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Investigation of Tuber Size and Nitrogen Fertilizer on Nitrogen Use Efficiency and Yield of Potato Tuber, Cultivar Agria

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Abstract: This study was done as factorial based on Randomized complete block design with three replications in 2006 in research field of Mohaghegh Ardabili University, Ardabil, Iran. First factor was nitrogen level (0, 80, 160 and 200 kg ha^{-1} net nitrogen) and second was tuber size (<40, 40-80 and >80 g). Results showed that tuber size increase and nitrogen usage reduced Agronomical Nitrogen Use Efficiency (ANUE) and increased Physiological Efficiency (PE), Apparent Recovery Efficiency (ARE) and Nitrogen Use Efficiency (NUE). The most tuber yield, total plant dry matter, number of tuber per plant, mean tuber weight and tuber dry weight were achieved in medium tuber size. Also, the most tuber yield, mean tuber weight and tuber dry weight were gained at 160 kg ha^{-1} net nitrogen. Utmost nitrogen uptake by plant and total plant dry matter was observed at 160 kg ha^{-1} nitrogen. So, utilization of 160 kg ha^{-1} nitrogen with medium tuber size in order to achieving most yields, planting and eating usages is recommended.

Key words: Tuber size, yield, nitrogen uptake, nitrogen use efficiency, potato

INTRODUCTION

Potato (*Solanum tuberosum*) is an annual plant from *Solanum* genus and Solanaceae family that has more than 200 cultivars from which eight cultivars are agronomical (Khajehpour, 2004). Tuber is a part of stem which adopted to starch storation and reproduction. It is a transformed stem with lateral pitted buds on it (Khajehpour, 2004). Nitrogen is the most important nutrient element and its main effect is on tuber quality and quantity. The most favorite results are derived from nitrogen as 50-60% applied in planting time and remain in tubering time. More values are determined by soil and plant petiole test (Vander Zaag *et al*., 1990; Evanylo, 1990). Efficiency has been defined as crop production against used sources. This means that nutritional efficiency is dry matter produced in return for plant nutrient element usage or absorption (Hashemidezfooli *et al*., 1998). To keep nitrogen use in plant at highest levels, it must all environmental factors act favorite during plant growth and this prevents soil and under ground waters pollution. Hashemidezfooli *et al*. (1998) defined nutrient elements efficiency as relative yield of one genotype in a poor soil compare to its yield in a favorite nutritional condition. Khajehpour (2004) classified nutrient elements efficiency into three categories and named them as Agronomical Nitrogen Efficiency (ANE), Physiological Nitrogen Efficiency (PNE) and Apparent

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Recovery Nitrogen Efficiency (ARNE). AE has defined as commercial yield produced in return for each used nutrient unit. In some cases, this kind of efficiency is called Commercial Efficiency (CE). PE has been defined as biological production in return for each nutrient element unit absorption and sometimes has been determined as Biological Efficiency (BE) or efficiency ratio. Maximum efficiency of nutrient element use (NEUE) is obtained while its concentration is near to critical level, because without excessive amounts of element in plant tissues, the highest yield is gained. Rates of NEUE at the abundance range of elements are reduced (Hashamidezfooli *et al*., 1998). Abbasi (2006) and Jamaati-e-Somarin *et al*. (2008) concluded that the most and the less ANE were resulted at 160 and 200 kg ha^{-1} net nitrogen, respectively. Schulz *et al*. (1998) concluded that larger mini tubers produce more tubers. Lommen (1995) reported that with increasing tuber weight, number of produced tuber per plant and yield of tuber were increased. Jam (2006) stated that the most number of tuber; mean tuber weight, tuber yield and tuber weight per plant were resulted in planted tuber of 50 g weight and the less values, at 1-10 g tuber weight. Babaei *et al*. (1992) concluded that tuber weight of 50-70 g caused the highest yield. Jenkins and Nelson (1992) reported that nitrogen increased large tubers per plant and hence, increased tuber yield per plant. Sufficient nitrogen application in early season extended leaf area and increased photosynthetically potential and assimilates (Khalghani *et al*., 1997; Koochaki and Mohassel, 2001). Vander Zage *et al*. (1990) found that while nitrogen application reached to 135 kg ha^{-1}, the most tuber yield and weight was obtained. Using excessive rates of nitrogen led to decrease of mean tuber weight and number (Kleinhenz and Bennet, 1992). Martin (1995) showed that while plant up took nitrogen, number of stolons decreased and aerial parts increased and thus, mean tuber weight, increased. Nitrogen deficit in early season can decrease tuber yield (Joern and Vitosh, 1995).

The aim of this study was evaluating effects of tuber size and different nitrogen levels on nitrogen use efficiency and determining the best tuber size and nitrogen levels to reach high yields in potato, cultivar Agria.

MATERIALS AND METHODS

This experiment was conducted as factorial based on randomized complete block design with three replications in research field of Agricultural Faculty, University of Mohaghegh Ardabili, Ardabil, Iran, in 2006.The first factor was nitrogen level (0, 80, 160 and 200 kg ha^{-1} net nitrogen) and the second factor was tuber size (<40, 40-80 and >80 g). Each plot contained six rows each 3 m spacing 60 cm rows. Between plots, distance of 1.5 m was exerted. This research was done in May, 2006. Soil texture was Loamy sand and depth of sowing was 12 cm. Nitrogen was from urea form and was applied at two stages: planting date and earthling up stage. Ten days before harvest, aerial parts were cut to improving tuber storage capability (Khajehpour, 2004). Plants of 10 m^2 were harvested from each plot and agricultural, physiological and apparent recovery nitrogen use efficiencies were calculated as follows:

$$\text{ANUE} = \frac{TY_{(n)} - TY_{(c)}}{TN} \ (\text{kg ha}^{-1}) \quad (1)$$

$$\text{PNUE} = \frac{TB_{(n)} - TB_{(c)}}{NU_{(n)} - NU_{(c)}} \ (\text{kg ha}^{-1}) \quad (2)$$

$$\text{ARNVE} = \frac{NU_{(n)} - NU_{(c)}}{TN} \times 100 \quad (3)$$

$$NEE = PNUE \times ARNUE \quad \text{and} \quad NEU = EC \times DM$$

Where:

ANUE	=	Agricultural nitrogen use efficiency
$TY_{(n)}$	=	Tuber yield with nitrogen
$TY_{(c)}$	=	Tuber yield without nitrogen (control)
TN	=	Total nitrogen
PNUE	=	Physiological nitrogen use efficiency
$TB_{(n)}$	=	Total biomass with nitrogen application
$B_{(c)}$	=	Total biomass without nitrogen (control)
$NU_{(n)}$	=	Nitrogen uptake under nitrogen application
$NU_{(c)}$	=	Nitrogen uptake without nitrogen application (control)
NEU	=	Nutrient element uptake
EC	=	Element concentration
DM	=	Dry matter
NEE	=	Nutrient element use efficiency

Analysis of variances and mean comparisons were done by SAS and graphs were drawn by Excel software's.

RESULTS AND DISCUSSION

ANUE

Results showed that nitrogen effects (main and interaction) were significant. In main effects, the most efficiency belonged to 80 kg ha^{-1} net nitrogen ($p \leq 0.01$). In interaction effects, the most efficiency belonged to medium tuber size and 80 kg ha^{-1} net nitrogen (as equal to medium tuber size and 160 kg ha^{-1} net nitrogen) and the less one belonged to large tuber size and 200 kg ha^{-1} net nitrogen (Table 1). Some studies have shown that increasing nitrogen application, results in decreasing nitrogen use efficiency (Jamaati-e-Somarin *et al*., 2008). This trait had positive and significant correlation with tuber dry weight (Table 4).

PNUE, ARNUE and ANUE

Results showed that tuber size×nitrogen had the significant effect ($p \leq 0.05$) on this trait. The most PNUE belonged to small tuber size (<40 g) and 160 kg net nitrogen (Table 3). This trait had negative and significant correlation with tuber dry weight (Table 4). Main and interaction effects of tuber size and nitrogen had significant ($p \leq 0.01$) effects on ARNUE. Medium and large tuber sizes (40-80 and >40 g) equally had the same effect on this trait and small size had the lowest effect (Table 1). In the interaction effects, the most value of ARNUE related to large tuber size and 200 kg ha^{-1} net nitrogen (which was equal to medium tuber size×160 kg ha^{-1} net nitrogen) and the less value belonged to small tuber size and 160 kg ha^{-1} net nitrogen (Table 3). Perhaps, for the reason that the most tuber yield and nitrogen uptake by tuber were obtained at 160 kg ha^{-1} net nitrogen, it could be said that the rate of nitrogen uptake at this level was much more than other levels. So, the highest ARNUE was achieved at this level and since, the most nitrogen uptake by plant was occurred at 200 kg ha^{-1} net nitrogen, hence, ARNUE was increased after 160 kg ha^{-1} net nitrogen, as well. These results are in accordance with Jamaati-e-Somarin *et al*. (2008). This trait had positive and significant correlation with nitrogen uptake by whole plant and had negative and significant correlation with number of tuber and total dry matter yield (Table 4). Tuber size had significant ($p \leq 0.01$) effect on this trait. The large tuber size had the most effect and the small tuber size had the least effect on ANUE (Table 1). Jamaati-e-Somarin *et al*. (2008) reported the decrease of ANUE with increasing nitrogen application.

Table 1: Effects of tuber size and nitrogen levels on measured traits

Treatments	Agronomical nitrogen use efficiency (kg kg^{-1})	Apparent recovery nitrogen efficiency (%)	Physiological nitrogen efficiency (kg kg^{-1})	Nitrogen use efficiency (kg kg^{-1})
Tuber size				
Small	91.91a	21.53b	0.41a	5.37c
Medium	95.06a	45.23a	0.23a	9.04b
Large	79.26a	46.42a	0.36a	15.109a
Nitrogen fertilizer levels (kg ha^{-1})				
0	0.00	0.00	0.00	0.00
80	103.87a	34.21a	0.29a	8.80a
160	101.45a	33.90a	0.47a	10.82a
200	61.01b	45.07a	0.23a	9.90a

Values with same letter(s) in each column, have no significant differences to each other

Table 2: Effects of tuber size and nitrogen levels on measured traits

Treatments	Total plant dry matter (kg m^2)	No. of tuber per plant	Mean tuber weight per plant (g)	Tuber yield (kg m^{-2})	Tuber dry weight per plant (g)	Nitrogen uptake by whole plant (g m^{-2})
Tuber size						
Small	0.579c	7.50b	39.46a	2.25b	35.75b	1423.85ab
Medium	0.648b	9.50a	45.86a	2.64a	37.91ab	1649.60a
Large	0.700a	10.50a	47.27a	2.87a	40.11a	1615.99a
Nitrogen fertilizer levels (kg ha^{-1})						
0	0.535c	8.55a	26.68c	1.67d	33.20c	1219.5b
80	0.593b	8.88a	51.39ab	2.50b	36.50b	1368.54b
160	0.708b	9.69a	55.17a	3.29a	43.41a	1766.94a
200	0.733a	9.55a	43.70b	2.89c	38.39b	1897.56a

Values with same letter(s) in each column, have no significant differences to each other

Nitrogen Uptake by Whole Plant per Unit Area

Main effects of nitrogen and tuber size had significant ($p \leq 0.01$) effects on nitrogen uptake by whole plant. Medium size had the most and small size had the least effects on this trait. At different nitrogen levels, with increasing nitrogen usage, the most nitrogen uptake by whole plant was occurred. This means that there is direct relation between nitrogen application and its uptake by whole plant. Levels of 160 and 200 kg ha^{-1} net nitrogen had the most effect on this trait and control level had the least effect (Table 2). These results are in accordance with Jamaati-e-Somarin *et al*. (2008). This trait had the positive and significant correlation with ARNUE (Table 4).

Tuber Yield

Effects of tuber size, nitrogen and their interaction effects on tuber yield were significant ($p \leq 0.01$). Large and medium tuber sizes jointly result in highest and small tuber size results in lowest tuber yield. Also, 160 kg ha^{-1} net nitrogen caused the most tuber yield and control treatment caused the least tuber yield (Table 2). The highest tuber yield was achieved at 160 kg ha^{-1} net nitrogen×medium tuber size and the least tuber yield, at control treatment×small tuber size (Table 3). Abbasi (2006) and Jamaati-e-Somarin *et al*. (2008) reported that with application of nitrogen up to 160 kg ha^{-1}, the most tuber yield was achieved. The same results have been obtained by Singh and Singh (1994) and Babaei *et al*. (1992). Khalafalla (2000) and Lommen (1995) illustrated that tuber yield is highly related to tuber size and smaller tubers had lower yields and larger tubers had higher yields. Jam (2006) showed that with increasing mini tuber size, yield was increased. This trait had negative and signification correlation with ANUE (Table 4).

Total Plant Dry Matter Yield

Nitrogen fertilizer, tuber size and their interaction effects had significant ($p \leq 0.01$) effects on this trait. The most Total Plant Dry Matter (TPDM) was gained at large tuber size and the least TPDM

Table 3: Effects of tuber size and nitrogen levels on measured traits

Interaction effects	Agronomical nitrogen use efficiency (kg kg^{-1})	Apparent recovery nitrogen efficiency (%)	Tuber yield (kg m^{-2})	Total plant dry matter (kg m^{-2})	Mean tuber weight per plant (g)	Tuber dry weight per plant (g)
Control×small	-	-	1.38g	0.503e	23.43e	32.16b
Control×medium	-	-	1.73efg	0.546cde	25.36de	32.83b
Control×large	-	-	1.90efg	0.536de	31.13cde	32.60b
80 kg×small	124.50ab	16.7cd	2.38de	0.515e	42.83bcd	32.83a
80 kg×medium	141.17a	56.33ab	3.12bc	0.613bcd	40.63cde	42.83b
80 kg×large	45.87de	33.93bcd	3.14bc	0.656b	70.73a	33.83b
160 kg×small	140.07a	14.00d	2.27def	0.661b	41.56bcd	42.50a
160 kg×medium	87.10abcd	45.50abc	3.63ab	0.663b	72.60a	42.16a
160 kg×large	77.20cde	40.47abcd	4.20a	0.803a	50.96b	46.16a
200 kg×small	115.00abc	33.87bcd	1.61fg	0.623bc	50.03bc	35.50b
200 kg×medium	56.97cde	33.83bcd	2.86cd	0.770a	44.86bc	33.83b
200 kg×large	11.13e	64.83a	2.87cd	0.806a	36.2bcde	45.83a

Values with same letter(s) in each column, have no significant differences to each other

Table 4: Correlation coefficients between measured traits

Measured traits	Tuber yield	No. of tuber	Tuber dry weight	Mean tuber weight	TPDM	NU	ANUE	ARE	PE	NUE
Number of tuber	0.333^{ns}	1.00								
Tuber dry weight	0.002^{ns}	0.100^{ns}	1.00							
Mean tuber weight	0.018^{ns}	0.238^{ns}	0.001^{ns}	1.00						
TPDM	0.001^{ns}	0.012^{ns}	0.001^{ns}	0.019^{ns}	1.00					
NU	0.120^{ns}	-0.023^{ns}	0.005^{ns}	-0.628**	0.146^{ns}	1.00				
ANUE	-0.199*	0.070^{ns}	0.222*	0.806*	0.230^{ns}	0.754^{ns}	1.00			
ARE	0.660^{ns}	-0.066*	0.248*	-0.751*	-0.204*	0.661*	0.001^{ns}	1.00		
PE	0.260^{ns}	0.159^{ns}	-0.076*	0.709*	-0.016^{ns}	-0.396^{ns}	0.260^{ns}	0.001^{ns}	1.00	
NUE	0.100^{ns}	0.182^{ns}	-0.168*	0.708^{ns}	0.526^{ns}	0.152^{ns}	0.154^{ns}	0.182^{ns}	0.001^{ns}	1.00

^{ns}Not significant, $^{*}p \leq 0.05$ and $^{**}p \leq 0.01$

at small one. Also, the highest and the lowest TPDM were resulted at 200 kg ha^{-1} net nitrogen and control, respectively (Table 2). Regarding to interaction effects, the highest and the lowest TPDM were obtained at large tuber size×160 kg ha^{-1} net nitrogen (as equal to medium tuber size×200 kg ha^{-1} net nitrogen) and at small tuber size×control treatment, respectively (Table 3). Zrust and Juzl (1996) found that plant growth was increased with increasing nitrogen application. Based on this study, tuber and whole plant dry weight was influenced by nitrogen fertilizer so that, the most value of this trait was obtained at 120 kg ha^{-1} net nitrogen. Gholipour (1996) found that with increasing tuber size, dry matter accumulation was increased perhaps the reason is that in plants produced from larger tubers, number of stems and leaves are higher and so, incident radiation into the canopy better can used and as a result, remarkable dry matter can be obtained per plant. This trait had negative and significant correlation with ARNUE (Table 4).

No. of Tuber per Plant

Tuber size had significant ($p \leq 0.01$) effect on this trait so, large and small sizes had the same effects (Table 2). Yazdandoost Hamedani (2003) also showed that number of tuber per plant was not affected by nitrogen usage. Lommen (1995) reported that with increasing tuber weight, number of produced tubers per plant was increased. Jam (2006) found that the most tuber number was obtained at 50 g tuber weight. Schulz *et al*. (1998) reported that large tubers produced more tubers. Beraga and Caeser (1990) and Kleinhenz and Bennet (1992) concluded that nitrogen increased yield via increasing larger produced tubers.

Mean Tuber Weight

Nitrogen and nitrogen×tuber size interaction had significant effect on mean tuber weight. Treatment of 160 kg ha^{-1} net nitrogen was the most effective one and caused the highest mean tuber weight. Also, interaction of medium tuber size×160 kg ha^{-1} net nitrogen had the most effect on this trait and the least value of this trait was observed at small tuber size×zero nitrogen (Table 3). Hassandokht and Kashi (1999), Abbasi (2006) and Jamaati-e-Somarin *et al*. (2008) also deducted that with increasing nitrogen level up to 160 kg ha^{-1}, mean tuber weigh per plant was increased to maximum. Other researchers have been concluded the same results, as well (Mollerhagen, 1993; Osaki *et al*., 1995). Nitrogen less influences on number of tuber but more influences on size of tuber and thereby, increases mean tuber weight (Struik *et al*., 1990) but if excessive values of nitrogen applied (over the favorite rate), both number and weight of tuber will decrease (Kleinhenz and Bennet, 1992).

Tuber Dry Weight

Tuber size, nitrogen level and their interaction had significant effects on tuber dry weight. Large tuber size caused the most weight (as equal to medium size) and small tuber size caused the least weight. 160 kg ha^{-1} net nitrogen had the most effect on this trait (Table 2). Referring to interaction effects, it was found that large tuber size×160 kg ha^{-1} net nitrogen led to highest tuber dry weight which was alike to medium tuber size×160 kg ha^{-1} net nitrogen (Table 3). Abbasi (2006) and Jamaati-e-Somarin *et al*. (2008) observed that with increasing nitrogen up to 160 kg ha^{-1}, tuber dry weight was increased and the least value was obtained at zero (control) level. Jam (2006) concluded that the most tuber weight per plant was achieved at large size. Lommen (1995) and Gholipour (1996) showed that with increasing tuber size, tuber dry weight was increased. This trait had positive and significant correlation with ANUE and had negative and significant correlation with PNUE (Table 4).

CONCLUSION

Based on the results, application of 160 kg ha^{-1} net nitrogen in order to achieving the most tuber yield along with the highest agricultural, physiological and nitrogen use efficiencies for Agria cultivar in Ardabil region is recommended. Also, using medium tuber size (40-80 g) is suitable to gain highest tuber yield besides the best planting and eating attributes.

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