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Nitrogen Use Efficiency and Nitrate Accumulation in Tubers as Affected by Four Fertilization Levels in Three Potatoes (*Solanum tuberosum* L.) Cultivars

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Abstract: To study Nitrogen (N) agronomic use efficiency and nitrate accumulation in potato (*Solanum tuberosum* L.) tubers as affected by cultivar and N fertilizer level, an experiment was carried out in Ardabil Agriculture Research Station, Iran in 2008. It was based on a completely Randomized Block Design with four replications. The factors included N fertilizer with four levels (0, 80, 160 and 240 kg pure N ha⁻¹) and three cultivars (Satina (V₁), Draga (V₂) and Agria (V₃)). Results showed that with the increase in N level up to 160 kg ha⁻¹, fresh tuber yield significantly increased in cv. Agria. At final harvest, late-maturity cultivar had the highest fresh tuber yield (51.75 t ha⁻¹) under the N level of 160 kg ha⁻¹. With further increase in N level up to 240 kg ha⁻¹, fresh tuber yield and tuber number of late-maturity cv. Agria started to fall. Cv. Agria had the highest N agronomic use efficiency with applying 160 kg N ha⁻¹ and cv. Draga (mid-maturity) had the lowest one with applying 240 kg N ha⁻¹. With the increase in N level, nitrate content of tuber fresh matter and dry matter significantly increased. Cv. Agria, which produced the highest tuber yield, had the lowest nitrate content. Early-maturity cultivars (e.g., Satina) were more prone to accumulate nitrate than late-maturity ones (e.g., Agria). With the increase in N over the optimum level, in addition to yield drop, nitrate content excessively increased. Therefore, fertilizer level of 160 kg N ha⁻¹ was the best level for cv. Agria to produce a high level, but Satina and Draga did not show statistically significant difference in their yields under different fertilizer levels. In group 2, however, under all N levels, Satina had significantly higher tuber yield than Draga. This study proposes fertilizer level of 160 kg N ha⁻¹ as the most optimum fertilizer level for cv. Agria to realize a high yield while Satina and Draga did not show statistically significant difference in their yields at different fertilizer levels.

Key words: Potato cultivars, yield, nitrate, nitrogen, efficiency

INTRODUCTION

Potato (*Solanum tuberosum* L.) as an important industrial crop plays a critical role in feeding the world and produces greater energy and protein than wheat and rice due to its very high yield (Stephen, 1999). Nutrient use efficiency or fertilizer use efficiency are two

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indices for evaluating the effectiveness of nutrient or fertilizer application in enhancing yield. The index is defined as the amount of produced dry matter per each unit of applied or absorbed nutrient or fertilizer, or as relative yield of a given genotype in a poor soil compared to its yield under optimum nutrition supply or as the increase in the yield of harvested part of crop per each unit of applied nutrient as fertilizer (Hashemidezfooli *et al.*, 1998). N Agronomic Use Efficiency (NAUE) is defined as a simple index for evaluating the efficiency of N in producing yield per each unit of applied N and is a proper index for determining N use efficiency in field (Jamaati-e-Somarin *et al.*, 2008). Experiments indicate that the amount of applied N changes the number of tubers, tuber mean weight, tuber size and even its composition and fresh and dry weight (Belanger *et al.*, 2000). The increase in tuber fresh weight due to applying N fertilizer is greater in late-maturity cultivars than that in early-maturity ones, nevertheless if excess N is applied, tuber fresh weight will sharply drop, but this drop will not be significant in early-maturity cultivars (Khajehpour, 2006). N fertilizer, on the other hand, increases tuber mean weight more in early-maturity cultivars than in late-maturity ones, but in total, because of the proportionality of the increase in tuber number with the increase in tuber mean weight in late-maturity cultivars, the final yield of late-maturity cultivars is often greater than the early-maturity ones (Koochaki and Mohassel, 2001). The increase in biological yield due to applying more N fertilizer is higher than the increase in economical yield, so harvest index decreases (Osaki *et al.*, 1995). Jamaati-e-Somarin *et al.* (2009) reported the increase in nitrate contamination of the tuber fresh and dry weight following the increase in applied N fertilizer so that the highest nitrate contamination was observed in the highest fertilizer level (200 kg N ha⁻¹). Haase *et al.* (2007) reported that N fertilizer increased plant dry weight and N content of tissues as well as N absorption in the tubers, also, N absorption increases tuber number and tuber weight. But N over-application delays growth and decreases qualitative and quantitative characteristics of tuber. Jamaati-e-Somarin *et al.* (2009) indicated that N fertilizer increases potato yield but its over-application decreases tuber mean weight, number, dry weight and yield. Jamaati-e-Somarin *et al.* (2008) concluded that different levels of applied N affect grain yield, N absorption level and N use efficiency.

The objective of the study was to evaluate the effect of various N fertilizer level and potato cultivars on the amount of N absorbed by plant, nitrate accumulation of tubers, yield and yield components in order to determine the optimum N fertilizer level and potato cultivar to realize the highest yield and nitrogen agronomic use efficiency and lowest nitrate accumulation in potato tubers and environmental pollution without decreasing the quality.

MATERIALS AND METHODS

To evaluate NAUE and nitrate accumulation in potato tubers as affected by cultivar and N fertilizer level, a factorial experiment was carried out in the Ardabil Agricultural Research Station, Iran in 2008 based on a Completely Randomized Block Design (CRBD) with four replications. The factors included four N fertilizer levels (0, 80, 160 and 240 kg pure N ha⁻¹) and three cultivars (Satina (V₁), Draga (V₂) and Agria (V₃)). At the depth of 0-30 cm, the salinity of soil was 0.41 dS m⁻¹, the pH was 9.62 and its total N, clay, silt and sand contents were 0.05, 28, 55 and 17%, respectively. It has a clay-silty texture. The seeds were planted in May 1 at the depth of 12-13 cm. Nitrogen fertilizer was applied in two stages: (1) it was scattered on rows during planting after furrowing and was thoroughly mixed with soil during soiling and (2) dressing with soil loosening. Each replication consisted of 12 experimental plots (4.5×6 m²). Each subplot had 6 rows with an interspacing of 75 cm and plants with an

interspacing of 25 cm. Harvested tubers were transferred to laboratory to measure different traits (Yield and yield components and etc.). Before measurement, they (Tubers) were washed with roots and stolons and finally were rinsed with distilled water. At the end of experiment, whole field was harvested and different cultivars were packaged in different sacks. Underground organs including tubers, roots and stolons were washed. Afterwards tubers were counted and their fresh weights were measured. Then, they were cut into small piece, were put in small packages and were dried in ventilated oven. Next, the packages of separate plant organs including roots with stolons were separately put in ventilated oven in a temperature of 75°C for 48 h (Jamaati-e-Somarin *et al.*, 2009). Finally, their dry matter was weighed. About 10 days before final harvest when 50% of aerial parts were yellowed and seared, they were cut to allow completing suberization of tubers and increasing their storing capacity (Khajehpour, 2006). After 10 days, 2 m² of each plot was sampled. Nitrogen agronomic efficiency (NAUE) was calculated using the formulae (Hashemidezfooli *et al.*, 1998):

$$NAUE = \left(\frac{Y_{fp} - Y_{fp0}}{N_f} \right)$$

Where:

NAUE : Is nitrogen agronomic efficiency (kg kg⁻¹)

Y_{fp} : Is tuber yield in plots with applied fertilizer (kg ha⁻¹)

Y_{fp0} : Is tuber yield in plots without applied fertilizer (kg ha⁻¹)

N_f : Is the amount of applied fertilizer (kg ha⁻¹)

To measure nitrate content, sulfosalicylic acid method using spectrophotometer device (Cecile, France) was used.

Harvest index was calculated using the formulae, too (Khajehpour, 2006):

$$HI = \frac{\text{Economical yield}}{\text{Biological yield}} \times 100$$

All observed mean values were subjected to statistical analysis and SAS Statistical Software was used for this. Mean values were grouped by Duncan Test.

RESULTS

Tuber Number

Variance analysis showed that in this trait, the difference among cultivars was significant only on the probability level of 1% and the difference among N levels as well as the interaction between these two factors were significant on the probability level of 5%. Also, in means comparison, cv. Draga had significantly lower tuber number than Satina and Agria which were in the same group. In the main effect of N fertilizer, control had the lowest tuber number which showed significant difference on the probability level of 5% with the N level of 160 kg ha⁻¹. In interaction between N and cultivar, Satina in N level of 160 kg N ha⁻¹ with a significant difference had the highest tuber number (108) (Table 1).

Tuber Dry Weight (TDW)

Studied cultivars and different N levels significantly affected this trait on the probability level of 1%, while variance analysis showed that their interactions were not significant. Also

Table 1: Mean comparison of main effects of studied traits

Effects	Experimented levels	No. of tuber per square unit (m ²)	Dry weight tuber per square unit (m ²)	Tuber yield (t ha ⁻¹)	Harvest index (%)	Average weight of tuber (g)
Nitrogen fertilizer	0 kg	72.00B	430.4C	24.32C	56.17AB	34.63A
	80 kg	81.78AB	577.2B	30.47B	60.35A	38.78A
	160 kg	92.00A	723.2A	37.64A	56.91AB	41.38A
	240 kg	82.67AB	575.5B	30.77B	51.34B	37.41A
Cultivars	Satina	97.33A	651.7A	34.40A	59.27A	36.03B
	Draga	61.33B	348.7B	19.53B	51.70B	33.59B
	Agria	87.67A	729.3A	38.47A	57.61A	44.52A

Values with the same letters in each column, have no significant differences to each other

Table 2: Mean comparison of nitrogen×cultivars interaction in studied traits

Parameters	Number of tuber per square unit (m ²)	Dry weight tuber per square unit (m ²)	Tuber yield (t ha ⁻¹)	Harvest index (%)	Average weight of tuber (g)
Satina×0 kg (check)	84.00ABCD	520.4CDE	30.29BCD	62.15A	36BC
Draga×0 kg (check)	58.67D	279.2G	16.59E	49.63CD	31.2C
Agria×0 kg (check)	73.33BCD	491.7DEF	26.08CDE	56.73ABCD	36.7BC
Satina×80 kg	98.67ABC	630.1BCD	32.29BC	63.20A	33.4BC
Draga×80 kg	62.67D	402.0EFG	21.93DE	57.44ABCD	37.3BC
Agria×80 kg	84.00ABCD	699.6BC	37.19B	60.41ABC	45.7AB
Satina×160 kg	108.0A	790.5B	39.40B	60.77AB	38BC
Draga×160 kg	65.33CD	394.8EFG	21.76DE	49.12D	34.9BC
Agria×160 kg	102.7AB	984.1A	51.75A	60.83AB	51.3A
Satina×240 kg	98.67ABC	665.9BCD	35.60B	50.97BCD	36.7BC
Draga×240 kg	58.67D	318.9FG	17.83E	50.58BCD	31.1C
Agria×240 kg	90.67ABCD	741.7B	38.87B	52.48ABCD	45.5ABC

Values with the same letters in each column, have no significant differences to each other

means comparison of cultivars indicated that cv. Draga had much lower TDW and Satina and Agria in a same group were significantly superior to Draga. Among different N levels, 160 kg N ha⁻¹ with a significant difference with other levels had the highest effect on this trait. The lowest TDW was observed in no-fertilizer level (Table 1).

Tuber Yield

Variance analysis showed that the studied factors (cultivar and N fertilizer level) were significant on the probability level of 1% and their interaction was significant on the probability level of 5%. Also, according to means comparison, cv. Agria and cv. Satina (in a same group) had the highest tuber yield which was significant compared with tuber yield of Draga. Among different N levels, the N level of 160 kg ha⁻¹ significantly produced the highest tuber yield (Table 1). Among interactions, the interaction of Agria×160 kg N ha⁻¹ significantly produced the highest tuber yield (Table 2).

Harvest Index (HI)

This trait showed a significant difference in variance analysis in main effect of cultivar on the probability level of 1% and in main effect of N level on the probability level of 5%, while the interaction between studied factors was not significant. In means comparison too, this trait in main effect of cultivars showed the highest rank in Satina and Agria but Draga had the lowest HI (Table 1).

Tuber Mean Weight (TMW)

According to variance analysis, the studied factors had obviously significant effect on this trait. Means comparison of cultivars showed the superiority of Satina and Agria (both in the same group) and Draga had significantly the lowest TMW. The fertilizer levels of 80 and 160 kg N ha⁻¹ (in the same group) had the highest TMW with a significant

difference. The trait started to decrease at the highest fertilizer level (240 kg N ha⁻¹). In fact, further increase in N level from 160 kg N ha⁻¹ had a reverse significant effect on TMW. According to Table 2, the interaction Draga×no-fertilizer had the lowest TMW.

Nitrate Accumulation

According to variance analysis, the main effect of cultivar and N fertilizer on nitrate accumulation in tuber from the viewpoint of both of the fresh and dry weight was significant on the probability level of 1%, while the interaction of N×cultivar was significant on the probability level of 5%. In the main effect of cultivar, Satina (early-maturity) had the highest nitrate accumulation and Agria (early-maturity) had the lowest one, while Draga (mid-maturity) and Satina stood in same group of highest nitrate accumulation in tubers. The results showed the effect of maturity date of cultivars on nitrate accumulation in tubers. The interaction between two factors indicated the significant increase in nitrate concentration in Satina×240 kg N ha⁻¹. With the increase in N, nitrate concentration sharply increased which was significant so that it reached to the highest concentration (339.3 ppm) at the highest N level, which was higher than permitted tolerable N concentration in potato tubers (300 mg kg⁻¹ dry matter). The highest fresh tuber yield was for Agria at 160 kg N ha⁻¹, in which nitrate concentration was 133.3 mg kg⁻¹. At N level of 160 kg ha⁻¹, nitrate concentration of all cultivars was acceptable and optimum and much lower than critical point, while at N level of 240 kg ha⁻¹, nitrate concentration of Satina and Draga exceeded the permitted point so that it was 480.8 mg kg⁻¹ in Satina which was greater than permitted concentration by about 180.8 mg kg⁻¹ (Table 3).

In nitrogen×cultivar interaction, the highest nitrate concentration in fresh tuber weight (145.9 mg kg⁻¹) was observed in Satina×240 kg N ha⁻¹ and lowest one was seen in Satina× no-fertilizer. The results showed that early-maturity cv. Satina accumulates more nitrate in its fresh tuber weight than other cultivars at higher fertilizer levels (e.g., 240 kg N ha⁻¹). In main effect of cultivar, Satina and Draga stood in same group of highest nitrate accumulation (61.71 and 56.43 mg kg⁻¹, respectively). In main effect of N, as shown in

Table 3: Mean comparison of main effects and cultivar×nitrogen interaction on nitrate accumulation and agronomy efficiency of nitrogen use in potato tubers

Factors	Factors level	Nitrate per dry tuber		Nitrate per fresh tuber		Agronomy efficiency of nitrogen use
		5% probability	1% probability	5% probability	1% probability	5% probability
Nitrogen (A)	0 kg	20.43D	20.43D	5.617D	5.617D	-
	80 kg	112.6C	112.6C	34.69C	34.69C	66.54A
	160 kg	199.6B	199.6B	63.24B	63.24B	80.66A
	240 kg	339.3A	339.3A	99.85A	99.85A	28.08B
Cultivars (B)	Satina	204.4A	204.4A	64.71A	64.71A	37.99B
	Draga	197A	197A	56.43A	56.43A	19.35B
	Agria	102.5B	102.5B	31.41B	31.41B	117.9A
Cultivar×nitrogen	A1B1	12.27G	12.27E	3.231E	3.231D	-
	A1B2	23.50FG	23.50E	5.970E	5.970D	-
	A1B3	25.54FG	25.54E	7.650E	7.650D	-
	A2B1	115.4DEFG	115.4CDE	37.34CDE	37.34CD	29.1B
	A2B2	133.7DEF	133.7CDE	39.91CDE	39.91CD	31.6B
	A2B3	88.83DEF	88.83DE	26.83DE	26.83CD	140A
	A3B1	209.3CD	209.3CD	72.38BC	72.38BC	58.7B
	A3B2	256.2C	256.2BC	75.76BC	75.76BC	22.8B
	A3B3	133.3DEF	133.3CDE	41.58CDE	41.58CD	160.5A
	A4B1	480.8A	480.8A	145.9A	145.9A	26.2B
	A4B2	374.6B	374.6AB	104.1B	104.1AB	3.57B
	A4B3	162.3CDE	162.3CDE	49.60CD	49.60CD	54.4B

Values with the same letters in each column, have no significant differences to each other

Table 3, the increase in N level from control up to 240 kg ha⁻¹ led to the significant increase in nitrate accumulation in tuber dry weight and fresh weight on the probability levels of 1 and 5%.

Nitrogen Agronomic Use Efficiency (NAUE)

According to variance analysis, the effect of N fertilizer and cultivar on NAUE in tuber fresh yield was significant on the probability level of 5 and 1%, respectively, while their interaction did not significantly affect this trait. According to means comparison on the probability level of 5%, N level of 160 kg ha⁻¹ had the highest agronomic efficiency. In this level, the increase in tuber fresh weight was 80.66 kg kg⁻¹ applied N ha⁻¹. In the main effect of N, the yield increased by about 13 t ha⁻¹ compared to control (no-fertilizer). Similarly, in the main effect of cultivar, late-maturity cv. Agria had the highest NAUE whose yield increased by 117.9 kg kg⁻¹ applied N with a significant difference with early-maturity cv. Satina and mid-maturity cv. Draga. In N×cultivar interaction, cv. Draga had the highest NAUE at N level of 160 kg ha⁻¹ whose yield increased by about 26 t ha⁻¹ with a significant difference with control (Table 3).

DISCUSSION

The results showed that cv. Satina (early-maturity) with a significant difference had the highest tuber number. In this means comparison, the main effect of cv. Satina stood in the second group with a significant difference. And there were significant differences among all three cultivars. N application with non-significant difference had positive significant effect on this trait up to 160 kg ha⁻¹. Saeidi *et al.* (2009a) reported a negative and significant effect of N over-application on tuber number. Also Saeidi *et al.* (2009b) found that with the increase in fertilizer level up to a certain point, TDW increased. Means comparison showed that among studied cultivars, cv. Satina was superior with a significant difference with other cultivars. There was a significant difference among all cultivars and cv. Draga had the lowest TDW. Among fertilizer levels, the levels of 80 and 160 kg ha⁻¹ had the best effect on TDW over time. These two levels stood in the same group, however.

The plants which receive higher level of N realize their highest productions sooner than the plants which receive lower levels. N stimulates the growth of foliage and although tuber formation may start somewhat simultaneously in high and low N levels, the tubers had lower dry matter in early growing season. It has been shown that high N levels and plant densities may cause rapid growth of foliage, delayed tuber formation, decrease in yield, obligatory harvest of immature tubers and even the decrease in tuber quality. According to means comparison of the main effects of studied factors over time, cv. Satina stood in the second rank and cv. Draga stood in the last rank from the viewpoint of tuber yield per plant. N level of 160 kg ha⁻¹ had the highest effect on single-plant yield. The same fertilizer level produced the highest yield per unit area and the highest yield per ha. No-fertilizer treatment (control) produced the lowest yield. The interaction of studied factors showed that Agria×160 kg N ha⁻¹ produced the highest yield (Table 2). Jamaati-e-Somarin *et al.* (2009) reported similar findings.

Since growing season is limited in Ardabil Region, fertilizer requirements of potato especially N need to be calculated precisely because over-application of nitrogen may lead to retarding of such traits as full green date, stolon formation, tuber formation, flowering and harvest date as well as decelerating of transport of materials to tubers, increasing vegetative growth and accordingly shortening tuber-formation period (due to the limitation of growing season and reaching early fall coldness) and finally decreasing the yield. On the other hand,

optimum fertilizer level may differ among different cultivars (early-maturity, mid-maturity, late-maturity). In potato, the tuber is the main product and other traits including stolon formation, tuber formation date, tuber growth period and tuber final size, which are affected by various factors, cultivar, climatic factors (day length and temperature), cropping factors and so on, can have critical effect on final tuber yield. Before applying nitrogen, it is important to understand its effects with interaction with other factors on different organs and stages of potato plants particularly tuber-related traits. With applying 240 kg N ha⁻¹, the yield of Agria (early-maturity) significantly decreased compared to applying 160 kg N ha⁻¹, which may be caused by vegetative over-growth, shadowing of some leaves and coincidence with summer hot temperatures and long days and the decline of tuber supplies. As variance analysis and means comparison tables indicate, with applying the highest N level plant height, branch number, leaf number, leaf dry weight and TDW of Agria significantly increased compared to two other cultivars. So we can conclude that a main reason of yield fall in cv. Agria was over-application of nitrogen. Yield, yield components and most other traits of cv. Draga (mid-maturity) was significantly lower than those of two other cultivars. In main effect of N levels, 80 kg N ha⁻¹ had the highest HI which had significant difference with the level of 240 kg N ha⁻¹ on the probability level of 5%. The latter had the lowest HI. N had more effect on the increase in biological yield and less effect on economical yield, thus HI decreases (Osaki *et al.*, 1995).

Studied factors had significant effects on this trait too and the effect of different samplings on HI was significant on the probability level of 1%, too. Means comparison of main effect of cultivars showed that Satina with the highest HI (51.40%) was significantly the most superior cultivar while Draga had the lowest one (39.06%). Among different N levels too, the level of 80 kg N ha⁻¹ had the highest HI (52.37 %). Considering the statistical difference of this trait among different N levels was significant on the probability level of 5%, the level of 240 kg N ha⁻¹ had the lowest HI (35.38%). Since, the yield depends upon intercepted radiation of canopy, shortening of actual growing season (from formation to senescence) leads to lose of potential yield (Emam and Niknejhad, 2004). N deficiency considerably limits the growth and resolving the deficiency can be seen in visible response and growth acceleration like leaf re-development. Therefore, the effect of nitrogen on photosynthesis is through increasing radiation interception. The yield of important economical parts of most crops depends on the transport of processed material from leaves to other photosynthesizing tissues. This is particularly important when economical yield merely includes non-photosynthesizing tissues. The stuff produced in green leaves in presence of light may be used in the growth of aerial parts, roots and tubers or may be stored in tubers. In early growth, all produced stuff is used in the growth of aerial parts and roots but some weeks after seedling emergence, they are used in the growth of stolon and tuber emergence. After some weeks, the tubers start to grow and more nutrients are dedicated to their growth. These nutrients are stored in tubers as starch. At final stages of growth, all produced stuff is transported to tubers.

In cold regions, it is particularly important to study the factors effective on the rate and amount of the growth of different organs and maximum accumulation of photosynthetic materials in crops like potato because of improper climate during planting and harvest and limitation of growing season. Applied N has less effect on tuber number and more effect on tuber size, the increase in large tuber number and eventually the increase in TMW, but its over-application will decrease TMW (Koochaki and Mohassel, 2001).

Dejonckheere *et al.* (1994) reported that most nitrates were lost during cooking. The 10-15% of nitrate in vegetable is lost during washing and 40% is lost during cleaning. Boiling

and discharging the boiled water considerably decreases nitrate level. Means comparison showed that in the main effect of cultivar, cv. Satina (early-maturity) had the highest nitrate accumulation and cv. Agria (late-maturity) had the lowest one while cv. Draga (mid-maturity) in a same group with Satina had the highest nitrate accumulation in tuber. This shows the effect of maturity time on nitrate accumulation in tubers. In the case of N levels, with over-increase in N level, nitrate concentration in tubers significantly increased, so that the highest nitrate concentration was at N level of 240 kg ha^{-1} while the lowest one was at N level of 80 kg ha^{-1} with a significant difference. The interaction between two factors showed that Satina $\times$ 240 kg N ha^{-1} led to a significant increase in nitrate level. With the increase in N level, nitrate content in TDW significantly and sharply increased and reached to the highest amount (339.3 ppm) at the highest N level. The cultivar which was late-maturity and produced the highest tuber yield had the lowest nitrate content. Cv. Agria produced highest fresh tuber yield at N level of 160 kg ha^{-1} , in which nitrate concentration (about 133.3 mg kg^{-1}) was lower than permitted level. At optimum fertilizer level, N has been well-used and N has been well-converted to protein and other nutrients.

At N level of 160 kg ha^{-1} , nitrate concentration of all cultivars was at acceptable level and below critical level, while at N level of 240 kg ha^{-1} , nitrate concentration of Satina and Draga exceeded permitted level so that nitrate content of Satina (480.8 mg kg^{-1}) exceeded permitted level by about 180.8 mg kg^{-1} . With over-increase in N application, the yield decreased and nitrate level as a negative trait sharply increased. Therefore, by using high-yield cultivars and applying optimum N level, costs can be decreased and yield quality and quantity, effectiveness and N use efficiency can be increase. In the study, it was concluded that the best N level for Satina and Agria was 160 kg ha^{-1} and for Draga was 80 kg ha^{-1} . In total, Agria (late-maturity) had the highest NAUE at N level of 160 kg ha^{-1} and Draga had the lowest one at N level of 240 kg ha^{-1} . The results showed that maturity time affected nitrate accumulation in tubers. With the increase in N level, nitrate content of tuber dry and fresh matter significantly increased and reached to the highest amount in the highest N level.

In cv. Agria the effect of cultivar on NAUE was stronger than the effect of N, but in Draga and Satina the effect of N level on that was stronger than the effect of cultivar. According to the main effect of N fertilizer, it is obvious that if the fertilizer is over-applied, NAUE starts to decrease and accordingly the yield decreases. Thus, NAUE increases just when a correct N level is applied and high-yield and N-efficient cultivars are used as well. N application usually increases tuber yield in potato. Mahmoodi and Hakimian (2005) reported the same results. Therefore, the tendency of farmers to its over-application is increasing which decreases yield quantity and quality. Hence, with selecting cultivars with higher N absorption capacity and use efficiency, it is possible to increase the quality and quantity of tuber yield and meantime maintain N application in proper level. Therefore, the costs will be saved and contamination of products, soil, surface water and water tables will be avoided. At N level of 160 kg ha^{-1} , cv. Agria dedicates greater photosynthetic matters to total dry matter and in the interaction, this cultivar had the highest NAUE at N level of 160 kg ha^{-1} .

CONCLUSION

According to results, the increase in tuber yield of cv. Agria (late-maturity) due to the increase in N level (up to 160 kg ha^{-1}) was greater than that in cv. Satina and both cultivars had significant differences with cv. Draga. With the increase in N level up to 160 kg ha^{-1} ,

tuber yield of both Agria and Satina increases and Agria had the highest tuber yield. Agria did not have a considerable increase in its tuber yield within this N application range. Late-maturity cv. Agria which produced the highest tuber yield had the lowest nitrate accumulation level. Cv. Agria produced its highest tuber fresh yield at N level of 160 kg ha⁻¹ in which nitrate concentration was lower than permitted level. It can be concluded that at appropriate fertilizer levels, effective application of N fertilizer and its conversion to protein and other substances has been properly carried out. At N level of 160 kg ha⁻¹, nitrate concentrations of all cultivars were within an acceptable range and much lower than critical point. According to the interaction between N fertilizer and cultivar it can be seen that at all fertilizer levels, cv. Agria accumulated lower nitrate in tuber dry and fresh weight. Also, it can be seen that with over-application of fertilizer, in addition to the increase in yield as an essential trait, nitrate concentration as a negative trait exceeded the critical point. Therefore, potato farmers with N over-application not only do not increase the yield but also increase the costs, decrease the quality of their products and increase nitrate concentration of tubers which is a threat to farmer, environment, etc. This study proposes fertilizer level of 160 kg N ha⁻¹ as the most optimum fertilizer level for cv. Agria to realize a high yield while Satina and Draga did not show statistically significant difference in their yields at different fertilizer levels.

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