Middle Eastern and Russian Journal of Plant Science and Biotechnology ©2009 Global Science Books

Potato Tuber Quality as Affected by Nitrogen Form and Rate

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ABSTRACT

Field experiments were conducted to investigate the performance of potato (*Solanum tuberosum* L.) cv. 'Valor' in relation to three different nitrogen (N) fertilizer forms (ammonium sulphate, $(NH_4)_2SO_4$, urea, $CO(NH_2)_2$ and ammonium nitrate, NH_4NO_3) and four N fertilizer rates (130, 180, 230 and 280 Kg N/feddan; 1 feddan (fed) = 4200 m^2) on the growth, yield and tuber quality of potato plants. Increasing N fertilizer rates up to 230 Kg N/fed enhanced vegetative growth as expressed by plant length, leaf number and area, plant fresh and dry weights, and leaf chlorophyll content. The same increase in N fertilizer rates significantly increased tuber number/plant, tuber yield (g)/plant, total tuber yield (ton/fed), marketable tubers (%) and tuber N content (%). On the other hand, the highest N rate (280 Kg N/fed) decreased all of the above-mentioned plant growth characters and yield. Furthermore, % protein content of tubers tended to increase with increasing N fertilizer rates while tuber dry matter (%), P (%), K (%), specific gravity and starch contents decreased with increasing N fertilizer rates. Using NH_4NO_3 significantly increased vegetative growth characters, leaf chlorophyll content, tuber yield/plant, total tuber yield (ton/fed), specific gravity and tuber starch content followed by $(CO(NH_2)_2$ then $(NH_4)_2SO_4$. There was no significant effect of N source on the tuber number/plant, N, P and K and protein content. It could be recommended that using N fertilizers in the form of NH_4NO_3 at a rate of 230 Kg N/fed gave the best growth characters, yield and % marketable tubers while using 130 Kg N/fed of the same source of N fertilizer gave the highest of tuber quality characters as expressed by specific gravity and % starch content.

Keywords: marketable tubers, protein, specific gravity, starch content

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important vegetable crops in the world and, particularly in Egypt, for its importance for local consumption and for export. Nitrogen (N) is important for economical potato production and represents about 4 to 5% of the total costs of production (Hochmuth and Jones 2004). Furthermore, growers are challenged to produce commercial potato crops with high tuber quality in a cost-efficient manner while minimizing the environmental impact of potato production (Zebarth and Rosen 2007).

With dramatic swings in the cost of N fertilizer, growers are taking a closer look at their N fertilizer application sources and rates. Regardless of fertilizer price, economic principles should be considered when determining which source and how much fertilizer to apply.

High soil fertility and optimal fertilization of the potato crop are the supreme goal for increasing tuber production. N is a very essential nutrient that affects yield and quality of potatoes. Proper N fertilization is critical for optimizing potato yield and quality (Millard and Marshall 1986; Porter and Sisson 1991; Rykbost *et al.* 1993; Miller and Rosen 2005). An adequate amount of N is required for best growth and potato plant development (Goins *et al.* 2004). Insufficient N leads to reduced growth (Roberts *et al.* 1982; Millard and Marshall 1986), limited yields (Lauer 1986b; Porter and Sisson 1991) and early crop senescence (Kleinkopf *et al.* 1981). On the other hand, excessive N can result in reduced yield (Lauer 1986a), especially in late-maturing varieties (Porter and Sisson 1991), delayed tuber set (Kleinkopf *et al.* 1981), and reduced tuber dry matter content (Millard and Marshall 1986; Porter and Sisson 1991). Excessive N also reduces uptake efficiency of other nutrients and increases the potential for environmental problems associated with N leaching or runoff (Westermann *et al.* 1988; Millard and Robinson 1990).

Commonly used N fertilizer sources available in Egypt are $(CO(NH_2)_2$, NH_4NO_3 and $(NH_4)_2SO_4$. Several studies had investigated the effect of different N fertilization forms on the growth, yield, and quality of potato. Although N fertilizer sources are NO_3, $(CO(NH_2)_2$, and NH_4, plants only take up N as either NO_3-N or NH_4-N (Westermann 1993). N applied as $CO(NH_2)_2$ is converted into NH_4-N by the enzyme urease (Benson and Barnette 1939). Karadogan (1995) indicated that the greatest growth of potato plants resulted by supplying N as NO_3-N followed by NO_3+NH_4 and least with NH_4-N. On the other hand, Westermann and Sojka (1996) showed that vegetative growth characters were higher by using $(NH_4)_2SO_4$ rather than NH_4NO_3. Also Lorenze *et al.* (1974) and Baker *et al.* (1980) indicated that in alkaline soils, higher yields were obtained by ammoniacal sources than by its counterpart urea. The N sources had significant effects on vegetative growth and tuber yield of potato cv. 'Nicola' with superiority of $(NH_4)_2SO_4$ when compared with NH_4NO_3 or $CO(NH_2)_2$ (Soliman *et al.* 2000). Also tuber yield of potato cv. 'Russet Burbank' was decreased when $(NH_4)_2SO_4$ was used as the N source but it was increased with $CO(NH_2)_2$ followed by NH_4NO_3 with no significant difference between them (Maier *et al.* 2002). Shaheen *et al.* (1989) reported, however, that both urea and ammonium sources had similar effects on potato tuber yield and specific gravity.

Although many investigators studied the effect of N on growth and yield of potato, there are some contradictions in the obtained results. Several reports stated that with each increment of N dose, the vegetative growth and tuber yield increased. For example, higher dry matter and tuber yields of potato cv. 'Kufri Chipsona-2' were obtained by increasing the N fertilizer rate from 90 to 270 kg N/ha (Kumar *et al.* 2007). Also, the increase in N fertilizer rate from 40 to 120 kg N/ha resulted in the highest yield of commercial potato tubers cv. 'Denar' (Czopek *et al.* 2005) Moreover, Mussaddak (2007) reported that tuber yield increases were

Received: 9 January, 2009. Accepted: 9 July, 2009.

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13, 27, 20, and 35% for N fertilizer rates of 70, 140, 210, and 280 kg N/ha, respectively for fall potato cultivars grown in a clay soil under Syrian Mediterranean climatic conditions. On the contrary, in the work of Long *et al.* (2004) using the highest N fertilizers did not enhance yields of potato plants. Similar results was obtained by Somarini *et al.* (2008) who revealed that the yield and number of tubers per unit area of potato cv. 'Agria' did not increase with N application over 80 Kg N/ha.

Due to the lack of information in previous studies regarding the optimum N fertilization rate and form for production of potato cv. 'Valor' and the need for a clear recommendation under Egyptian new reclaimed sandy soil conditions, this work aims to investigate the performance of this potato cultivar to different rates and sources of N fertilizers.

MATERIALS AND METHODS

Two field experiments were carried out during the two successive winter seasons of 2006 and 2007 respectively at the Agriculture Research Center Station at Kafr El-Zayat, El-Gharbia Governorate, Egypt. The experiment soil had a clay loam texture with pH of 8.2, EC of 2.17 (mmhos/cm/25°C) and the organic matter was 1.74% with 148.20, 5.36, 0.46 mg/100 g soil of N, P, and K respectively.

Plant material

Potato seed tubers cv. 'Valor' (a promising cultivar for higher yield and quality processing under Egyptian new reclaimed land) were planted on October 5th and 7th in 2006 and 2007, respectively. Harvesting was done 110 days after planting in both seasons. Normal agricultural practices took place whenever necessary according to the recommendations of the Egyptian Ministry of Agriculture. Three plants were randomly sampled at 100 days after planting to record the vegetative growth characters. At harvesting time tubers were taken from 10 plants in each treatment to record the tuber yield, quality and chemical contents.

Treatments

The experiment tested the effect of three N sources ($(NH_4)_2SO_4$, 20.6% N; $CO(NH_2)_2$, 46% N; and NH_4NO_3, 33.5% N) in combination with four N rates (130, 180, 230 and 280 Kg N/fed). The N fertilizers were added at 3 equal doses, the first application was at 3 days pre-planting then 45 days after planting and the third application was 14 days after the second application.

Measurements

1. Vegetative growth characteristics: Plant length (cm), number of main stems/plant, leaf number /plant, and fresh and dry weights of whole plant (g) were recorded. Leaf area/plant (cm^2) was measured according to the method described by Moursi *et al.* (1968). Moreover, total chlorophyll content of leaves was measured after 60 days from planting, samples of the fourth leaf were taken for determination of chlorophyll content according to Moran and Porath (1982).

2. Tuber yield: Tuber number/plant, average tuber weight (g), and total yield/plant (g) were measured by counting and weighing tubers of 10 plants then all tubers less than 65 g and tubers with external disorders that reduce marketability were excluded such as sunburned (green) potatoes, misshaped tubers, cracked tubers, and rotten potatoes and the difference was considered as the marketable yield (%). Total tuber yield (ton/fed) was calculated from tuber yield per plant.

3. Tuber quality characteristics: Specific gravity was measured by the weight in air/weight in water method (Edgar 1951). Specific gravity is a ratio of water to solid content in a potato tuber. Percentage of starch content in tuber was determined according to AOAC (1995). Tubers were dried in a 70°C oven to constant weight (for about 72 hrs) and then dry matter (%) was determined. Protein content (%) was measured using the Kjeldahl method (Rutkowska 1981).

4. Tuber chemical contents: N, P and K were determined as a percentage on a dry weight basis. N was determined using the micro-Kjeldal method (Kock and McMecking 1924), P was determined colorimeterically using a spectrophotometer (Shimadzu UV-1201, Shimadzu Scientific Instruments, Inc., Tokyo, Japan) at 410 nm according to Truog and Meyer (1929) and K was determined by flame photometry (Jenway Model PFP7, Bibby Scientific Ltd., UK) according to Jackson (1967).

Experimental design and statistical analysis

The experimental design used in the two successive seasons was a split plot design with three replicates. However, the three different forms of mineral N fertilizers were laid out in main plots while the four rates of N fertilizers were distributed randomly in sub-plots. Each sub-plot area was 14 m^2. The obtained data were statistically analyzed using ANOVA and mean separation at 5% level was done using the LSD test according to the method described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Vegetative growth characteristics

N fertilizer source and rate significantly interacted in all vegetative growth characteristics as expressed by plant length, leaf number/plant, leaf area/plant, leaf chlorophyll content, and plant fresh and dry weights (**Table 1, Fig. 1**). Using NH_4NO_3 at a rate of 230 Kg/fed resulted in the highest values in all studied vegetative parameters followed by $CO(NH_2)_2$ with the same rate, while the lowest values of all mentioned parameters were recorded by using $(NH_4)_2SO_4$ at a rate of 130 Kg/fed. The general trend was that vegetative growth values increased with increasing N application rate

Table 1 Effect of the interaction between different sources and rates of nitrogen fertilizer on vegetative growth characters of potato plants in the 2006 season.

Treatments		Plant length (cm)	Leaf No./plant	Leaf area/plant	Plant fresh weight	Plant dry weight
Nitrogen sources	Nitrogen rates (Kg/feddan)			(cm^2)	(g)	(g)
Ammonium sulphate	130	41.0	20.0	1243.2	115.8	8.3
	180	45.0	23.7	1823.3	139.9	10.1
	230	50.0	27.0	2558.0	159.7	12.2
	280	47.7	25.3	2497.5	144.9	11.4
Urea	130	45.3	24.0	1718.2	111.6	9.6
	180	45.7	26.3	2296.6	131.4	10.7
	230	49.0	29.3	4284.4	175.8	12.5
	280	48.0	27.0	3271.1	164.1	11.6
Ammonium nitrate	130	48.7	25.7	2404.1	136.2	10.8
	180	50.3	29.3	3322.4	150.8	11.9
	230	53.3	29.7	6295.5	211.2	14.7
	280	51.3	29.7	5923.4	185.3	13.9
L.S.D at 5% level		0.8	1.2	110.2	7.4	0.2

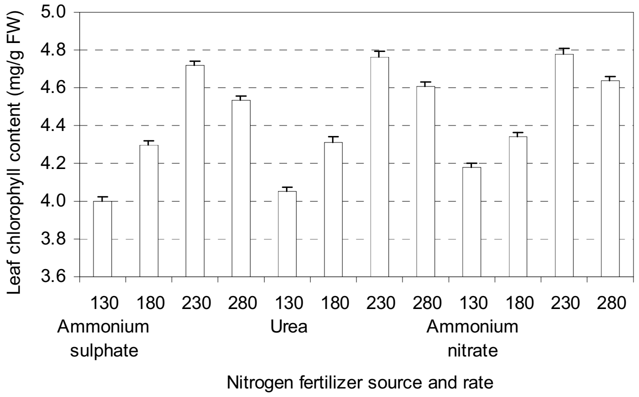

Fig. 1 Effect of N fertilizer source and rate on potato leaf chlorophyll content (mg/g FW). Vertical bars present LSD value at $p \geq 5\%$.

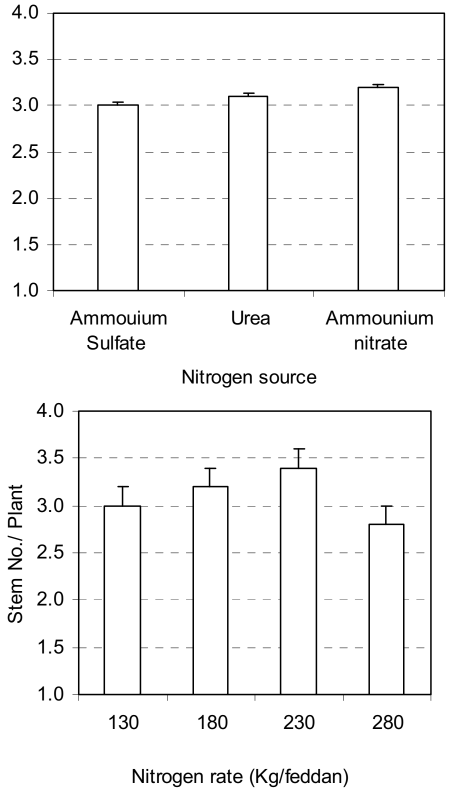

Fig. 2 Effect of N fertilizer source and rate on stem number of potato plants. Vertical bars present LSD value at $p \geq 5\%$.

from 130 to 230 Kg/fed within each type of N source. However, these values significantly decreased with increasing N application rate to 280 Kg/fed of the same type of N source.

On the contrary, stem number per plant (**Fig. 2**) was not affected by the interaction between N source and rate. While the N source had no significant effect on stem number/plant, and also there was no significant difference with increasing N application rate from 130 to 230 Kg/fed but it significantly decreased with increasing N application rate to 280 Kg/fed. The presented data are from the 2006 season, although 2007 season's data followed the same pattern and was not presented.

Other investigators also found that applying N fertilizer in the form of NH_4NO_3 gave the most vigorous vegetative growth of potato plants (Baker *et al.* 1980) while use of $(NH_4)_2SO_4$ resulted in the weakest plants (Dabis *et al.* 1986).

The vigorous vegetative growth obtained with using NH_4NO_3 may be due to the fact that although plants take up N as either NO_3-N or NH_4-N they prefer NO_3-N followed by NO_3+NH_4 and least with NH_4-N. Thus taller plants with increased growth and yield are usually obtained when using NO_3+NH_4-N than NH_4-N (Westermann 1993; Karadogan 1995).

Results from previous investigations showed that increasing N application rate linearly increased the vegetative growth (Ibrahim *et al.* 1987; Mandy and Munshi 1990; Barakat *et al.* 1991; Maler *et al.* 1994; Abdel-Razik 1996). Also, recently Kumar *et al.* (2007) reported that the crop growth traits (stem number, plant height and compound leaf number) of potato cultivars, 'Kufri Chipsona-1' and 'Kufri Chipsona-2' responded positively to an increase in N application rate up to 270 kg N/ha.

Tuber yield

The different N fertilization sources and rates greatly affected yield measurements. It is clear from the obtained data that using NH_4NO_3 at 230 kg N/fed resulted in the highest tuber number per plant followed by $CO(NH_2)_2$ at the same rate and NH_4NO_3 at 280 kg N/fed with no significant difference between them (**Fig. 3**).

Generally $(NH_4)_2SO_4$ reduced the number of tubers per plant and the lowest number was obtained when using low application rates of 130 and 180 kg N/fed with no statistical difference between these two treatments.

Similar findings were obtained by Casa *et al.* (2005) where N deficiency caused a decrease in tuber number and size. Regarding average tuber weight, it is evident from the illustrated data in **Fig. 3** that NH_4NO_3 (in general) at 280 kg N/fed was superior in increasing average tuber weight followed by $CO(NH_2)_2$ at the same rate then NH_4NO_3 at 180 kg N/fed with no significant difference among these treatments. The least values for average tuber weight were obtained when using $(NH_4)_2SO_4$ and NH_4NO_3 at 130 kg N/fed.

When total tuber yield per plant was measured, a close pattern was also obtained where NH_4NO_3 gave the highest

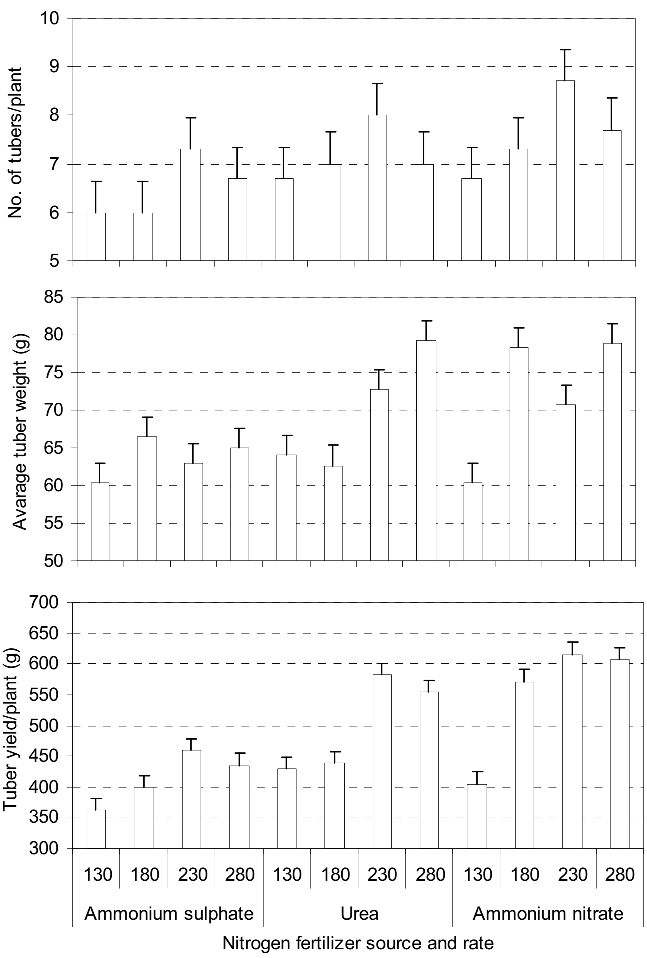

Fig. 3 Effect of N fertilizer source and rate on potato tuber number/ plant, avarage tuber weight (g), tuber yield/plant (g). Vertical bars present LSD value at $p \geq 5\%$.

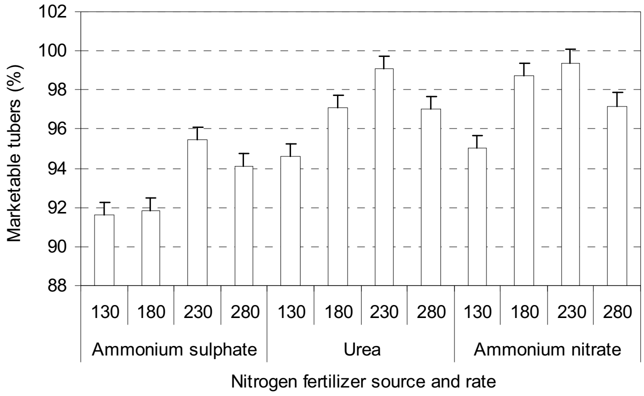

Fig. 4 Effect of N fertilizer source and rate on potato tuber total yield (ton/fed) and percentage of the marketable tubers. Vertical bars present LSD value at p ≥ 5%.

tuber yield per plant (g) with no statistical difference between using 230 or 280 Kg N/ fed with the exception of the low application rate of 130 Kg N/ fed which caused a severe reduction in tuber yield per plant. Also using $(NH_4)_2SO_4$ reduced the tuber yield per plant and the lowest was obtained with using $(NH_4)_2SO_4$ at 130 kg N/fed followed by 180 Kg N/fed with a statistical difference between both rates (**Fig. 3**).

Similar to these results, Polizotto *et al.* (1975) found that growth of tops, roots, and tubers of potatoes in solution cultures was greatest with N supplied as NO_3, intermediate with NH_4+ NO_3, and least with NH_4. Also, Dabis *et al.* (1986) reported similar findings where changing the N source from NO_3 or NH_4+NO_3 to NH_4 reduced both shoot and root growth and also tuber yield while changing the N source from NH_4 to NH_4+NO_3 improved growth and yield. They concluded that some NO_3-N should be available to potatoes for proper growth, development and yield. Moreover, results of Maier *et al.* (2002) showed that tuber yield of potato cvs. 'Russet Burbank' and 'Atlantic' decreased when using $(NH_4)_2SO_4$ compared to NH_4NO_3 or $CO(NH_2)_2$ at rate of 50 kg N/ha.

On the contrary the present results are not in agreement with those reported by Soliman *et al.* (2000) on 'Nicola' potato plants; they showed that $(NH_4)_2SO_4$ was superior in increasing total tuber yield followed by $CO(NH_2)_2$ and NH_4NO_3, respectively and 180 kg N/fed was the optimum N application rate.

As for total tuber yield/fed, it showed the same pattern as tuber yield/plant (**Fig. 4**). The percentage marketable tubers was also statistically affected by N source and rate. NH_4NO_3 at 230 and 180 kg N/fed and $CO(NH_2)_2$ at 230 kg N/fed increased the marketable tubers with no significant difference among them. On the other hand, ammonium sulphate at 130 and 180 kg N/fed resulted in the lowest tuber marketable percentage with no statistical difference between both rates (**Fig. 4**).

Tuber yield findings were in agreement with previous work of Soliman *et al.* (2000) who mentioned that the highest potato yield was obtained with increasing N application rate from 140 to 180 kg N/fed. These finding matched the obtained results from Barakat *et al.* (1991) where tuber yield of potato cv. 'Alpha' was increased by increasing N from 40 to 80 Kg N/fed. Also, Joern and Vitosh (1995), where total tuber yield of potato cv. 'Russet Burbank' generally increased with increasing N application up to 112 kg N/ha. Furthermore, Gabr and Sarg (1998) found that fertilizing potato cvs. 'Arenda', 'Ajiba', 'Liseta', 'Picaso', and 'Sante' with 150 kg N/fed resulted in highest tuber yield per plant and per feddan compared with 0, 50 and 100 kg N/fed.

On the other hand, few reports indicated that increasing N fertilizers rates did not enhance yield (Long *et al.* 2004) and this might be due to not reaching the threshold point of the N application rate. Generally results of N fertilizer application rates follow a curvilinear relationship where there is an increase in measured parameters with increasing application rate followed by a steady stage until reaching the threshold point, and then there is a decrease in N efficacy with higher application rates (Arsenault *et al.* 2001).

As for % marketable tubers, our results matched with those of Soliman *et al.* (2000) who indicated that fertilizing potato plants with NH_4NO_3 as the N source produced the highest marketable tuber yield. Also, they indicated that increasing N fertilizer from 140 to180 kg/N/fed increased the yield of marketable tubers, while the highest N dose (260 kg/N/fed) increased the yield of non-marketable tubers.

Tuber quality

The price of potato tubers is usually determined based on a combination of yield and tuber quality factors such as tuber specific gravity, starch and protein content, and dry matter percentage. Many tuber quality attributes are promoted by an adequate N supply, but decreased by further application.

Tuber specific gravity is one of the most important quality factors, especially for processing potatoes. There is a range of specific gravities that is considered optimal. Many factors influence tuber specific gravity such as climatic conditions and N fertilization. Generally, using NH_4NO_3 increased both specific gravity and starch content and the least values were obtained when using $(NH_4)_2SO_4$ while $CO(NH_2)_2$ was intermediate. In all N sources used, the higher the N application rate, the lower the tuber specific gravity and starch content. Least specific gravity and starch content values were obtained with using $(NH_4)_2SO_4$ at 280 kg N/fed while the highest values resulted from NH_4NO_3 application at 130 kg N/fed (**Fig. 5**).

These findings matched with other studies where speci-

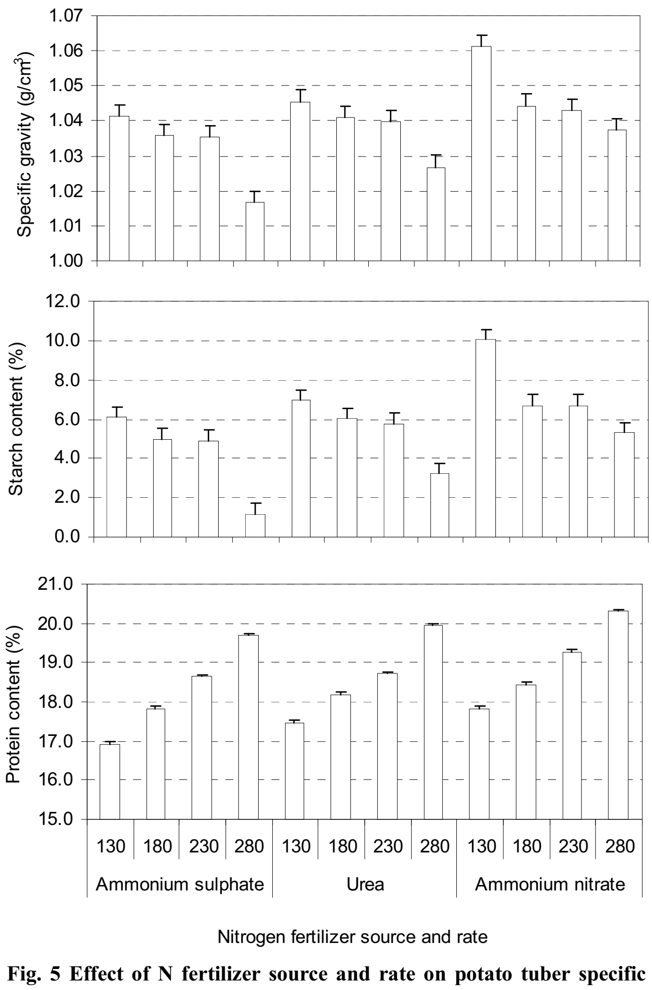

Fig. 5 Effect of N fertilizer source and rate on potato tuber specific gravity, starch and protein content (%). Vertical bars present LSD value at p ≥ 5%.

Table 2 Effect of the interaction between different sources and rates of nitrogen fertilizer on chemical composition and dry matter percentage of potato tubers in the 2006 season.

Treatments		Dry	N	P	K
Nitrogen sources	Nitrogen rates (Kg/feddan)	matter %	%	%	%
Ammonium sulphate	130	17.600	2.624	0.938	2.197
	180	17.100	2.764	0.893	2.161
	230	15.933	2.889	0.790	2.092
	280	14.600	3.052	0.653	2.080
Urea	130	17.267	2.707	0.929	2.188
	180	16.567	2.820	0.790	2.163
	230	16.133	2.902	0.807	2.109
	280	16.100	3.093	0.650	2.093
Ammonium nitrate	130	18.267	2.764	0.940	2.216
	180	16.867	2.860	0.893	2.173
	230	16.500	2.989	0.793	2.115
	280	16.067	3.147	0.653	2.097
L.S.D at 5% level		0.399	0.017	0.044	0.052

fic gravity and starch content decreased with increasing N fertilizer rates as mentioned by Lin *et al.* (2005) who found that as N increased from 0.5 to 3.5 (g N/pot), specific gravity were decreased from 1.10 to1.06 and starch content was decreased from 70 to 49% of potato var. 'Atica'. Also, Dahlenburg *et al.* (1990) who found that increasing N fertilization up to 320 Kg N/ha significantly reduced specific gravity in potato plants cv. 'Kennebec'. However, some researchers observed that tuber specific gravity was not significantly influenced by different pre-plant N rates (from 56 up to 168 kg N/ha) or total N rates (from 336 up to 448 kg N/ha) for potato cvs. 'Ranger Russet' and 'Umatilla Russet' (Alva 2004).

An opposite pattern was observed when protein content was measured where increasing N application caused a significant increase in protein content. The highest values resulted from plants that received 230 kg N/fed of NH_4NO_3 while plants received 130 kg N/fed of $(NH_4)_2SO_4$ produced tubers with lowest protein content. Such results are in agreement with those of Lin *et al.* (2005) who found that protein content of potato var. 'Atica' was increased from 7 to 22 (% DM) when N fertilization was increased from 0.5 to 3.5 (gN/pot).

Dry matter percentage behavior was similar to specific gravity and starch content where it was increased with applying N mineral fertilization in form of NH_4NO_3 followed by $CO(NH_2)_2$ then $(NH_4)_2SO_4$. Also, increased N application rate caused a decrease in dry matter percentage with a significant interaction between N mineral fertilization sources and rates. Using NH_4NO_3 at 130 kg N/fed produced tubers with the highest percentage of dry matter while the lowest values were obtained when using $(NH_4)_2SO_4$ at 280 kg N/fed (**Table 2**).

Several published reports have observed similar findings where there was a reduction in tuber dry matter with increasing N application rate (MacKerron and Davies 1986; Casa *et al.* 2005); others have shown that increasing N rates from 0 to 150 kg N/ha had no significant effect on tuber dry matter (Sharifi *et al.* 2005). However, increasing N rate from 70 to 140 or 210 kg N/ha resulted in a non-significance increase in tuber dry matter (Mussaddak 2007).

The noted reduction of specific gravity with increasing N application might be due to the reduction in dry matter content. Schippers (1976) reported a high correlation between specific gravity in tubers and dry matter or starch.

Increasing N application significantly increased tuber yield but at the same time, it reduced tuber dry matter. This contradiction might be attributed to the increase of tuber water content caused by excessive N application. Such explanation is also supported by Schippers (1968) who showed that most of the yield increase from N application was from increased tuber water content.

Tubers chemical contents

Generally, N application rates had a greater impact on N% content than N application sources with a significant statistical difference (**Table 2**). The highest values of N content % of tubers were obtained with NH_4NO_3 at the highest rate of (280 Kg N/fed) and the lowest values were recorded with $(NH_4)_2SO_4$ at the lowest nitrogen rate of (130 Kg N/fed).

In contrast, the highest values of tubers P and K % contents were obtained with NH_4NO_3 at the rate of 130 Kg N/fed and the lowest values were recorded with $(NH_4)_2SO_4$ at the rate of 280 Kg N/fed (**Table 2**).

It can be concluded that using N fertilizers as NH_4NO_3 at a rate of 230 Kg N/fed gave the highest values of tuber yield, number of tubers/plant, and marketable tuber % while using the same source of N fertilizer at a rate of 130 Kg N/fed gave the highest values of specific gravity, starch content %, dry matter %, P% and K% contents of tubers.

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