The expected long-term detrimental effects of continuous application of ammonia on soil strength, aggregate stability and dry bulk density[1]

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ABSTRACT

Soil strength has increased due to ammonium hydroxide (NH_4OH) treatment as much as 112, and 150% for the 0 to 5 cm depth and 102, and 49% for the 5 to 10 cm depth in the SiL and SiC soil, respectively. The increase at the 0 to 5 cm depth was highly pronounced for the NH_4OH + NaOH treatment in the SiC soils but not for the SiL soils (18 and 361% for the 0 to 5 cm depth, and 82, and 112% for the 5 to 10 cm depth in the SiL and SiC soils, respectively) probably due to the high moisture content of the 0 to 5 cm depth of the SiL soils as a result of the water bonding because of low infiltration rate and water penetration caused by the dispersion effect of high sodium. No other explanation can be given at this point. The increase was a lot more for the soil treated with 5% $CaCO_3$, approximately 12 times, and 7 times for the 0 to 5 cm depth, and 8 times, and 3.5 times for the 5 to 10 cm depth in the SiL and SiC soils, respectively. The overall soil strength, however, is higher in the SiC soils than the SiL soils for both depths in all the treatments including the control.

The NH_4OH had caused also a reduction in the size of soil aggregates or a break down of the aggregates due to the dispersion effect on both soils. The DBD, however, was not affected by the used treatments.

Inspite of the slight changes in the chemical analysis of the soils after the treatments, I consider no major change has occurred due to NH_4OH and that the effect of NH_4OH was mainly a physical effect rather than chemical.

INTRODUCTION

Water applied ammonia (NH_3) initiated some problems which are caused by the nature of the reactions of the chemical with water and soil. When NH_3 is added to water the following reactions occur:

$$(1) \quad NH_3 + H_2O \rightleftharpoons NH_4OH$$
$$(2) \quad NH_4OH \rightleftharpoons NH_4^+ + OH^-$$
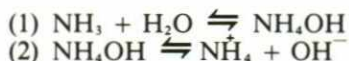
Reaction (1) causes a problem with water quality, especially in low salt waters or in water containing higher quantities of sodium (Na^+) than calcium (Ca^{+2}). Ammonium hydroxide (NH_4OH) is highly alkaline in irrigation water and may result in the precipitation of soluble Ca as $CaCO_3$, while the Na remains in solution. Thus continuous use of NH_3 under wet, well aerated and warm conditions may gradually cause the formation

of a sodic soil, resulting in slow infiltration and water penetration (author's unpubli-shed data of 1982).

Concern about the deterioration of soil structure due to continuous application of NH_3 has prompted interest in measurements of the various components of the term structure, which represents a complete set of physical properties of the soil, with emphasis on the term or terms expected to be more responsible for the deterioration.

Soil strength increases with decreasing soil moisture, with increasing silt and clay and exchangeable sodium content, and slow drying (6). Gerard (6) stated that «the cohesive action of water molecules during slow drying, similar to the dispersing action of Na, increase close-packing of soil particles and, therefore, soil strength». Gerard et al (7, 8) suggested that a slow rate of drying probably causes greater physicochemical bonding or close-packing of soil particles which enhances hard pan formation in certain soils. Agassi et al (1) suggested that crust formation is due to the physical dispersion of soil aggregates caused by the impact action of raindrops, and the chemical dispersion due to ESP of the soils and the electrolyte concentration of the applied water. The DBD is also an important physical parameter of soil structure subject to changes as soil structure changes. The DBD is known to have an effect on soil structure through its effect on soil porosity.

The objective of this study is to demonstrate how continuous application of NH_3 fertilizer may influence soil strength, soil aggregate analysis, and DBD as indexes of soil structure.

MATERIALS AND METHODS

Two selected soils were collected from the surface horizons. These soils were classi-fied as an orthic grey brown luvisol, and a gleyed orthic grey brown luvisol, being the silty clay (SiC), and silt loam (SiL) textures, respectively. The two soils then were air dried and sieved through a 5 mm sieve. The physicochemical properties of the two soils are given in Table 1.

Two kilograms of each of the two soils were packed silimarly in ceramic pots, 13.8 cm inside diameter by 17 cm long. Calcium carbonate ($CaCO_3$ — 99.2% purity) was incorporated in the soils at a rate of 5% by weight (100 g. per pot) and mixed thoroughly and packed the same way in another set of pots. All the treatments were triplicated.

Each pot received 250 ml of: deionized (DI) water for the control, ammonium hydroxide solution (1000 mg NH_4OH per pot) for the NH_4OH treatment, and a mixture of NH_4OH plus sodium hydroxide (NaOH at a rate of 2000 ppm Na) for the NH_4OH + NaOH treatment, at each irrigation.

Each pot received 6 irrigations over the total period of 75 days. The volume of the last irrigaiton, however, was doubled (500 ml) and was applied at 2 increments of 250 ml each. The first increment was to close and fillout the soil cracks and the second to insure complete saturation of the soil.

Four days after the last irrigation, penetrability or soil strength was measured in soils in all the pots at 2.5 cm and 7.5 cm depths using a 1.6 mm diameter proble. Core samples were then collected for the DBD determinations, other samples were also collected for aggregate analysis from the two depths.

Soil strength measurements were done by sticking the penetrometer probe (60° cone point, 1.6 mm outside diameter probe attached to Chatellon 719-40 penetrometer) in the soil at a depth of 2.5 cm and 7.5 cm, 4 days after the last watering to assess soil mechanical resistance. To avoid any soil disturbance the permeability measurements were done directly in the pots by placing the pots under the probe. The probe was then driven manually into the soil.

Two core samples from the 0 to 5 cm and 5 to 10 cm depth, were collected from each pot 4 days after the last watering. The cores (66 core) were then carried to the laboratory and dried at 105°C for 24 hours. The oven dry weight of the soil was determined and the DBD was calculated by the mass/volume relation.

Table 1 — The physicochemical properties of the two soils used in the study.

Soil texture	Sand	Silt	Clay	DBD	Sat.	Water content FC	WP	pH	Ca	Exchangeable Mg	K	Na	CaCO$_3$
	%			g/cm^3		g/g				me/100g			%
Silt loam	29	54	17	1.60	0.43	0.24	0.10	7.7	35.5	2.4	0.46	0.21	4.2
Silty clay	7	52	41	1.43	0.57	0.31	0.20	6.7	23.0	4.8	0.83	0.63	0.5

Table 2 — Effect of the various treatments on dry bulk density and soil strength.

Soil Texture	Treatment	Soil Depth cm	Dry bulk density [a] g/cm^3	Soil Strenght [b] kg/cm^2
SiL	Control	0-5	1.37	2.71
	Control	5-10	1.33	7.14
SiC	Control	0-5	1.25	5.71
	Control	5-10	1.17	15.91
SiL	NH$_4$OH	0-5	1.32	5.75
	NH$_4$OH	5-10	1.25	14.39
SiC	NH$_4$OH	0-5	1.25	14.26
	NH$_4$OH	5-10	1.13	23.71
SiL	NH$_4$OH + NaOH	0-5	1.39	3.20
	NH$_4$OH + NaOH	5-10	1.30	12.98
SiC	NH$_4$OH + NaOH	0-5	1.19	26.33
	NH$_4$OH + NaOH	5-10	1.08	33.65
SiL	CaCO$_3$ + NH$_4$OH [c]	0-5	1.34	32.93
	CaCO$_3$ + NH$_4$OH	5-10	1.27	51.60
SiC	CaCO$_3$ + NH$_4$OH	0-5	1.20	44.65
	CaCO$_3$ + NH$_4$OH	5-10	1.17	54.30

[a] The values are averages of 3 determinations.
[b] The values are averages of 5 measurements in each of the three pots (15 measurements).
[c] Soil mixed with 5% by weight CaCO$_3$, and irrigated with NH$_4$OH solution.

Most investigators have used wet-sieving techniques for aggregate analysis with variations in the numbers of sieves, rates and times of sieving, and sedimentation techniques. Bryant et al (3) have devised a technique using two sieves for getting one size fraction and have suggested using the 0.5 mm fraction. Russel and Feng (11) used one sieve and obtained the 0.25 mm fraction. It was found also that changes in aggretate stability were reflected most by 0.5 to 2.0 mm aggregates (4).

In this study the collected samples from the two depths (O to 5 and 5 to 10 cm) for the control and treated pots were oven dried at 105°C for 24 hours and passed through a nest of 5 sieves (4.699 –, 1.981 –, 0.991 –. 0.495 –, and 0.246 mm). A sample of 50 g oven dry soil was spread on the top sieve. The nests were immersed in DI water and allowed to move gently up and down for 10 minutes. The machine was set to run at 40 oscillations per minute with a 35 mm stroke. The nests then were put in a forced air oven and left for 3 to 4 hours at 105°C to dry. The material in each sieve was then collected, oven dried and weighed. The percent of the size particles was calculated relative to the total oven dry weight of the original soil sample (50 g).

Soil samples were collected four days after the last irrigation from 0 to 5 cm, and 5 to 10 cm depths, air dried and sieved through a 2 mm screen. The samples used for N analysis were further ground and passed through a 0.246 mm screen. The samples then analyzed for ammonium nitrogen ($NH_4 – N$), nitrate nitrogen ($NO_3 – N$), $CaCO_3$, exchangeable Na, K, Ca, and Mg, and available P. The pH and EC were also measured in a 2:1 soil extract.

Exchangeable NH_4^+ was extracted using 2 N KCl and determined on the auto analyzer using a 500 mm flow cell and 610 mu filters. Soil NO_3 was determined on the Tecnicon Auto Analyzer Two using a 0 to 1 calibration range (2).

RESULTS AND DISCUSSION

Soil strength

The data plotted in Fig. 1 show the effect of the various treatments on the soil strength. The NH_4OH increased the soil strength as much as 112, 150% for the 0 to 5 cm depth and 102, 49% for the 5 to 10 cm depth in the SiL, and SiC soils, respectively. The increase was more pronounced for the SiC on the 0 to 5 cm depth due to the dispersion effect of NH_4OH which increased accordingly the friction on the probe. This also led to clogging of the pores and enhanced clodding, crusting, and rapid drying of of the surface. For the 5 to 10 cm depth, the higher moisture content in the SiC than the SiL made the penetrometer resistance lower. The soil strength for the NH_4OH treatment was higher in both soils at the two depths than the control, probably due to the effect of NH_4OH on the particle rearrangement and the new structure build up initiated as a result of dispersion and break down of soil aggregates. The effect of $NH_4OH + NaOH$ followed the same pattern as NH_4OH, except that the effect was higher in the SiC due to more dispersion of clay due to the high Na concentration. In the case of $CaCO_3$ the high soil strength in both soils at both depths is explained as a result of better orientation and distribution of soil particles due to high concentration of Ca^{+2} ions which is known to cause a great physicochemical bonding and close-packing of soil particles particularly the silt and clay (6) and/or due to the quick dryness of the soil containing high $CaCO_3$ because of the high water absorbing capacity of $CaCO_3$.

The results shown in Table 2 indicate that the penetrometer resistance is a more sensitive indicator of soil structural changes than the DBD, these data are in agreement with the findings of Voorhees et al, (13). Thus the DBD values changed about 6.0% or less in the SiL, and 3.4% in the SiC soils due to NH_4OH treatment, whereas penetrometer resistance values increased as much as 361%.
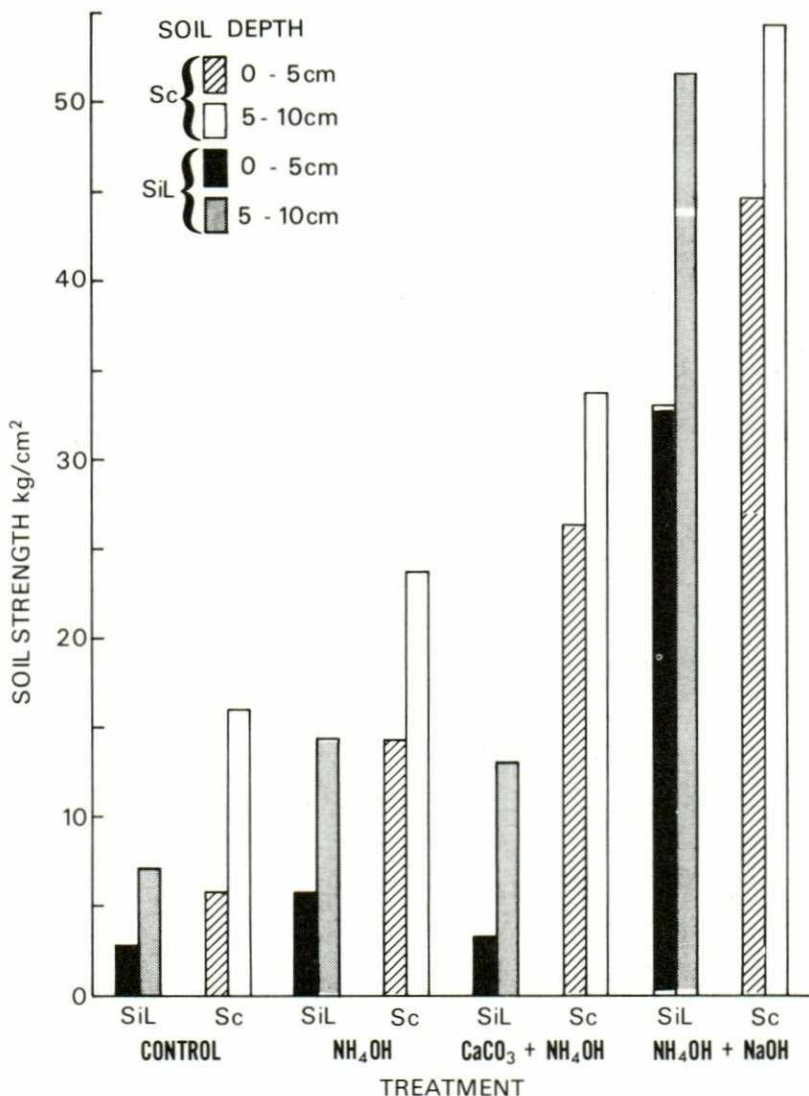
Fig. 1 — *Effect of the various treatments on soil strength.*

Soil aggregate analysis

Data presented in figures 2 to 5 show that the various treatments caused some variations in the percent cummulative of above size 0.246 mm for the SiL soils as compared to the control in all cases except with the $CaCO_3$ + NH_4OH treatment at the 0 to 5 cm depth where it increased by 1.9%, a decrease of 8.1% and 5.7% had occurred at the 0 to 5 cm depth for the NH_4OH and NH_4OH + NaOH treatment, respectively, and a decrease of 4.9, 9.5 and 22.6% at the 5 to 10 cm depth for the $CaCO_3$ + NH_4OH, NH_4OH and NH_4OH + NaOH treatment, respectively. In the SiC soils the trend is little different, for the 0 to 5 cm depth, the decrease in the percent cummulative of above size 0.246 mm due to NH_4OH treatment was very slight (0.95%), no effect due to $CaCO_3$ + NH_4OH, and a 25.9% increase due to NH_4OH + NaOH treatment. For the 5 to 10 cm depth, the percent cummulative of above size 0.246 mm stayed the same for
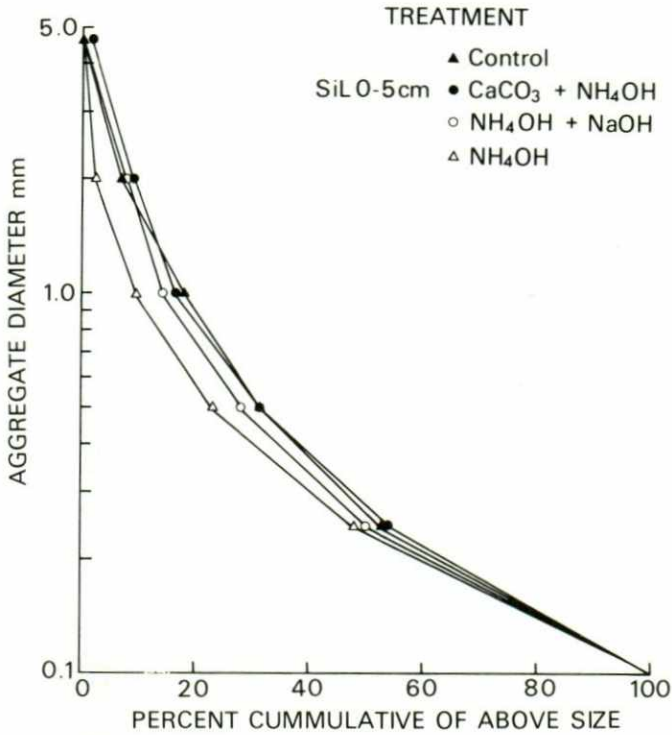
Fig. 2 — *Effect of the various treatments on the aggregate size analysis for the 0-5 cm depth of SiL soils.*
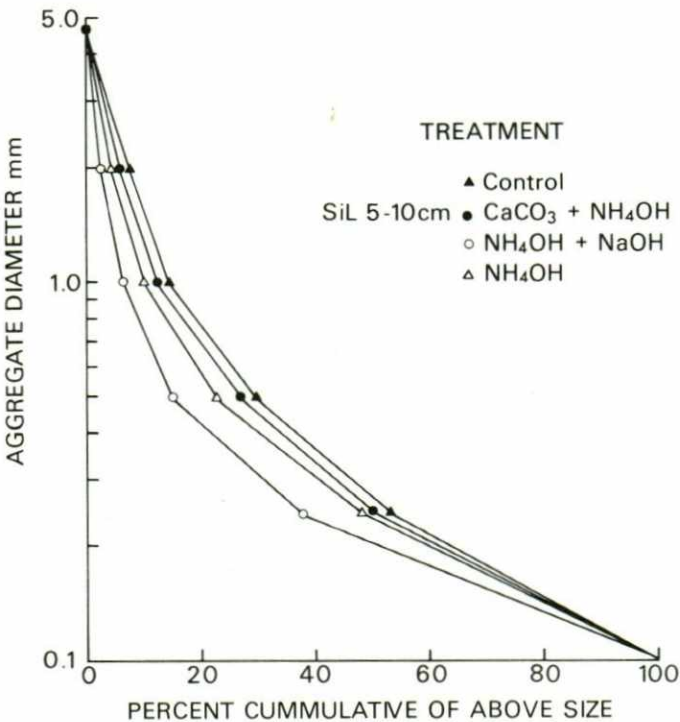

Fig. 3 — *Effect of the various treatments on the aggregate size analysis for the 5-10 cm depth of the Sil soils.*
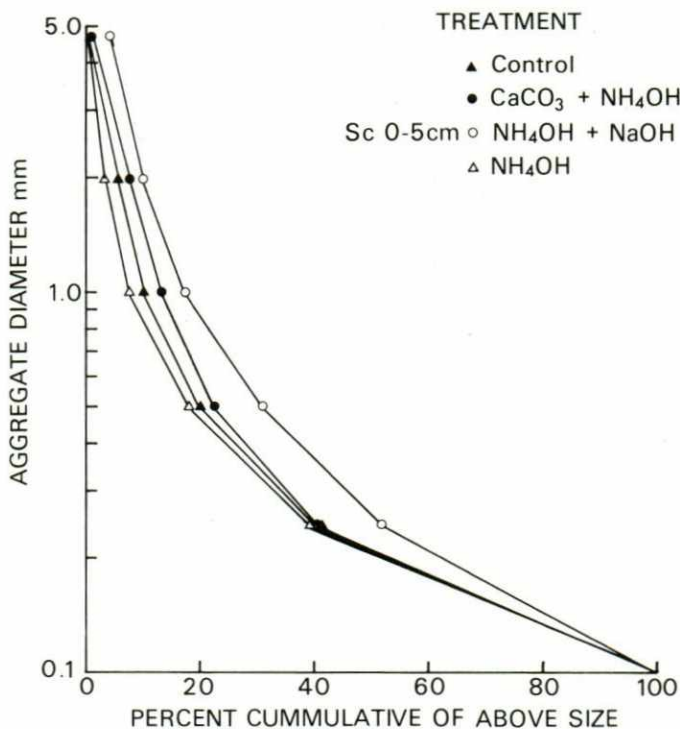
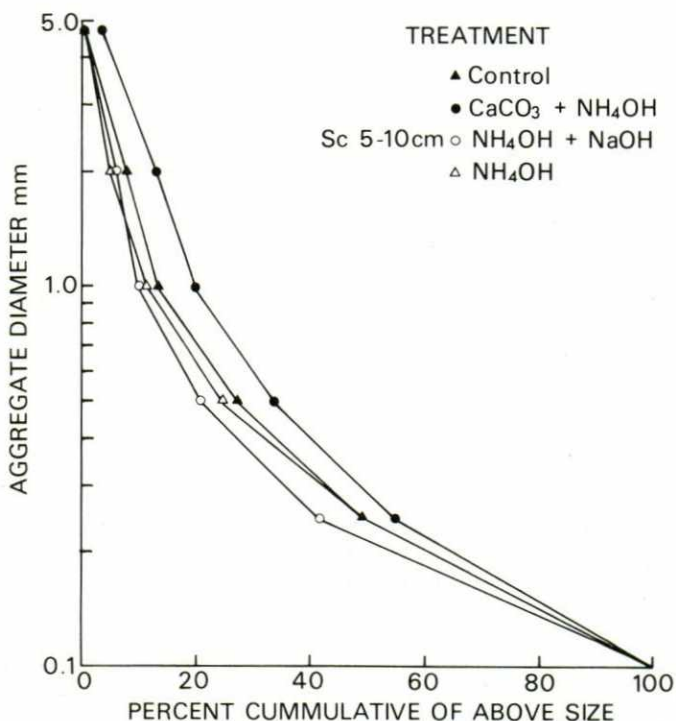Fig. 4 — *Effect of the various treatments on the aggregate size analysis for the 0-5 cm depth of the Sc soils.*

Fig. 5 — *Effect of the various treatments on the aggregate size analysis for the 5-10 cm depth of the Sc soils.*

the NH$_4$OH treatment, increased 12.9% due to CaCO$_3$ + NH$_4$OH treatment, and decreased 15.6% due to NH$_4$OH + NaOH.

The decrease in the percent cummulative of above size due to NH$_4$OH is thought to be due to the dispersion effect of NH$_4$OH and/or the dehydration effect of NH$_4^+$ on clay. One may question then why the decrease is more pronounced in the SiL than the SiC soils. The answer for that probably has to do with the type of clay. The SiL soils have high contents of vermiculite (32 to 53%), and illite (25 to 32% in the clay fraction) (5).

The only recorded increase in the percent cummulative of above size due to treatment with NH$_4$OH + NaOH has occurred at the 0 to 5 cm depth of SiC soil as a result of the high dispersion effect which caused a sealing of the soil surface so it became as one clod, especially when it dried out, it was very hard to crush, and so the aggregates were big and did not break completely after the sieving. Oven drying the soil seemed to play a part in that case as well as in the other cases. Oven drying the soil seemed to cause an over estimate in the percent cummulative of above size in all the cases, and the NH$_4$OH + NaOH treatment in particular due to clodding. Accordingly I suggest that aggregate analysis should be done on the samples at various moisture contents if a better picture on the nature of the size of aggreagates is sought, the moisture contents can vary between air drying and field capacity.

The mechanical action of the applied water seemed to have a large effect on the dispersion and lodgement of fine particles. These observations are in agreement with the findings of Oster and schroer (10).

Dry bulk density (DBD)
The data in Table 2 show that the DBD values decreased about 3.65% for the 0 to 5 cm depth, and 6.0% for the 5 to 10 cm depth of the SiL soil, however, there was no change in DBD of the 0 to 5 cm depth, and a 3.4% decrease in the 5 to 10 cm depth. Neither the NH$_4$OH treatment nor the other treatments used indicated any pronounced effect on DBD. The data also indicated that the correlation betwenn DBD and soil strength is very low as compared to moisture content. Thus soil strength was more influenced by soil moisture and clay content regardless of the DBD.

Chemical analysis
The data presented in Table 3 are mean values of three replicates. Treatment with NH$_4$OH slightly increased the availability of P in the SiL soils, had little effect on increasing exchangeable K, and a decrease in the exhangeable Ca and Mg. The magnitude of the effects of NH$_3$ on these ions is probably of little practical importance particularly in the SiL soils. The slight increase in the availabilty of P might be explained by the high concentration of NH$_4$OH which serves to react with the calcium phosphate of the soil converting it to ammonium phosphate, which is more soluble in water (12).

The decrease in exchangeable Ca and Mg is due to the precipitation of Ca and Mg as carbonates or other insoluble compounds. The slight decrease in the pH of the SiL soils due to NH$_4$OH treatment could also be explained due to the above phenomena, and/or due to the high NH$_3$ concentration.

The data presented in Table 3 also indicate an increase in the NH$_4$ − N content of the soils due to treatment with NH$_4$OH. The soil NH$_4$ − N in most of the cases was higher in the 0 to 5 cm depth than the 5 to 10 cm due to the adsorption of NH$_4$ ion by soil especially in the NH$_4$OH, and CaCO$_3$ + NH$_4$OH treatment, the NH$_4$ − N content of the soil treated with NH$_4$OH + NaOH was lower than the above two treatments because of the competition of Na$^+$ with NH$_4^+$ on the adsorption site, which is strongly supported by the high exchangeable Na content of these soils, particularly at the 0 to 5 cm depth.

The concentration of the NH$_3$ − N (Table 3) was also increased by all the treatments as compared with the NH$_4$OH, NH$_4$OH + NaOH, and CaCO$_3$ + NH$_4$OH, in both soils for both depths, with the exception of the 5 to 10 cm depth in SiC soils of the CaCO$_3$ + NH$_4$OH treatment where it is found to be higher than the NH$_4$OH + NaOH treatment.

Table 3 — Effect of the various treatment on the chemical analysys oo soils.

| Soil texture | Soil depth | Treatment | pH | EC | Exchangeable | | | | $CaCO_3$ | Available | | |
| | | | | | K | Mg | Ca | Na | | P | $NH_4 - N$ | $NO_3 -$ |
	cm			mmhos/cm	ppm				%	ppm		
SiC	0-5	Control	7.1	0.48	273	704	4000	160	2.2	100	33	340
	0-5	Control	6.9	0.45	275	720	3900	147	1.3	100	34	192
SiL	0-5	Control	8.0	0.15	100	268	6000	85	3.9	14	38	25
	5-10	Control	8.0	0.14	108	260	6200	91	3.4	15	38	48
SiC	0-5	NH_4OH	7.5	1.13	292	576	3733	145	0.7	100	435	640
	5-10	NH_4OH	6.9	0.82	294	693	3900	151	0.6	100	151	467
SiL	0-5	NH_4OH	7.7	1.43	117	268	6200	96	4.7	18	222	820
	5-10	NH_4OH	7.9	0.70	108	260	5900	87	3.9	16	74	468
SiC	0-5	$CaCO_3$	7.9	0.61	300	488	6300	157	4.3	100	344	195
	5-10	NH_4^+OH	7.6	1.03	280	616	7400	172	2.6	100	74	448
SiL	0-5	$CaCO_3$	7.8	0.77	116	198	7200	69	7.9	18	239	235
	5-10	NH_4^+OH	8.1	0.72	112	247	7600	71	7.5	16	50	297
SiC	0-5	NH_4OH	8.7	1.08	3.8	236	3767	6000	1.8	100	118	305
	5-10	Na^+OH	7.8	1.00	300	520	3800	3200	1.2	100	120	327
SiL	0-5	NH_4OH	8.9	1.93	126	129	4400	6100	6.0	21	60	620
	5-10	Na^+OH	8.2	1.05	120	185	5533	3333	4.8	18	47	475
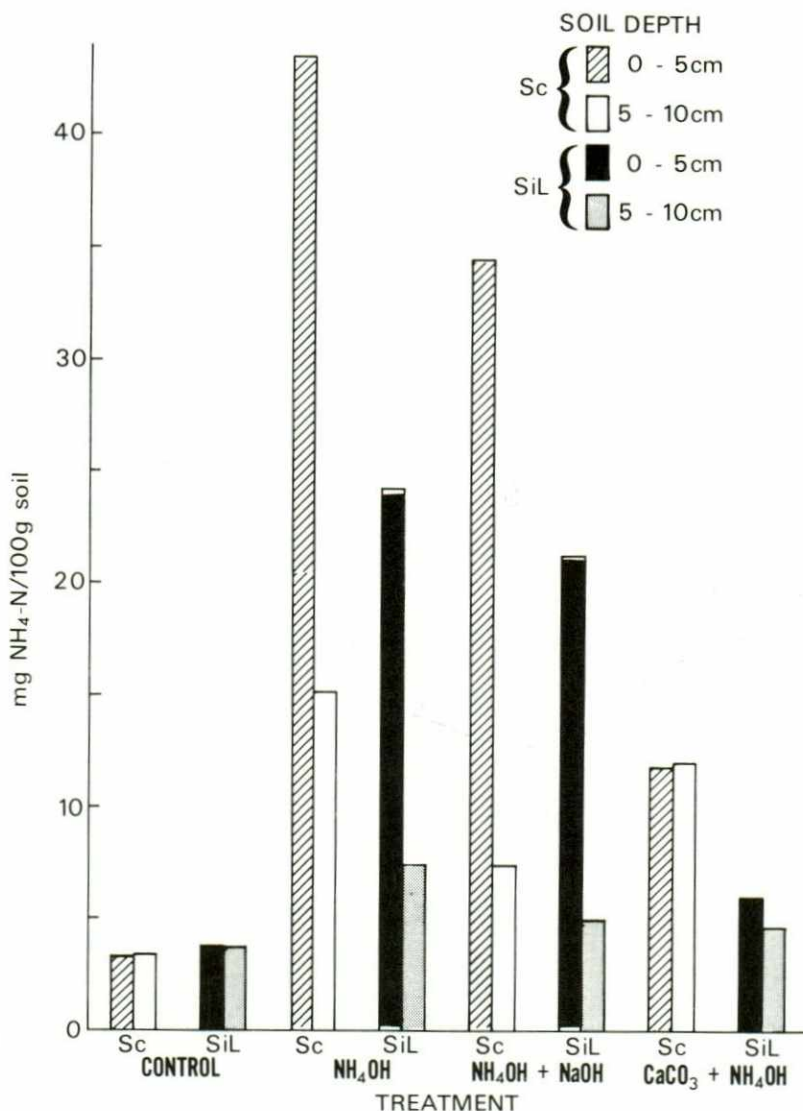
Fig. 6 — *Effect of the various treatments on soil* $NH_4 - N$.

The chemical analysis data showed that a higher concentration of exchangeable Ca and Mg occurred at the 5 to 10 cm depth in most cases, as a result of the down movement of Ca^{+2} and Mg^{+2}, NH_4^+ being adsorbed on the soil surface, and along with the Na^+ occupy the exchange sites. Accumulation also caused $CaCO_3$ precipitation on the 0 to 5 cm depth which was in all cases higher than the 5 to 10 cm depth.

The data presented in Table 3 indicated that the retentive capacity of a soil for NH_3 increases as the texture becomes heavier (McDowell and Smith, 1958). The data also indicated that $CaCO_3$ addition to the soils (or soils containing high $CaCO_3$) have an effect on the rate of nitrification, which is demonstrated by the change in the percentage of the N in the NO_3 form. Figure 6 shows that treating the soil with NH_4OH increased the $NH_4 - N$ content of the soil, the increase was higher in the SiC than the SiL obviously because of the higher exchangeable capacity of SiC soils compared with the SiL, the in-

crease was also higher in 0 to 5 cm depth than the 5 to 10 cm depth in both soils because of the slow mobility of NH_4^+ ions and the wash-down of part of the other cations such as Ca^{+2}, Mg^{+2}, Na^+ and K^+ which leaves more space for NH_4^+ adsorption on the soil surface. The increase of $NH_4 - N$ on the SiC surface of $CaCO_3$ treated soil, however, was less than NH_4OH treatment because of the competition of Ca^{+2} ions on the exchange sites, and as a result of the high exchange capacity and more space exposed for NH_4^+ on the SiC soil surfaces, the $NH_4 - N$ was higher on the SiC than the SiL soils in both depths. The concentration of $NH_4 - N$ in the NH_4OH + NaOH treatment was higher than the control but less than the other two treatments, because Na^+ was occpying a great deal of the exchange site and gave no chance to the NH_4^+ ion to be adsorbed.

The results have shown that continuous application of NH_3 fertilizers to soils might cause an accumulation of NH_4^+ being adsorbed on the soil surface or may be fixed by the lattice structure of clay soils causing dispersion of clay, break down of the soil aggregates, and an increase in soil strength which may lead to bad structurre and poor growth. A more detailed study of the mineralogy aspect is needed since the clay fraction is recognized as being the most active in the fixation process of NH_4^+.

In spite of some of the chemical changes that occurred due to NH_4OH application, the changes are considered slight and of little significance and the NH_3 effect is mostly of a physical manner.

ACKNOWLEDGEMENT

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