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Two Iranian Rice Cultivars' Response to Nitrogen and Nano-Fertilizer

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Abstract

This experiment was carried out as split factorial in randomized complete blocks design with three replications in Sari, Iran during 2013 and 2014. Rice cultivars were chosen as the main factor including Tarom Mahalli and Tarom Hashemi. Nitrogen rates (34 and 69 kg N ha⁻¹ and nitroxin) with nano-particle (nano-potassium, nano-silicon and control) selected as the subfactor. The results indicated that the amount of total tiller per hill and fertile tiller per hill for Tarom Hashemi was more than Tarom Mahalli in both years. The highest paddy yield in both years was observed for Tarom Hashemi, the main reason behind it is increasing panicle length and fertile tiller number for this cultivar. For Tarom Hashemi, the highest paddy yield (5000 kg·ha⁻¹) was produced with 34 kg N ha⁻¹ and nano potassium application. For Tarom Mahalli, the highest paddy yield 4657 kg·ha⁻¹ was obtained with nitroxin and nano potassium consumption. The highest harvest index was achieved with nitroxin and nano-silicon consumption. Therefore, nano particle consumption in both cultivars resulted in improved yield.

Keywords

Nano Particle, Nitrogen, Nano Silicon, Rice, Yield

1. Introduction

Rice (*Oryzasativa* L.) is the main staple food for more than half of the population worldwide. In 2011, worldwide rice production exceeded 672 million mt. Iran has been ranked 20th in terms of rice production internationally speaking [1]. Fertilizers have an important role in enhancing food production and quality es-

pecially after the introduction of high-yielding and fertilizer responsive varieties. Most of the major crops grown such as rice require large quantities of inorganic inputs. Studies have been conducted to improve rice production but only a few can be seen in the literature involving nano-materials [2]-[8]. Nano-materials are defined as the materials with a single unit between 1 and 100 nm in size in at least one dimension [9]. Some studies already proved the significance of nano-fertilizers. Some beneficial effects include increased nutrient use efficiency, better yield and reduced soil pollution [10]. Rice yield largely depends on soil conditions and also on the supply of the available nutrients like nitrogen, phosphorus, potassium, sulphur and zinc [11]. Rice plants require large amounts of mineral nutrients including nitrogen for their growth, development, and grain production [12]. The development of efficient nitrogen management protocols requires recognizing cultivar differences and critical stages of crop growth that fertilization is necessary to avoid potential yield loss [13]. Managing rice crop's nitrogen nutrition is difficult because lowland rice crop culture leads to nitrogen losses through ammonia volatilization, nitrification, denitrification, leaching, and runoff [14], which decreases the availability of nitrogen for rice plants. Grain protein concentration is directly related to nitrogen concentration in grains [15]. Rice is the most widely consumed cereal in the world [16]. Therefore, it is important for rice breeders to consider selecting highly efficient genotypes in remobilizing nitrogen from vegetative parts to the grain or genotypes with high grain protein concentration. Grain yield rise can be attributed to the increasing number of grains per panicle [17]. Spikelet fertility has also been associated with rice silicon concentration [18]. Rice low productivity observed in dry land systems results from a series of biotic and abiotic factors. Among these factors, we can mention the occurrence of diseases, inadequate rainfall distribution in the main producing regions, and little fertilizers and lime use [19]. Within the nutrients group, silicon is not considered as essential or functional for plant growth; however, its absorption brings several benefits especially for rice, such as increased cell wall thickness below the cuticle [20], imparting mechanical resistance to the fungi penetration, transpiration drop [20], and leaf angle improvement, making leaves more erect, thus reducing self-shading, especially under high nitrogen rates [21]. A positive correlation has been observed between grain yield and 1000-seed weight at 5% probability level. Harvest index and rice straw had positive correlation at 1% probability level. Hence, the treatment of irrigation halting and silicon amount has shown maximum effect in 1000-seed weight compared to other contributing parameters to yield [22]. Yield rise via adding silicon was attributed to a great number of grains per panicle, whereas 1000-seed weight and the number of panicle per square meter exhibited less change [17]. Therefore, silicon alone could boost grain rice cultivars' yields without further genetic improvements. Silicon helps plants to overcome multiple stresses including the biotic and abiotic ones [12]. For instance, silicon plays an important role in increasing plants' resistance to pathogens such as blast on rice

[23]. Silicon also alleviates other abiotic stresses' effects including salt stress, metal toxicity, drought stress, radiation damage, nutrient imbalance, high temperature, and freezing [12] [24]. Increased levels of silicon in rice plants are associated with dropped grain discoloration levels at harvest. Silicon has been reported to reduce rice seeds shattering and to increase filled grains number and weight [25]. Therefore, this research aims to evaluate nitrogen nano-fertilizers' effect on rice cultivars growth.

2. Material and Methods

The field experiment was conducted in Sari, the northern part of Iran (Latitude 36°38N, Longitude 53°12E and Altitude 13.5 m above sea level), in 2013 and 2014. Meteorology, physical and chemical properties of soil characteristics location of this experiment were presented in **Table 1** and **Table 2**, respectively.

Table 1. Selected soil traits for composite samples at experimental site.

Soil traits	Unit	2013	2014
Soil depth	cm	0 - 30	0 - 30
EC	dS·m ⁻¹	0.68	0.62
pH	-	7.8	7.6
Organic matter	%	1.5	1.4
N	%	0.12	0.10
P	ppm	8	9
K	ppm	140	165
Mg	mg/kg	704	680
Fe	mg/kg	33.7	29
Mn	mg/kg	8.3	7.6
Zn	mg/kg	1.2	1.4
Cu	mg/kg	3.9	3.5
Soil texture	-	Clay	Loam clay

Table 2. Weather condition in experiment site in rice growth stages.

Months	Rainfall level (Mm)	Monthly evaporation (Mm)	Maximum Temperature (°C)	Minimum Temperature (°C)
20 Mar - 20 Apr	12.4	110.3	20.5	9.2
	12	91.5	19.3	9.8
20 Apr - 20 May	10.6	187.5	27.0	15.8
	42.6	134.9	24.6	13.2
20 May - 20 June	41.4	222.5	20.6	19.8
	9.3	166.4	29.1	18.7
20 June - 20 July	16.8	144.1	30.0	22.2
	0	217.3	31.7	21.2
20 July - 20 Aug	2.6	204.6	34.1	23.1
	29.5	133.4	30.3	21.4
20 Aug - 20 Sep	100.3	135.7	29.9	21.1
	10.8	122.2	31.1	21.4

Rice cultivars were chosen as the main factor including Tarom Mahalli and Tarom Hashemi. Nitrogen rates (34 and 69 kg N ha⁻¹ and nitroxin) with nano-particle (nano-potassium, nano-silicon and control) selected as the sub-factor. Clean seeds with a minimum of 95% germination rate were soaked in water for 24 h and incubated for another 24 h. Then, the pre-germinated seeds were sown in seedling trays filled with soil to produce uniform seedlings. The total number of unit was 54 plots. Each plot was in 2 × 5 m² size. After transplanting, five centimetres water depth was maintained in the experimental plots. Ten days before harvest, the plots were drained to facilitate harvest. Insects, diseases, and weeds were intensively controlled to avoid any yield loss. Phosphorous fertilizers were used at the rates of 100 kg P₂O₅ ha⁻¹ as urea and triple superphosphate as basal fertilizers, respectively. Basal fertilizers were applied and incorporated in all plots one day before transplanting. Nitrogen was split-applied in the form: 50 kg N ha⁻¹ at basal, 50 kg N ha⁻¹ at panicle initiation, 50 kg N ha⁻¹ at full heading. The traits of panicle length (on average, 20 clusters per plot), plant height, the number of total tillers and the number of the effective tillers per hill (on average, 12 piles per plot), paddy yield (with the harvest of 4 m² from the middle of each plot) and harvest index [(Grain yield/Biological yield) × 100] were measured. The obtained data were analysed with statistical software SAS and the averages were compared through LSD multiple range test at probability level 0.05. Also the charts and tables were drawn with Excel.

3. Results and Discussion

3.1. Plant Height and Panicle Length

Plant height and panicle length had significant effect under cultivar treatment at probability level 1% in both years. In the 1st year, plant height had meaningful effect under nitrogen treatment at probability level 5%. Also in the 2nd year, panicle length was significant under the nano particles' effect and double interaction of nitrogen and nano particle at probability level 5% (**Table 3**). In both years, the plant height for Tarom Hashemi (136.26 and 143.14 cm) was more than that of Tarom Mahalli cultivar (127.45 and 130.08 cm). Also, in both years, the panicle length for Tarom Hashemi (27.72 and 28.97 cm) was more than that of Tarom Mahalli cultivar (24.81 and 23.68 cm). The maximum plant height 133.87 cm was observed with 34 kg N ha⁻¹ and the minimum plant height 129.62 cm was achieved with nitroxin. Also the maximum panicle length 26.88 cm was observed with using nano-silicon (**Table 4**). The maximum panicle length under double interaction of nitrogen and nano particle was gained with 34 and 69 kg N ha⁻¹ with applying nano silicon (corresponding 27.02 and 27.15 cm) and nitroxin use with control treatment (27.13 cm). Also the lowest panicle length was seen in other interactions (**Figure 1**). Nitrogen influenced jiberlin hormone indirectly through cytoxin. Thus, it resulted in the growth increase of the branches' end parts and the plant young leaves and about rice, it raised the number of the tillers [26]. In a research by Bahmaniar and Sooaee Mashae (2010),

Table 3. Variance analysis of Morphological characteristics and yield component under the effects of density and time of nitrogen application.

S.O.V	df	Plant height		Panicle length		No. Tiller per hill		No. Fertile tiller per hill		Paddy yield		Harvest index	
		2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Repeat (R)	2	72.62*	349.25**	4.44*	2.48	32.78**	22.77**	4.02	22.24**	683251.85*	126705.56 ns	2.12 ns	1.09 ns
Cultivar (C)	1	104.91**	2302.08**	206.98**	377.47**	13.67*	15.09*	15.52*	6.00*	1622400.00**	1284979.63**	8.49 ns	1.56 ns
R × C	2	45.94	38.18	0.26	3.07	2.69	1.46	5.69	0.39	334822.22	147404.07	40.80	23.66
Nitrogen (N)	2	82.13*	98.25 ns	0.92 ns	0.84 ns	80.26**	14.79*	48.30**	15.41**	4924.07 ns	42016.67 ns	41.16**	14.94*
C × N	2	3.69 ns	17.15 ns	1.09 ns	0.90 ns	1.41 ns	0.86 ns	3.63 ns	0.22 ns	115772.22 ns	110812.96 ns	1.68 ns	1.99 ns
Nano particles (P)	2	13.01 ns	15.80 ns	1.51 ns	4.19*	1.30 ns	2.53 ns	0.57 ns	0.96 ns	382812.96 ns	254772.22 ns	5.14 ns	6.84 ns
C × P	2	35.64 ns	12.27 ns	1.41 ns	1.88 ns	1.48 ns	5.31 ns	2.35 ns	2.89 ns	106672.22 ns	10279.63 ns	6.24 ns	2.93 ns
N × P	4	46.34 ns	44.52 ns	3.22 ns	3.67*	1.72 ns	2.72 ns	0.69 ns	0.91 ns	343776.85 ns	184197.22 ns	9.88*	4.44 ns
C × N × P	4	23.72 ns	19.72 ns	1.19 ns	0.92 ns	2.91 ns	3.76 ns	2.30 ns	1.94 ns	334402.78 ns	476671.30*	5.10 ns	1.87 ns
Error	32	22.52	43.17	1.64	1.60	2.64	3.34	2.14	2.06	180403.70	159806.48	4.28	5.36
CV (%)	-	3.60	4.81	4.78	4.84	8.70	13.04	11.42	14.48	9.37	9.32	4.68	5.38

*, **, NS: significant at 5% and 1% probability levels and non-significant, respectively.

Table 4. Mean comparison of nitrogen and nano fertilizers in some parameters of rice cultivars.

Treatment	Plant height (cm)		Panicle length (cm)		No. Tiller per hill		No. Fertile tiller per hill		Paddy yield (kg·ha ⁻¹)		Harvest index (%)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Cultivar												
Tarom Hashemi	136.26 a	143.14 a	27.72 a	28.97 a	19.20 a	14.54 a	13.33 a	10.26 a	4708.5 a	4444.8 a	43.76 a	43.22 a
Tarom Mahalli	127.45 b	130.08 b	24.81 b	23.68 a	18.19 b	13.48 b	12.30 b	9.59 b	4361.9 b	4136.3 b	44.55 a	42.88 a
LSD 0.05	7.94	7.24	0.59	2.05	1.92	1.41	2.79	0.73	677.6	449.63	7.48	6.70
Nitrogen												
Nitroxin	129.62 b	133.93 a	26.51 a	26.47 a	16.94 c	13.06 b	11.56 b	8.89 b	4543.9 a	4251.1 a	45.07 a	42.02 b
N34	133.87 a	138.18 a	26.92 a	26.08 a	18.11 b	14.12 ab	12.22 b	10.22 a	4545.6 a	4276.1 a	44.99 a	43.74 a
N69	132.09 ab	137.73 a	26.86 a	26.44 a	21.04 a	14.86 a	14.67 a	10.67 a	4516.1 a	4344.4 a	42.41 b	43.39 ab
LSD 0.05	3.22	4.46	0.87	0.86	1.10	1.24	0.99	0.98	288.39	271.40	1.40	1.57
Nano particle												
Control	130.88 a	136.54 a	26.44 a	25.98 b	18.45 a	13.62 a	12.61 a	9.67 a	4389.4 b	4156.1 a	43.58 a	42.34 a
Nano potassium	132.31 a	135.72 a	26.99 a	26.12 ab	18.66 a	14.37 a	12.89 a	10.00 a	4681.1 a	4382.2 a	44.64 a	43.35 a
Nano silicon	132.39 a	137.57 a	26.86 a	26.88 a	18.98 a	14.62 a	12.94 a	10.11 a	4535.0 ab	4333.3 a	44.25 a	43.46 a
LSD 0.05	3.22	4.46	0.87	0.86	1.10	1.24	0.99	0.98	288.39	271.43	1.40	1.57

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

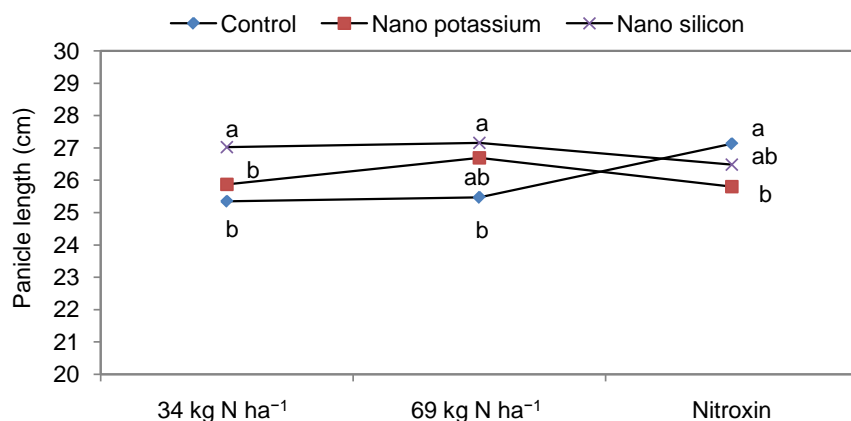


Figure 1. Interaction of nitrogen and nano particle on panicle length.

the effect of nitrogen on height was reported. Cells growth increase under nitrogen might be a reason for plant height rise [27]. Several studies indicated that exogenous application of some nanoparticles can significantly improve plant growth [28] [29]. Previous studies reported that applying 3.0 L·ha⁻¹ doses of Nanonat and Ferbanat has promoted tomatoes' yield and plant growth [30]. The plant height was enhanced via using full recommended rate of nanofertilizer at 15 and 30 DAT (days after transplanting). In addition, plant height was more enhanced when nanofertilizer was mixed with the conventional ones, even at a lower application rate [31]. It has been revealed that exogenous application of nano-silicon on plants enhances the plant growth and development by increasing the accumulation of proline, free amino acids, nutrients content, antioxidant enzymes activity, gas exchange and improving photosynthetic apparatus efficiency [32] [33].

3.2. Tiller Number and Fertile Tiller Number per Hill

Tiller per hill and the number of fertile tiller per hill had significant effect under cultivar treatment at probability level 5% in both years. Under the simple effect of nitrogen in the 1st year, both traits had meaningful impact under nitrogen treatment in 1% probability level. But in the 2nd second year, the number of tiller per hill and that of fertile tiller per hill had significant effect under nitrogen treatment at probability levels 5% and 1%, Respectively (Table 3). In both years, the number of tiller per hill (19.20 and 14.54 tillers) and that of fertile tiller per hill (13.33 and 10.26 tillers) for Tarom Hashemi were more than those of Tarom Mahalli. The max and min number of tiller per hill and the number of fertile tiller per hill in both years were observed with 69 kg N per hectare and nitroxin use, respectively (Table 4). Thus this behaviour is a consequence of nitrogen participating in plant structural functions such as cell multiplication and differentiation, genetic inheritance and formation of tissues. Generally, increasing trends of tiller number was seen as N rates increased. Similar work also confirmed increasing nitrogen rate as the number of tillers got more [34] [35] [36] [37]. Lampayan *et al.* (2010) suggested that tiller number rise resulted from ap-

plying nitrogen fertilizer [38]. The number of effective tillers produced is a good indicator as it is a major yield determinant. Tiller number increased by N levels increase [39]. Applying 150 kg N ha⁻¹ and nitrogen of 33.3% - 50% at the onset of tillering led to the number of tiller per hill increase [40]. The number of reproductive tillers was significantly affected by applying conventional fertilizer and its combination with nano-fertilizer [31].

3.3. Paddy Yield

This parameter had critical impact under cultivar treatment at probability level 1% in both years. Also in the 2nd year, paddy yield was meaningful under the triple interaction of C × N × P at probability level 5% (Table 3). The paddy yield for Tarom Hashemi was more than Tarom Mahalli in both years (Table 4). Triple interaction showed that the highest paddy yield (5000 kg·ha⁻¹) for Tarom Hashemi was produced with 34 kg N ha⁻¹ and nano potassium use. Also for this cultivar, the least paddy yield 4133 kg·ha⁻¹ was observed with 69 kg N ha⁻¹ and control treatment. For Tarom Mahalli, the max paddy yield (4657 kg·ha⁻¹) was obtained with applying nitroxin and nano potassium. Also the least of that 3667 kg N ha⁻¹ was spotted with nitroxin use and control treatment (Table 5). Nitrogen is an essential nutrient for rice production and plays an important role in

Table 5. Mean comparison of interaction of cultivar and nitrogen and nano fertilizer in paddy yield in 2014.

Cultivar	Treatment		Paddy yield (k·ha ⁻¹)		
	Nitrogen	Nano particle			
Tarom Hashemi	N34	Control	4533 bc		
		Nitroxin	Nano potassium	4200 cd	
			Nano silicon	4400 bcd	
			Control	4267 cd	
		N69	Nitroxin	Nano potassium	5000 a
				Nano silicon	4500 bc
	Control			4133 d	
	Control		Nano potassium	4337 cd	
			Nano silicon	4633 b	
			Control	3667 c	
	Tarom Mahalli	N34	Nitroxin	4657 a	
			Nitroxin	Nano potassium	4200 ab
Nano silicon				4033 b	
Control				4033 b	
N69			Nano potassium	4200 ab	
			Nano silicon	4067 b	
	Control	4303 ab			
N69	Nano potassium	3900 bc			
	Nano silicon	4200 ab			

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

sustaining high yields [41]. Soil nitrogen supply shortage is one of the main limiting factors for achieving high rice yields, and nitrogen fertilizer is an important component in rice production [42]. Nitrogen application level increase could critically raise rice production within limits [43] [44]. Nitrogen as one of the main nutrients in agricultural production, might be given only very few parts to plant and soil need, though reports stated that using very small nanofertilizer particles is more effective than this rate [45]. The researchers suggested that nano-fertilizers considerably influenced the straw yield and grain yield [46] [47] [48] [49] [50]. Several studies proved the significance of nanofertilizers. For instance, Sirisena *et al.* (2013) gained higher grain yield in rice via applying nano-K fertilizer [7]. This is in agreement with the findings of Liu and *et al.* (2009) reporting that nanofertilizer application increased crop yield by 20% - 40% [51]. Another experiment conducted by Delfani *et al.* (2014) obtained the highest yield in black-eyed pea (245 g, a 13.5% increase over the control) when a regular Fe salt fertilizer was combined with Mg-NPs [52].

3.4. Harvest Index

Harvest index had significant effect under nitrogen treatment at probability levels 1% and 5% in the 1st year and 2nd year, respectively. Also in the 1st year, Harvest index was significant under the double interaction of nitrogen and nano particle at probability level 5% (Table 3). In the first year, the lowest harvest index was observed with 69 kg N per hectare as 42.41%. In the second year, the maximum harvest index as 43.74% was gained by 34 kg N hectare and the minimum harvest index 42.02% was obtained by nitroxin use (Table 4). At the interaction of nitrogen and nano fertilizer, the highest harvest index 46.59% was achieved with nitroxin and nano silicon use. Also the lowest harvest index 41.78% was gained by 69 kg N per hectare and nano silicon use (Figure 2). The physiological efficiency and ability of a crop to convert the total dry matter into economic yield is known as harvest index (HI). Nitrogen rates showed significant difference for HI. Means comparison indicated the maximum harvest index was recorded when 225 kg N ha⁻¹ was applied [53]. Harvest index increase

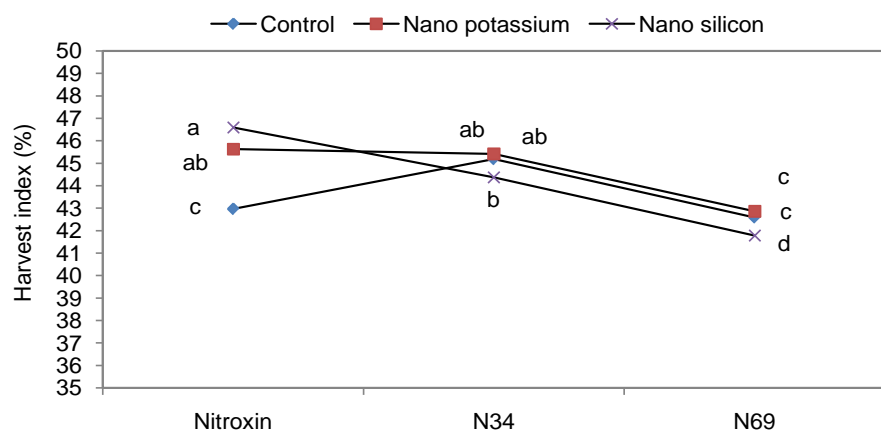


Figure 2. Interaction of nitrogen and nano fertilizer on harvest index.

would mean improvement in grain yield. It seems that the function of nanofertilizer at the reproductive stage of rice was only supplemental. Nonetheless, it was evident that nanofertilizer application enhanced the abovementioned parameters. Nanofertilizer may have synergistic effect on the conventional fertilizer for better nutrient absorption by plant cells resulting in optimal growth [31]. Janmohammadi *et al.* (2016) denoted that a significant increase of grain yield in response to nanofertilizer use statistically improved the harvest index (HI) compared with control [46].

4. Conclusions

Plant nutrients, primarily originating from chemical fertilizer, are essential for crop production. Nitrogen is an essential element for crop growth and development in agriculture; it is the basic constituent of chlorophyll, proteins and all enzymes involved in photosynthesis, especially Rubisco which alone accounts for more than 75% of the total leaf nitrogen. Rice plants require large amounts of mineral nutrients including nitrogen for their growth, development, and grain production. Rice grain yield increased by nitrogen fertilizer use rate rise. At the same time, nitrogen has been known as an important factor influencing rice milling quality.

A lot of studies noted that the nitrogen use efficiency is relatively low in paddy fields. This indicates that a major portion of applied nitrogen is wasted in paddy fields. Nitrogen losses occur through denitrification, volatilization, and leaching which may cause air and water pollutions. Therefore, reducing the chemical nitrogen rate by applying the bio fertilizers may be a solution. Bio-fertilizers are substances comprising living microorganisms that stimulate the plant growth by increasing the primary nutrients supply or availability for the plant and growth promoting substances synthesis.

On the other hand, in the last few years, some researchers tried to examine the potential of nanotechnology to improve fertilizer use efficiency. These efforts led to nano-fertilizer design and development. Nano formulated fertilizers can be easily absorbed by plants and they may exhibit prolonged effective nutrient supply duration in soil or on plant. Nanotechnology-based fertilizers could be more soluble or more reactive than their bulk counterparts. Applying nano-fertilizers may improve soil insoluble nutrients' solubility and dispersion, reduce nutrient immobilization (soil fixation) and increase bio-availability.

This study derived results exhibit two important subjects. Firstly, modified cultivars have higher fertility than older cultivars. Secondly, nano-potassium more contributes to increased performance compared to nano-silica. So that, in the presence of nano potassium, the highest grain yield for Tarom Hashemi and Tarom Mahalli cultivar was obtained with 34 kg N/ha and nitroxin, respectively.

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