Volatilization Losses of Applied Nitrogen in Some West Pakistan Soils

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The effect of soil texture, soil moisture, time interval, nature of nitrogen carriers and their placement at various depths in the soil on the volatilization loss of applied nitrogen was studied. The soil samples taken after the expiry of the desired time intervals were analysed for total nitrogen.

The losses from urea were maximum in soil having low clay content and decreased with an increase in clay content of the soil. At a moisture level equivalent to 100 per cent field capacity, the losses were the minimum and increased with an increase and decrease of moisture. Losses also increased gradually with time and maximum loss was observed after 8 weeks' incubation period. The form of nitrogen contained in various nitrogen carriers influenced the losses which were higher from ammonium sulphate than from ammonium nitrate and urea. The placement of the fertilizers at various depths exerted a marked influence on the volatilization losses of nitrogen. Such losses were maximum when the fertilizers were placed on the surface and decreased with an increase in the depth of placement of the fertilizers. Major nitrogen losses are in the form of ammonia due to the alkaline pH of our soils.

INTRODUCTION

Nitrogen added to the soil may be lost from the soil in various ways. Nitrogen uptake by plants may be considered a loss from the soil if the plants are subsequently removed, as is the case with many agricultural crops. A similar process is the assimilation of nitrogen compounds by soil micro-organisms, which is, however, only a temporary loss since most of the nitrogen in the microbial cells is returned to the soil upto the death of the organism. Soluble forms of nitrogen like nitrates may also be leached from the soil in areas of high rainfall. In recent years, losses of nitrogen in gaseous forms, due to volatilization of ammonia and denitrification, have been shown to be of considerable agronomic importance. Volatile nitrogen losses are permanent. Because nitrogen is the first limiting factor for the growth of crop plants in most of our soils, the study of the volatilization losses of applied nitrogen under varying conditions, *viz.*, moisture, texture, time, nature of the nitrogen carriers and their placement at various depths was undertaken.

REVIEW OF LITERATURE

Barrit (1931) observed that free nitrogen was liberated by soil bacteria during denitrification. Reduction of nitrates and nitrites was affected most

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rapidly in the presence of compounds of low carbon-nitrogen ratio and the formation of nitrogen was strictly confined to the reduction of oxidized nitrogen.

In laboratory experiments by Sreenivasan and Subrahmanyan (1935), it was found that the loss of nitrogen as ammonia from water logged soils, to which had been added high amounts of dried blood or urea, was much greater than from soils maintained at 60 per cent saturation. They argued that in water logged soils ammonification proceeds at a more rapid rate than nitrification and naturally it would result in the accumulation of ammonia which would volatilize and thus be lost from the soil system.

Studies made by Steenbjerg (1946) showed that losses of ammonia from soils supplied with ammonium sulphate ranged from approximately 5 per cent at pH 6 to 60 per cent at pH 8 in four weeks. This loss was almost eliminated when the fertilizer was covered with 6 cm. of soil layer. It was found by Jackson and Chang (1947) that volatilization of ammonia was greatly reduced when anhydrous ammonia was injected in soil at a 2 or 4 inch depth.

Jones (1951) studied the loss of elemental nitrogen under anaerobic conditions. He found that a moist soil lost about 80 per cent of the nitrogen added in the nitrate form and the loss took place within three days in the form of nitrogen gas. He concluded that the evolution of nitrogen gas was probably the result of the activities of denitrifying bacteria, that utilized oxidized form of nitrogen as hydrogen acceptors.

Ali (1953) and Hussin (1957) found that loss of applied nitrogen decreased with the increase in clay content of different soils and also with the increase in the depth of placement of the fertilizers.

Laboratory studies by Wahhab *et al.*, (1957) indicated that twice as much ammonia volatilized from a sandy than from a sandy loam soil. The loss of ammonia decreased with the increase in the depth of fertilizer placement. Negligible loss of ammonia occurred from air dry soils, maximum loss occurring at 0.25 moisture saturation. The loss subsequently decreased with increase in moisture.

Bremner and Shaw (1958) concluded that the rate of denitrification of nitrate in soil was profoundly affected by the water contents of the soil. They found that even under most favourable conditions, little loss of nitrogen occurred when the moisture contents of the soil were less than 60 per cent of the total water-holding-capacity.

Wagner and Smith (1958) incubated Weldon and Sharkey soils treated with urea for 20 weeks. They found that nitrogen was lost rapidly in the Sharkey soil up to a period of 8 weeks, after which nitrogen losses seemed to be at a minimum. Nitrogen losses from the urea-treated Weldon soil appeared to have been rapid and rather constant for the duration of 20 weeks.

Robertson and Hansen (1959) found that when a nitrogen solution was dribbled on the surface of the soil at various rates, losses of volatile ammonia content of the solution varied from 63 to 100 per cent but were very small where the solution was injected to a depth of two inches.

Chin and Kroontje (1962) reported that soils having high clay contents, high cation exchange capacity and/or low pH values favoured the sorption of ammonia, thereby decreasing its loss as gaseous ammonia.

Fuller (1963) reported that losses of surface applied ammonia-nitrogen increased as the pH increased above neutral. He observed that volatilization of ammonia was markedly influenced by placement. Losses were greatly reduced or eliminated by placing the ammonium fertilizers below the surface of the soil at a depth of few inches.

MATERIAL AND METHODS

Three soils of varying textures, sandy clay loam, sandy loam and loamy sand were selected for the study. The physical and chemical analysis of the soils is given in Table 1.

TABLE 1.—*Physical and chemical analysis of the soils used in the experiment*

(a) Physical analysis

Soil type	Sand (per cent)	Silt (per cent)	Clay (per cent)	Field Capacity	Saturation percentage
Sandy clay loam	58.5	20.0	21.5	18.7	36.8
Sandy loam	72.5	13.3	14.2	13.7	30.6
Loamy sand	86.5	5.6	7.9	10.0	

(b) Chemical analysis

Soil type	Free lime (per cent)	Organic matter (per cent)	pH	EC×10³	C. E. C. mg. 100 g.	Nitrogen contents expressed as mg. N/100g.			
						NH_4^+—N	NO_2^-—N	NO_3^-—N	Total N
Sandy clay loam	1.58	1.14	7.5	1.65	9.26	1.350	0.010	11.25	112.3
Sandy loam	2.78	0.75	7.5	2.21	6.60	0.776	0.015	16.25	80.3
Loamy sand	1.38	0.20	7.8	1.40	4.11	0.510	0.005	5.00	37.9

The investigations were carried out in four different sets of experiments in order to study the influence of texture, moisture, time, different nitrogen carriers and their placements at various depths on the volatilization loss of nitrogen.

To study the influence of texture, 3 soils of different textures were treated with urea and incubated at 100 per cent field capacity for 8 weeks. Effect of moisture on the volatilization loss was studied in sandy loam soil fertilized with urea. Four moisture treatments including 30 per cent field capacity, 100 per cent field capacity, 150 per cent field capacity and complete saturation were given to this soil and incubated for 8 weeks. Volatilization loss of nitrogen as affected by various time intervals, 2 days, 1 weeks, 2 weeks, 4 weeks and 8 weeks was observed from urea, applied to sandy loam soil and incubated at 100 per cent field capacity. The effect of various nitrogen carriers including urea, ammonium sulphate and ammonium nitrate applied on the surface, 3 cm. deep and 5 cm. deep was studied from sandy loam soil after 8 weeks incubation period. The fertilizer in all the cases was applied at the rate of 25 mg. N/100 g. of soil. The soil samples taken after the expiry of the planned time intervals were analysed for ammoniacal-nitrogen, nitrite-nitrogen, nitrate-nitrogen and total nitrogen. The differences between the total nitrogen contents of the respective check samples plus applied nitrogen and that of the treated samples were designated as the volatile losses of applied nitrogen.

The methods used for the quantitative determination of various nitrogen contents were those as given by Jackson (1958).

RESULTS AND DISCUSSION

The losses of applied nitrogen from sandy clay loam, sandy loam and loamy sand treated with urea were 20.5, 39.5 and 58.0 per cent respectively (Table 2).

The observed higher loss of nitrogen from loamy sand soil may be due to small amount of clay and organic matter present in it. The ammonium applied as a fertilizer or formed in the soil is adsorbed on the exchange complex of the soil. In soils, having alkaline reaction, there is a strong tendency for the ammonium ions to hydrolyze from the colloidal surfaces according to the reaction.

$$\text{clay } NH_4 + HOH \longrightarrow \text{Clay } H + NH_4OH \qquad (i)$$

A solution of NH_4OH is, in reality an equilibrium mixture of molecular NH_4OH, NH_4+ and $OH+$ ions, water and dissolved, molecular ammonia. This equilibrium is expressed as

$$2NH_4OH \rightleftarrows NH_4^+ + OH^- + HOH + NH_3 \qquad (ii)$$

TABLE 2. *Loss of applied nitrogen from different types of soils treated with urea and kept moist at 100 per cent field capacity for 8 weeks.*

Treatment	Total nitrogen* mg./100 g.	Loss of applied nitrogen*	
		mg.	per cent
	(a) Sandy clay loam		
Check soil ..	135.20**	—	—
Soil+Urea ..	130.07	5.12	20.5
	(b) Sandy loam		
Check soil ..	103.20**	—	—
Soil—Urea ..	93.32	9.87	39.5
	(c) Loamy sand		
Check soil ..	61.05**	—	—
Soil+Urea ..	46.55	14.50	58.0

* Average of four replications.

** Increased by 25 mg. to make the value comparable to samples receiving this amount of nitrogen.

As indicated in the equation (*ii*), the ammonia form of nitrogen is subject to volatilization. This volatilization proceeds most rapidly as the soil dries (Hausenbuiller, 1963) and causes the reaction expressed in equation (*ii*) to proceed to completion. So the high losses of nitrogen from sandy soil might be due to rapid volatilization of ammonia because this soil dries sooner than the soils having high clay content. The other factor which contributes to the high losses of nitrogen from sandy soils may be excessive aeration of these soils. Due to excessive aeration gas exchange between atmospheric air and soil air will occur faster. Thus ammonia formed in such soils will be hastily removed causing more NH_4OH to dissociate. Similar results have been reported by Husain (1957), Ali (1953), Chin and Kroontje (1962 and Wahhab *et al.* (1957).

The losses of nitrogen from sandy loam soil treated with urea were 51.2, 40.2, 52.3 and 66.9 per cent at 50 per cent field capacity, 100 per cent field capacity, 150 per cent field capacity and at complete saturation, respectively (Table 3).

TABLE 3. *Loss of applied nitrogen from sandy soil treated with urea and kept moist at various moisture levels for 8 weeks.*

Treatment	Total nitrogen* mg./100 g.	Loss of applied nitrogen*	
		mg.	per cent
	(a) 50 per cent field capacity		
Check soil ..	100.82**	—	—
Soil+Urea ..	88.02	12.80	51.2
	(b) 100 per cent field capacity		
Check soil ..	103.12**	—	—
Soil+Urea ..	93.07	10.05	40.2
	(c) 150 per cent field capacity		
Check soil ..	103.10**	—	—
Soil+Urea ..	90.02	13.07	52.3
	(d) Complete saturation		
Check soil ..	99.87**	—	—
Soil+Urea ..	83.15	16.72	66.9

* Average of four replications.

** Increased by 25 mg. to make the value comparable to samples receiving the amount of nitrogen.

It is seen that losses increased both with increase and decrease of moisture from 100 per cent field capacity. High losses of nitrogen at 150 per cent field capacity and at complete saturation, which produced water-logged conditions in the soil, might have been caused by restricted aeration causing a decrease in the rate of nitrification and the ammonium ion was being continuously lost as such. Another possible mechanism for the loss at high moisture level may be due to denitrification. Although the process of nitrification is retarded at high moisture contents due to anaerobic conditions, yet some of the ammonium might have been oxdized to nitrates in the upper zone of oxygen penetration. Then with the leaching down of the water applied at the surface these nitrates might also have been leached down to the underlying anaerobic zone and lost through denitrification. Eremner and Shaw (1958) confirmed that the rate of denitrification of nitrates in the soil is profoundly affected by the water content of the soil. Even under most favourable conditions, little loss of nitrogen occurs if the moisture content is less than 60 per cent of the water-holding-capacity.

The losses of applied nitrogen were 6.7, 6.6, 20.3, 38.3 and 55.1 per cent after 2 days, 1, 2, 4 and 8 weeks, respectively, from sandy loam soil treated with urea (Table 4). These losses were not significant at 2 days and 1 weeks' incubation periods and later the losses increased significantly with time. The absence of significant loss of added nitrogen in case of 2 days and 1 week's incubation may be due to the slow hydrolysis of urea into ammonia. Further, on the conversion of urea to ammonium-nitrogen, these ammonium ions might have been absorbed on the clay-complex and then lost gradually by the interaction of OH^- ions through the mechanism already outlined. This also explains a gradual increase in the loss of applied nitrogen with time.

TABLE 4. *Loss of applied nitrogen from sandy loam soil treated with urea, and kept moist at 100 per cent field capacity for different time intervals.*

Interval	Treatment	Total nitrogen*	Loss of applied nitrogen*	
			mg.	per cent
2 days	Check soil	.. 106.00**	—	—
	Soil+Urea	.. 104.32	1.67	6.7
1 week	Check soil	.. 105.47**	—	—
	Soil+Urea	.. 103.82	1.65	6.6
2 weeks	Check soil	.. 105.07**	—	—
	Soil+Urea	.. 100.00	7.07	20.3
4 weeks	Check soil	.. 103.77	—	—
	Soil+Urea	.. 94.20	9.57	38.3
8 weeks	Check soil	.. 101.92	—	—
	Soil+Urea	.. 88.15	13.77	55.1

*Average of four replications

**Increased by 25 mg. to make the value comparable to samples receiving this amount of nitrogen.

Wagner and Smith (1958) incubated Weldon and Sharkey soils treated with 500 ppm. nitrogen as urea for 20 weeks. They found that nitrogen was lost rapidly in the Sharkey soil upto a period of 8 weeks, after which nitrogen losses seemed to be a minimum. Nitrogen losses from the urea-treated Weldon soil appeared to have been rapid and rather constant for the duration of 20 weeks.

The losses of applied nitrogen were 48.9, 32.8 and 6.9 per cent from urea, 55.3, 30.3 and 10.3 per cent from ammonium nitrate and 76.3, 49.8, and 8.5 per cent from ammonium sulphate when applied at the surface, 3 cm. and 5 cm. depths, respectively (Table 5). Losses were significantly higher in case of ammonium sulphate as compared with urea and ammonium nitrate. Losses were almost the same in case of urea and ammonium nitrate. Higher losses from ammonium sulphate may be attributed to the higher rate of loss of ammonia to the atmosphere through the interaction of NH_4^+ and OH^- ions as all the nitrogen contained in this fertilizer is in ammonium form. On the other hand in ammonium nitrate only about 50 per cent nitrogen is in ammonium form and the chances of ammonia volatilization are decreased 60 per cent as compared with ammonium sulphate. In urea all the nitrogen is present in organic form and it takes sometime for the conversion of organic nitrogen to the inorganic form. Hence, the time lag required for the hydrolysis of urea might have played a part in decreasing the volatilization of nitrogen.

TABLE 5. *Loss of applied nitrogen from sandy loam soil treated with different nitrogen carriers at various depths and kept moist at 100 per cent field capacity for 8 weeks.*

Placements	Total nitrogen*	Loss of applied nitrogen*	
		mg.	per cent
Check soil	104.60**	..	..
	(*a*) Urea		
Surface	92.37	12.22	48.9
3 cm. deep	96.40	8.20	32.8
5 cm. deep	102.87	1.72	6.9
	(*b*) Ammonium nitrate		
Surface	90.77	13.82	55.3
3 cm. deep	97.02	7.57	30.3
5 cm. deep	102.02	2.57	10.3
	(*c*) Ammonium sulphate		
Surface	85.52	19.07	76.3
3 cm. deep	92.15	12.45	49.8
5 cm. deep	102.47	2.12	8.5

*Average of four replications.

**Increased by 25 mg. to make the value comparable to samples receiving this amount of nitrogen.

The losses of nitrogen from all the fertilizers were highest when they were placed on the surface and decreased significantly with the increase of the depth of placement of the fertilizer. Lower losses of nitrogen with the increase in the depth of placement of the fertilizer might be due to the covering of the fertilizer with a soil layer and because the losses of nitrogen through ammonia volatilization are greatly reduced due to adsorption of ammonium ions by the colloidal complex. The results also suggest that the losses in these investigations occurred largely through the volatilization of ammonia. Had they been through any other mechanism such as denitrification, there would have been no significant increase in the nitrate-nitrogen content of the samples with the increase of the depth of placement of the fertilizers. These results are similar to those reported by Jackson and Chang (1947), Steenbjerg (1946), Ali (1953), and Hussain (1957).

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