Quantitative and Qualitative Yield of Potato Tuber by Used of Nitrogen Fertilizer and Plant Density

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Abstract: In order to investigate of quantitative and qualitative yield of potato tuber cultivar Agria, by applying nitrogen fertilizer levels and plant density a factorial experiment based on randomized complete block design was conducted with three replications, Ardabil, Iran. Factors were nitrogen levels (0, 80, 160 and 200 kg ha\(^{-1}\) net nitrogen) and plant densities (5.5, 7.5 and 11 plant m\(^{-2}\)). Results showed that the most nitrogen uptake by plant aerial parts and the most nitrate concentration in dry and fresh tuber weight were observed at 200 kg ha\(^{-1}\) nitrogen, 11 plant m\(^{-2}\) and 200 kg ha\(^{-1}\) nitrogen, 5.5 plant m\(^{-2}\), respectively. At 160 kg ha\(^{-1}\) nitrogen (as equal to 80 kg ha\(^{-1}\) nitrogen) and 11 plant m\(^{-2}\), the most tuber and yield were gained. With increasing nitrogen application up to 160 kg ha\(^{-1}\), nitrogen uptake by tuber, number of tuber and mean tuber weight was increased. The highest nitrogen percent of tuber and mean tuber weight was achieved using 80 kg ha\(^{-1}\) along with 5.5 plant m\(^{-2}\). The highest phosphorus and copper uptake by tuber was observed at 80 kg ha\(^{-1}\) nitrogen and density of 7.5 plant m\(^{-2}\). With increasing nitrogen application up to 200 kg ha\(^{-1}\) and densities of 7.5 and 11 plant m\(^{-2}\), the highest uptake of calcium and potassium was done, respectively. So, treatment of 80 kg ha\(^{-1}\) nitrogen and 11 plant m\(^{-2}\) in order to gain tubers having high edible quality and high yield along with the lowest nitrate accumulation is recommended.

Key words: Nitrate · NPK · Plant density · Nitrogen uptake and Potato

INTRODUCTION

Potato (Solanum tuberosum L.) is classified as tuber crops which has important impact on human feeding and in terms of high yield per unit area, energy content and produced protein, is superior to wheat and rice [1]. The fate of nitrogen fertilizers used in potato production is an important environmental concern [2]. Nitrogen is an essential element for plant growth and is a main part of proteins. When plant grows up in unfavorable environmental conditions, protein production is reduced and nitrogen accumulates as non-protein compounds. Belanger et al. [3] reported that estimation of optimum fertilizer rates is of interest because of growing economic and environmental concerns. Usually, there is a close relationship between light intensity and nitrate reduction in green leaves. Also, nutrient elements deficit has important effect on nitrate accumulation. With increasing nitrogen application and plant density, potato yield increases [4]. Plant density in potato affects some of important plant traits such as total yield, tuber size distribution and tuber quality [5]. Haase et al. [6] found that tuber N uptake and nitrate concentration were significantly influenced by amounts of nitrogen fertilizer. Also, nitrogen uptake increases number of tuber, tuber weight, qualitative and quantitative aspects of tuber. But, over-usage of nitrogen delays tuber growth and reduces its qualitative and quantities aspects. The role of nutrient elements in plants involves: cell osmotic potential controlling, cell constructive component, PH adjustment, cell membrane penetrability adjustment and catalytic imbibitions activity [7]. Over-application of nitrogen, results in decrease in pH, base saturation and lack of calcium, magnesium and potassium. Also, this can lead to increase in potassium to calcium ratio [8]. As we know, potato, like other plants, needs all the elements to growth naturally but in soils without trace elements deficit, potato tuber yield, associates with the presence of elements N-P-K and its requirement to the two later elements is much more than nitrogen and there are various evidences indicating impact of potassium and phosphorous on physiological aspects of potato [8], but on account of accumulation of available calcium and phosphorous in the majority of soils, fields receiving
advise amounts of the mentioned elements, generally, do not response to the excessive values of calcium and phosphorous so, nitrogen is a most limiting element for potato plant [7]. The rate of applied nitrogen fertilizers is a key factor in soil fertility management, as its over-usage can delay plant maturity and directs dry matter storage into aerial parts rather than tubers [9]. Belanger et al. [3] found that application of appropriate amounts of nitrogen (80 kg ha$^{-1}$) resulted in more favorable effects than higher rates. Waddell et al. [10] and Saeidi et al. [11, 12] reported that application of nitrogen, led to increase in tuber yield than control. This rate has been obtained 34.3% by Marguerite et al. [13]. Maher [14] reported that with increasing plant density, mean tuber weight decreased and in low densities, number of harvested tubers, was decreased. Increasing plant density led to mean tuber weight decrease and number of tuber and yield per unit area, increase [15]. Increment of plant density decreases mean tuber size probably because of plant nutrient elements reduction, increment of interspecies competition and large number of tubers produced by high numbers of stems [16]. Marguerite et al. [13] showed that the mean maximum increase in total tuber yield, generated by N fertilization against the zero-N treatment, was 34.3% and ranged from 10.5% to 54.7% and in regard to potato, the improvement of N efficiency should be also achieved by splitting N fertilizer applications and by monitoring the crop N needs to match crop N requirements and mineral N soil supply throughout the growing season. Joern and Vitosh [17] indicated that increasing nitrogen values resulted in increase of tuber nitrate concentration. Georgakis et al. [18] concluded that by increasing plant density, the tuber yield was increased. Karafyllidis et al. [19] reported that plant density strongly affected yield, both by number and by weight and more tubers and yield per square meter were expected in higher plant densities. Wadas et al. [20] reported that, with increasing the level of nitrogen fertilization, the nitrate content of tuber was increased and higher applications of nitrogen, caused higher nitrate content in tubers, too.

Since, over-application of nitrogen in potato cultivation results in decrease in tuber quality, exposure of human health to the risk as well as environmental accumulation s, the objective of this work was to Study of nutritional quality and yield of potato tuber cultivar Agria, by applying nitrogen fertilizer levels and plant density and determine the best nitrogen rates to get the highest yield and quality of potato tuber along with the lowest environmental accumulation.

**MATERIALS AND METHODS**

In order to investigate of quantitative and qualitative yield of potato tuber, Agria cultivar, a factorial experiment based on randomized complete block design with three replications was conducted at the research field of University of Mohaghegh Ardabili, Ardabil, Iran, with longitude of 48°15’ and latitude of 38°15’ in 2008. Ardabil region has very cold winters, rainy spring, dry and warm summers and with mean precipitation of 400 mm yearly. First factor was nitrogen levels (0, 80, 160 and 200 kg ha$^{-1}$) and second was plant densities (5.5, 7.5 and 11 plant m$^{-2}$). Nitrogen was given as urea at 2 stages namely, planting date and date of earthing up. According to soil analysis results, total nitrogen content was 0.56% and soil texture was sandy-loam. Based on soil test from depth of 0-30 cm, total saturated electrical conductivity (TSEC) was 3.68 mmhos cm$^{-1}$, soil PH was 8.09, total nitrogen was 0.56% and soil texture was loamy sand. Rows were spaced 60 cm to each other and plots contained 6 rows each 3 meters. In order to prevent nitrogen effects in adjacent plots (border effects), 1.5 meter border was made. Tubers of 60-70 grams were sown on 13 May 2008. Sowing depth was 12-13 cm. The last harvest was assigned to yield. To promote storage capability, ten days prior to harvest, aerial parts were removed [1]. Sampling was done from 2 m$^{2}$ plot area, then, tubers were transferred to the laboratory. Before measurements were done, tubers were washed along with roots and stolons. Different plant tissues were dried separately for 48 hours at 75°C and weighed. In order to calculate total nitrogen percent of tuber, Kjeldahl method was used. After that, tubers were dried and turned into ash at 500°C, different elements were measured. Calcium via titration, phosphorous using spectrophotometer, potassium using flame photometer and copper using atomic absorption devices (PerkinElmer, model: 640) were calculated.

Before measurements, tubers were washed along with roots and stolons. Different plant tissues were dried separately for 48 hours in 75°C and weighed. Tuber nitrate accumulation was calculated by sulfosalicylic acid method using spectrophotometer device (Cecile, France). Calculation of nitrogen uptake rate was made according to the Hashemidezfouli et al. [9]: $\text{NEU}=\text{DM} \times \text{EC}$ where: $\text{NEU} = \text{nutrient element uptake}, \text{DM} = \text{dry matter}$ and $\text{EC}= \text{element concentration}$. Results were analyzed by SAS software, mean comparisons were done via Duncan's multiple range test and graphs were drawn by Excel software.
RESULTS AND DISCUSSION

Nitrogen Uptake: Results showed that simple effects of plant density and nitrogen level on nitrogen uptake by aerial parts and tubers (P<0.01) and interaction effects of plant density × nitrogen level (P<0.05) only for nitrogen uptake by aerial parts, were significant. Since, increasing nitrogen application led to over-growth of aerial parts and consequently, increases of leaves and stems dry weight, so, it increased nitrogen uptake. The most nitrogen was uptaken at 200 kg ha⁻¹ nitrogen and the less at control level, for all aerial parts. But in tuber, it was increased up to 160 kg ha⁻¹ and then, decreased. Increment of density increased dry matter of aerial parts per unit area. This led to more nitrogen uptake in aerial parts and tubers so, the most and the fewer uptakes were observed in 11 and 5.5 plant m⁻². With increasing plant density and constant rate of available nitrogen, competition for nitrogen, increased. In 200 kg ha⁻¹ nitrogen and 11 plant m⁻² treatments, the most uptakes and in 80 kg ha⁻¹ nitrogen and 5.5 plant m⁻², the fewer uptakes were observed (Figs 1 and 2). Haase et al. [6] reported that with increasing N application, nitrogen uptake in tuber was increased and it is in accordance with our work. Also, they revealed more nitrogen uptake by tuber in case of increased nitrogen. Since, nitrogen uptake in tuber per unit area increased as a result of plant density and nitrogen level increment, so this increase, has affected positively tuber yield and yield components and probably, the best reason to yield increment.

Nitrate Accumulation: Simple effect of plant density and nitrogen and their interaction effect on tuber nitrate accumulation based on dry weight (P<0.01) and fresh weight (P<0.05) was significant. With increasing nitrogen level, nitrate content in tuber dry and fresh weight significantly increased. More nitrate content in tuber, as a result of increase nitrogen application, has been reported by Wadas et al. [20]. Increase of density, reduced tuber nitrate accumulation, as well. Perhaps, this is because of low fertilizer distribution between the large number of plants and consequently, the tubers. In 200 kg ha⁻¹ nitrogen and 5.5 plant m⁻², the most nitrate accumulation in fresh and dry weight, was observed (Figs 3 and 4). In all nitrogen levels, Agria cu. has accumulated the less nitrate rate in both fresh and dry tuber weight. Also, it could be found that nitrogen usage over the favorite range either caused to yield reduction or, increased nitrate accumulation in tuber.

Nitrogen and Calcium Percent of Tuber: Nitrogen (P<0.05) and calcium (P<0.01) percent were significantly affected by plant density × nitrogen level interaction effect. While 160 kg ha⁻¹ nitrogen along with the 5.5 plant m⁻² treatments was employed, the highest nitrogen percent of tuber was obtained. In contrast, treatments of 200 and 0 kg ha⁻¹ nitrogen as well as 5.5 plant m⁻², led to the lowest one (Fig 5). Since, at 200 kg ha⁻¹ nitrogen application, the highest amounts of this element have been spent to increase the growth of leaves and stems rather than tubers so, yield has decreased. But in treatment of 160 kg ha⁻¹ nitrogen, the highest yield has been gained. This shows that tubers have more used nitrogen and hence, nitrogen percent of tuber has been more than other treatments. Increase in applied nitrogen has led to increase in calcium percent of tuber so that, at 200 kg ha⁻¹ nitrogen along with the 7.5 plant m⁻², the highest rate was observed but, in treatment of 80 kg ha⁻¹ nitrogen as well as 5.5 plant m⁻², the lowest value was obtained (Fig 6). Koochaki and Sarmadnia [8] have reported the same results, as well.

Phosphorous and Potassium Percent of Tuber: Phosphorous content of tuber was affected (P<0.05) by nitrogen and interaction effect of plant density × nitrogen level (P<0.01). With increasing nitrogen rates (over the 80 kg ha⁻¹), phosphorous content of tuber was decreased. As shown in results, the highest phosphorous content was achieved in 80 kg ha⁻¹ nitrogen treatment and the lowest rate was obtained at levels of 160 and 200 kg ha⁻¹ nitrogen. Also, it was observed that by application of 80 kg ha⁻¹ nitrogen in density of 7.5 plant m⁻², the highest value of phosphorous was resulted. In contrast, the lowest ones were achieved by application of 0, 160 and 200 kg ha⁻¹ nitrogen at 7.5 plant m⁻² level (Fig 7). Clearly it was observed that with increasing nitrogen usage, phosphorous content was decreased so that, at the first level of nitrogen, the highest rate of phosphorous was taken up. Increase in nitrogen application had more significant impact on potassium percent of tuber than control. At the control level, the lowest rate of this trait was obtained but at the other three levels, the highest values were resulted. In terms of plant density, it can be said that densities of 7.5 and 11 plant m⁻² resulted in the highest amount of potassium content but density of 5.5 plant m⁻² led to lowest one. According to the interaction effects (Fig 8), same to the simple effects, treatment done as 200 kg ha⁻¹
Fig. 1: Effect of nitrogen and plant density on nitrogen uptake by tuber.

Fig. 2: Interaction effects of plant density × nitrogen on nitrogen uptake by shoot.

Fig. 3: Interaction effects of plant density × nitrogen on nitrate accumulation in dry weight.

Fig. 4: Interaction effects of plant density × nitrogen on nitrate accumulation in fresh weight.
Fig. 5: Interaction effects of plant density × nitrogen on nitrogen percent of tuber.

Fig. 6: Interaction effects of plant density × nitrogen on calcium percent of tuber.

Fig. 7: Interaction effects of plant density × nitrogen on phosphorus percent of tuber.

Fig. 8: Interaction effects of plant density × nitrogen on potassium percent of tuber.
Fig. 9: Interaction effects of plant density × nitrogen on copper percent of tuber.

Fig. 10: Effect of nitrogen and plant density on mean tuber weight.

Fig. 11: Effect of nitrogen and plant density on number of tuber.

Fig. 12: Effect of nitrogen and plant density on tuber yield.
nitrogen × 11 plant m⁻² density caused the highest rate of this trait but other treatment, 0 kg ha⁻¹ nitrogen × 5.5 plant m⁻², resulted in the lowest rate. Mahmoodi and Hakimian [21] found that increase in nitrogen application, leads to increase in potassium content of tuber. This finding is in accordance with our results on this element.

Copper Percent of Tuber: Amount of this element was affected by effects of nitrogen fertilizer, plant density and interaction effect of nitrogen level × plant density (P<0.01). Over-application of this element (over the 80 kg ha⁻¹) led to decrease in copper content of tuber and its highest and lowest rates was observed at 80 kg ha⁻¹ and 200 kg ha⁻¹ (equal to control) nitrogen, respectively. Also, increase in plant density, led to increase in this element so that, the highest values were achieved in densities of 11 and 7.5 plant m⁻² but the lowest one was obtained in density of 5.5 plant m⁻². In terms of interaction effect, the highest copper percent of tuber was resulted in treatment of 80 kg ha⁻¹ nitrogen × 7.5 plant m⁻² density while, the lowest value was observed in 160 kg ha⁻¹ nitrogen × 5.5 plant m⁻² density (Fig 9).

Mean Tuber Weight: Effect of nitrogen (P<0.01) and plant density (P<0.01) was significant on mean tuber weight. With increasing nitrogen up to definite point, this trait was increased so that, the highest value was obtained by application of 160 kg ha⁻¹ nitrogen. Meanwhile, control and 200 kg ha⁻¹ rates had significant effect on mean tuber weight. Also, it was seen that the lowest mean tuber weight was achieved at 7.5 and 11 plant m⁻² and the highest one was achieved at 5.5 plant m⁻² (Fig 10). Increase in density probably causes the increase in competition between and within plants and hence, leads to decrease in availability of nutrients to each plant and consequently, results in decline of mean tuber weight [19]. It seems that except for the competition, potato plant assigns more stored maters into the stems and leaves rather than tubers under high vegetative status. Applied nitrogen less affects number of tuber but more affects tuber size and increases it and directly increases mean tuber weight but in case of excessive rates of nitrogen, mean tuber weight is decreased [8].

Number of Tuber: Number of tuber per unit area for nitrogen level and plant density was significant (P<0.05). Nitrogen level up to definite point had the incremental effect on this trait and then, led to decrease in it. Khajehpour [1] approved increase in number of tuber with increasing nitrogen fertilizer. Increase in plant density resulted in increase in number of tuber so that; densities of 7.5 and 11 plant m⁻² jointly were at highest value and 5.5 plant m⁻² placed afterwards (Fig 11). Increase in number of tuber occurred as a result of increase in number of stolon and increase in density. Increasing stolons, eventually increased tuber yield. It is obvious that with increasing plant number, number of stems grown from the planted tubers and consequently, number of produced tubers per stem, is increased. Thus, increase in plant density leads to increase in produced tubers [1].

Tuber Yield: Effect of plant density and nitrogen level was significant (P<0.01) on tuber yield. Results showed that increase in nitrogen rates up to favorite point led to increase in tuber yield per unit area. This result has been reported by Osaki et al [15] and Georgakis et al.[18]. The highest values of this trait affected by nitrogen were obtained at 80 and 160 kg ha⁻¹ nitrogen and the lowest one was belonged to control. With increasing nitrogen application, number of stolons, number of tubers and consequently, yield were increased. This may attributable to the fact that in such conditions, vegetative growth of the aerial parts can increase and hence, inhibit transferring photosynthetically matters into the storage parts (tubers). Marguerite et al. [13] and Alam et al. [22] revealed that tuber yield per unit area was increased with increasing nitrogen fertilizer up to suitable level. Also, increase in density led to significant increase in tuber yield so that, the most and the least tuber yield was achieved at 11 plant m⁻² and at 5.5 and 7.5 plant m⁻², respectively (Fig 12). According to the Arsenault et al. [4], in high densities, number of tuber and yield of potato is increased. As we know, this crop needs to earth up to produce remarkable tuber yields so, in higher densities, lower distances are provided for tubers and hence, smaller tubers can be produced. But generally, tuber yield per unit area was increased as a result of more produced tubers.

CONCLUSION

Generally, it can be said that since majority of traits such as phosphorus, potassium and cupper content of tuber had the highest values at the level of 80 kg ha⁻¹ nitrogen and levels of 80 and 160 kg ha⁻¹ nitrogen were in the same group in terms of producing yield, number of tuber and mean tuber weight and also, increase in plant density caused the highest amounts of potassium, cupper and tuber yield. The most amount of nitrate in dry and fresh weight of tuber was observed in 200 kg ha⁻¹ nitrogen, 5.5 plant m⁻² treatments. Nitrate accumulation at
80 and 160 kg ha\(^{-1}\) net nitrogen was 170.52 and 214.47 mg kg\(^{-1}\) tuber dry weight and 38.88 and 50.82 mg kg\(^{-1}\) tuber fresh weight, respectively. At these nitrogen levels especially 80 kg ha\(^{-1}\), nitrate accumulated was lower than critical range so, application of 80 kg ha\(^{-1}\) nitrogen to gain most tuber yield with less nitrate accumulation in tuber, is recommended for Agria cv. in Ardabil region. Noticing mean tuber yield in Ardabil region of 28.7 t ha\(^{-1}\) and its comparison with yield of 80 and 160 kg ha\(^{-1}\) nitrogen treatment (29.44 and 31.74 t ha\(^{-1}\), respectively), it seems that can be recommended for this cultivar. so, application of 80 kg ha\(^{-1}\) nitrogen along with the density of 11 plant m\(^{-2}\) in order to gain the highest tuber yield having the most suitable edible quality per unit area in addition to decrease in environmental accumulation s and costs, is recommended for this cultivar.

REFERENCES


