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Urea and Urea-Based Fertilizers Influence on Oat Forage Yield, Nitrogen Uptake and Nitrogen Leaching Losses

A.S. Modaihsh
Department of Soil Science, College of Agriculture, King Saud University, Riyadh, Saudi Arabia

Abstract. A pot experiment was conducted under greenhouse conditions, using a sandy loam calcareous soil, to evaluate the effect of urea and urea-based fertilizers, N-application rate and leaching fraction on oat dry forage yield, N-uptake and N-leaching losses.

At low leaching fraction (L_1), single (U_1) and split (U_2) urea additions were superior to the sulfur coated urea (Scu) and urea formaldehyde (UF) at low and high N-rates of application (80-160 ppm). At high leaching fraction (L_2), yield and N-uptake were significantly reduced for all treatments except Scu. U_2 and Scu proved to be more effective, at high leaching and high N rate, giving higher yield, higher N-uptake, better forage yield seasonal distribution and less N-leaching loss.

Nitrogen leaching losses varied from 1.1 to 11.8% of applied N; and were mainly in the NO_3^- form except when urea was mixed with sulfur (U_1 + S), where leaching in the NH_4^+ form was of considerable magnitude.

Introduction

Soils of the Kingdom of Saudi Arabia, being a part of arid and semi-arid regions, are subjected to the problem of inherently low N content. Thus, heavy N fertilizer applications are often necessary to obtain high yields for most crops grown on these soils. Most of these soils are coarse-textured and high in $CaCO_3$ content [1], where N fertilizer efficiency may be low due to N losses by leaching and volatilization.

The efficiency of fertilizer N applied to the soil is influenced by various factors such as N source, N rate of application, time of application, species of plant and other conditions specific to the site. The effect of the source and N rate on the leachability and atmospheric loss of N fertilizers has received considerable attention. Many researchers have demonstrated that using slow-release N sources as sulphur coated urea (Scu) has increased the efficiency of N fertilizers [2-6]. Contrary to these results, it was reporteld that Scu was of no greater benefit than urea and urea combined with sulfur in fertilizing California annual grass lands [7]. Also Allen *et al.* [8] found that Scu was not more effective in reducing leaching losses than soluble N sources for fescue grass (*Festuca arundinacea* L.) and rye grass (*Lolium multiflorum* L.).

Recently, much interest has been developed in utilizing some of the marginal lands in Saudi Arabia for growing oat (*Avena sativa* L.) as a winter forage crop beside alfalfa. (Medicago sativa L.). Therefore it was thought necessary to initiate an experiment to study the fate of N applied to these soils. The purpose of this research was, therefore, to study the effect of N source, rate of N application and leaching fraction on the productivity of oat forage and to determine the effect of such treatments on N losses.

Materials and Methods

A surface sandy loam (Torrifluvent) calcareous soil was obtained from the College of Agriculture, King Saud University Experimental and Research Farm at Derab, 25 km south west of Riyadh (24° 42⁻ N, 46° 44⁻E, Alt. 600 m). The soil is low in organic matter, native available N, P, Zn and Fe (Table 1). The soil was dried,

Table 1. Characteristics of the soil under investigation

Soil property	Derab soil
Great soil group	Torrifluvent
pH, 1:1 soil water ratio	7.45
Ec., dS/m	7.1
$CaCO_3$ %	33.3
Organic matter %	0.2
CEC meq/100g	4.5
Sand %	63
Silt %	21
Clay %	16
Soil texture	Sandy loam
WHC %	30
available N ppm	54.88
Sodium bicarbonate soluble-P ppm	1.0
Available K, NH_4OAc ppm	192
DTPA extractable Fe ppm	0.36
DTPA extractable Mn ppm	1.26
DTPA extractable Zn ppm	0.26
DTPA extractable CU ppm	0.34

crushed and passed through 2 mm sieve. A greenhouse experiment was carried out using plastic pots 20 cm in diameter and 15 cm height, each containing 11 kg of soil. The treatments consisted of two leaching fractions (L_1, L_2) and two rates of nitrogen (80 and 160 ppm) equivalent to 200 and 400 kg N/ha, respectively. Each rate of N-application included the following six treatments:

1) Urea one addition (U_1), 2) Urea split addition (U_2), before planting and eight weeks later. 3) Urea + Sulfur (U_1 + S), 4) Sulfur coated urea (Scu), 5) 2/3 Sulfur coateld urea +1/3 urea (2/3 Scu + 1/3 u), 6) 2/3 urea formaldehyde + 1/3 urea (2/3 UF + 1/3 U).

The Scu was supplied by the Tennessee Valley Authority (TVA). The sulfur added to urea in (u_1 + S) treatment is equivalent to sulfur in Scu (13.3% S); and it was applied as elemental sulfur (<100 μ). Each pot received 7.87 g P as superphosphate and 1.58 g K as K_2SO_4 before planting. All fertilizers were thoroughly mixed with soil at 5 cm depth.

Twenty seeds of oat were planted in each pot and seedlings were thinned to 10, two weeks after planting. Micronutreints were added after thinning at rates of 10 ppm Fe as EDDHA, 10 ppm Zn as Zn EDTA and 5 ppm Mn as Mn EDTA. The pots were weekly irrigated, by adding distilled water, in excess of the field capacity to collect approximately 70 and 140 ml of the leaching water. These were designated as leaching fractions L_1 and L_2, respectively. Leachates were collected in plastic bottles during a 24 hr. period after each irrigation and kept in cold room between irrigations. At the end of each plant cut the cumulative leachates in each bottle were measured and analysed for NO_3^- and NH_4^+ using Microkjeldahl method described by Chapman and Pratt [9]. Four cuts were taken after 8, 12, 16 and 20 weeks of planting. Plants were ovendried at 70°C for 48 hr. and dry weight was recorded. Total nitrogen was determined by digesting 0.2 g of plant material using sulfuric-salycilic acid mixture by Kjeldahl method, Chapman and Pratt [9].

Pots were arranged in the greenhouse in a split-split plot design, with three replicaitons. The main plot, sub-plots and sub sub-plots were assigned to fertilizer source, nitrogen rate, and leaching fraction, respectively. The data obtained were statistically analysed using ANOVA procedures and the differences among the means were separated according to the LSD method [10].

Results and Discussion

The analysis of variance (Table 2) shows that differences in forage yield, N-uptake and total nitrogen leaching losses were highly significant ($P \leq 0.01$) among

Table 2. Summary of the anlayses of variance for the effect of urea and urea-based fertilizers on oat forage yield, N-uptake and n-leaching losses.

S.O.V.	Yield g/pot	Total N-uptake mg/pot	Total N loss %
(Fertilizers) F	**	**	**
(Rates) R	**	**	**
(Leaching) L	**	**	**
F × R	N.S.	**	**
F × L	**	**	**
R × L	*	N.S.	N.S.
F × R × L	**	**	**

* and ** significant at the 5% and 1% level of probability, respectively; N.S. = not significant.

fertilizer treatments (F), N-application rates (R) and leaching fraction (L). Differences due to interactions among these factors were significant with the exception of those in yield due to F×R and differences in N-uptake and total N-losses due to R×L.

Dry forage yield and N-uptake at low leaching fraction (L_1)

At low leaching fraction (L_1), (Table 3) split adition of urea (U_2) gave significantly higher yield than Scu, 2/3 Scu + 1/3U, U_1+S and 2/3UF + 1/3U at the low rate of N-application (80 ppm), whereas the single addition of urea (U_1) was superior to these treatments at the higher rate of N-application (160 ppm). The effect of U_1 +S, Scu and 2/3 Scu + 1/3U on dry forage yield of oat was not significantly different at 80 or 160 ppm N. The slightly soluble urea formaldehyde (UF), combined with urea in the 2/3UF + 1/3U treatment, gave the lowest yield in all cuts regardless of the N-application rate and leaching fraction. The split addition of urea (U_2) gave higher yield than the single addition at 80 ppm N, while the opposite was true at 160 ppm N, though differences were not significant.

The effect of different fertilizer treatments on N-uptake at low leaching fraction (L_1) was almost parallel to their effect on yield (Fig. 1) except that differences between U_2 and U_1 were statistically significant ($P \leq 0.05$). This could be attributed to luxuary N-uptake in U_1 under restricted leaching conditions.

Table 3. Oat forage yield as affected by nitrogen source, rate of N-application and leaching fraction

Nitrogen fertilizer source	L_1					L_2				
	Cut 1	Cut 2	Cut 3	Cut 4	Total	Cut 1	Cut 2	Cut 3	Cut 4	Total
	g/pot									
	A- 80 ppmN									
Urea one addition (u_1)	31.27	17.07	4.10	1.67	54.11	34.10	5.00	3.70	0.70	43.50
Urea two additions (u_2)	25.57	23.30	9.00	0.40	58.27	28.17	11.37	7.87	1.77	49.18
U_1 + S	30.17	13.40	1.80	0.40	45.77	23.87	5.47	2.30	0.70	32.34
Scu	25.37	12.17	7.93	3.30	48.77	25.87	6.93	7.70	2.67	43.17
2/3 Scu + 1/3 u	23.30	18.93	5.27	0.27	47.77	23.77	6.20	6.36	0.93	37.26
2/3 uF + 1/3 u	23.27	6.77	1.00	0.10	31.14	25.90	4.20	0.20	0.10	30.40
	B- 160 ppmN									
Urea one addition (u_1)	26.90	28.20	7.27	3.07	65.44	24.2	8.93	4.47	1.76	39.16
Urea two additions (u_2)	29.50	14.30	10.50	4.30	58.60	25.70	8.20	9.87	2.67	46.44
u_1 + S	30.00	17.10	2.07	0.57	49.74	18.40	22.80	2.90	1.17	45.27
Scu	17.40	17.83	10.90	5.57	51.70	17.50	16.87	8.0	5.37	47.74
2/3 Scu + 1/3 u	19.60	23.17	8.90	3.10	54.77	21.87	8.27	3.67	4.30	38.11
2/3 uF + 1/3 u	27.90	8.60	0.40	0.53	37.43	25.57	6.30	0.67	0.50	33.04

$LSD_{0.05}$ (cut$_1$-, $_2$-, $_3$-, $_4$, total 6.58, 3.55, 1.69, 0.35 and 7.71 respectively)

Combining elemental sulfur with urea (U_1 + S) significantly reduced the forage yield (Table 3) and N-uptake by oat plants (Fig. 1), especially at the high N-application rate (160 ppm). This may be due to the oxidation of S, added as fine particles (< 100μ) which would raise the S:N ratio in soil and decrease soil pH. High S:N ratio in soil, as a result of S-addition was shown to reduce the yield of some crops [11, 12]. Also the acidity produced, in the fertilizer layer, as a result of S-oxidation might inhibit the nitrification process causing the NH_4^+ accumulaiton and therefore, affecting plant growth [13].

Substituting soluble urea for a portion of Scu in the treatment 2/3 Scu + 1/3U considerably enhanced N-uptake by oat plants relative to the Scu alone. However, this had no significant effect on the yield (Table 3). Contrary to these results, El-Wali

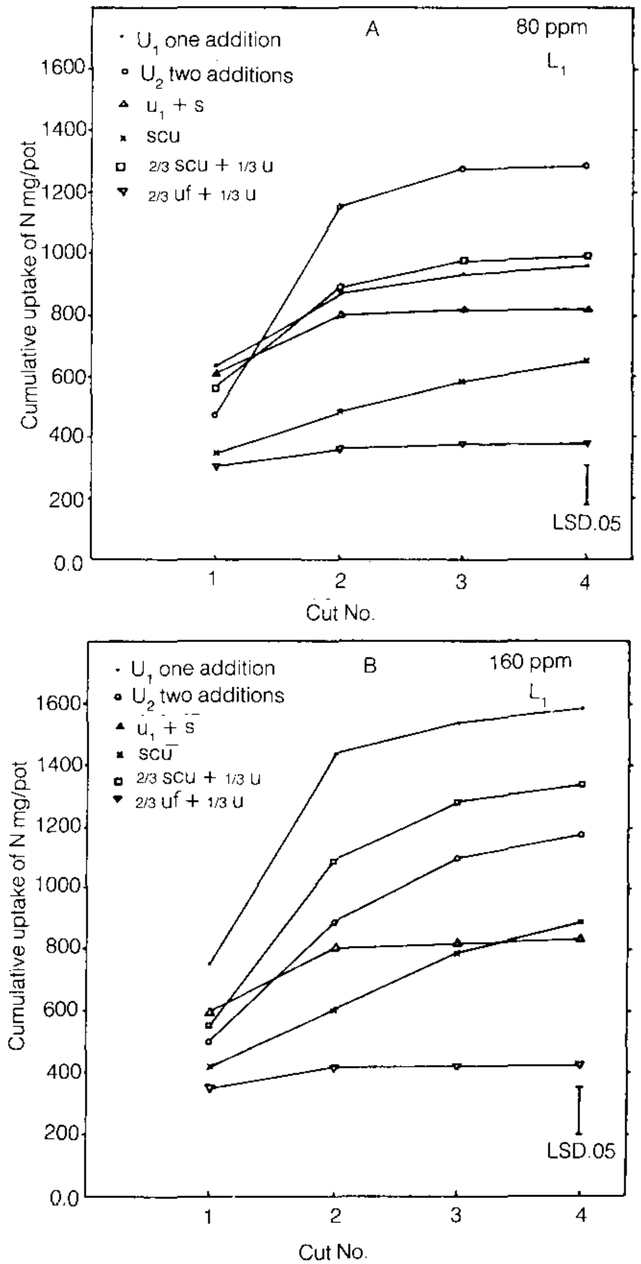

Fig. 1. **Cumulative uptake of N by oat at low leaching fraction (A and B for 80 and 160 ppm N)**

et al. [14] showed that the sugar cane yield was improved when Scu was mixed with urea.

The above-mentioned indicate that under low leaching (L_1) conditoins, such a sprinkler irrigation, the readily soluble urea seems to be superior to the slow release Scu and UF even when combined with urea.

Dry forage yield and N-uptake at high leaching (L_2)

Increasing the leaching fraction from L_1 to L_2 significantly reduced the oat forage yield (Table 3) for all treatments except for the slow release N-source treatments (Scu and U.F.), where the reduction was insignificant. This is due to the slow release characteristics of the N-sources. The large reduction in yield was obtained with the single addition of urea (U_1) at 160 ppmN probably due to high leaching losses of readily soluble urea. Under these conditions of high leaching, the relative effect of different fertilizer treatments on yield and N-uptake, generally, presented pattern similar to that at L_1, except that higher forage yield was obtained with Scu at high N-application. The N-uptake in U_2 was, however, higher than in the Scu at 80 ppm N but comparable to that at 160 ppm N (Fig. 2 and Table 3).

The dry forage yield of oat was highest in the first cut in all treatments. This was mainly the result of rapid early-season N-uptake. The yield decreased sharply in the third cut due to the drop in N-supply. Oat plants suffered from severe N-deficiency in most treatments in the fourth cut. It is worth mentioning that the highest forage yield in the third and fourth cuts was obtained from Scu and split addition of urea (U_2). This is due to the slow-release characteristic of Scu that makes N available to plants over a more extended period of time. Split addition of urea (U_2) reduces N-losses and early luxuary N-uptake leaving more N for latter growth, giving a better seasonal distribution of forage production [6, 15, 16].

These results show that under conditions of heavy leaching and high rate of N-applications, both Scu and U_2 proved to be more effective whereas U_1 was less effective. These results agree with those obtained by Vaughn *et al.* [7] and Allen *et al.* [8].

Nitrogen leaching losses

Data obtained for the cumulative leaching of N under the various treatments are presented in Table 4. Total N-leaching losses varied from 1.1 to 11.8% of the applied N depending on fertilizer source, N-application rate and leaching fraction. The percent of N loss, generally, decreased with the high N-application rate. Similar results were reported by Brown *et al.* [17] and Wesely *et al.* [18]. The least leaching losses resulted from Scu application (1.1 – 2.5%) followed by 2/3 UF + 1/3U (1.9 – 5.8%)

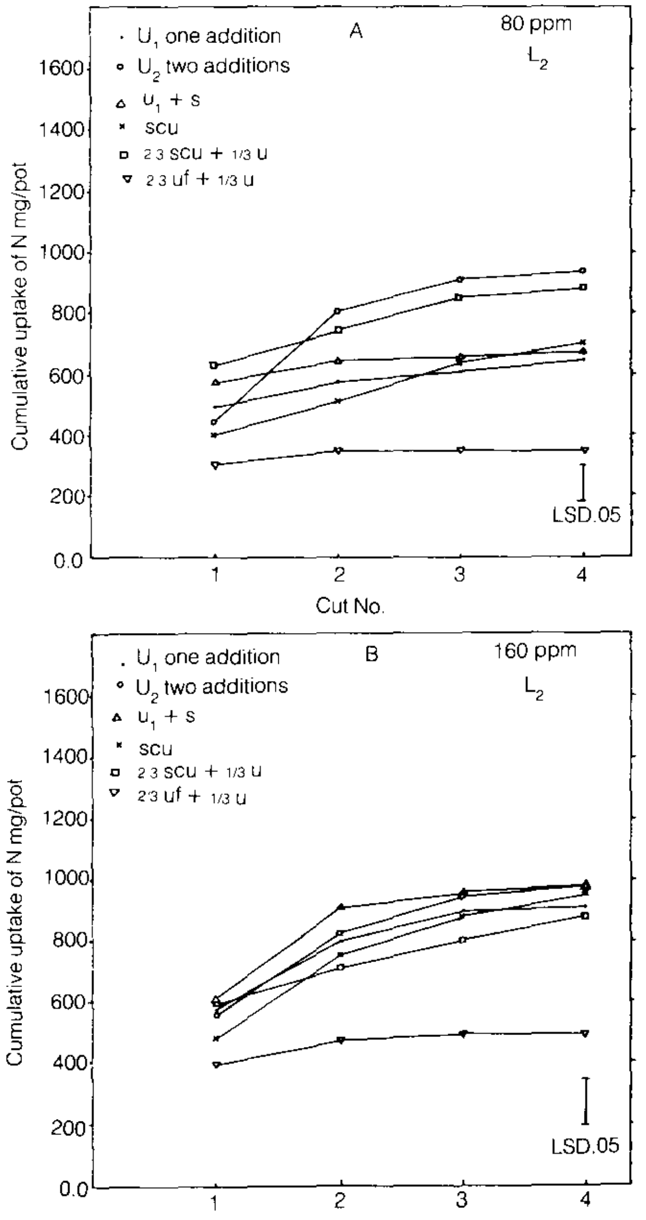

Fig. 2. Cumulative uptake of N by oat at high leaching fraction (A and B for 80 and 160 ppm N)

Table 4. Cumulative N-leaching losses from various N-sources as affected by rate of N-application and leaching fraction

Nitrogen fertilizer source	80 pm N								160 ppm N							
	L_1				L_2				L_1				L_2			
	NH_4^+-N	NO_3^--N	Total N	N loss	NH_4^+-N	NO_3^--N	Total N	N loss	NH_4^+-N	NO_3^--N	Total N	N loss	NH_4^+-N	NO_3^--N	Total N	N loss
	mg/pot			%	mg/pot			%	mg/pot			%	mg/pot			%
Urea one addition (u_1)	4.8	47.9	52.7	6.0	8.6	68.3	76.9	8.7	14.4	62.9	77.3	4.4	30.5	134.3	164.3	9.4
Urea two additions (u_2)	2.7	40.1	42.7	4.9	2.6	65.9	68.5	7.8	8.3	43.9	52.2	3.0	18.0	68.5	86.5	4.9
u_1 + S	21.6	42.4	64.0	7.3	32.4	71.8	104.1	11.8	58.8	40.1	98.9	5.6	86.2	94.3	180.5	10.3
Scu	3.1	8.7	11.8	1.3	2.5	15.9	18.4	2.1	1.3	17.9	19.2	1.1	11.4	32.6	44.0	2.5
2/3 Scu + 1/3u	6.9	76.6	83.5	9.5	21.5	71.1	92.6	10.5	10.3	101.0	112.3	6.4	15.0	133.8	148.8	8.4
2/3 uF + 1/3u	7.3	22.6	29.9	3.4	9.4	41.4	50.8	5.8	9.8	24.1	33.9	1.9	15.9	46.9	62.8	3.6

$LSD_{0.05}$ (NH_4^+-N, NO_3^--N, Total N, 10.6, 31.9 and 32.0, respectively) and U_2 (3.0 – 7.8%) treatments. However, N-leaching losses from 2/3 Scu + 1/3 U and U_1 + S treatments were significantly higher ($P \leq 0.05$) than the above mentioned treatments and considerably increased at high leaching fraction (L_2). Although, Hummel and Waddington [19] reported similar findings, further investigations are needed to explain why substituting soluble urea for a portion of Scu in the treatment 2/3 Scu + 1/3U_1 greatly increased N-leachability. Mixing S with urea in a single addition (U_1 + S), generally increased the N-leaching loss. This may be associated with inhibition of nitrification process effected by the acidity produced by S-oxidation in the fertilizer layer. N-leaching losses from U_1 were significantly higher than from U_2 only at 160 ppm N and L_2 (Table 4). N-leaching losses were mainly in the NO_3^- form, with the exception of the U_1 + S treatment, where loss in the NH_4^+ form was appreciable and reached as high as 47-60% of the total N-loss at 160 ppm N. This may, also, be attributed to the inhibition of nitrificaiton leading to the accumulation of NH_4^+ in soil. Prasad [13] reported similar findings and attributed the high leaching loss as NH_4^+ to the acidic conditions that existed in soil which reduced the development of substantial population of nitrifying microorganisms.

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تأثير اليوريا والأسمدة من أساس يوريا على إنتاجية الشوفان كعلف وعلى امتصاص النيتروجين وفقده بالغسيل

عبدالله سعـــد المديهش

قسم علوم التربة، كلية الزراعة، جامعة الملك سعود، الرياض،

المملكة العربية السعودية

ملخص البحث. أجريت هذه الدراسة في أصص تحت ظروف الصوبة الزجاجية، لدراسة تأثير اليوريا والأسمـدة من أسـاس يوريا، ومعدل إضافة النيتروجين والغسيل على إنتاجية محصول الشوفان كعلف وامتصاص النيتروجين وفقده بالغسيل في تربة جيرية طميية رملية.

أوضحت النتائج تفوق إضافة اليوريا على دفعة أو دفعتين على الأسمدة النيتروجينية بطيئة التحلل «اليوريا المغطاة بالكبريت واليوريا فورمالدهيد» عند المعدل المنخفض والعالي من النيتروجين «٨٠-١٦٠ جزءا في المليون» وتحت ظروف الغسيل المنخفضة.

أما تحت ظروف الغسيل العالية، فقد انخفضت الإنتاجية وامتصاص النيتروجين إنخفاضًا معنويًا في جميع المعاملات ما عدا اليوريا المغطاة بالكبريت. واتضح أيضًا أن إضافة اليوريا على دفعتين وكذلك اليوريا المغطاة بالكبريت كانت أفضل المعاملات تأثيرًا عند الغسيل العالي والمعدل المرتفع من النيتروجين حيث أعطيا إنتاجية عالية من العلف وامتصاصًا عاليًا للنيتروجين بالإضافة إلى توزيع أفضل للإنتاج على الحشات المتتالية أثناء الموسم كما كان فقد النيتروجين بالغسيل أقل.

وجد أيضًا أن فقد النيتروجين بالغسيل قد تروراح ما بين ١,١ ، ٨,١١٪ وكان الفقد بصورة أساسية على هيئة نترات عدا معاملة اليوريا عند خلطها بالكبريت والتي كان فقد النيتروجين بها عاليًا على هيئة أمونيوم حيث تراوح بين ٤٧ إلى ٦٠٪ من مجموع النيتروجين المفقود بالغسيل.