous increases in food production as well as reductions in food waste (Fedoroff, 2015). The final capacity of food production in the world is limited by the amount of suitable land and available water resources for crop production as well as the biophysical limits of crop growth (van Ittersum et al., 2013). Reducing the gap between the yields that are current achieved by farmers and those potentially attainable using the cultivars most compatible with the environment, available water resources, as well as soil and crop management practices is the key to overcoming the nutritional challenges we face in the coming decades (Ilkaee et al., 2011). Here, yield gap analyses provide a quantitative estimate of the potential for increasing production capacity, which is an important component in the design of food security strategies at the regional, national and global levels (van Wart et al., 2013).

Two variables - seedling age and transplanting date - have been entered into the comparative performance analysis (CPA) equation. This prompted examining the seedling age of local and improved rice cultivars in field experiments to select the best seedling age for each group of cultivars. Worldwide, however, this analysis has more

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closely involved soil factors (nutrient content, organic matter, acidity, etc.) and yield estimations (Kitchen et al., 2003). Nonetheless, estimating potential yields and determining the minimum inputs to achieve potential yields has received less attention. Simulation models can be used for this purpose (Abeledo et al., 2008; Aggarwal and Kalra, 1994; Menendez and Satorre, 2007). Understanding the full potential as well as the extent and the effect of each limiting factor on yield separately plays an important role in determining alternatives management strategies to achieve maximum yield. Studies for rice plants can be used to analyze the rice yield gap in organic and conventional cultivation systems elsewhere, for example in the Mediterranean (Delmotte et al., 2011). They can also be use to determine the factors influencing the yield variation of flooding rice in southern-central Benin (Tanaka et al., 2013); determine the factors behind the rice yield stagnation in floodplain systems in the Senegal River Valley (Tanaka et al., 2015); analyze the yield gap of rice planting systems in the United States (Espe et al., 2016); simulate the global rice yield gap (Mueller et al., 2012); determine the yield gap of rice in China (Xu et al., 2016); conduct yield gap analyses of rice in the Philippines using modeling (Silva et al., 2017); and estimate the yield gap of rice in Netherlands to be 1855 kg ha^{-1} (Kayiranga, 2006).

Aslam et al. (2015) reported that rice yield and yield components including panicle length, number of tillers per hill, number of spikelets per panicle and 1000-grain weight in different cultivars were significantly different statistically by seedling age. Moreover, young seedling – by faster growth, faster leaf growth, more tillering and proper utilization of environmental resources – can increase the grain yield of rice compared to older seedlings (Pramanic and Bera, 2013). Sasaki (2004) reported that the best seedlings for rice transplanting are those with 2-3 leaves, which enabled a better transfer of young seedlings by mechanized means.

Multiple studies have shown that the first step in reducing the yield gap is to identify the key variables that restrict yield. This calls for understanding yield-limiting traits. Reducing the gap not only increases yield and production, but also improves land use and human resource efficiency, which in turn reduces production costs and increases, yield sustainability. This research was therefore conducted in two steps: (i) in a first step we examined 100 paddy fields of local farmers in the region to quantify the rice yield gaps and identify the most important variables entered in CPA models; (ii) we then investigated the effect of seedling age on local and improved cultivars in terms of quantitative parameters in the Sari region, Mazandaran province, northern Iran.

MATERIAL AND METHODS

This study was conducted in two phases. In the first, 100 paddy fields were surveyed to determine the most important variables to enter into the yield gap equation in the CPA method. In the second, seedling age and transplanting date were entered into the produced equation. These variables contribute significantly to the yield gap and have direct and indirect effects on other variables and on rice growth traits. Accordingly, seedling ages for local and improved rice cultivars were investigated to determine the best seedling age for each cultivar type.

Monitoring of 100 farmers' paddy fields

Description of the region

The research was conducted in 100 paddy fields between the Alborz Mountain range and the Caspian Sea from 2015 to 2016. Sari is located in Mazandaran province in the north of Iran. The paddy field area in the Sari region is about 23,000 hectares, equivalent to 10% of the total paddy cover in Mazandaran province (Ministry of Jihad-e-Agriculture of Iran, 2016). The experimental region is geographically situated at 36°4' N latitude and 53°5' E longitude. The mean annual rainfall in the coastal area of the province is 977 mm. The maximum rainfall occurs in fall, the minimum in spring. Hot and humid summers and mild and humid winters are the main characteristics of the weather here. Therefore, the weather in some parts of this area is similar to that of the Mediterranean.

Data collection

All the crop management practices from nursery preparation to harvesting were recorded through field monitoring. To estimate yield gap, we recorded all agricultural practices in 100 paddy fields. All the farm data involved local cultivars. All data on agricultural management were collected, including soil preparation (time and number of plough, disk, etc.), transplanting time, fertilizer consumption (amount and time of the applied fertilizer), pests, diseases and weeds control, irrigation (number and time of irrigation) and harvesting information (harvest time and yield). This information was obtained and completed in questionnaire form by paddy fields monitoring. At the end of growing season, the actual harvested yield amount was registered.

The 100 farmers were chosen randomly in a manner that covered all main production methods and different management approaches. Initially, all the agricultural variables were separated in obtaining information on paddy field management. Then, after each operation started, we collected data on temperature changes, variation in production methods, and different input quantities by farmers. Moreover, we recorded broader information such as the date of starting operations and entry quantity in each implementation stage (cultivation to harvest) from the paddy fields.

Estimation of yield gap by CPA method

In order to determine the yield model (production model), the relationships between all the variables were measured and the yield was evaluated using the regression method (Soltani et al., 2016). The final model was obtained through the controlled trial and error method, which can quantify the effect of yield limitations. The average paddy yield was calculated by the model by placing the observed average variables (Xs) in the fields under study in the yield model. Thereafter, we calculated the maximum obtainable yield by putting the best observed value of the variables in the yield model. The difference between these two approaches is considered the yield gap. The difference between multiplying the average observed value for each variable by its coefficient, and multiplying the best observed value for the same variable by the coefficient of the same variable, presents the value of the yield gap for that variable. The ratio of yield gap for each variable to the total yield gap represents its share in creating the yield gap (in percent). Different procedures of the software SAS version 9.1 were used for this analysis.

Field trial experiment

Description of the experiment

The field experiment was carried out in a factorial experiment based on a randomized complete block design (RCBD) with three replications in the Sari region, Mazandaran province, Iran, during 2016 and 2017. The three seedling ages considered were 20, 27 and 34 days old for six Iranian rice cultivars (three local cultivars: Tarom Hashemi, Tarom Mahalli and Sang Tarom; three improved cultivars: Fajr, Neda and Shiroodi). Considering the climate of the Sari region, the seedlings were transplanted according to seedling age. Considering the type of the cultivar, the transplanting practices were performed at sites with similar conditions. Each plot size was 3×5 m (15 m^2) and the planting density was 16 plants per square meter in a 25×25 cm arrangement.

Evaluation of traits

During the growth period, after removing the 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.

Phenological traits, including the number of days from seeding in the nursery to the start of germination, 50 percent of flowering, pollination, and the physiological maturity stages, were determined from 8 tillers per hill in every experimental plot. In order to quantitatively determine the morphological traits, sampling was performed 30 days after the full-heading stage (from the 12 stems selected from the 4 tillers per hill in each experimental plot). The data recorded included stem length, panicle length, flag leaf length, flag leaf width, and plant height. The number of tillers per hill, and the number of fertile and infertile tillers per hill were quantified based on 12 hills per plant in each experimental plot. The number of panicles per square meter was obtained by counting the number of panicles present per square meter. The number of spikelets per panicle and the number of filled spikelets per panicle were measured by counting them from 15 panicles in each experimental plot. The 1000-grain weight was obtained by counting 10 samples of 100 grains and weighing them with 14% moisture.

Paddy yield, straw yield, and biological yield were measured by harvesting the hills from 4 m^2 in the middle part of each plot, based on 12% moisture

The nitrogen concentration in grain and straw was determined by the Kjeldahl method. The nitrogen use efficiency (NUE) was obtained from the ratio of grain weight to the amount of the nitrogen uptake by the rice plant and expressed in kg kg^{-1}.

Statistical analysis

After normalization, the data analyzed by the SAS statistical software and the comparisons of averages were calculated by LSD tests at a 5% probability level.

RESULTS AND DISCUSSION

Yield gap estimation by CPA method
Production model

The results of the stepwise regression to determine the most important management variables that affected the yield and production model are presented in Table 1. In this regression model, the paddy yield per unit area was considered as a dependent variable. The other variables such as seedling age, crop rotation, transplanting date, seedling number per hill, potassium usage, nitrogen usage after flowering, fertilizer top-dressing frequency and combine-machine harvesting were considered as independent variables, and the result was presented in the final equation. Finally, using this production equation, the actual farm yield, the attainable yield, and the share of each variable on yield reduction were determined. Therefore, from about 150 studied variables, the stepwise model (final regression equation) was selected with five independent variables (Table 1). The final yield equation is as follows:

$$Y\ (\text{kg ha}^{-1}) = 4885 - 8\ X_1 + 654\ X_2 - 14\ X_3 - 178\ X_4 + 4\ X_5 + 27\ X_6 + 292\ X_7 - 29\ X_8$$

where Y is the paddy yield in kilogram per hectare, X_1 is seeding age, X_2 is crop rotation, X_3 is transplanting date, X_4 is seedling number per hill, X_5 is potassium usage, X_6 is nitrogen usage after flowering, X_7 is fertilizer top-dressing frequency and X_8 is combine-machine harvesting. These continue for the evaluation of each of the factors that influenced the paddy yield.

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Table 1. Quantifying the canola yield gap and the contribution of each variable entered in the production equation in the CPA method

Variable	Coefficients	Variable in model				Predicted yield by model		Yield gap (kg ha^{-1})	Yield gap share
		Min.	Mean	Max.	Best	Mean	Best		
Intercept	4885	25	-	-	-	4885	4885	-	-
Seedling age (X_1)	-8	0	38	57	25	-304	-200	104	5
Crop rotation (X_2)	654	28	0.60	1	1	392	654	262	12
Transplanting date (X_3)	-14	2	44	70	28	-616	-392	224	10
Seedling number per hill (X_4)	-178	0	5	8	2	-890	-356	534	24
Potassium usage (X_5)	4	0	35	137	137	140	548	408	18
N after flowering (X_6)	27	0	10	25	25	270	675	405	18
Top-dressing frequency (X_7)	292	0	2	3	3	584	876	292	13
Combine-machine harvesting (X_8)	-29	0	0.83	1	0	-24	0	24	1
Paddy yield (kg ha^{-1})	-	3350	4221	5950	-	4437	6690	2253	100

Paddy yield limiting factors and yield gap estimation

Table 1 presented the variables applied in the production equation with the mean, minimum and maximum values observed in the paddy fields. The characteristics of the variables applied in the model as the average, minimum, maximum, and best values that could be applied in the yield regression model are presented in Table 1. To achieve the best condition for the variables including crop rotation, potassium usage, nitrogen usage after flowering, fertilizer top-dressing frequency with positive effect, their maximum values were selected. Seedling age, transplanting date, seedling number per hill and harvesting by combine-machine variables were negative variables and selected in small amounts, therefore, the optimal value was equivalent to the minimum of these two variables. The increase in paddy yield caused by the difference between the best and the medium state of seedling age, transplanting date, seedling number per hill and harvesting by combine-machine variables was equal to 5, 10, 24 and 1% of the total paddy yield increase of 104, 224, 534 and 24 kg ha^{-1}, respectively. The paddy yield increase related to the effect of crop rotation, potassium usage, nitrogen consumption after flowering, fertilizer top-dressing frequency was 262, 408, 405 and 292 kg ha^{-1}, respectively, and equal to 12, 18, 18 and 13% of the total changes in yield (Table 1).

Among the eight variables used in the model, the effects of potassium usage and nitrogen consumption after flowering were remarkable, which compensated for a significant part of the yield gap in the fields with the farmers managing potassium consumption and nitrogen splitting after flowering. The results listed in Table 1 show the total yield and the share of each factor limiting the production relative to it. In the production model, the average and the maximum yields were estimated to be 4437 and 6690 kg ha^{-1}, respectively, which is comparable to the average and maximum, yields (4221 and 5950 kg ha^{-1}).

The total yield gap estimated was equal to 2253 kg ha^{-1}. This means that there was a gap between the actual yields of the farmers and what they could have potentially harvested with 2253 kg ha^{-1}, which could be eliminated or reduced with better management (Table 1). The results in Figure 1 illustrate the contribution of each variable to the yield gap along with the actual and the potential yields. Therefore, the actual yield and the potential yield were estimated to be 4437 and 6690 kg ha^{-1}, respectively, and the yield gap was 2253 kg ha^{-1}. This result suggests that this yield gap could be compensated. The findings in Figure 1 show the relationship between the actual yield (observed yield) and the predicted yield (simulated yield). These statistics shows that the accuracy of the model (production equation) is appropriate, and it can be used to estimate the yield gap and to determine the contribution of each production-limiting variable. With all these interpretations it can be said that the calculated yield gap in this study is close to that given by researchers regarding the attainable yield gap and shows the difference between the actual yield and attainable yield in relation to the environmental conditions of the area. One of the limitations of this research is the number of years of the implementation; the more the years spent, the more accurate the estimation of the impact of climate and climate fluctuations. To reduce the yield gap, it is necessary to specify the yield limits in a particular area (van Ittersum et al., 2013). However, there is no such limitation on the potential yield obtained at a research station or in potential yield simulation with plant models. The goal of many researchers is to increase yield to a reasonable level for maintaining food prices to the extent that it is both desirable for the consumer and the product price can cover the costs for the farmer as well.

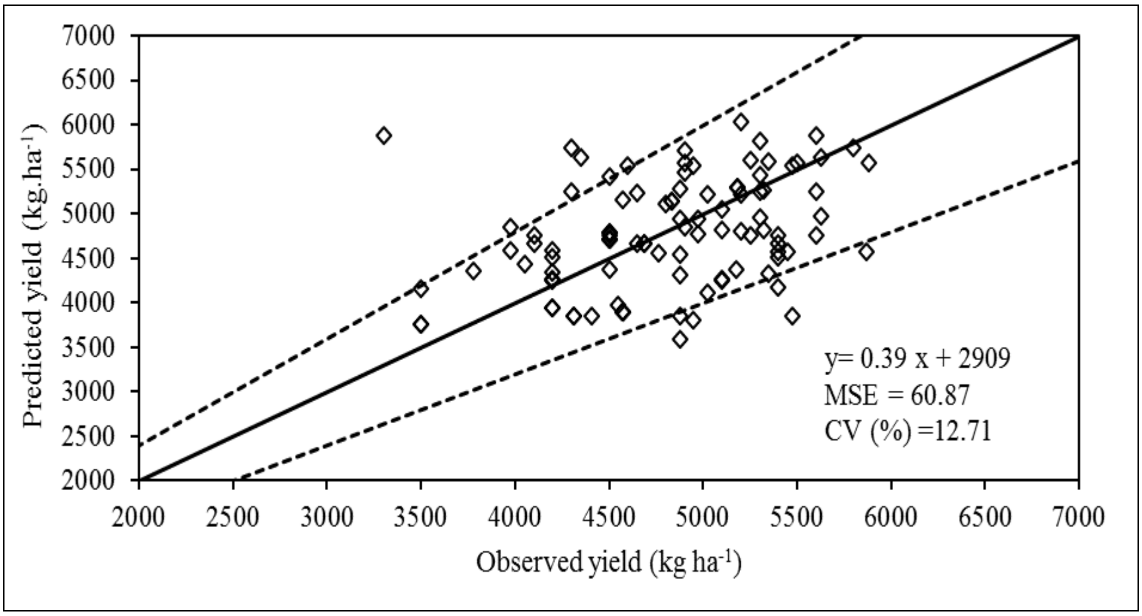

Figure 1. The relationship between observed and predicted yields.
Twenty percent of the differences between the two yields are shown by dashed lines

Reducing the yield gap requires specifying the yield limits in a particular area (van Ittersum et al., 2013). However, there is no such limitation on the potential yield obtained at a research station or in a potential yield simulation with plant models. The ultimate goal of most researchers is to increase yield to a reasonable level to maintain food prices at a level that it is both desirable for consumers and covers the costs for farmers. Generally, our results demonstrate that using the CPA method in yield gap studies can illustrate the effects of managerial factors by identifying the contribution of each variable. Using these effects, the best management and planning responses to achieve the highest yield can be determined. This method also has certain disadvantages: it considers the interaction of variables affecting yield to be non-significant and only analyzes the impact of a variable on yield. In reality, yield is the result of the interaction of a set of factors (Kitchen et al., 2003). Importantly, the use of other methods for estimating potential yields, such as plant models combined with boundary line analysis, can reveal important points regarding production limitations in a region. Understanding potential as well as the extent and effect of yield limiting factors separately is important in determining alternative management strategies to achieve maximum yield. The importance of each factor in each region changes with crop type. In this context, Oerke (2006) studied yield loss due to biotic stress (insects, diseases, viruses and other organisms) through meta-analysis. In another study, the yield decrease for rice was reported to be 34% of the field yield in tropical Asian regions (Savary et al., 2012).

Peng et al. (2008; 2009) evaluated the yield limitations of paddy fields in China. They showed that most limitations were the result of poor irrigation regimes, incorrect agricultural management, and overuse of pesticides and chemical fertilizers. The yield potential reported for rice differs depending on the cultivar and environmental conditions. For instance, the yield potential of rice for the direct cultivation of seeds in America (Epse et al., 2016) was much less than that of rice (20.1 t ha^{-1}) reported by Sheehy and Mitchell (2015) for a dwarf cultivar in a semi-tropical region with a growing period of 168 days. Nonetheless, the estimated potential yield in Epse et al. (2016) was higher than that calculated based on the maximum average paddy yield in a similar climate (Mueller et al., 2012; Foley et al., 2011). Unlike previous studies (Licker et al., 2010; Mueller et al., 2012; Foley et al., 2011), Epse et al. (2016) analyzed paddy yield and reported that it is impossible to obtain 100% attainable yield (potential yield). Moreover, the yield gap varies in different regions and years based on the diversity of pests and climate phenomena (Lobell et al., 2009). Other researchers reported that using improved cultivars of rice, soil fertility management, weed management and irrigation were important in increasing the attainable yield in China in the past decades (Huang et al., 2011). Therefore, analyzing the yield gap to help determine the attainable yield due to improved technologies is necessary (Nhamo et al., 2014). Although it is useful to calculate attainable yields in a particular region – taking into account the best combination of genotypes, environmental conditions and management (G×E×M) – it is not possible to entirely eliminate biotic and abiotic stress during the plant growth period (van Ittersum et al., 2013). Therefore, these functions are insufficient estimates of regional potential with regard to the prevailing climatic and soil conditions. Certain regional climatic factors can also reduce maximum yields.

Effect of seedling age on local and improved rice cultivars

Bartlett test results

In order to investigate the effect of seedling ages on local and improved cultivars of rice in the two years, firstly the data were measured by using the Bartlett method of variance homogeneity test. The results showed significant differences among all the studied traits except for the Bartlett test revealed significant differences for local cultivars traits including no. of panicle per m^2, nitrogen harvest index. In addition, this test for improved rice cultivars shows significant differences among days to full maturity, number of tiller per hill, paddy yield and nitrogen harvest index (Table 2). Therefore, the analysis and interpretation of these traits did by simple mean square analysis (ANOVA) and other traits that not shows significant differences analyzed by combined variance analysis.

Table 2. Bartlett test results for seedling ages of local and improved cultivars

Investigated traits	Local cultivar	Improved cultivars
		Chi-squares
Days to full maturity	1.85^{ns}	8.14**
Panicle length	0.0542^{ns}	0.6058^{ns}
Flag leaf length	0.0101^{ns}	0.9279^{ns}
Plant height	1.54^{ns}	0.0301^{ns}
No. of tiller per hill	0.9940^{ns}	6.15*
No. of panicle per m^2	11.48**	0.4280^{ns}
No. of spikelet per panicle	0.2954^{ns}	0.7870^{ns}
Filled spikelet percentage	0.2210^{ns}	0.4448^{ns}
Paddy yield	1.54^{ns}	9.87**
Harvest index	0.0995^{ns}	0.8717^{ns}
Protein yield	0.6530^{ns}	0.5171^{ns}
Nitrogen harvest index	71.25**	148.3**
Nitrogen utilization efficiency	0.5092^{ns}	2.60^{ns}

Simple analysis (ANOVA)

According to analysis of variance in local cultivars no. of panicle per m^2 in second year, and nitrogen harvest index were statistically significant under seedling age effect. In addition, number of panicle per m^2 in both years was significant under cultivar effect.

Based on the findings of analysis of variance for improved cultivars, days to physiological maturity, no. of tiller per hill and paddy yield were statistically significant at seedling ages in both years. By cultivar effect, days to physiological maturity and no. of tiller per hill was significant in first year, but no. of tiller per hill was significant in second year.

Mean comparison of traits in local cultivars demonstrated that the most number of panicle per m^2 and nitrogen harvest index, were observed in seedling of 20 days, but seedling of 27 days stood ranks next. The minimum amount of these parameters was observed for seedling of 34 days (Table 3). The maximum number of panicle per m^2 was observed for Tarom Mahalli cultivar, but Tarom Hashemi and Sang Tarom cultivars stood ranks next (Table 3).

Mean comparison of traits in improved cultivars revealed that days to physiological maturity and number of tiller per hill were highest in seedling of 34 days, but paddy yield was highest in seedling of 20 days. Also, the most no. of tiller per hill was observed for cv. Shiroodi (Table 4).

Mean comparison of seedling age and cultivar by slice interaction of cultivars shows that in all improved cultivars seedling of 34 days shows the maximum days to physiological maturity. Seedling of 27 and 20 days stood ranks next (data not shown). In addition, the most no. of tiller per hill for all improved cultivars was observed in seedling of 34 days and seedlings of 27 and 20 days stood ranks next (data not shown).

Table 3. Mean comparison of phenological and agronomical traits under effect of three seedling ages for local cultivars of rice

Treatment	No. of panicle per m^2		Nitrogen harvest index (%)	
	First year	Second year	First year	Second year
Seedling age				
20 days	308.33 a	339.56 a	76.42 a	74.26 a
27 days	306.22 a	308.94 b	74.88 ab	74.93 a
34 days	276.50 a	275.06 c	64.00 b	73.66 a
LSD 0.05	62.27	17.52	12.01	1.59
Cultivar				
Tarom Hashemi	301.89 ab	294.67 b	71.03 a	74.08 a
Tarom Mahalli	334.67 a	320.11 a	69.13 a	73.86 a
Sang Tarom	254.49 b	308.78 ab	75.14 a	74.96 a
LSD 0.05	62.27	17.53	12.01	1.59

*: Values within a column followed by same letter are not significantly different at LSD (P≤0.05).

Table 4. Mean comparison of phenological and agronomical traits under effect of three seedling ages for improved cultivars of rice

Treatment	Days to physiological maturity		No. of tiller per hill		Paddy yield (kg ha^{-1})		Nitrogen harvest index (%)	
	First year	Second year	First year	Second year	First year	Second year	First year	Second year
Seedling age								
20 days	103.61 b	103.72 b	17.37 b	16.60 b	7698 a	7648 a	76.16 a	74.96 a
27 days	104.06 b	104.39 b	17.92 b	16.62 b	7303 b	7375 ab	74.83 a	74.94 a
34 days	109.72 a	107.17 a	20.83 a	19.67 a	7136 b	6675 b	65.67 a	75.13 a
LSD 0.05	1.95	1.61	0.93	1.05	196.16	534.92	13.08	0.40
Cultivar								
Fajr	107.22 a	105.67 a	18.28 b	16.72 b	7272 b	7180 a	70.29 a	75.15 a
Neda	105.33 ab	104.50 a	19.28 a	17.42 b	7390 ab	7137 a	69.62 a	74.93 a
Shiroodi	104.83 b	105.11 a	18.56 ab	18.74 a	7475 a	7381 a	76.75 a	74.95 a
LSD 0.05	1.95	1.61	0.93	1.05	196.16	534.92	13.08	0.40

*: Values within a column followed by same letter are not significantly different at LSD (P≤0.05).

Combined analysis

Findings of the combined analysis variance demonstrated that all investigated quantitative traits including phenological traits, agronomical traits, yield components, grain yield and harvest index were statistically significant in 5% and 1% probability level on seedling age in both local and improved cultivars group. Moreover, filled spikelet percentage in improved cultivar was statistically significant in 5% probability level under double interaction of seedling age and cultivar. With attention to interaction of seedling age and cultivar we can find that the vegetative and reproductive periods especially days to tillering, days to panicle initiation, days to 50% flowering and days to physiological maturity in young seedling (20 days old) were lower than two other seedling ages in both cultivars group. The highest vegetative and reproductive growth periods of both cultivars group were observed for seedling ages of 24 days old (Table 5).

Table 5. Double interaction of seedling age and cultivars on quantitative and qualitative traits of rice

Interaction	Days to physiological maturity in improved cultivar	Number of tiller per hill in improved cultivars	Filled spikelet percentage in improved cultivar	Nitrogen utilization efficiency (kg.kg^{-1}) in local cultivar
A_1C_1	104.92 b	16.46 b	90.00 a	50.50 bc
A_1C_2	102.83 c	17.04 b	87.67 ab	43.58 c
A_1C_3	104.92 b	17.45 b	88.88 ab	43.13 c
A_2C_1	104.67 b	16.63 b	90.67 a	43.40 c
A_2C_2	103.00 bc	16.76 b	90.25 a	38.63 d
A_2C_3	103.33 bc	18.43 ab	87.08 ab	49.58 bc
A_3C_1	109.75 a	19.42 ab	83.83 b	80.72 a
A_3C_2	108.92 a	21.25 a	82.17 b	56.47 b
A_3C_3	106.67 ab	20.08 a	86.42 ab	63.08 ab

*: Values within a column followed by same letter are not significantly different at LSD (P≤0.05).
A_1, A_2 and A_3 are seedling ages of 20, 27 and 34 days respectively.
C_1, C_2 and C_3 are Tarom Hashemi, Tarom Mahalli and Sang Tarom in local cultivars group.
C_1, C_2 and C_3 are Fajr, Neda and Shiroodi in improved cultivars group.

According to other researchers' findings, phenology is one of the major topics in the field of ecology, and its aim of that is a study of changes in the vital stages of plants. Determining the vital stages of plants, including the evaluation of phenological traits to improve yield and help to make decisions to maximize available plant sources is very important (Yin et al., 2005). The phenology and growth period of rice is one of the main factors determining the agronomical and ecological suitability of cultivars in the cultivated area (Yin et al., 2005). Therefore, proper prediction of phonological stages of crops is important for optimizing management activities in the field and better adaptation of crop schedule (Itoh et al., 2005; Khanal, 2005). In fact, phenological developmental stages in plants are affected by temperature, photoperiod and vernalization (Gonzalez et al., 2002; Streck et al., 2003). Adaptation of the growth period of cultivars to achieve acceptable yields, increase productivity, reduce losses and maintain their cultivation is always one of the important and influential topics. Therefore, the development of medium and late cultivars cultivation in paddy fields in the northwestern part of Iran is highly dependent on the crop rotational calendar, especially seeding date in nursery, seedling age, transplanting date and growth period of rice cultivars. In fact, flag leaf, with its location close to the panicles, has a major contribution to the transfer of photosynthetic material and grain filling. So, in order to achieve maximum yield, the amount of leaf in the shoots of the plant is essential. Davatgar et al. (2009) revealed that most of the reduction in leaf area appears to be the consequence of revealed cell expansion, the closing of stomata and inhibition of photosynthesis.

Mean comparison of agronomic traits revealed that panicle length and flag leaf length in both cultivars group was decreased by transplanting of old seedling compared to young seedling. Thus, panicle length and flag leaf length for seedling age of 20 days old was 11.48% and 25.40% higher than seedlings of 27 and 34 days old in local cultivars. Moreover, in improved cultivars panicle length and flag leaf length for seedling age of 20 days old was 10.58% and 14.48% higher than seedlings 27 and 34 days old (Table 6). But, plant height for local cultivars in seedling age of 34 days was 3.70% higher than 20 days (Table 6). Mean comparison for yield components shows that number of tiller per hill for both cultivars group with transplanting seedling age of 20 days old was 17.26% and 31.04% higher than seedling ages of 27 and 34 days old in local cultivars and 19.92% and 29.78% in improved cultivars. As a result, number of panicle per m^2 in seedling age of 20 days old was 9.49% and 17% higher than seedling ages of 27 and 34 days old in local cultivars and 5.32% and 17.46% respectively (Table 7). Furthermore, number of spikelet and filled spikelet percentage for seedling ages of 20 days old was higher than seedling ages of 27 and 34 days old in both cultivars group (Table 7). According to interaction of seedling age and improved cultivar, it was demonstrated that the highest filled spikelet percentage was observed for seedling ages of 20 and 27 days for Fajr and Neda cultivars and the least one was shown for seedling ages of 34 days old for Fajr and Neda cultivars (Table 5).

Table 6. Mean comparison of phenological and agronomical traits under effect of three seedling ages for local and improved cultivars of rice

Treatment		Plant height (cm)		Flag leaf length (cm)		Panicle length (cm)		Days to physiological maturity
Year		Improved cultivar	Local cultivar	Improved cultivar	Local cultivar	Improved cultivar	Local cultivar	Local cultivar
First year (2016)		105.48 a	160.57 a	29.31 a	36.04 a	25.66 a	30.96 a	100.20 a
Second year (2017)		104.02 a	160.97 a	29.14 a	36.28 a	25.65 a	31.48 a	100.48 a
LSD 0.05		3.38	1.50	2.98	2.9	1.77	1.47	1.89
Seedling age								
20 days		106.47 a	159.06 b	31.00 a	39.99 a	26.87 a	32.81 a	99.39 b
27 days		104.28 a	158.28 b	29.60 a	36.60 b	25.98 b	31.42 a	99.64 b
34 days		103.51 a	164.95 a	27.08 b	31.89 c	24.30 c	29.43 b	102.00 a
LSD 0.05		4.99	4.10	1.68	1.92	1.35	1.20	1.27
Improved cultivar	Local cultivar							
Fajr	Tarom Hashemi	109.75 a	160.41 a	31.14 a	32.93 c	26.33 a	28.09 c	100.92 a
Neda	Tarom Mahalli	99.50 b	161.07 a	26.96 b	39.64 a	24.76 b	34.39 a	99.64 b
Shiroodi	Sang Tarom	105.01 ab	160.81 a	29.58 a	35.91 b	25.89 a	31.17 b	100.47 ab
LSD 0.05		16.40	1.17	1.84	1.14	1.65	2.14	0.59

*: Values within a column followed by same letter are not significantly different at LSD (P≤0.05).

In fact, seedling age of 20 day have a higher growth rate than seedling age of 27 and 34 days old. Increasing panicle length and plant height in younger seedlings may be due to better root growth, less seedling damage during folding, and also a smaller leaf area at the onset of the growth period, which stimulates cell division and ultimately prolongs the stem (Pramanik and Bera, 2013). Mishra and Salokhe (2008) in Thailand showed that younger seedlings of rice can better adapt to the environmental conditions compare to older ones, and those with an age of 12 days, under favorable growth conditions, have better growth and have good stems and roots, larger leaves and plant height are more suitable.

The number of fertile tillers per plant depends on heredity capacity of cultivars, climatic and weather conditions, plant density, available nutrients in soil, agricultural operations, tillers growth rate, plant area occupation and competition between plants. Also, number of panicle per m^2 is the most important yield component of rice, which depends on number of plants per unit area and number of fertile tiller per hill. Improved root growth and increased cell division and development due to the higher amount of photosynthesis leads to an increase in the number of tillers per panicle in younger seedling compared to older seedling. Also, proper plant development and better utilization of light, food and space will result in the production of more fertile tillers per panicle (Pramanik and Bera, 2013). The results obtained by Subedi (2013) also indicate the superiority of 20-day seedlings compared to 40-day seedling in terms of the number of fertile tillers per square meter. Moreover, the ability to produce spikelet per panicle in younger seedlings is significantly more than older seedlings (Subedi, 2013).

Simple mean comparison for grain yield and harvest index showed that grain yield and harvest index was statistically significantly decreased with increasing of seedling ages. Hence, grain yield in seedling age of 20 days old was 5.45% and 10.76% higher than seedling ages of 27 and 34 days old in local cultivars and 4.55% and 11.11% in improved cultivars respectively (Table 8). The main cause for higher grain yield production for seedling ages of 20 days for both cultivars group was increase of panicle length, flag leaf length, panicle per m^2 and filled spikelet percentage Furthermore, harvest index for seedling age of 20 days old was 1.70% and 3.27% higher than seedling ages of 27 and 34 days old in local cultivars and 0.56% and 6.42% in improved cultivars (Table 8).

Table 7. Mean comparison of yield components under effect of three seedling ages for local and improved cultivars of rice

Treatment		Filled spikelet percentage		Number of spikelet per panicle		Number of panicle per m^2	Number of tiller per hill
Year		Improved cultivar	Local cultivar	Improved cultivar	Local cultivar	Improved cultivar	Local cultivar
First year (2016)		87.46 a	80.93 a	79.84 a	115.86 a	388.44 a	13.93 a
Second year (2017)		87.42 a	81.47 a	81.40 a	117.17 a	386.67 a	13.76 a
LSD 0.05		4.40	2.24	14.86	7.95	34.81	4.76
Seedling age							
20 days		88.85 a	83.28 a	87.86 a	123.31 a	420.03 a	12.29 b
27 days		89.33 a	83.13 a	79.23 b	117.06 b	383.64 b	13.30 b
34 days		84.14 b	77.20 b	74.76 b	109.18 c	359.00 c	15.95 a
LSD 0.05		3.10	5.87	10.50	5.59	5.16	0.91
Improved cultivar	Local cultivar						
Fajr	Tarom Hashemi	88.17 a	74.97 c	89.03 a	120.35 a	399.06 a	12.60 b
Neda	Tarom Mahalli	86.69 a	87.47 a	74.41 b	113.14 b	384.00 b	14.00 a
Shiroodi	Sang Tarom	87.46 a	81.16 b	78.42 b	116.06 ab	379.61 b	14.94 a
LSD 0.05		1.56	4.27	6.67	7.48	66.46	6.60

*: Values within a column followed by same letter are not significantly different at LSD (P≤0.05).

Table 8. Mean comparison of grain yield, harvest index, nitrogen utilization efficiency and nitrogen harvest index under effect of three seedling ages for local and improved cultivars of rice

Treatment		Nitrogen utilization efficiency ($kg.kg^{-1}$)		Harvest index (%)		Paddy yield ($kg.ha^{-1}$)
Year		Improved cultivar	Local cultivar	Improved cultivar	Local cultivar	Local cultivar
First year (2016)		37.93 a	50.71 a	51.80 a	33.77 a	4885 a
Second year (2017)		38.46 a	53.50 a	52.36 a	33.43 a	4816 a
LSD 0.05		6.31	16.29	1.09	2.22	651
Seedling age						
20 days		33.11 b	45.58 b	53.74 a	35.26 a	5104 a
27 days		37.44 b	43.97 b	53.18 a	33.55 b	4840 b
34 days		44.03 a	66.76 a	47.32 b	31.99 c	4608 c
LSD 0.05		5.63	6.31	3.22	0.67	142.63
Improved cultivar	Local cultivar					
Fajr	Tarom Hashemi	41.30 a	58.06 a	49.53 b	36.02 a	5004 a
Neda	Tarom Mahalli	34.85 b	46.23 b	54.98 a	33.44 b	4606 b
Shiroodi	Sang Tarom	38.42 b	52.03 ab	51.73 b	31.34 c	4942 a
LSD 0.05		0.46	8.43	5.61	0.62	205.27

*: Values within a column followed by same letter are not significantly different at LSD ($P \leq 0.05$).

Due to the high temperature of the environment during transplantation, the younger seedlings, due to having a lower leaf area during transfer, have been able to balance the amount of transpiration and water absorption by the root, the length of the recycle period from 14-15 days in the middle ages to 8-7 days. As the leaves and stem burns were minimized, as a result of re-growth of the tiller, they started earlier and, with a longer growing period in the mainland, had more opportunity to exploit the growth factors and ultimately produced higher yields. Salem et al. (2011) with investigating rice seedling ages of 20, 30 and 40 days in 2009 and 2010 reported that the highest grain yield in both years was produced at the seedling age of 20 days, and with increase of seedling age to 40 days, grain yield decreased by 13% and 10% respectively. Researcher reported that the harvest index in seedling age of 30 days was longer than seedling age of 40 days (Bagheri et al., 2011). By field trials of two fertilizer levels and 18 modern cultivars on the paddy yield of rice, Li et al. (2016) revealed that variation among cultivars had a great effect on paddy yield. Close correlations were observed between paddy yield and effective panicles and dry matter production. Harvest index, the ratio of grain weight to total shoot weight, is an important trait associated with the dramatic increases in crop yields. Most progress in improving harvest index occurred following the introduction of semi-dwarf traits into rice in the 1960s (Sinclair, 1998). However, the scope for continued harvest index increases in modern rice cultivars was limited by the need for maintaining sufficient leaf area and stem biomass for interception of solar radiation, physical support and storage of assimilates and nitrogen used in grain filling (Cassman, 1999).

CONCLUSIONS

Understanding yield-limiting traits can help researchers reduce rice yield gap, a key step in increasing yield and sustainability. Twenty-day-old seedlings yielded the greatest panicle length, flag leaf length, number of panicles per m^2, filled spikelet percentage, grain yield, harvest index, protein content, protein yield, nitrogen harvest index. Accordingly, the model’s precision is good and can be applied both to estimate the quantity of yield gap and to determine the portion of each constraint in the yield variables. Importantly, as the calculated yield potential is reached based on actual data in each paddy field, the yield potential is attainable. A seedling age of 20 days created better conditions for growth and yield for both local and improved cultivars.

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