The Effect of Different Nitrogen Sources from Urea and Ammonium Sulfate on the Spikelet Number in Egyptian Spring Wheat Cultivars on Well Watered Pot Soils

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Abstract: The spikelet number (SPN) is an important wheat yield component decided before anthesis. Our objective was to determine the effect of nitrogen (N) from urea and ammonium sulfate split-applied at different rates before anthesis on the SPN in the recent Egyptian cultivars Sakha93 and Sakha94 and two commonly used cultivars in pots. The response of SPN to applied N from ammonium sulfate was higher than that from urea in all four cultivars used. However, there was no difference in the responses of SPN to absorbed N from the two fertilizers in any of the cultivars. The SPN per applied and absorbed N was the highest in Sakha94 among the four cultivars. These cultivar differences in the SPN were due to the difference in the spike number. The results suggested that the N from ammonium sulfate has a greater effect on SPN than that from urea in recent Egyptian cultivars.

Key words: Ammonium sulfate, Egyptian cultivars, Spike number, Spikelet number, Urea, Wheat.

Wheat (Triticum aestivum, L.) is the most important grain crop for bread flour and straw crop for livestock feed in Egypt (Mesbah, 2009). The recent wheat production of 8 million tons in Egypt was not sufficient to keep up with the population growth, and hence yield increases are greatly anticipated (Seleiman et al., 2010). Nitrogen (N) is the most effective fertilizer element to increase wheat yield (Harper, 1994; Salwau, 1994). In the Nile basin in Egypt, N fertilizer is applied to irrigated wheat several times from the sowing to stem elongation stages to realize the maximum economic yield (Otteson et al., 2007). However, the hazards of soil pollution resulting from excessive N application have increased (Sawires, 2000). Furthermore, the price of N fertilizer has increased in the past decade, and a more efficient use of fertilizer is greatly needed (El-Gizawy, 2005). Although urea is a popular N fertilizer, researchers are examining the superiority of ammonium sulfate for improving the efficiency of N use for wheat production (Chien et al., 2011). However, the superiority of ammonium sulfate has not been confirmed in recent Egyptian wheat cultivars under irrigated conditions.

The spikelet number is one of the important yield components directly manipulated by the fertilizer application before anthesis, although changes in grain number per spikelet and the weight of a single grain as other yield components change in response to environmental conditions after anthesis (McKenzie, 2002).

Our objective was to determine the effect of N from urea and ammonium sulfate on spikelet number in the recent Egyptian spring wheat cultivars Shaka93 and Shaka94 under moist soil conditions, to determine whether an increase in the efficiency of applied N had an effect on the bearing spikelet number.

Materials and Method

1. Plant materials and cultivation

Egyptian spring wheat cv. Sakha93 and Sakha94, Turkish cv. Adana99 and Japanese cv. Norin61 were grown in 4-liter pots at the experimental field of the Faculty of Life and Environmental Science, Shimane University. Sakha93 and Sakha94 originated in the Field Crops Department, Agricultural Research Centre, Ministry of Agriculture, Giza, Egypt, and were the new bread wheat cultivars, released in 2005, which have white grains, high tillering, resistance to yellow rust and resistance to leaf rust under irrigated conditions in the Nile delta area (Shehab et al., 2005). Adana99 and Norin61 are popular in the Mediterranean zone in Turkey and in western Japan.
respectively. Pots were filled with black soil for rice seedling (andosol; Green soil, Izumo Green Co. Izumo, Japan). Six seeds were sown in a pot on 30 October 2010 and the seedlings were reduced to three plants per pot after establishment. The pots were irrigated with a hand sprayer to maintain near field capacity moisture when there was no rainfall. Anthesis was the earliest in Norin61 (27 April 2011) and the latest in Sakha94 (7 May 2011).

2. N treatments

The andosol was supplied with garden lime, 20 g per pot to adjust the soil pH to 6.6 before sowing. N component of urea and ammonium sulfate was 46.5 and 20.6%, respectively; and urea and ammonium sulfate were applied at the rate of 0, 0.2, 0.4 and 0.6 g N pot⁻¹ (0, 100, 200 and 300 kg N ha⁻¹, respectively) three times: 20% before sowing, 50% at tillering and 30% at booting. Superphosphate (P₂O₅) and potassium chloride (K₂O) were applied at the rate of 0.6 g pot⁻¹ (300 kg ha⁻¹) before sowing. To trap leaked water from soils, we set a small pipe with a rubber stopper in a hole in the bottom of the pot and attached a plastic 2-liter bottle to the pipe. After measuring the leaked water volume, we sampled 0.1 liter of the water in a plastic bottle and reserved in a refrigerator. The experiment was laid out in randomized complete design of two fertilizer types × four amounts of fertilizer with four replicates in four cultivars.

3. Measurements

(1) Plant dry weight, spike and spikelet number

Three above-ground plants per pot were sampled at anthesis. After the leaf area was measured with a leaf area meter, plants were dried in an oven at 80°C for 48 hr and weighed. The numbers of spikes and spikelets per spike were

Fig. 1. Spikelet number and spike number per pot and spikelet number per spike in the plants supplied with different amounts of nitrogen fertilizer of urea (○) and ammonium sulfate (●) in two Egyptian (Sakha93 and Sakha94), one Japanese (Norin61) and one Turkish (Adana99) spring wheat cultivars. The data are the mean ± standard error of four replicates.
counted. The relationship between these parameters and the amounts of applied N or absorbed N was curve-fitted by a quadric curve by the least square method, because plant responses to applied or absorbed N generally should have an optimum or a ceiling point (Marschner, 1995).

(2) N contents of plants and soils

Plants sampled at anthesis were grained with a ball mill and N content was measured by the Dumas method (Rapid N III Donaustr-7, D-63452 Hanau, Germany). The NO$_3$-N contents of stored leaked water samples were measured with a NO$_3$-N meter and a sensor (PRN-41, Fujiwara Co., Tokyo). The amounts of NO$_3$-N leaked from pots were calculated as the content × sample volume. The soil pH at anthesis of Egyptian cultivars was measured with a pH sensor (PRN-41) in soil solutions extracted from air-dried 20-g soil samples with 0.1 liter of distilled water (McLean, 1982). Soil available NO$_3$-N and NH$_4$-N were measured with the NO$_3$-N meter and by the indophenol method. The NO$_3$-N was extracted with distilled water and NH$_4$-N with 10% KCL solution of 100 ml each from 10-g air-dried soil samples (Mulvaney, 1996).

Results

1. The effect of N from urea and ammonium sulfate on spikelet number

In all four cultivars, spikelet number increased with the increase in applied N from both N fertilizers. The rate of increase decreased with the increase in the amounts of applied N, and the increase by applied N from ammonium sulfate was greater than that by applied N from urea (Fig. 1). The spikelet number consists of the spike number and spikelet number per spike. The difference in spikelet number and spikelet number per spike in the plants with different amounts of absorbed nitrogen at anthesis from urea (○) and ammonium sulfate (●) in the four spring wheat cultivars. The data are the mean ± standard error of four replicates.
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number between the plants treated with the two fertilizers resulted mainly from the difference in spike number, not from spikelet number per spike, in all cultivars. The spikelet number and spike number reached near maximum when the amount of applied N was 0.5 g pot⁻¹ in most cultivars. The spikelet number and spike number per pot at applied N of 0.5 g pot⁻¹ in Sakha93 estimated from the regression in Fig. 1 was 110 and 10, respectively, for urea, and 118 and 9, respectively, for ammonium sulfate, but in other cultivars they were over 130 and over 11, respectively, for both fertilizers (Fig. 1). Thus, the response of spikelet number to applied N was much lower in Sakha93 than in the other cultivars.

2. Relationships between spikelet number and the amount of absorbed N
Correlation of the amounts of N absorbed from two fertilizers with the spikelet number per pot, spike number per pot and spikelet number per spike are shown by a single curve with higher regression coefficient (R²) for each cultivar (Fig. 2). The spikelet number and spike number reached near maximum when an amount of absorbed nitrogen was 0.3 g pot⁻¹ in most cultivars. The spikelet number and spike number per pot at the amounts of absorbed nitrogen of 0.3 g pot⁻¹ estimated from the regression in Fig. 2 were 149 and 11, respectively, in Sakha94, 148 and 11, respectively, in Norin61 and Adana99, and 114 and 9, respectively, in Sakha93 (Fig. 1). Thus, the response of spikelet number to absorbed N was the highest in Sakha94, intermediate in Norin61 and Adana99 and the lowest in Sakha93.

3. Correlation of spikelet number with plant dry weight and spike number
The dry weight of the above ground part of plant at anthesis increased with the increase in the amounts of absorbed N in all cultivars, and was highest in Sakha93 (Fig. 3-top). There were linear relationships between spike number and the dry weight in each cultivar, although the slope of the line and hence the dry weight per pot varied with the cultivar (Fig. 3-middle). The spikelet number closely correlated with the spike number in all cultivars (Fig. 3-bottom). Therefore, the increase in plant dry matter by an increase in N absorption before anthesis was accompanied with an increase in spike number, resulting in higher spikelet number.

4. Leaked and absorbed N
The amount of N absorbed by plants increased with the increase in applied amounts of N and was larger in the plants supplied with the N from ammonium sulfate than from urea, in all four cultivars (Fig. 4). The difference in N absorption between the two fertilizers in Sakha94 and Adana99 was smaller than that in the other cultivars (Fig. 4).
The total leaked N from sowing to anthesis in all cultivars ranged from 50% of the total absorbed N in the no fertilizer condition to 10% in 0.6 g N application, and the amount of leaked N from the plants supplied with urea was slightly larger than that from the plants supplied with ammonium sulfate.

**Discussion**

The response of spikelet number to N from ammonium sulfate applied before anthesis was higher than that to N from urea in our spring wheat cultivars (Fig. 1). However, the response of spikelet number to absorbed N from both fertilizers was similar (Fig. 2). This resulted from the difference in use efficiencies of N from ammonium sulfate and urea for plant growth (Fig. 3). The increase in spikelet number per plant by N fertilizer was due to an increase in spike number, that is, fertile tiller number (Figs. 1, 2 and 3) as it was previously shown by field experiments (Power and Alessi, 1978). Among the cultivars we tested, Sakha94 showed a greater increase in spikelet number per applied and absorbed N, and Sakha93 showed a greater biomass production at anthesis than other cultivars, though the spikelet number was lower (Figs. 1, 2 and 3). The increase in spikelet number by increased N absorption was the result of high assimilation until anthesis, i.e., biomass production at anthesis increased with the increase in the amount of N application (Fig. 3).

The efficiency of N use for wheat growth can be evaluated by N absorption efficiency (NAE).

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\text{NAE} = \frac{\text{AN}}{\text{SAN} + \text{NF}}
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where, AN is the N absorbed by plants at anthesis, SAN is an available N in soil at NF = 0 and NF is the N in fertilizer (g pot\(^{-1}\)). The NAE decreased with the increase in the amount of applied NF in all cultivars, more greatly by N from urea than N from ammonium sulfate (Fig. 4-right). The NAE in the soil supplied with ammonium sulfate ranged from 1 to 0.5 and that with urea from 1 to 0.38, although cultivar differences in the NAE were not clear.

The lower N absorption from urea than from ammonium sulfate might result from greater leakage of N from urea. The water leaked with N should increase when the amount of supplied water is greater than the water capacity of soils (Barrows and Kilmer, 1963). In our case accumulated rainfall was 680 mm (JMA, 2011) and tap water were applied to soils having a water-holding capacity of around 40 mm under cool weather and low evaporative conditions, and hence leaking might have been high. The leaked nitrate N increased with the increase in the amount of applied N, and amount of leaked N from urea was higher than that from ammonium sulfate. Leaked N ranged from 50% of total amounts of absorbed N at low fertilizer applications to 10% at high fertilizer applications in both fertilizers (Fig. 4). In the Egyptian cultivars, soil inorganic N \([\text{NO}_3^-\text{N}+\text{NH}_4^+\text{N}], \text{NO}_3^-\text{N}/(\text{NO}_3^-\text{N}+\text{NH}_4^+\text{N}) > 0.95\]
increased with the increase in applied N in both fertilizers (Fig. 5). The increase was greater in the treatment with ammonium sulfate than with urea. Therefore, the amount of N remaining in soils from ammonium sulfate would be larger than that from urea.

Another reason for the lower N absorption from urea is the low N volatilization from soils with ammonium sulfate. Ammonia volatilization can be a significant problem for urea regardless of the soil type, while ammonium sulfate resists N loss through ammonia volatilization (Norman, 2004). In wheat, the loss of N via ammonia volatilization from the surface-applied urea, may exceed 40% of applied N, and generally greater under high pH soils such as the Mediterranean zone soils (Buress and De Datta, 1990; Bijay and Yadavinder, 2003). In our study, ammonium sulfate decreased the soil pH of the two Egyptian cultivars (Fig. 5). Reduction of soil pH by ammonium sulfate significantly increased the NAE of Sakha93 and Sakha94 (Fig. 4). The reduction in soil pH (urea minus ammonium sulfate) correlated with the ratio of increase in NAE (ammonium sulfate / urea) \((r=0.763, P<0.05)\). Nitrification of ammonium sulfate can produce soil acidity due to the production of \(H^+\) ions (Pierre, 1928). Ammonium sulfate should be two times more effective in acidifying than ammonium nitrate or urea (Adams, 1984). Therefore, ammonium sulfate may have reduced N volatilization loss by sulfur ions, although pH in original soils might not be so high to cause active N volatilization. Furthermore, it was possible for the lower pH to relate with a reduction of leaked N.

Regardless of N source an increase in absorbed N increased spikelet number through an increase of spike number in four wheat cultivars. Therefore, the increase in fertile tiller number should be a more important factor for bearing high spikelet number in Egyptian cultivars when the amount of nitrogen fertilizer is increased.

Our results suggested that ammonium sulfate increases the spikelet number more effectively than urea in spring wheat cultivars, including the two recent Egyptian cultivars, under well irrigated conditions. Egyptian cultivar such as Sakha94 can bear higher spikelet number per applied and absorbed N than other cultivars to increase yield potential, and Sakha93 produces a larger biomass to contribute to an increase in straw production. Although our experiment was done under well watered pot conditions, N and water absorption are influenced by root development particularly in desiccated soils. Vigor root development in the deep soils should utilize N leaked from soil surface (Palta et al., 2011). Furthermore, the benefits of ammonium sulfate as N fertilizer for grain and straw productions in these cultivars should be certified by trials on the farm.

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