

AMMONIUM AND AMMONIA FIXATION
IN SOME OREGON SOILS

by

RAY AUGUST CATTANI

A THESIS

submitted to

OREGON STATE COLLEGE

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1960

APPROVED:

Redacted for privacy

Assistant Professor of Soils

In Charge of Major

Redacted for privacy

Head of Department of Soils

Redacted for privacy

Chairman of School Graduate Committee

Redacted for privacy

Dean of Graduate School

Date thesis is presented April 22, 1960

Typed by Irene Cattani

ACKNOWLEDGMENTS

The author wishes to thank Dr. J. Lowell Young for his suggestions and assistance during the course of this study. Also appreciated were the helpful suggestions of Dr. M. E. Harward and Dr. E. G. Knox.

Appreciation is extended to Phillips Petroleum Company, the Agriculture Research Service, and Oregon State College for their support of the project.

Finally the author wishes to acknowledge the moral support and typing assistance of his wife as well as the lab assistance of Brian L. McNeal.

TABLE OF CONTENTS

	page
INTRODUCTION	1
Terminology	2
Objectives	4
LITERATURE REVIEW	6
Mechanism of NH_4 Fixation	6
Some Factors to Consider in NH_4 Fixation Determinations	8
Methods to Determine Fixed NH_4	9
Rate of NH_4 Fixation	15
Effect of Concentration of NH_4 on NH_4 Fixation	16
Effect of pH and Temperature on NH_4 Fixation	16
Effect of the Source of NH_4 on NH_4 Fixing Capacity	17
NH_3 Fixing Capacity	18
EXPERIMENTAL METHOD	22
Soils Studied	22
Laboratory Procedure	24
Native Fixed NH_4	24
Total NH_4 Fixing Capacity Using $\text{N NH}_4\text{OH}$	25
NH_4 Fixing Capacity	26
Ammoniating Soils with Anhydrous NH_3	26
NH_3 Retention Capacity	27
NH_3 Fixed by Mineral and Organic Fractions	27
NH_3 Fixed by the Mineral Fraction	28
NH_3 Fixed by the Organic Fraction	28
RESULTS AND DISCUSSION	30
Fixation of Added NH_4 , Added NH_3 , and Native NH_4 by the Mineral Fraction	31
Comparison of NH_4 and NH_3 Fixing Capacities of the Mineral Fraction	39
Influence of Content and Type of Clay on NH_4 Fixation	40
NH_3 Retention Capacity	47
NH_3 Fixing Capacity of the Organic Fraction	47
SUMMARY	59
BIBLIOGRAPHY	60
APPENDIX	64
(Profile Description of Soils Used)	

LIST OF TABLES

		page
Table 1.	Native Fixed NH_4 , NH_4 and NH_3 Fixing Capacities Attributed to the Mineral Fraction of Ten Oregon Soils .	32
Table 2.	Native Fixed NH_4 and NH_4 Fixing Capacity of some Standard Minerals	42
Table 3.	Fixing Capacities Expressed per Unit Clay and per Unit Clay and Silt	44
Table 4.	The NH_3 Retention Capacity and the NH_3 Fixing Capacity Attributed to Mineral and Organic Fractions of Ten Oregon Soils	48
Table 5.	NH_3 Fixing Capacity Attributed to the Organic Fraction Expressed per Unit Soil and per Unit Organic Matter	54
Table 6.	(Appendix) Lab Characterization of Soils Used	75
Table 7.	(Appendix) Relationships of Soils Used with Respect to Parent Material and Annual Rainfall	78

LIST OF FIGURES

	page
Figure 1. Native NH_4 , NH_4 , and NH_3 , m Fixing Capacities of Ten Oregon Soils	34
Figure 2. NH_3 , cm Fixing Capacity of Ten Oregon Soils	50

AMMONIUM AND AMMONIA FIXATION IN SOME OREGON SOILS

INTRODUCTION

It has long been established that part of the NH_4^* in some soils is not readily available to plants. It was first demonstrated by McBeth (25), in 1917, that NH_4 added to the soil could not be completely recovered by the ordinary methods of determining the NH_4 content of soils. He further noted that "fixed NH_4 " was not available to nitrifying bacteria. It has since been claimed that "fixed NH_4 ", or the unrecovered portion of added NH_4 , is not readily available to either microorganisms or plants (4, 5, 6, 7, 8, 12, 16, 19, and 28, p. 421).

In an attempt to find an explanation for this phenomena of " NH_4 fixation", it was first suggested that the clay fraction of the soil was responsible for "fixing" the unrecovered portion of added NH_4 (15). It was demonstrated that this "fixed NH_4 " could be liberated by treating the soil with hydrofluoric acid which would presumably dissolve the clay and release any NH_4 that had been trapped, or "fixed", by the clay.

It has since been noticed that all clays do not possess the same capacity to "fix" added amounts of NH_4 . Recent workers (5, 6, 11, 29, 34) indicate that vermiculite, illite, and montmorillonite each have a definite capacity to "fix" added NH_4 under a certain set of conditions. Many other types of clay show no capacity whatever to "fix" added NH_4 .

It has more recently been suggested that clays are not the only part of the mineral fraction of the soil that can "fix" added amounts of NH_4 .

* The ionic charge for the chemical symbols used in the text is not shown unless the charge is considered essential to the meaning.

Evidence seems to indicate that silt is also able to "fix" added NH_4 (23, p. 408 and 28, p. 57-70).

It has been observed that in addition to "fixing" added NH_4 , some minerals also contain native "fixed NH_4 " (19; 23, p. 57; 28, p. 408; 36; 37) i.e., the NH_4 that is formed as a result of the gradual breakdown of organic matter. Evidence shows that horizons of some soils hold a considerable percentage of their total N as native or naturally occurring "fixed NH_4 " (19, 35, 37).

It has also become apparent that soil organic materials, in addition to inorganic minerals, are capable of "fixing" large quantities of N from applied anhydrous NH_3 . Sohn and Peech (33), in 1958, reported that acid soils high in organic matter content "fixed" large amounts of NH_3 . As much as 50% of the NH_3 "fixed" in some New York surface soils was attributed to some reaction of NH_3 with organic matter.

Much progress has been made in establishing the existence of " NH_4 fixing capacities" and in understanding some of the basic principles related to " NH_4 fixation". Nevertheless, universally acceptable definitions for the various terms related to " NH_4 fixation" have yet to be developed. Before stating the specific objectives of this study, it becomes necessary to define the various terms related to " NH_4 fixation".

Terminology

The various terms related to " NH_4 fixation" which are used in this thesis are defined below. The values for the various terms are dependent on certain specific conditions, e.g., moisture content, pH, concentration of NH_4 applied, etc. (see literature review). The specific conditions employed in each situation need to be made clear in order for

the value of any term to be meaningful.

A. Fixed NH_4 is generally defined as that NH_4 not extractable from the soil by either 0.5 N or 1.0 N KCl. The definition of fixed NH_4 as applied in this thesis will be that NH_4 that is not extractable from the soil by 0.5 N KCl. The term is applied to the NH_4 fixed by the mineral fraction of the soil and does not include NH_4 that becomes unavailable as a result of reaction with organic matter. Fixed NH_4 is a general term that is applied to any NH_4 that is thought to be entrapped between two adjacent mineral plates, presumably in the voids formed by the hexagonal oxygen rings in the oxygen layer of some silicate minerals. Entrapment of the NH_4 probably results from a decrease in the basal spacing of the mineral to the extent that the distance between the adjacent mineral plates is not sufficient to allow exchange reactions to occur. Replacement requires prior expansion of the mineral (23, p. 2).

B. Native fixed NH_4 is the naturally occurring, or indigenous, fixed NH_4 that is present in the mineral fraction of a soil sample, i.e., a sample that has not been treated with a source of NH_4 .

C. NH_4 fixing capacity conventionally is the amount of added NH_4 that the mineral fraction of the soil is capable of fixing against extraction by 0.5 N KCl. While this is actually a potential fixing capacity, in that it does not include the native fixed NH_4 (B), the term will be used as stated above to conform with popular usage.

D. Total NH_4 fixing capacity is the total quantity of fixed NH_4 that the mineral fraction of soils will retain against extraction with 0.5 N KCl. This includes the native fixed NH_4 (B), plus the amount of added fixed NH_4 (C) that the mineral fraction of the soil is capable of fixing.

E. NH₃ retention capacity is the difference between the total N content of an ammoniated soil, (subsequently degassed - see methods) and that of a corresponding control soil. It represents the total amount of added NH₃ retained by the mineral and organic fractions of the soil. It includes fixed plus exchangeable forms of NH₃.

F. NH₃ fixing capacity is the amount of added anhydrous NH₃ that is fixed by the mineral and organic fraction of the soil against extraction with 0.5 N KCl. This differs from the NH₃ retention capacity (E) in that it does not include any exchangeable forms of NH₃. The main difference between the NH₃ fixing capacity and the NH₄ fixing capacity (C), other than the source of N applied, is that the NH₃ fixing capacity includes the added NH₃ that is fixed by both the mineral and organic fractions of the soil, whereas the NH₄ fixing capacity (C) includes the amount of added NH₄ fixed by only the mineral fraction of the soil.

G. NH₃, m fixing capacity is the amount of added anhydrous NH₃ that is fixed solely by the mineral fraction of the soil, presumably as NH₄, against extraction with 0.5 N KCl. This value does not include any native fixed NH₄ present in the mineral fraction of the soil.

H. NH₃, om fixing capacity is the amount of added anhydrous NH₃ that is fixed solely by the organic fraction of the soil against extraction with 0.5 N KCl.

Objectives

While work has been reported in other parts of the country on NH₄ fixation, no known work along this line has been done in Oregon. There appeared a need to know the extent and significance of the amount of native fixed NH₄, the NH₃ and NH₄ fixing capacities, and the NH₃

retention capacities of some agriculturally important Oregon soils. At the same time a need for more basic information about NH_4 and NH_3 reactions in soils was evident. The purpose of this investigation was to obtain information in filling the above needs.

The specific objectives were:

1. To determine the native fixed NH_4 in some Oregon soils.
2. To determine the NH_4 fixing capacity and the NH_3 fixing capacity of these Oregon soils.
3. To compare the relative contribution of organic and mineral fractions of the soil to fixation of N from applied anhydrous NH_3 .
4. To determine the native fixed NH_4 and the NH_4 fixing capacity of some standard clays.

LITERATURE REVIEW

Mechanism of NH_4 Fixation

McBeth (25), in 1917, did not have enough information to suggest a possible mechanism for NH_4 fixation. He did observe that Al, Fe, and K salts added to soils prior to the addition of NH_4 , decidedly reduced the NH_4 fixing capacity of the two soils that he used.

In 1936, Chaminade and Drouneau (16) expressed the idea that one mechanism was probably responsible for Mg, K, and NH_4 fixation. They suggested that Mg, K, and NH_4 were rendered unavailable due to the inclusion of the elements in the crystal nuclei of the soil colloids. They further pointed out that energetic grinding of the soil restored these cations to their exchangeable state due to an alteration of the crystal nuclei of the colloids.

Page and Bayer (29) suggested that K and NH_4 were most likely fixed by the same mechanism. They pointed out that NH_4 and K have approximately the same ionic radius, and that it was this ionic radius that was the important factor contributing to their being fixed. They reasoned that since NH_4 was fixed almost as strongly as K, it was more logical to conclude that ionic size, not chemical combination as some workers had suggested, was responsible for the phenomenon.

Stanford and Pierre (34), in 1946, decided that the logical way to prove that an identical mechanism was operative in fixation of K and NH_4 was to establish that fixation of either of these cations resulted in an equivalent reduction in fixation of the other cation. They demonstrated that this definite relationship existed between K and NH_4 fixation in the soils studied, and concluded that the same

mechanism was involved.

The evidence presented by all of these workers seems to indicate that the mechanism of fixation is the same for the two cations. Much work has been done in studying the mechanism responsible for K fixation. This work can be used in understanding the mechanism responsible for NH_4 fixation.

Page and Baver (29) developed the first working hypothesis to explain the mechanism of K fixation. They succeeded in explaining what seemed to have been rather divergent opinions about K fixation by postulating that the K ions were literally trapped by contraction of the expanding lattice of montmorillonite type clays. They explained that the exposed surface between the silica sheets of the expanding lattice type mineral was thought to consist of a layer of oxygen ions, arranged hexagonally. The empty spaces in the center of the hexagon should be exactly the diameter of an oxygen ion, which they reported to be 2.8 Å. They said that the diameter of a K ion was 2.66 Å., so that it would fit snugly in this space. They further explained that as a K system was dehydrated the sheets would contract and the K would lose its hull of oriented water molecules, thus becoming effectively smaller. This would gradually occur until the contracting silica sheet forced the ion into the free space in the exposed surface. Once in this space, the K ion is very close to the negative electric charges originating within the crystal. This, coupled with the snugness of fit, would prevent the sheets from re-expanding, keeping the K fixed. They concluded that the size of the ion and type of colloid were the two important contributing factors in the mechanism responsible for K fixation.

Wear and White (38) further postulated that the important factors which determine whether or not a cation would become fixed are the source or the charge on the clay (whether isomorphous substitution occurs in the octahedral or tetrahedral layer) and the energy with which the water of hydration is held on the cation. They further pointed out that Wyoming bentonite would not fix NH_4 although it would fix K. They attributed this to the fact that water of hydration was still accompanying the NH_4 ions, whereas it was not accompanying the K ions under the same conditions. This seems to be in contradiction with the workers (16, 29, and 34) who suggested a similarity between K and NH_4 fixation. At any rate, the literature still seems to contain some apparently divergent views on the mechanism of K and NH_4 fixation. Although the mechanism for fixation does seem to be associated with such things as the type of colloid, the size of the ion, and the energy with which the water of hydration is held on the cation, it seems apparent that a more inclusive hypothesis is necessary to co-ordinate these ideas into a single theory.

Some Factors To Consider In NH_4 Fixation Determinations

Many factors need to be considered when reporting values related to NH_4 and NH_3 fixation. As was mentioned in the section on terminology, the NH_4 and NH_3 fixation values must be accompanied by a statement referring to any specific conditions that would affect the fixation values. It is therefore important to examine some of the factors that might affect the fixation values.

Methods to Determine Fixed NH_4

One of the most important factors that might influence a reported NH_4 fixation value is the method used to obtain the value.

KCl Extraction Method. Various methods have been used to determine the NH_4 fixing capacity. The most common method employed in recent years is that method referred to as the KCl extraction method, as introduced by Allison, Doetsch, and Roller (4) in 1951. The basic premise of this method is that fixed NH_4 will not be removed from the soil by leaching N KCl. There are various modifications to the procedure but generally the method is followed as outlined below:

- a) Minerals are ground in a mortar to pass a 40 mesh sieve.
- b) NH_4 is fixed by leaching 5 to 20 gm. samples in glass extraction tubes with 100 ml. of N NH_4Cl , added in portions.
- c) If NH_4 fixation under moist conditions is desired, the soluble and readily exchangeable NH_4 is removed by extracting with N KCl until the leachate shows a negative test for NH_4 . If NH_4 fixation after heating is desired, the soluble NH_4 is first removed by alcohol, leaving the exchange surface saturated with NH_4 . After heating, the exchangeable NH_4 is removed by extracting with N KCl until the leachate shows a negative test for NH_4 .
- d) A blank (sample not treated with NH_4Cl) is extracted with the same volume of N KCl that was used on the NH_4Cl treated samples.
- e) Total N is determined by the Kjeldahl method on the NH_4Cl treated sample extracted with the N KCl and on the blank extracted with N KCl.

The difference between the total N content of the NH_4Cl treated

sample extracted with \underline{N} KCl and the blank extracted with \underline{N} KCl represents the NH_4 fixing capacity.

This method has limitations in that native fixed NH_4 , and subsequently the total NH_4 fixing capacity, cannot be determined. Another limitation encountered showed that soils high in organic matter gave erroneous results (23, p. 10; 33). Some organic matter apparently was made soluble by the NH_4Cl treatment. Leggett reasoned that this differential dispersion of organic matter between the NH_4Cl treated sample and the untreated sample (blank) resulted in more organic matter being leached out of the NH_4Cl treated sample, making the total N value of that sample less. This would make the difference between the NH_4Cl treated sample and the blank less, giving a low result for the NH_4 fixing capacity.

Barshad's Double Distillation Procedure. Barshad (9, 11) introduced the double distillation procedure to determine the NH_4 fixing capacity. In theory it should be useful for determining the total NH_4 fixing capacity and native fixed NH_4 .

The basic premise of this method is that fixed NH_4 will be released by distillation in NaOH but will not be released by distillation in KOH. It assumes that both NaOH and KOH will release the same proportion of organic matter.

Generally the method is followed as outlined below:

- a) Large samples of soils are saturated with NH_4OAc .
- b) One aliquot of the NH_4 saturated soil is distilled using NaOH.
- c) One aliquot of the NH_4 saturated soil is distilled with KOH.
- d) The total NH_4 fixing capacity is calculated as the difference

in NH_4 replaced from the two NH_4 saturated soils when distilled with NaOH and KOH , respectively.

e) The native fixed NH_4 could be calculated as the difference in NH_4 replaced from two untreated soils when distilled with NaOH and KOH , respectively.

f) The NH_4 fixing capacity would be the difference between the total NH_4 fixing capacity (d) and the amount of native fixed NH_4 (e).

Barshad suggested that this was the simplest way to determine the NH_4 fixing capacity of a soil. However, Allison and Roller (2) in comparing the KCl extraction method with the double distillation procedure of Barshad, reported that on soils heated to effect NH_4 fixation, Barshad's method gave results that were too low as compared to the KCl extraction method. Allison and Roller suggested that the NaOH distillation failed to remove all the NH_4 . Hanway and Scott (19) reasoned that the NaOH didn't release all the NH_4 because of the blocking effect of K in the sample. Nommik (28, p. 410) suggested that the interfering effect of K could be reduced by increasing the concentration of Na during NaOH distillation. On unheated soils Allison and Roller observed that the distillation procedure gave results that were too high as compared to the KCl extraction procedure. They blamed this on fixation of readily exchangeable NH_4 during distillation. Actually, the high results obtained by the double distillation procedure are partially because the two methods yield two different values. Barshad's procedure determines the total NH_4 fixing capacity, whereas the KCl extraction procedure determines only the conventional NH_4 fixing capacity.

It should be noted that Allison and Roller used a somewhat modified double distillation procedure, so their comparison may not be valid.

They used a rapid distillation procedure. It is possible under a more rapid distillation process that there would be a differential release of NH_3 from organic matter between the samples distilled with KOH and NaOH respectively. However, even under slow distillation it is a rather dubious assumption that the amount of NH_3 released from organic matter on distillation of soil with KOH is the same as that amount of NH_3 released on distillation with NaOH.

The double distillation procedure for determining the total NH_4 fixing capacity may be fairly satisfactory for some soils under some conditions. Much more work needs to be done to prove its quantitative value. Comparing this procedure with the KCl extracting procedure is probably not the best approach since the KCl extraction procedure has its own limitations.

Rodrigues' HF Method. Rodrigues (31) employed HF acid to measure the total NH_4 fixing capacity of soil. He showed that a considerable amount of the N in some tropical soils was resistant to the procedures that were usually used to extract organic N compounds. He demonstrated that this same N was immediately released as NH_4 by treatment of the soils with hydrofluoric acid. This HF treatment had little effect on organic matter but dissolved the clay crystal. He concluded that this HF liberated NH_4 resulted from fixed NH_4 in the clay minerals and not from the organic fraction of the soil.

The method is generally followed as outlined below:

a) One gm. of soil is mixed with 1 ml. of 50% H_2SO_4 and 4 ml. of HF in a platinum dish.

b) The sample is allowed to stand one hour and then the supernatant liquid is decanted and the residue is washed with water in a

centrifuge.

c) HF is driven off in the presence of H_2SO_4 .

d) NH_3 is determined in an aliquot of the extract by the Markham micro-distillation method.

Hanway and Scott (19) compared the HF treatment method used by Rodrigues with the double distillation procedure introduced by Barshad. They found that the methods gave similar results for subsoils but very different results with surface soils. Like Allison and Roller (2), they suggested that the different results from the two methods, in the case of surface soils, were due to the inability of the NaOH in the double distillation procedure to release all of the fixed NH_4 . They pointed out that small amounts of K are able to interfere with the replacement of fixed NH_4 in soils by a NaOH distillation. Although comparing the results of one method with the results of another method doesn't necessarily prove the validity of either method, particularly if negative results are obtained, it is interesting to note that comparable results were obtained for the subsurface soils used. It does seem logical to assume that if the methods are measuring the same thing (total NH_4 fixing capacity) that the results should be the same for both methods. Although this does not conclusively prove the validity of either method, it is an argument in favor of both methods - at least under the conditions that they are comparable i.e., for subsoils.

Bremner (13) suggests that the Rodrigues method is open to criticism on the grounds that the techniques used to release fixed NH_4 from the clay colloids may also be releasing N from the organic fraction of the soil. He further points out that it has not been shown that the

HF-H₂SO₄ treatment brings about a quantitative release of fixed NH₄ from clay minerals.

Stevenson's HF Method. Dhariwal and Stevenson (17) improved on the Rodrigues method used to determine fixed NH₄. They used more dilute concentrations in their acid mixture and began by first destroying the nitrogenous part of the organic fraction with hot KOH. This would eliminate the possibility of the acid mixture dissolving any N from the organic fraction of the soil.

The basic premises of the Stevenson procedure are: interference through deamination of nitrogenous organic compounds is eliminated by treating the soil with hot KOH before the removal of fixed NH₄ with an HF mixture; no NH₄ is fixed by the soil during the KOH treatment; and an acid mixture consisting of 5.0 N HF, 0.75 N HCl, and 0.6 N H₂SO₄ quantitatively releases fixed NH₄ from the soil.

The general outline of the procedure is given below:

- a) A finely ground 2 gm. sample of soil is weighed into a 150 ml. beaker; 50 ml. of N KOH is added; and the sample is placed in an autoclave for 8 hours at 20 lbs. pressure and at a temperature of 120°C.
- b) After cooling, the sample is transferred to a 50 ml. polyethylene centrifuge tube and the residue is recovered by centrifugation. The residue is washed 3 times with 0.5 N KCl.
- c) Fifteen ml. of an acid mixture consisting of 5 N HF, 0.75 N HCl, and 0.6 N H₂SO₄ are added to the residue. This HF mixture is allowed to remain in contact with the soil for about 12 hours, with occasional stirring.
- d) The sample is then transferred to a Parnos-Wagner distillation unit for NH₄ estimation.

e) Native fixed NH_4 is determined on an untreated (no source of NH_4 added) sample. Total NH_4 fixing capacity is determined by the same method on a sample previously treated with a source of NH_4 to effect fixation. The conventional NH_4 fixing capacity can be calculated as the difference between the above two values.

The procedure is slightly modified for use with highly calcareous soils. The method is an improvement over the method suggested by Rodrigues in that the possibility of the acid mixture reacting with some nitrogenous organic compounds is eliminated. The value of the method is further established in that Dharival and Stevenson (17) clearly demonstrate that the method quantitatively releases fixed NH_4 from three standard clays.

It is obvious that considerable variations could be obtained for NH_4 fixing capacities of soils depending on the method used to determine the fixing capacity. Some other factors that need to be considered when reporting NH_4 fixation values will be discussed below.

Rate of NH_4 Fixation

McBeth (25) demonstrated that most fixation occurred within the first few minutes after the addition of the NH_4 source. He further showed that fixation continued with time as long as the NH_4 source was allowed to remain in contact with the soil.

Nomnik (28, p. 399) has shown that the longer an NH_4 source is allowed to remain in contact with a soil before leaching it with KCl, the more NH_4 can be fixed by that soil. Leggett (23, p. 15) showed that a greater NH_4 fixation resulted from a contact time of 24 hours than from 1 hour. When the time of contact was extended to seven days

the NH_4 fixation was not increased appreciably from NH_4 fixed after 24 hours.

Effect of Concentration of NH_4 on NH_4 Fixation

McBeth (25) demonstrated that the NH_4 fixing capacity varied greatly with different concentrations of the same NH_4 source. Nommik (28, p. 399) showed that as the concentration of the sources of NH_4 was increased, the amount of NH_4 capable of being fixed was also increased. On the other hand, the per cent of the added NH_4 that became fixed decreased as the concentration of the added NH_4 was increased. This would indicate that an equilibrium is established between the concentration of added NH_4 and the amount of NH_4 that a soil will fix. Leggett (23, p. 15) observed that the concentration of the added NH_4 solution would determine the NH_4 fixing capacity of a soil provided that sufficient time is allowed for equilibrium to be attained.

Effect of pH and Temperature on NH_4 Fixation

Nommik (28, p. 400) noted that with a reduction in pH there was a corresponding reduction in the NH_4 fixation capacity of a soil. He did not postulate whether this decrease in fixation was a result of the increased H concentration or an increase in Al concentration. Scott et al. (32) stated that any fixation value determined would be a function of the pH of the KCl extracting solution.

McBeth (25) noted that NH_4 fixation was greater at 100°C. than at 50°C. Allison et al. (4) showed that heating some soils to 100°C. increased the NH_4 fixing capacity of these soils from 50% to 100% of their original values under air dry conditions. Nommik (28, p. 399) also

presented evidence to show that fixation was increased with small increases in temperatures. Nommik did not present enough evidence to decide whether the effect of temperature was due to the rate with which the equilibrium is reached, or whether the fixation capacity itself was influenced by the temperature.

Effect of the Source of NH_4 on NH_4 Fixing Capacity

McBeth (25) suggested that anions apparently had little or no effect on the NH_4 fixing capacity of soil. He observed that the amount of NH_4 fixed was practically the same, whether added as a SO_4 , Cl, or NO_3 source. However, Leggett (23, p. 17) presented evidence that the various anions do have an effect on the NH_4 fixing capacity of a soil. He showed NH_4 fixation to be greater when $(\text{NH}_4)_2\text{HPO}_4$ was used as the source of NH_4 than when other sources were used. Leggett's observations supported McBeth's findings that there is no significant difference in the NH_4 fixing capacity arising from a SO_4 or Cl source. (Leggett did not use a NO_3 source.) However, he demonstrated that there is quite a difference in fixing capacities arising from other anions such as HPO_4 , OAc, and citrate. This would suggest that McBeth was not correct in stating that anions have little or no effect on the NH_4 fixing capacity. However, he was probably correct in observing that there is no difference in the fixing capacity when SO_4 , Cl, or NO_3 are used as the source.

NH₃ Fixing Capacity

It has been shown that clay minerals have the capacity to fix NH₄. More recently it has been suggested that organic matter may be responsible for fixing large quantities of NH₃ when applied as anhydrous NH₃.

Mattson and Koutler-Andersson (24) demonstrated that lignin could fix an appreciable quantity of NH₃ in a chemically stable form.

Sohn and Peech (33) have suggested that the fixation of NH₃ from anhydrous NH₃ by soils might be expected to exceed the fixation of NH₄ from neutral NH₄ salts. Not only would NH₃ be fixed as NH₄ by the clay minerals, but NH₃ would react directly with the soil organic matter to form organic nitrogen compounds that would be unavailable to plants. They presented evidence to indicate that at least 50% of the NH₃ fixed by some New York mineral surface soils was due to some reaction of NH₃ with the soil organic matter.

Sohn and Peech modified the KCl extraction method to determine the NH₃ fixing capacity of soils. They pointed out that one of the main limitations of the KCl extraction method was the differential dispersion of organic matter between the NH₃ treated sample and the untreated sample (blank) when they were leached with KCl. To eliminate this source of error they determined total N on an ammoniated sample that had been aerated in a shallow pan for one week and total N on a blank, neither of which were previously leached with KCl. They called the difference between these two values the NH₃ retention capacity. They further modified the procedure by substituting NaCl for KCl because they felt Na to be more effective than K in replacing exchangeable NH₄. They recognized that use of NaCl would free some of the

fixed NH_4 , but they indicated that they felt this to be of minor consequence. They then determined the exchangeable forms of NH_3 for both the ammoniated and blank samples by leaching with NaCl and determining the NH_3 in the extract. (The NaCl extract would actually include not only exchangeable NH_4 but also physically adsorbed NH_3 held by H bonding and NH_3 held by weakly acidic groups.) The difference between the NH_3 in the extract from the ammoniated sample and the NH_3 in the extract from the blank was subtracted from the NH_3 retention capacity (total N of ammoniated soil minus the total N of blank). This value (Δ total N minus $\Delta\text{NH}_4\text{-N}$) would be equivalent to the NH_3 fixing capacity. (The difference between $\text{NO}_3\text{-N}$ of the ammoniated sample and the $\text{NO}_3\text{-N}$ of the blank was found to be very small and so no correction for nitrification was made.)

The above method allowed Sohn and Peech to determine the NH_3 fixing capacity of a soil without destroying the organic matter. Their next step involved destruction of the organic fraction of the soil with H_2O_2 and determination of the NH_3, m fixing capacity, again using the modified KCl extraction method explained above. The difference between the NH_3 fixing capacity of the soil (which includes the organic matter) and the NH_3, m fixing capacity of the soil (without the organic matter) represented the amount of NH_3 fixed by the organic fraction of the soil (NH_3, om fixing capacity).

Sohn and Peech stated that the H_2O_2 treatment used to destroy the organic matter probably affected the clay fraction in the following ways:

- 1) It eliminated the presence of organic matter which may have

been hindering fixation of NH_4 by blocking the entrance of the NH_4 ions between the clay plates. If anything, this should have increased the capacity of the clay to fix NH_4 .

2) The soils that were H_2O_2 treated were first H saturated and therefore would be expected to retain and fix more NH_3 . (This seems to contradict the report by Nommik (28, p. 13) that a decrease in pH would give a subsequent decrease in the NH_4 fixing capacity of a soil.)

3) Exfoliation of the clay minerals, giving decreased particle size, should have increased both the uptake and fixation of NH_4 .

In light of the above effects they pointed out that if the capacity of a soil to fix NH_3 resided solely in the clay fraction, the amount of NH_3 fixed should have been increased by the H_2O_2 treatment. However, their data showed that the amount of NH_3 fixed decreased with the H_2O_2 treatment in every case. They therefore concluded that organic matter did possess the ability to fix NH_3 . To further support this conclusion, they found that more NH_3 than K was fixed by surface soils. They reasoned that since NH_4 and K are supposedly fixed by the same mechanism in clay minerals, the difference in the amount of NH_3 and K fixed was due to the fact that part of the NH_3 was fixed by organic matter. The K would have been less likely to react with organic matter.

The Sohn and Peech modification of the KCl extraction procedure seems to be an improvement over the procedure introduced by Allison *et al.* (4), at least for determining the NH_3 fixing capacity of a soil at air dry conditions. The justification for substituting NaCl for KCl is questionable, especially since fixed NH_4 is most generally defined as that NH_4 not leachable with KCl. Their H_2O_2 treatment no

doubt altered the NH_3, m fixing capacity of the clay minerals. Although they conclude that this H_2O_2 treatment would only tend to increase the NH_3, m fixing capacity giving a subsequent low value for their estimation of NH_3, om fixing capacity, they do not show any quantitative evidence to demonstrate this point. In spite of the shortcomings, the magnitude of the values was such that the conclusion that organic matter is capable of fixing large quantities of NH_3 appears justified.

EXPERIMENTAL METHOD

Soils Studied

Profile samples of ten agriculturally important Oregon soils were taken. All of the soils except the Walla Walla series, found in the Columbia basin, were located in western Oregon. The soil samples were air dried and crushed to pass a 2 mm. sieve. Subsamples obtained by repeated quartering or random spoon sampling were further ground to pass a 40 mesh sieve.

A complete profile description of each soil is included in the appendix. Some characterization data of these soils as determined by the soil testing lab., soil physics lab., and A.R.S. research lab. located at Oregon State College are given in table 6 of the appendix. All the data, except mechanical analyses, in table 6 are reported on an air dry weight basis. Moisture content of the air dry soils is provided in the table should it be desirable to calculate any values on an oven dry basis. The conclusions reached in this thesis would not have been significantly affected by such a conversion. A chart prepared by Dr. E. G. Knox showing the relationships of the soils with respect to parent material and annual rainfall appears as table 7 of the appendix.

A very brief description of the soils is given below:

1) The Aiken silty clay loam is often referred to as a red hill soil. It is derived from basalt and is utilized for small grains, forage crops, and tree fruits throughout the Willamette Valley.

2) Amity silty clay loam is an imperfectly drained valley floor soil developed on old alluvium. It is used extensively throughout the

Willamette Valley for small grains and forage crops. With improved drainage it is used for fruits and vegetable crops.

3) Cascade silt loam is developed from loess and is found along the Columbia River near Portland. It is used extensively for grain, forage crops, and horticultural crops.

4) Chehalis silt loam is found on the flood plain of the Willamette River throughout the Willamette Valley. It is used extensively for intertilled crops and is one of the better agricultural soils in the Willamette Valley.

5) The Dayton silt loam is a clay pan soil developed from old alluvium. It is found in the Willamette Valley and is a catenary associate of the Amity series. Because of poor drainage it is limited in its agricultural use. Improved areas support oats, forage crops, and pasture.

6) Nehalem silt loam is a soil developed from recent alluvium. It is found in the coastal areas of Oregon. The value of the soil is limited because of the shortness of the growing season in the area. It is dominately used for forage and pasture.

7) Steiwer silt loam is a shallow foothill soil developed from sandstone. It is found in the Willamette Valley and is used extensively for pasture.

8) Tillamook silt loam is developed on old alluvium in the coastal area of Oregon. It is found extensively in the dairy country surrounding Tillamook and is used for pasture. It is subject to the same seasonal limitation as the Nehalem.

9) Walla Walla silt loam is developed from loess and is found in the 12 to 16 inch rainfall areas throughout the Columbia basin. It is

used extensively for wheat.

10) Willamette silt loam is developed on old alluvium and is the well drained catenary associate of the Amity and Dayton series. It is found throughout the Willamette Valley and is used extensively for intertilled crops.

Laboratory Procedure

Since the NH_4 fixing capacity of a soil varies, depending on the method employed to determine the value, a study of the different methods was necessary. Some of the considerations in the study of the different methods used to determine NH_4 fixation values are discussed in the section on "Methods to Determine NH_4 Fixation" in the literature review.

It was decided that the approach by Dharwal and Stevenson (17) would best serve the purpose of this investigation. A modification of their HF method (called Stevenson's HF method in the literature review) was used to determine all of the NH_4 fixation values in this thesis.

Native Fixed NH_4 . A 2 gm. sample of finely ground soil is weighed into a 200 ml. beaker. Fifty ml. of N KOH is added, and the sample is placed in an autoclave for at least 8 hours at 20 lbs. pressure and a temperature of 120°C . (This step is designed to remove the organic matter from the sample.) Bremner (13) demonstrated that this KOH treatment has little effect on the capacity of the minerals to fix NH_4 .

After cooling, the sample is transferred to a 50 ml. polyethylene centrifuge tube and the residue recovered by centrifugation. The residue is washed 3 times with 0.5 N KCl; then 15 ml. of an acid mixture consisting of 5.0 N HF, 0.75 N HCl, and 0.6 N H_2SO_4 is added.

At this point Stevenson's method was modified. Instead of letting the sample stand in contact with the HF mixture for 12 hours with occasional stirring, a rubber stopper is placed on the centrifuge tube containing the soil and HF mixture and the tube is placed on a shaker for at least 14 hours. The sample is then transferred to a micro-distillation unit for NH_4 determination. Contamination of the distillate and attack on the distillation unit by HF is prevented by adding alkali to the distillation unit prior to adding the HF extract. The amount of alkali added is sufficient to make the sample about 1 N with respect to NaOH. A distillation time of 4 minutes is used and the NH_4 is collected in 2% boric acid solution containing a mixed indicator. The amount of NH_4 in the distillate is determined by titration with standardized 0.01 N HCl.

Total NH_4 Fixing Capacity Using N NH_4OH . A 2 gm. sample of finely ground soil is weighed into a 50 ml. centrifuge tube. Ten ml. of N NH_4OH is added, a rubber stopper is placed on the centrifuge tube, and the soil in contact with the NH_4OH is allowed to shake for 12 hours.

After shaking, the stopper is removed and the centrifuge tube with its contents is placed in the centrifuge where it is subjected to an R.C.F. of 3,000 times gravity for 10 minutes. On removal from the centrifuge the NH_4OH is decanted and N KOH is added to the soil in the centrifuge tube. The centrifuge tube is again stoppered and this mixture of soil and KOH is shaken for 30 minutes on the shaker. After shaking, the soil and KOH mixture is washed into a 200 ml. beaker and brought to a total volume of approximately 50 ml. with N

KOH. The sample is placed in an autoclave for 8 hours. The procedure from this point is the same as that outlined for determination of native fixed NH_4 . Note that this value includes the sum of the native fixed NH_4 and the conventional NH_4 fixing capacity.

NH_4 Fixing Capacity. This value can be calculated as the difference between the total NH_4 fixing capacity and the native fixed NH_4 .

Ammoniating Soils With Anhydrous NH_3 . A 15 gm. soil sample, finely ground to pass a 40 mesh sieve, is weighed into a 500 ml. erlenmeyer flask. Two glass tubes about 10 cm. in length are inserted into a two holed stopper. The stopper in turn is placed on an erlenmeyer flask containing the soil sample. A tygon tube is connected between an anhydrous NH_3 tank and one of the glass tubes inserted in the stopper on the erlenmeyer flask. NH_3 is allowed to flow for a period of 10 minutes through the flask which is open to the atmosphere by the second glass tube. The flask is shaken by hand at least twice during this 10 minute period. The flask is then closed off from the atmosphere and the NH_3 source by means of pinch clamps. The sample is allowed to remain in contact with the anhydrous NH_3 for 1 hour during which time it is shaken at least 5 times by hand. Both pinch clamps are opened again and NH_3 is allowed to circulate through the flask for about 1 minute while shaking the flask by hand. The source of NH_3 is then turned off and the flask is disconnected from the system by removing the stopper from the flask. The open flask is left under the hood for about 1 hour. The soil is then transferred to paper cups and placed in an oven where a vacuum is pulled with a water aspirator at room temperature for at least 12 hours. This soil

was labeled ammoniated soil and used to determine the values described below.

NH₃ Retention Capacity. A 1 gm. sample of ammoniated soil is weighed onto a filter paper and placed into a micro-kjeldhal flask. Total N is then determined by the micro-kjeldahl procedure. Total N is also determined on a 1 gm. sample of untreated soil. The difference between these two total N values (total N of ammoniated sample minus total N of the untreated sample) is taken as the NH₃ retention capacity.

NH₃ Fixed by Mineral and Organic Fractions. An approach similar to that introduced by Sohn and Peech (33) was developed for determination of the NH₃ fixed by the mineral and organic fractions of the soil (NH₃ fixing capacity).

A 10 gm. sample of untreated soil is leached with 0.5 N KCl. The extract is diluted to a constant volume and an aliquot taken to determine exchangeable NH₄ using Nessler's reagent. This would give an estimate of the exchangeable NH₄ of the untreated (control) soil.

A 2 gm. sample of ammoniated soil is placed in a 50 ml. centrifuge tube. Twenty-five ml. of 0.5 N KCl is added; the centrifuge tube is stoppered with a rubber stopper; and the contents are shaken for at least 30 minutes. After shaking, the contents are washed with 0.5 N KCl into a funnel lined with no. 5 Whatman filter paper and the extract is collected in a 100 ml. beaker. The soil in the filter paper is washed two additional times with 5 ml. portions of 0.5 N KCl. The total extract is transferred to a micro-kjeldahl distillation unit. About 5 ml. of 20 N NaOH is added and the NH₄ is distilled

into a 2% boric acid solution containing a mixed indicator. NH_4 in the distillate, determined by titration with standardized 0.01 N HCl, is regarded as "exchangeable NH_4 " of the ammoniated soil. This "exchangeable NH_4 " includes NH_4 on the exchange complex, physically sorbed NH_3 , plus any other forms of NH_3 that would be extracted with 0.5 N KCl.

The exchangeable NH_4 of the untreated soil (determined by the Nessler procedure) is subtracted from the "exchangeable NH_4 " of the ammoniated soil (determined by distillation of the KCl extract). This difference is then subtracted from the NH_3 retention capacity for the same soil, and the result is reported as the NH_3 fixing capacity of the soil. It is recognized that the presence of any organic nitrogen compounds in the KCl extract that would be capable of liberating NH_3 upon hydrolysis during alkaline distillation would give low results for the amount of NH_3 fixed by the soil. However, Sohn and Peech (33) reported identical results between the nesslerization and distillation procedures and so the amount of NH_3 found in the KCl extract is assumed to represent exchangeable NH_4 .

NH_3 Fixed by the Mineral Fraction. A 2 gm. sample of ammoniated soil is weighed into a 200 ml. beaker. The procedure from this point is the same as outlined for determination of native fixed NH_4 . The NH_3 fixed by the mineral fraction (NH_3, m fixing capacity) is calculated by subtracting native fixed NH_4 from the above determined value.

NH_3 Fixed by the Organic Fraction. This value (NH_3, om fixing capacity) is calculated as the difference between the NH_3 fixing capacity and the NH_3, m fixing capacity.

All data represent means of at least duplicate determinations with one exception, "exchangeable NH_4 " of the ammoniated samples. Shortage of sample dictated acceptance of single determinations or reammoniation and degassing of a complete new series. Good duplication of "exchangeable NH_4 " on a number of ammoniated soils was obtained and individual determinations of the remaining samples were therefore considered satisfactory.

RESULTS AND DISCUSSION

Investigators have shown that the amount of NH_4 a soil is capable of fixing increases with depth in the profile (5, 19, and 28, p. 430).

It was suggested by Allison et al. (5) that the lower NH_4 fixing capacity of surface soils was probably due to interfering effects of organic matter, K, and an increase in the level of native fixed NH_4 .

Since there is generally more organic matter in the surface horizons than in the lower horizons, any interfering effect by organic matter on the fixation of NH_4 should be more apparent in the surface horizons. The same reasoning may hold for K. Hanway and Scott (19) when using the Rodrigues HF method to determine native fixed NH_4 showed data that would confirm the contention that there is more native fixed NH_4 in the surface horizon. However, they suggested that their high values for native fixed NH_4 in the surface horizon might have been because of some decomposition of the organic matter which occurred in greater quantity in the surface soil. They (Hanway and Scott) did not get correspondingly high values for native fixed NH_4 in the same surface soils when using the double distillation procedure and stated that no conclusion could be drawn since the results of the two methods did not agree. However, Dhariwal and Stevenson (17) presented evidence indicating that there was not any more native fixed NH_4 in surface horizons than in lower horizons.

It is often observed that the clay content of a soil profile increases with depth. Any increase in clay content with depth could partially account for the observations that the NH_4 fixing capacity of soils frequently increases with depth. This assumes, of course,

that the clay fraction alone is responsible for NH_4 fixation.

Fixation of Added NH_4 , Added NH_3 , and Native NH_4 by the Mineral Fraction

In examining the data of table 1 which contains the NH_4 fixing capacity, NH_3 , m fixing capacity, and native NH_4 fixing capacity of some profile samples of Oregon soils, it becomes obvious that some of the forementioned generalities are not necessarily true.

Data pictured in figure 1 show that the NH_4 fixing capacity of all of the soils in Oregon does not increase with increasing depth in the profile. The NH_4 fixing capacity varies little throughout the profile depth of the Aiken, Chehalis, Steiwer, Tillamook, and Walla Walla soils. It is also apparent that the NH_3 , m fixing capacity varies only slightly more between the surface and the bottom of the profile in the above five soils. Except for the Chehalis soil there appears to be an irregular increase in the NH_3 , m fixing capacity with increasing depth in the profiles of the above mentioned soils. However, it must be admitted that the differences are slight.

In contrast, figure 1 shows that the mineral fraction of the bottom horizons of the remaining soils (Amity, Cascade, Dayton, Nehalem, and Willamette) fix much greater amounts of NH_4 and NH_3 than their corresponding surface horizons. This supports the observations of other workers (5, 19, and 28, p. 430). Nevertheless, the fact remains that the NH_4 fixing capacity of many soils does not increase with depth in the profile.

Table 1

Native Fixed NH_4 , NH_4 and NH_3 Fixing Capacities
Attributed to the Mineral Fraction of Ten Oregon Soils

Soil	Horizon	Native fixed NH_4	Native fixed NH_4	NH_4 fixing capacity	NH_3 , m fixing capacity
		ppm N	% of total N	ppm N	ppm N
Aiken	A _p	35	1.7	0	30
	B ₁	44	2.1	0	29
	B ₂₁	30	1.7	18	56
	B ₂₂	30	2.0	10	20
	Deep	37	3.4	2	33
Amity	A ₁	74	3.5	3	70
	A ₂	70	10.5	31	166
	B ₁	66	17.4	72	429
	B ₂₁	60	21.6	361	620
	C _m	61	24.4	334	584
	C	61	32.1	437	704
Cascade	A _p	42	2.1	10	55
	A ₃	44	5.8	2	46
	B ₁	46	20.0	5	87
	B ₂	47	22.4	368	619
Chehalis	A ₁	32	1.1	130	260
	A ₃	17	1.5	176	387
	C ₁	21	2.1	149	342
	C	19	2.3	139	326
Dayton	A ₁₁	72	2.9	38	53
	A ₁₂	70	6.3	38	44
	A ₂	71	12.8	47	110
	B ₂₁	57	15.7	398	689
	B ₂₂	53	20.2	579	862
	Deep	57	35.3	639	928
Nehalem	A _{1p}	122	3.1	58	465
	A ₁₂	125	6.2	92	672
	AC	121	6.2	47	590
	C ₃	111	8.7	221	1015

Table 1 (cont.)

Native Fixed NH_4 , NH_4 and NH_3 Fixing Capacities
 Attributed to the Mineral Fraction of Ten Oregon Soils

Soil	Horizon	Native fixed NH_4	Native fixed NH_4	NH_4 fixing capacity	NH_3 m fixing capacity
		ppm N	% of total N	ppm N	ppm N
Steilwer	A ₁	111	7.5	37	103
	A ₃	112	9.1	39	113
	B ₁	111	13.7	37	116
	B ₃	112	23.8	18	125
	D _r	121	41.6	16	139
Tillamook	A _{1p}	81	1.3	11	36
	A ₁₂	91	1.8	9	27
	C	78	8.6	10	45
Walla Walla	A _{1p}	48	5.0	29	6
	A ₁₂	48	8.7	22	26
	AC	59	15.1	47	66
	AC ₂	58	21.3	31	45
	Cca ₁	55	28.9	36	48
	Cca ₂	57	27.4	36	55
Willamette	A _p	110	3.8	23	28
	B ₁₁	108	8.2	25	69
	B ₁₂	106	14.7	52	129
	B ₂	73	26.1	254	455
	C	71	29.6	348	553

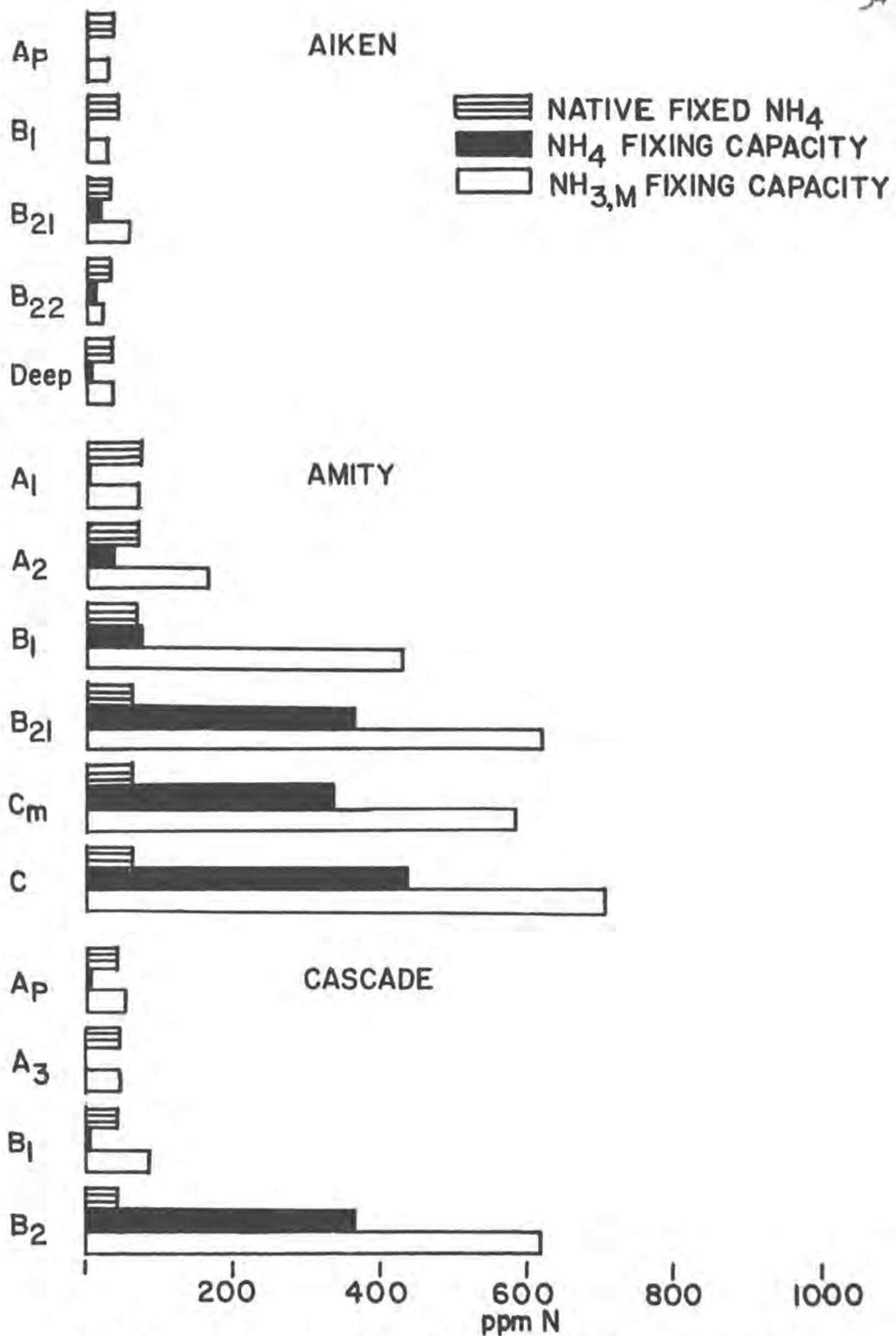
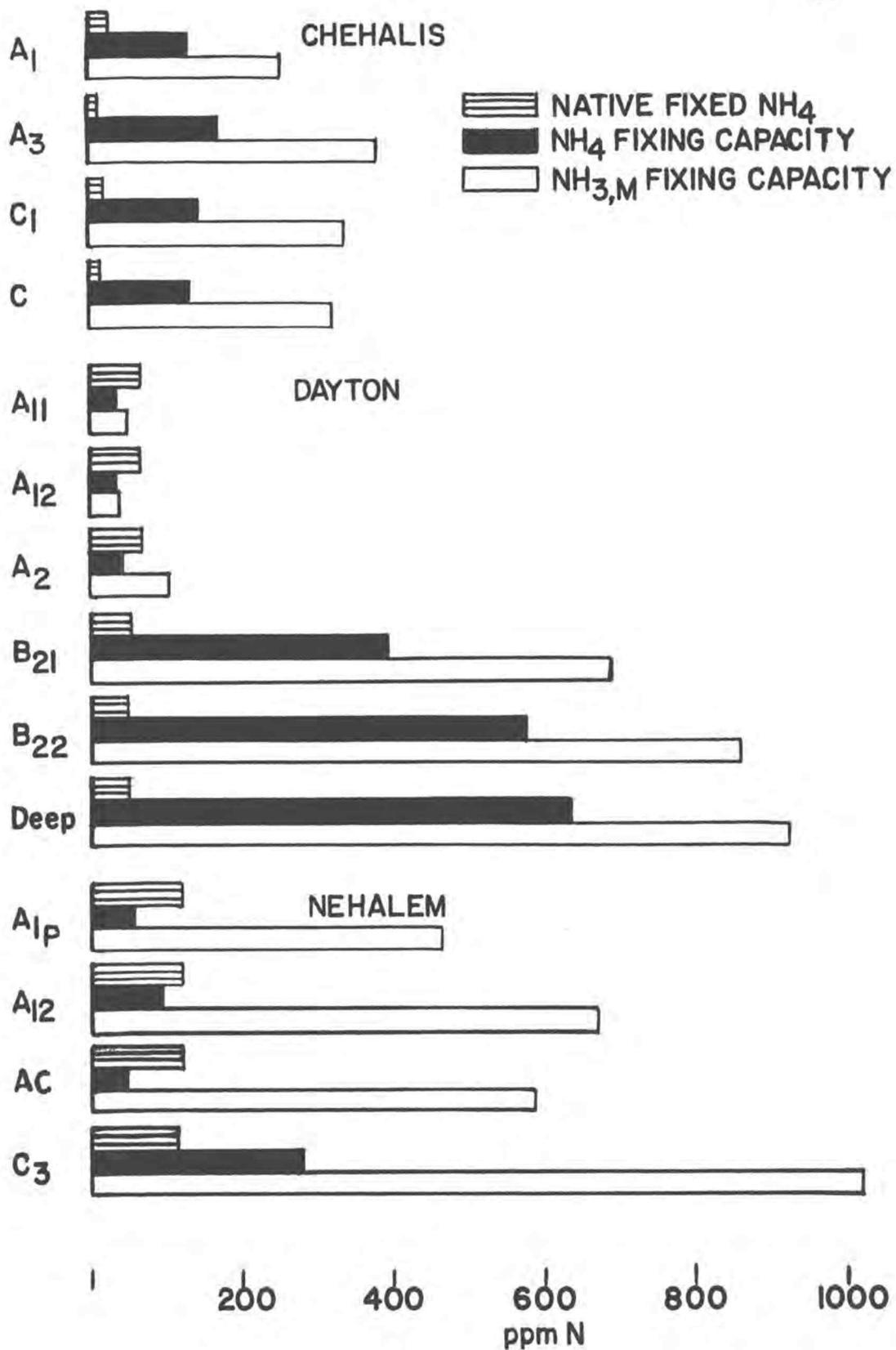
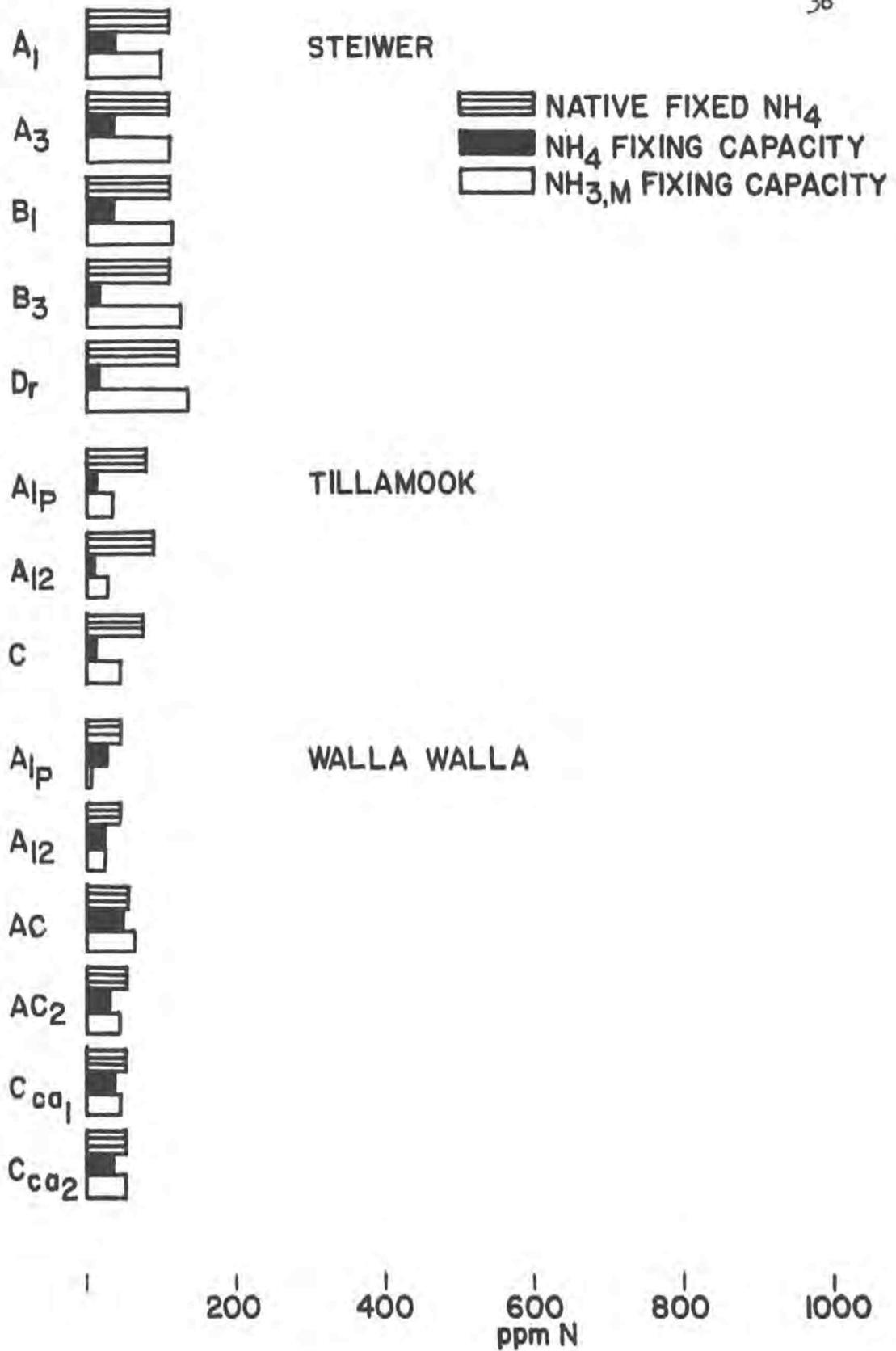
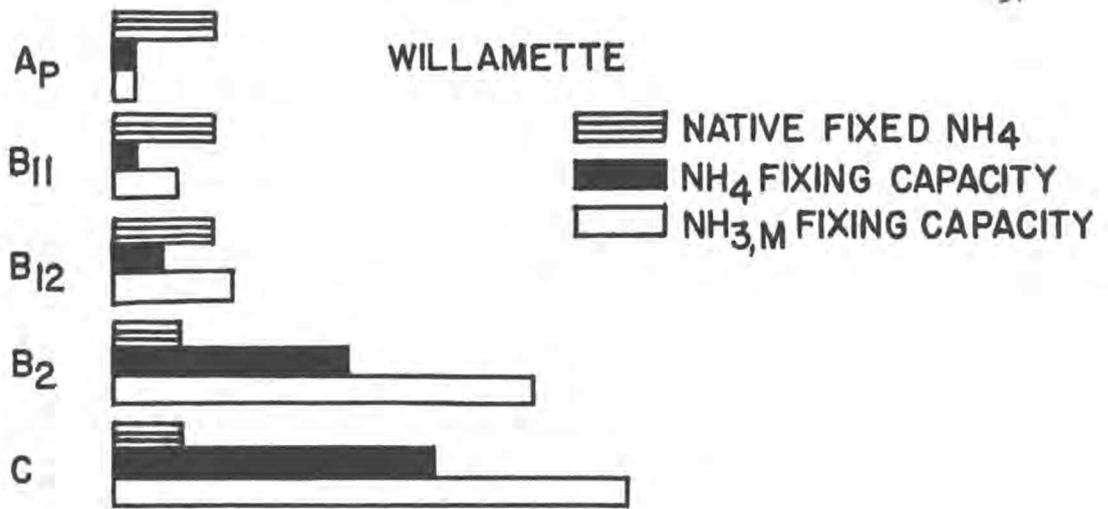


FIGURE I. NATIVE NH₄, NH₄, AND NH_{3,M} FIXING CAPACITIES OF TEN OREGON SOILS







1 200 400 600 800 1000
ppm N

The results showing the distribution of native fixed NH_4 in some Oregon soils appears in figure 1. It is interesting to note that there is not much variation in the native fixed NH_4 from the top to the bottom of any particular profile. Since the total N content of the soils decreases down the profile, it is apparent that the native fixed NH_4 must constitute an increasingly larger per cent of the total N in the lower horizons. Column 2 of table 1 shows that more than 20% of the total N in the lowest horizon of six of the soils appears as native fixed NH_4 . This certainly supports the conclusion of Stevenson et al. (37) that N obtained by using the Kjeldahl method should not be reported as "organic N" except where fixed NH_4 is known to be absent.

The suggestion by Allison et al. (5) to the effect that the lower NH_4 fixing capacity in surface soils might be partially due to higher amounts of native fixed NH_4 in surface soils does not seem to be confirmed by these data. Column 1 of table 1 shows that the native fixed NH_4 only ranges between 19 ppm N in the Chehalis C horizon to 125 ppm N in the Nehalem A_{12} horizon. The widest range in variation of native fixed NH_4 within any one profile (Willamette) is only 39 ppm N. In the Amity, Dayton, Willamette, and Chehalis profiles there is more native fixed NH_4 in the surface horizons than in the lower horizons, but the difference at best is slight. In the case of the Aiken, Cascade, Steiwer, and Walla Walla profiles there is more native fixed NH_4 in the lower horizons than in the surface horizons. Again the difference is only slight. It would, therefore, appear that the lower NH_4 fixing capacity in surface soils is not necessarily due to

Allison's suggestion that the minerals of the surface horizon are partially satisfied with native fixed NH_4 . Dhariwal and Stevenson (17) came to a conclusion similar to that of the writer.

Comparison of NH_4 and NH_3 Fixing Capacities of the Mineral Fraction

Table 1 shows the results for the NH_4 fixing capacity and the NH_3 , m fixing capacity of various horizons of the ten Oregon soils. The results are not strictly comparable since the two N sources (N NH_4OH and NH_3) were applied under different conditions. Although both sources were applied to air dry samples, the NH_4OH permitted complete moisture saturation.

Saturation conditions with respect to NH_4 were sought in both cases. The NH_4OH and anhydrous NH_3 were therefore applied in large excess. Admittedly, the conditions used for wet fixation are exaggerated in comparison to field situations. However, application of anhydrous NH_3 in the field produces essentially saturation conditions in a small volume around the point of injection. The interest in these studies, of course, was not to derive absolute quantities representing fixation values. Fixing capacities can be altered by far too many variables (see Literature Review) to permit such an undertaking with the funds and time involved. The studies did hope to discover the relative differences between soils and between horizons within the same soil under a standardized set of conditions. The magnitudes of fixation achieved should be indicative of possible fixations even though exaggerated in comparison to field situations.

The considerably larger fixation from anhydrous NH_3 by the mineral fraction of air dry soils as compared to wet fixation from NH_4OH was a little surprising at first observation. The extreme penetrating ability of anhydrous NH_3 had not been appreciated. In many cases the differences in fixation from anhydrous NH_3 and NH_4OH could largely have been eliminated if the NH_4OH treated soils had been air-dried after treatment with NH_4OH to increase fixation. This conclusion is based on Allison's report (1) that air-drying essentially doubles NH_4 fixation in the 100-200 ppm N range and substantially increases fixation at higher ranges.

Since the air dry samples contain only a few per cent moisture, one might expect collapsible mineral lattices to be at least partially contracted, effectively hindering access of NH_3 to internal mineral surfaces. Further, one could expect organic matter coatings to be an additional barrier to mineral fixation from anhydrous NH_3 . That organic matter appears to be no obstacle is evident from results on the Nehalem soil which has a relatively high organic matter content. The data clearly illustrate the extreme penetrating power of anhydrous NH_3 . As a matter of fact, further reference to the literature revealed that anhydrous NH_3 has been used for determination of internal surface area of dry mineral substances (39).

Influence of Content and Type of Clay on NH_4 Fixation

It was demonstrated that native fixed NH_4 was probably not responsible for the lower NH_4 fixing capacities of surface soils. The organic matter content and K content of the surface horizons may be

partially responsible. However, it seems more than likely that the differences in the NH_4 fixing capacity between a surface and sub-surface horizon are due to the different contents and types of clays present.

It is obvious that clay content alone will not account for the differences in the amount of NH_4 fixed by the different horizons in a soil profile. As a matter of fact, mechanical analysis data (table 6, appendix) show that the clay content for the Amity and Nehalem profiles actually decreases with depth while the NH_4 fixing capacity increases with depth. Even when there is an increase in clay content with depth and a corresponding increase in NH_4 fixing capacity, it is apparent that the increased fixation of NH_4 in the lower horizon cannot be entirely explained on the basis of clay content of the samples. For example, table 1 shows that the Dayton A₂ horizon (25% clay) fixes 47 ppm $\text{NH}_4\text{-N}$, while the Dayton B₂₁ horizon (52% clay) fixes 398 ppm $\text{NH}_4\text{-N}$. Thus, while the clay content increases 108% the NH_4 fixing capacity increases 747%. No doubt the clay minerals which fix NH_4 are present in different amounts in the various horizons.

Table 2 shows the NH_4 fixing capacity for some standard clays. The kaolinite, illite, and montmorillonite samples were obtained from Wards Natural Science Establishment and are used and described by the American Petroleum Institute as reference clay minerals. The allophane sample is a soil thought to be high in allophane. It was obtained through the courtesy of A. A. Theisen from M. Williams, S.C.S. correlator in Hawaii. The vermiculite and pro-chlorite samples were obtained from Wards Natural Science Establishment but are not

Table 2

Native Fixed NH_4 and NH_4 Fixing Capacity
of Some Standard Minerals

Mineral	Native Fixed NH_4 ppm N	NH_4 Fixing Capacity ppm N
Allophane (moist) Hawaii	2**	-*
Allophane (air dry) Hawaii	11	8
Illite No. 36 Morris, Ill.	486	124
Kaolinite No. 5 Lemar Pit, Bath, So. Carolina	0	2
Montmorillonite No. 11 Santa Rita, New Mexico	1	14
Pro-chlorite	2	6
Vermiculite	6	3,834

* The NH_4 fixing capacity was not determined on a moist sample of allophane.

**This value was calculated on a moist weight basis.

A.P.I. reference minerals. X-ray diffraction patterns showed that the vermiculite sample contained some impurities.

Air dry samples of the standard minerals were saturated with N NH_4OH and the NH_4 fixing values were determined as outlined (p. 25). One moist sample of allophane was included.

The results in table 2 agree with other reports that vermiculite is capable of fixing the greatest quantities of NH_4 . The sample of illite tested was able to fix a substantial amount of NH_4 even though it contained a large quantity of native fixed NH_4 . The montmorillonite sample fixed a small amount of NH_4 . This seems to agree with the observation of others (4, 5, 29, 34) that montmorillonite is not capable of fixing NH_4 under moist conditions. Most investigators agree that montmorillonite is capable of fixing large amounts of NH_4 on drying. This fact was not investigated in this study. It is interesting to note that White and Wear (38) stated that substitution in the tetrahedral layer is necessary for fixation to occur. This would suggest that beidillite and not montmorillonite is mainly responsible for fixing NH_4 on drying. Since it is difficult to distinguish between beidillite and montmorillonite, and since some investigators make no attempt to differentiate between the two (calling them both montmorillonite), it is difficult to evaluate the situation. It is perfectly possible that workers who have reported a high NH_4 fixing capacity for montmorillonite were actually working with a sample of beidillite. The list of clay minerals in table 2 is by no means complete. However, the minerals listed illustrate the wide variation in fixing capacities of the different clay minerals.

Table 3

Fixing Capacities Expressed
per unit Clay and per unit Clay and Silt

		NH ₄ fixing capacity per unit clay me/100g	NH ₃ , n fixing capacity per unit clay me/100g	NH ₄ fixing capacity per unit clay & silt me/100g
Aiken	A _p	0.00	0.34	0.00
	B ₁	0.00	0.31	0.00
	B ₂₁	0.18	0.57	0.14
	B ₂₂	0.10	0.19	0.07
	Deep	0.02	0.31	0.01
Anity	A ₁	0.07	1.72	0.03
	A ₂	0.76	4.09	0.29
	B ₁	1.84	10.94	0.63
	B ₂₁	9.92	17.03	3.39
	C _m	10.37	18.14	3.85
	C	15.61	25.14	4.16
Cascade	A _p	0.36	1.96	0.10
	A ₃	0.06	1.43	0.02
	B ₁	0.17	2.96	0.05
	B ₂	11.43	19.22	3.33
Chehalis	A ₁	2.65	5.31	0.96
	A ₃	3.93	8.64	1.34
	C ₁	3.55	8.14	1.22
	C	3.68	8.62	1.14
Dayton	A ₁₁	1.43	1.99	0.28
	A ₁₂	1.29	1.50	0.28
	A ₂	1.34	3.14	0.35
	B ₂₁	5.47	9.46	2.87
	B ₂₂	9.62	14.32	4.26
	Deep	16.30	23.67	4.70
Behalem	A _{1p}	1.09	8.74	0.44
	A ₁₂	1.73	12.63	0.69
	AC	0.96	12.04	0.36
	C ₃	4.93	22.66	1.73

Table 3 (cont.)

Fixing Capacities Expressed
per unit Clay and per unit Clay and Silt

		NH ₄ fixing capacity per unit clay me/100g	NH ₃ , m fixing capacity per unit clay me/100g	NH ₄ fixing capacity per unit clay & silt me/100g
Steilwer	A ₁	0.85	2.37	0.33
	A ₃	0.93	2.69	0.36
	B ₁	0.80	2.51	0.33
	B ₃	0.34	2.35	0.16
	D _r	0.25	2.21	0.13
Walla Walla	A _{1p}	1.55	0.33	0.35
	A ₁₂	1.31	1.55	0.28
	AC	2.40	3.37	0.48
	AC ₂	2.21	3.21	0.33
	Cca1	3.21	4.29	0.38
	Cca2	4.29	6.55	0.38
Willamette	A _p	0.61	0.74	0.17
	B ₁₁	0.64	4.52	0.18
	B ₁₂	1.38	6.22	0.39
	B ₂	5.49	11.43	1.87
	C	8.88	15.92	2.56

Values for Tillamook were not calculated as mechanical analyses data were not determined for this soil.

The data in table 3 lend support to the hypothesis that the difference in the NH_4 fixing capacity between a surface and sub-surface horizon is probably due to differences in kinds as well as quantities of clay minerals. Expressing the data on a unit of clay basis as is done in table 3 eliminates any differences between horizons due to the quantity of clay in the sample. It is noted that the NH_4 fixing values expressed per unit clay still differ between horizons so it is logical to suppose that the difference is associated with the kind of clay present in each horizon. It is admitted that columns 1 and 2 in table 3 could be misleading since they are calculated on the assumption that the clay fraction alone of the inorganic fraction of the soil is responsible for fixing NH_4 . Recently Nommik (28, p. 408) and Leggett (23 p. 78) reported that the fine silt fraction is capable of fixing large quantities of NH_4 . However, any difference in NH_4 values between horizons due to the quantity of clay plus silt present could be eliminated by expressing the values on a unit of clay plus silt basis. This is done in column 3 of table 3 and it can be seen that the NH_4 fixing capacity still varies between horizons. The conclusion still holds that the differences between horizons are not only due to the varying amounts of clay and silt present but also to the different kinds of clay and silt. It is assumed here that the total silt fraction in addition to the total clay fraction is active in fixing NH_4 . This may not be the case but it is doubtful that it would affect the above conclusion.

NH₃ Retention Capacity

While not a specific objective of the present thesis, NH₃ retention capacities were determined in the process of obtaining other necessary values. The data should be of considerable interest to organizations that have provided support for the project. NH₃ retention values are therefore recorded in column 1 of table 4. It should be recalled that the NH₃ was retained against degassing for 12 hours at room temperature (25-27°C.) under a vacuum equivalent to 30 inches of Hg. Such degassing should remove much, if not all, of the physically sorbed NH₃. Nevertheless, the quantities of NH₃ retained in practical terms (ppm times 2 equal lbs. N per acre furrow slice) are exceedingly large.

NH₃ Fixing Capacity of the Organic Fraction

Sohn and Peech (33) recently demonstrated that organic matter was responsible for fixing large amounts of NH₃ from applied anhydrous NH₃. They determined the NH₃ fixing capacity of the whole soil (including organic matter). The organic fraction of the soil was destroyed with H₂O₂ and the NH₃,_m fixing capacity of the mineral residue then determined. The difference between the NH₃ fixing capacity and the NH₃,_m fixing capacity would then be equal to the NH₃,_{om} fixing capacity. They suggest that the H₂O₂ treatment had some drastic effects on the clay minerals but point out that these effects would generally increase the fixation by clay minerals. This would make the estimated NH₃,_{om} fixing capacity less than it actually was.

Table 4

The NH_3 Retention Capacity and the NH_3 Fixing Capacity
 Attributed to Mineral and Organic Fractions of Ten Oregon Soils

Soil	Horizon	NH_3 retention capacity ppm N	NH_3 fixing capacity ppm N	NH_3 , m fixing capacity ppm N	NH_3 , on fixing capacity ppm N
Aiken	A _p	3470	887	30	857
	B ₁	2670	313	29	284
	B ₂₁	2700	462	56	406
	B ₂₂	2350	344	20	324
	Deep	2320	350	33	317
Amity	A ₁	2538	540	70	470
	A ₂	1678	256	166	90
	B ₁	2040	604	429	175
	B ₂₁	2268	406	620	-
	C _m	2698	907	584	323
	C	2848	981	704	277
Cascade	A _p	2188	511	55	456
	A ₃	1648	338	46	292
	B ₁	1468	301	87	214
	B ₂	1978	803	619	184
Chehalis	A ₁	3268	958	260	698
	A ₃	2978	867	387	480
	C ₁	2868	844	342	502
	C	2718	674	326	348
Dayton	A ₁₁	1960	390	53	337
	A ₁₂	1520	212	44	168
	A ₂	1400	234	110	124
	B ₂₁	3840	1195	689	506
	B ₂₂	3860	1333	862	471
	Deep	3390	1370	928	442
Nehalem	A _{1p}	6120	1386	465	921
	A ₁₂	5680	1277	672	605
	AC	5610	1236	590	646
	C ₃	5700	1492	1015	477

Table 4 (cont.)

The NH_3 Retention Capacity and the NH_3 Fixing Capacity
 Attributed to Mineral and Organic Fractions of Ten Oregon Soils

Soil	Horizon	NH_3 retention capacity ppm N	NH_3 fixing capacity ppm N	NH_3 , m fixing capacity ppm N	NH_3 , on fixing capacity ppm N
Steiwer	A ₁	1810	255	103	152
	A ₃	1860	354	113	241
	B ₁	1900	339	116	223
	B ₃	2500	389	125	264
	D _r	3900	589	139	450
Tillamook	A _{1p}	9190	1796	36	1760
	A ₁₂	8070	2351	27	2324
	C	5390	585	45	540
Walla Walla	A _{1p}	830	215	6	209
	A ₁₂	770	179	26	153
	AC	850	178	66	112
	AC ₂	820	132	45	87
	Cca1	890	189	48	141
	Cca2	930	201	55	146
Willamette	A _p	1980	360	28	332
	B ₁₁	1380	205	69	136
	B ₁₂	1380	243	129	114
	B ₂	2710	672	455	217
	C	2740	823	553	270

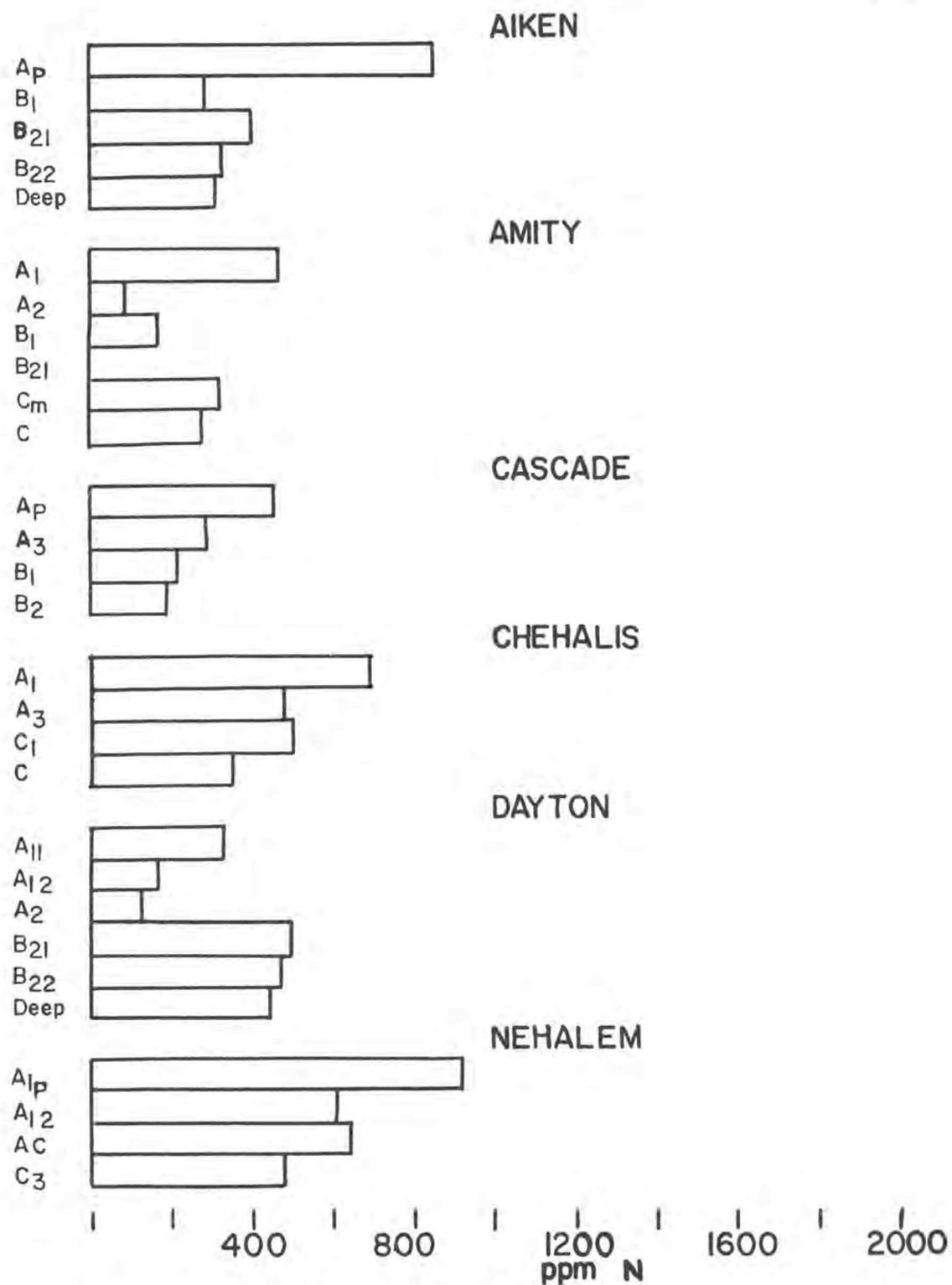
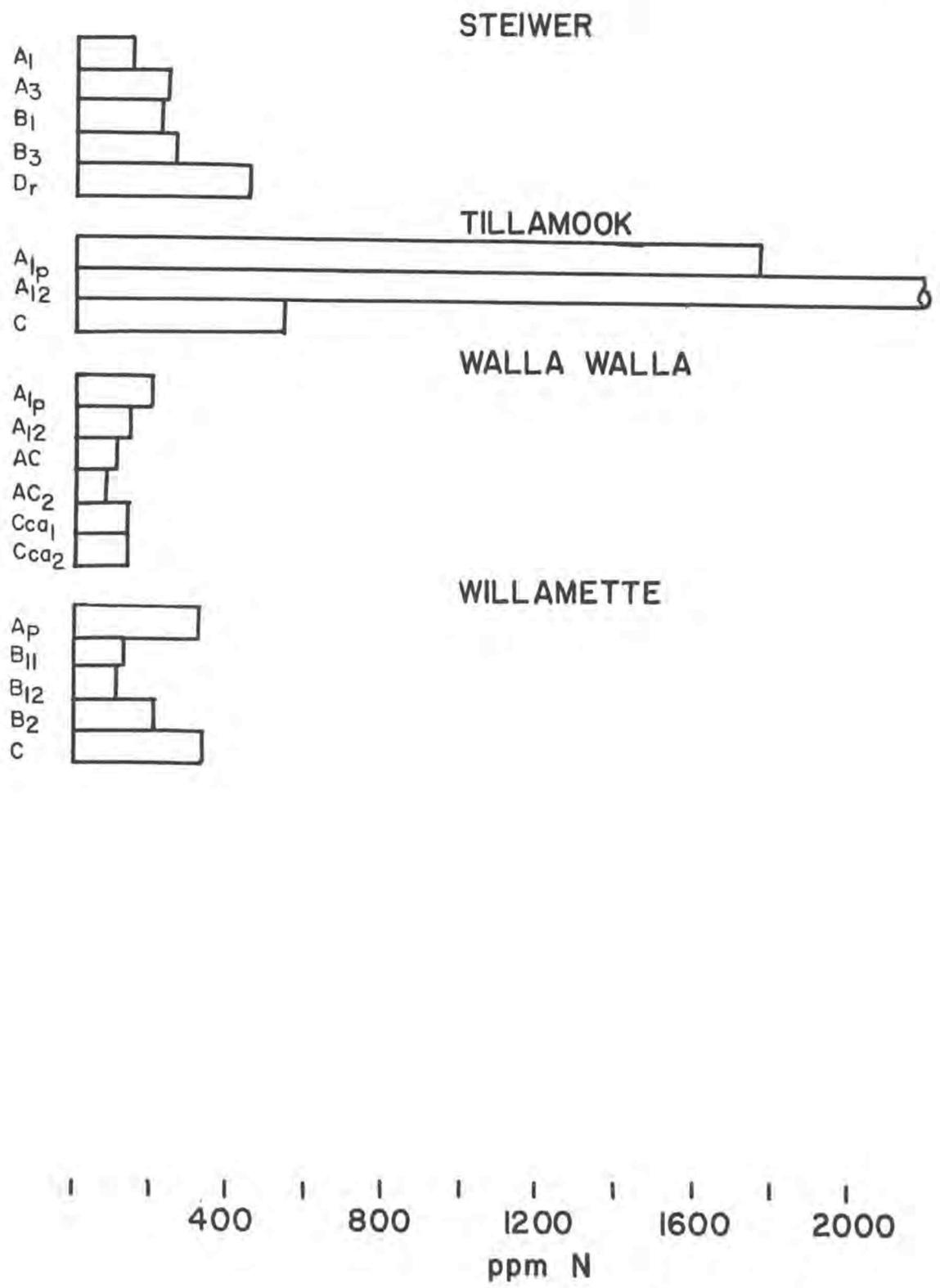


FIGURE 2. $\text{NH}_3,0\text{M}$ FIXING CAPACITY OF
TEN OREGON SOILS



Since the purpose of Sohn and Peech was to demonstrate the existence of an NH_3 , om fixing capacity, the effect of H_2O_2 was not considered to be of serious consequence.

For this study, an approach quite similar to that of Sohn and Peech for determination of the NH_3 , om fixing capacity was worked out. It differs in that the NH_3 , m fixing capacity was determined on subsamples of the original NH_3 treated sample using the modified Stevenson HF method (p. 24). The HF method did not subject the mineral fixing capacity to any of the disadvantages of a H_2O_2 pretreatment. One might suspect the hot KOH pretreatment to have disadvantages of its own. However, Bremner (13) demonstrated that the hot KOH pretreatment did not appreciably affect the capacity of minerals to fix NH_4 . Actually, Bremner presented evidence to show that when using a HF mixture method to determine the NH_4 fixing capacity it was not really necessary to use any pretreatment to destroy organic matter. It had previously been reported (30) that HF did not liberate distillable NH_3 from soil organic matter but would release it from silicate minerals. However, Bremner subsequently found that the hot KOH pretreatment to remove organic matter was necessary on soils that had been exposed to anhydrous NH_3 or NH_4OH . On all samples reported here, organic matter was removed with hot KOH pretreatment prior to silicate decomposition with the HF mixture.

The results (table 4) indicate that the organic matter in the soil is responsible for fixing large quantities of NH_3 . It could be concluded from these data that more than 60% of the NH_3 fixed by the surface horizons of the ten Oregon soils was attributable to some

reaction of NH_3 with soil organic matter. One might expect the surface horizons to fix much greater quantities of NH_3 than the lower horizons, since there is generally a much higher content of organic matter in the surface horizons than in the sub-surface horizons. However, figure 2 indicates that such is not the case. Practically all of the soils have a large NH_3 , om fixing capacity in the lower horizons where there is a relatively small percentage of organic matter in the sample. As a matter of fact, the Dayton, Steiwer, and Willamette have larger NH_3 , om fixing capacities in the bottom horizon than in the surface horizon.

The data in table 5 were calculated on the basis that organic matter is completely responsible for the NH_3 , om fixing capacity. It can be seen from these data that the NH_3 , om fixing capacity per unit organic matter differs markedly from horizon to horizon, possibly reflecting differences in the kind or quality of organic matter.

Mattson and Koutler-Andersson (24, p. 133) suggested that fixation of NH_3 by organic matter was associated with a simultaneous oxidation reaction. They pointed out that the oxidation status of the organic material had a direct effect on its NH_3 , om fixing capacity. Accomplished oxidation was observed to suppress, and simultaneous oxidation to favor the fixation of NH_3 . The oxidation process, and therefore NH_3 fixation, is favored by an alkaline reaction which occurs with the application of NH_3 . The data in table 5 show that the NH_3 , om fixing capacity per unit organic matter generally increases with increasing depth. This could be interpreted to support Mattson and Koutler-Andersson's observations if it could be assumed

Table 5

NH₃ Fixing Capacity Attributed to the Organic Fraction
Expressed per Unit Soil and per Unit Organic Matter

		organic matter in sample %	NH ₃ , om fixing capacity me/100g	NH ₃ , om fixing capacity per unit organic matter me/100g
Aiken	A _p	6.11	6.12	100.19
	B ₁	4.33	2.03	46.85
	B ₂₁	2.82	2.90	102.84
	B ₂₂	0.94	2.31	246.20
	Deep	0.29	2.26	780.29
Amity	A ₁	4.58	3.36	73.30
	A ₂	0.90	0.64	71.43
	B ₁	0.15	1.25	833.33
	B ₂₁	0.33	-	-
	C _m	0.19	2.31	1214.28
	C	0.19	1.98	1041.35
Cascade	A _p	4.35	3.26	74.88
	A ₃	1.27	2.09	164.23
	B ₁	0.31	1.53	493.09
	B ₂	0.17	1.31	733.11
Chehalis	A ₁	6.65	4.99	74.97
	A ₃	2.03	3.43	168.89
	C ₁	1.70	3.59	210.92
	C	1.38	2.48	180.12
Dayton	A ₁₁	6.60	2.41	36.47
	A ₁₂	2.16	1.20	55.56
	A ₂	0.70	0.89	126.53
	B ₂₁	0.70	3.61	516.28
	B ₂₂	0.40	3.36	841.07
	Deep	0.32	3.16	986.61
Nehalem	A _{1p}	8.34	6.58	78.88
	A ₁₂	3.68	4.32	117.43
	A ₃	3.52	4.61	131.09
	C ₃	2.19	3.41	155.58

Table 5 (cont.)

NH₃ Fixing Capacity Attributed to the Organic Fraction
Expressed per Unit Soil and per Unit Organic Matter

		organic matter in sample %	NH ₃ , om fixing capacity me/100g	NH ₃ , om fixing capacity per unit organic matter me/100g
Steiwer	A ₁	3.16	1.09	34.36
	A ₃	2.32	1.72	74.20
	B ₁	1.33	1.59	119.76
	B ₃	0.58	1.89	325.12
	D _r	0.17	3.21	1890.75
Tillamook	A _{1p}	20.80	12.57	60.44
	A ₁₂	15.29	16.60	108.57
	C	1.59	3.86	242.59
Walla Walla	A _{1p}	1.97	1.49	75.78
	A ₁₂	0.94	1.09	116.26
	AC	0.46	0.80	173.91
	AC ₂	0.22	0.62	282.47
	Cca ₁	0.11	1.01	915.58
	Cca ₂	0.11	1.04	948.04
Willamette	A _p	6.56	2.37	36.14
	B ₁₁	2.53	0.97	38.40
	B ₁₂	1.20	0.81	67.86
	B ₂	0.29	1.55	534.48
	C	0.25	1.93	771.43

that the organic matter is in a more reduced state in the lower depths of the profile. Although the data within any individual profile would support Mattson and Koutler-Andersson's theory if the above assumption were true, the data when comparing one profile with another do not always seem to support their theory. For example, the organic matter in the lower horizons of the Dayton, which is a poorly drained catenary associate of the imperfectly drained Amity, does not have as high an NH_3 , om fixing capacity per unit organic matter (841 me/100g) as that of the organic matter in the lower horizon of the Amity (1214 me/100g). Since the Dayton is assumed to be formed under poorer drainage conditions (which would result in organic matter in a more reduced state) than the Amity, it would seem that the organic matter in the Dayton should have a higher NH_3 , om fixing capacity per unit organic matter than the organic matter in Amity. The data, of course, show the reverse situation to be true.

As previously suggested, the data in table 5 do show a definite difference in the capacity of the organic matter per unit organic matter in the different horizons to fix NH_3 . Whether this difference is a result of the state of oxidation of the organic matter in a particular horizon or the result of a particular mixture of different kinds of organic matter in a given horizon, or both, can not be ascertained from the data here.

Attention should be given to the fact that the data in table 5, column 3 are based on the assumption that the Walkley-Black determination of organic matter is generally a good estimate of the percentage of organic matter in the sample. Some workers have emphasized

that the factor employed by Walkley-Black is erroneously low, especially for subsoil horizons. The data in table 5 seem to justify some doubt as to the accuracy of the Walkley-Black method, at least as applied to these soils. For example, the Nehalem and Chehalis profiles, which have a fairly high organic matter content all the way down the profile, do not show the wide variation in a NH_3 , om fixing capacity per unit organic matter basis that horizons of other soil profiles exhibit. Obviously, the smaller the organic matter content in a particular horizon, the greater any error in the estimate of its content will be magnified in determining the final NH_3 , om fixing capacity on a per unit organic matter basis.

Even if the Walkley-Black method were assumed to yield estimates 30% low for subsoil horizons, the per unit organic matter NH_3 fixing values would be large and would still vary widely between horizons. The conclusion that there is a definite difference in the capacity of organic matter from different horizons to fix NH_3 would still appear valid. Actually, a visual qualitative estimate of the percentage organic matter present in different horizons when compared with the NH_3 , om fixing capacity of the soil for the different horizons could demonstrate this conclusion. For example, one could see and would expect to find more organic matter in the Dayton A₁₁ horizon than in the Dayton B₂₂ horizon. However, the Dayton A₁₁ horizon has an NH_3 , om fixing capacity of 2.41 me/100g as compared to 3.36 me/100g in the Dayton B₂₂.

Certainly the data demonstrate that organic matter plays an important role in fixing NH_3 . It becomes obvious that the organic

fraction as well as the mineral fraction should be considered from the standpoint of NH_3 fixation when applying anhydrous NH_3 . There is definitely a need to study the availability of the NH_3 fixed by the organic fraction of the soil. If this NH_3 fixed by the organic fraction were found to become slowly available, it might well prove to be of considerable residual importance in the application of anhydrous NH_3 .

SUMMARY

Native fixed NH_4 was found to be present in all horizons of ten Oregon soil profiles. Values ranged from 19 ppm N in a Chehalis C horizon to 125 ppm N in a Nehalem A₁₂ horizon.

The mineral fraction of ten Oregon soil profile samples was shown to fix varying amounts of NH_4 applied as $\text{N NH}_4\text{OH}$. Generally, the mineral fraction of the lower horizons in the profiles fixed larger amounts of NH_4 than the surface horizons, although this was not true in all cases. The amount of NH_4 , applied as $\text{N NH}_4\text{OH}$, fixed by the mineral fraction of some Oregon soils under moist conditions ranged from 0 ppm N in the surface horizon of the Aiken series to 695 ppm N in the B₂₂ horizon of the Dayton series.

From 60% to 98% of the applied NH_3 fixed in surface horizons of ten Oregon soils was fixed by the organic fraction of the soil. More than 80% of the NH_3 fixed by the surface horizons of seven of the ten soils was attributable to some reaction of NH_3 with organic matter. Organic matter in subsoil horizons was also shown to fix large quantities of NH_3 .

The mineral fraction of the air dry soils was shown to fix large quantities of anhydrous NH_3 . The NH_3 , m fixing capacities of these soils varied from 20 ppm N fixed in the Aiken B₂₂ horizon to 1015 ppm N fixed in the Nehalem C₃ horizon.

BIBLIOGRAPHY

1. Allison, F. E. Fixed ammonia in soils and its availability to crops. *Agricultural Ammonia News* 8:19-20, 43. Nov.-Dec. 1958.
2. Allison, F. E. and E. M. Roller. A comparison of leaching and distillation procedures for determining fixed ammonium in soils. *Soil Science* 80:349-362. 1955.
3. _____ Fixation and release of ammonium ions by clay minerals. *Soil Science* 80:431-441. 1955.
4. Allison, F. E., J. H. Doetsch, and E. M. Roller. Ammonium fixation and availability in Harpster clay loam. *Soil Science* 72:187-200. 1951.
5. Allison, F. E., M. Kefauver, and E. M. Roller. Ammonium fixation in soils. *Soil Science Society of America, Proceedings* 17:107-110. 1953.
6. Allison, F. E., E. M. Roller, and J. H. Doetsch. Ammonium fixation and availability in vermiculite. *Soil Science* 75:173-180. 1953.
7. Aomine, S. and T. Higashi. Studies on the fixation of ammonium in soils. V. Availability of fixed ammonium to crops. *Journal of Science, Soil, and Manure* 23:105-108. 1953. (Abstracted in *Chemical Abstracts* 47:6079. 1953)
8. _____ Studies on the fixation of ammonium in soils. VI. Nitrification of fixed ammonium. *Journal of Science, Soil, and Manure* 23:185-188. 1953. (Abstracted in *Chemical Abstracts* 47:9536. 1953)
9. Barshad, Isaac. Vermiculite and its relation to biotite as revealed by base exchange reactions, x-ray analyses, differential thermal curves, and water content. *American Mineralogist* 33:655-678. 1948.
10. _____ The effect of interlayer cations on the expansion of the mica type of crystal lattice. *American Mineralogist* 35:235-238. 1950.
11. _____ Cation exchange in soils. I. Ammonium fixation and its relation to potassium fixation and to determination of ammonium exchange capacity. *Soil Science* 72:361-371. 1950.
12. Bower, C. A. Availability of ammonium fixed in difficulty exchangeable form by soils of semi-arid regions. *Soil Science Society of America, Proceedings* 15:119-122. 1950.

13. Bremner, J. M. Determination of fixed ammonium in soil. *Journal of Agricultural Science* 52:147-160. 1959.
14. Bremner, J. M. and T. Harada. Release of ammonium and organic matter from soil by hydrofluoric acid and effect of hydrofluoric acid treatment on extraction of soil organic matter by neutral and alkaline reagents. *Journal of Agricultural Science* 52:137-146. 1959.
15. Chaminade, Raymond. Fixation of ammonium ions in a non-exchangeable form by colloidal clay of soil. *Comptes Rendus Hebdomadaires des Seances de l'Academie des Sciences* 210:264-266. 1940. (Abstracted in *Chemical Abstracts* 34:7509. 1940)
16. Chaminade, Raymond and Gustave Drouineau. The chemical mechanics of exchangeable cations. *Annales Agronomiques publiees sous les auspices du Ministere de l'Agriculture et du Commerce* 6:677-690. 1936. (Abstracted in *Chemical Abstracts* 31:2725. 1937)
17. Dhariwal, A. P. S. and F. J. Stevenson. Determination of fixed ammonium in soils. *Soil Science* 86:343-349. 1958.
18. Dyal, R. S. and S. B. Hendricks. Formation of mixed layer minerals by potassium fixation in montmorillonite. *Soil Science Society of America, Proceedings* 16:45-48. 1952.
19. Hanway, J. J. and A. D. Scott. Ammonium fixation and release in certain Iowa soils. *Soil Science* 82:379-386. 1956.
20. Hanway, J. J., A. D. Scott, and G. Stanford. Replaceability of ammonium fixed in clay minerals as influenced by ammonium or potassium in the extracting solution. *Soil Science Society of America, Proceedings* 21:29-34. 1957.
21. Jenny H., A. D. Ayers, and J. S. Hosking. Comparative behavior of ammonia and ammonium salts in soils. *Hilgardia* 16:429-457. 1945.
22. Legg, J. O. and F. E. Allison. Recovery of N¹⁵ - tagged nitrogen from ammonium-fixing soils. *Soil Science Society of America, Proceedings* 23:131-134. 1959.
23. Leggett, Glen E. Ammonium fixation in soils and minerals. Ph.D. thesis. Pullman, Washington State College, 1958. 85 numb. leaves.
24. Mattson, Sante and Elisaveta Koutler-Andersson. The acid-base condition in vegetation, litter and humus. VI. Ammonia fixation and humus nitrogen. *Lantbrukshogskolans Annaler* 11:107-134. 1943.

25. McBeth, I. G. Fixation of ammonia in soils. *Journal of Agricultural Research* 9:141-155. 1917.
26. Mortland, M. M. Adsorption of ammonia by clays and muck. *Soil Science* 80:11-17. 1955.
27. _____ Reactions of ammonia in soils. *Advances in Agronomy* 10:325-348. 1958.
28. Nommik, Hans. Fixation and defixation of ammonium in soils. *Acta Agriculturae Scandinavica* 7:395-436. 1957.
29. Page, J. B. and L. D. Bayer. Ionic size in relation to fixation of cations by colloidal clay. *Soil Science Society of America, Proceedings* 4:150-155. 1939.
30. Rather, J. B. An accurate loss-on-ignition method for determination of organic matter in soils. Fayetteville, 1917. 16 p. (Arkansas. Agricultural Experiment Station. Technical Bulletin no. 140)
31. Rodriguez, G. Fixed ammonia in tropical soils. *Journal of Soil Science* 5:264-274. 1954.
32. Scott, A. D., J. J. Hanway, and A. P. Edwards. Replaceability of ammonium in vermiculite with acid solutions. *Soil Science Society of America, Proceedings* 22:388-392. 1958.
33. Sohn, S. B. and M. Peech. Retention and fixation of ammonia by soils. *Soil Science* 85:1-7. 1958.
34. Stanford, G. and W. H. Pierre. The relation of potassium fixation to ammonium fixation. *Soil Science Society of America, Proceedings* 11:155. 1947.
35. Stevenson, F. J. Distribution of the forms of nitrogen in some soil profiles. *Soil Science Society of America, Proceedings* 21:283-287. 1957.
36. Stevenson, F. J. and A. P. S. Dhariwal. Distribution of fixed ammonium in soils. *Soil Science Society of America, Proceedings* 23:121-125. 1959.
37. Stevenson, F. J., A. P. S. Dhariwal, and M. B. Choudhri. Further evidence for naturally occurring fixed ammonium in soils. *Soil Science* 85:42-46. 1958.
38. Wear, J. I. and J. L. White. Potassium fixation in clay minerals as related to crystal structure. *Soil Science* 71:1-14. 1951.

39. Zettlemyer, A. C., G. J. Young, and J. J. Chesick. Studies of the surface chemistry of silicate minerals. III. Heats of immersion of bentonite in water. *Journal of Physical Chemistry* 59:962-966. 1955.

APPENDIX

Profile Descriptions of Soils Used

Aiken silty clay loam (Reddish Brown Lateritic Soil, locally called Reddish Brown Latosol.)

Location: NE 1/4, section 10, T. 14S, R. 1W. Bonkowski farm, Linn County, Oregon.

Description by: E. G. Knox, July 26, 1957 in connection with Oregon Agricultural Experiment Station Project 331.

Profile samples collected by: G. Ashcroft, D. L. Carter, R. A. Cattani, A. A. Theisen, and J. L. Young. July 22, 1958.

Site: Soil from basalt, 10% east slope.

<u>Horizon</u>	<u>Depth (in.)</u>	<u>Description</u>
A _p	0-6	Dark reddish brown (5YR 3.5/3) dry, dark reddish brown (5YR 3/2) moist; silty clay loam; weak, very fine sub-angular blocky structure; hard, plastic, and sticky; few, fine soft shot; abrupt, smooth lower boundary.
B ₁	6-15	Dark reddish brown (5YR 2.5/3) moist; silty clay; moderate, very fine sub-angular blocky breaking to moderate, very fine granular structure; slightly hard, friable, very plastic, very sticky; very thin nearly continuous clay flows; clear, smooth lower boundary.
B ₂₁	15-26	Dark reddish brown (4YR 3/4) moist; silty clay; weak, medium and fine sub-angular blocky breaking to moderate, very fine sub-angular blocky structure; friable, very plastic, and very sticky; thin, nearly continuous clay flows; clear, smooth lower boundary.
B ₂₂	26-40	Dark reddish brown (4YR 3/4) moist; silty clay; moderate, coarse sub-angular blocky breaking to moderate, fine angular blocky structure; firm, very plastic, very sticky; common, large black MnO ₂ coatings; thin, continuous clay flows.

Amity silt loam (Gray-Brown Podzolic or Prairie Soil)

Location: SW 1/4, SW 1/4, NW 1/4, section 6, T. 5S, R. 1W. (Hole no. 75 as per J. Pomerening.)

Description by: J. Pomerening, Summer 1957; L. H. Robinson, July 29, 1958.

Profile samples collected by: D. L. Carter, R. A. Cattani, L. H. Robinson, and J. L. Young, July 29, 1958.

Site: Grass waste land, no slope, old alluvium.

<u>Horizon</u>	<u>Depth (in.)</u>	<u>Description</u>
A ₁	0-12	Very dark brown (10YR 2/2) silt loam; strong medium and fine granular structure; slightly sticky, slightly plastic; many roots and concretions.
A ₂	12-20	Very dark grayish brown (10YR 3/2) moist, with very dark gray (10YR 3/1) in worm holes and on some ped surfaces; silt loam; moderate, fine sub-angular blocky structure; very friable, slightly sticky, slightly plastic; many roots and worm holes; very many concretions (looks like mottling), smooth, clear boundary; pH 5.2.
B ₁	20-29	Dark grayish brown (2.5Y 4/2) moist, with common, fine and medium dark yellowish brown (10YR 4/4) mottles, also many concretions with brown streaks; silty clay; weak, medium sub-angular blocky into weak, very fine sub-angular blocky structure; very friable, slightly sticky, slightly plastic; porous and loose; many worm holes, roots, and concretions; smooth gradual boundary; pH 5.3.
B ₂₁	29-37	Dark gray (2.5Y 4/1) moist, with 5 to 10 mm. chunks of dark brown (10YR 3/3) that are connected to one another between worm holes; large chunks of fragipan in lower 5"; silty clay; weak, medium and coarse sub-angular blocky into moderate, very fine sub-angular blocky structure; friable, slightly sticky, slightly plastic; loose and porous; one continuous network of worm holes; some concretions and roots; wavy clear boundary; pH 5.5.

<u>Horizon</u>	<u>Depth</u>	<u>Description</u> (Amity cont.)
C _m	37-41	Dark brown (10YR 3/2.5) and dark grayish brown (2.5Y 4/2) moist (50-50); silt loam; no structure; slightly sticky, slightly plastic; many worm holes with clay flows; few roots; mica conspicuous; pH 6.5; water at 50".

Cascade silt loam (Reddish Brown Lateritic soil with fragipan)

Location: NE 1/4, SW 1/4, section 1, T. 5N, R. 2W. Lloyd farm in Columbia County, Oregon, on alfalfa plots established by T. L. Jackson.

Description by: A. A. Theisen, June 10, 1958.

Profile samples collected by: B. McNeal, J. Yahner, D. Carter, and R. A. Cattani, July 1958.

Site: Cultivated field, on 10% west slope. Imperfectly drained; from loess over water-deposited silts.

<u>Horizon</u>	<u>Depth</u> (in.)	<u>Description</u>
A _p	0-8	Dark yellowish brown (10YR 3/4) moist; silty loam; moderate, very fine sub-angular blocky to fine granular structure; friable, non-sticky, non-plastic; common, spherical concretions (shot); pH 5.4.
A ₃	8-18	Dark yellowish brown (10YR 4/4) moist; silt loam; weak, fine sub-angular blocky structure; friable, slightly sticky, slightly plastic; few shot; pH 5.4.
B ₁	18-27	Yellowish brown (10YR 5/6) moist; silty clay loam with mottles; moderate, fine sub-angular blocky structure; friable, sticky, plastic; common black coatings of manganese dioxide; pH 5.2.
B ₂	27-32	Dark yellowish brown (10YR 4/4) moist; silty clay loam with ped borders of light brownish gray; weak, very coarse prismatic structure; very firm; sticky, plastic; manganese dioxide coatings; pH 5.2.

Chehalis silt loam (Alluvial soil)

Location: NW 1/4, NE 1/2, section 36, T. 11S, R. 5W. Horticulture farm, Linn County, Oregon.

Description by: J. Pomeroy, July 30, 1958.

Profile samples collected by: D. L. Carter, J. Pomeroy and B. McNeal, July 30, 1958.

Site: Maple, ash, poison oak; no slope; from post pleistocene alluvial mixture of igneous and sedimentary materials; well drained.

<u>Horizon</u>	<u>Depth</u> (in.)	<u>Description</u>
A ₁	0-11	Very dark brown (10YR 2/2) moist; silt loam; strong, fine and very fine sub-angular blocky structure; friable, slightly sticky, slightly plastic; numerous, fine (1-2mm.) roots, several large (1-2") tree roots; numerous earthworm holes and casts; distinct wavy horizon boundary.
A ₃	11-18	Very dark grayish brown (10YR 3/2) moist; silt loam; moderate, fine and very fine sub-angular blocky structure; friable, slightly sticky, slightly plastic; common fine roots and numerous worm holes; clear, smooth horizon boundary.
C ₁	18-28	Very dark grayish brown (10YR 3/2) moist on ped surface, dark grayish brown (10YR 4/2) in peds; silt loam; weak, medium sub-angular blocky to moderate, very fine and fine sub-angular blocky structure; friable, slightly sticky, slightly plastic, common fine roots; numerous, fine worm holes, common, large verticle worm channels; clear, gradual horizon boundary.
C	28-48	Very dark grayish brown (10YR 3/2) moist on ped surface, dark grayish brown (10YR 4/2) in peds; silt loam; weak, very fine and fine sub-angular blocky structure; friable, slightly sticky, slightly plastic (very smooth); common, large (2-5mm.) verticle worm holes; few, fine roots below 36".

Dayton silt loam (Planosol)

Location: SE 1/4, SE 1/4, SW 1/4, section 8, T. 13S, R. 4W, about 800 feet E of road intersection at Peoria, Linn County, Oregon, about 60 feet N of the road.

Description by: E. Knox, May 21, 1959.

Profile samples collected by: E. G. Knox and J. L. Young, May 21, 1959.

Site: Abandoned field or pasture, with grass, rose and weeds; level, poorly drained, from old, silty, water deposited material (Willamette silts).

<u>Horizon</u>	<u>Depth (in.)</u>	<u>Description</u>
A ₁₁	0-3	Dark gray (10YR 4/1) moist; silt loam with common, fine, distinct reddish mottles; moderate, very fine sub-angular blocky structure; friable, slightly plastic, slightly sticky; abundant roots; common, fine interstitial pores; few dark concretions (2-4 mm.); lower boundary abrupt and smooth; pH 5.0.
A ₁₂	3-9	Dark gray (10YR 4/1) moist; silt loam with common, medium, distinct reddish mottles; weak, fine sub-angular blocky structure; friable, slightly plastic, slightly sticky; common roots; few, fine tubular pores; few concretions (1-2 mm.); lower boundary abrupt and smooth; pH 5.0.
A ₂	9-18	Gray (10YR 5/1) moist; silt loam with common, medium, distinct mottles; weak, medium sub-angular blocky structure; friable, slightly plastic, slightly sticky; few roots; common, fine and medium tubular pores; common concretions (1-2mm.) with a concentration at the upper boundary; lower boundary abrupt and wavy; pH 5.0.
B ₂₁	18-30	Gray (2.5Y 5/1) moist; clay with few, faint, fine mottles; weak, very coarse prismatic breaking to weak, very fine angular blocky structure; very plastic, very sticky; very few roots; common, very fine tubular pores; common, thin clay skins; common, spherical black concretions; lower boundary diffuse and smooth; pH 5.4.

Dayton silt loam (cont.)

<u>Horizon</u>	<u>Depth</u> (in.)	<u>Description</u>
B ₂₂	30-40	Grayish brown (2.5Y 4.5/2) moist; clay or silty clay with common, fine, distinct mottles; weak, very coarse sub-angular blocky structure; very plastic, very sticky; few, very fine tubular pores; common, thin clay skins; common concretions (1-2 mm.); lower boundary diffuse and smooth; pH 6.6.
Deep	40-52	Olive brown (2.5Y 4/3) moist; silty clay loam with common, medium, distinct mottles; very weakly platy structure; firm, plastic, sticky; common, fine and very fine tubular pores; few, clay skins; common, small black coatings of manganese dioxide; pH 7.0.

Nehalem silt loam (Alluvial soil)

Location: NW 1/4, SW 1/4, section 5, T. 2S, R. 9W, SW corner of the enclosure of the Nehalem soil fertility plots established on the Tillamook Naval Air Base, Tillamook County, Oregon, by T. L. Jackson, E. Jenne and others.

Description by: E. G. Knox, L. H. Robinson and C. Bowlsby, March 27, 1958.

Profile samples collected by: R. A. Cattani and L. H. Robinson, August 1958.

Site: Silt from recent silty alluvium on the flood plain of the Trask River. Well drained on less than 1% slope.

<u>Horizon</u>	<u>Depth (in.)</u>	<u>Description</u>
A _{1p}	0-9	Dark yellowish brown (10YR 3/4) moist, brown (10YR 5/3) dry; silt loam (but almost silty clay loam); strong, fine and very fine sub-angular blocky structure; friable, slightly sticky, slightly plastic; abundant roots; abundant, fine and very fine interstitial pores; lower boundary clear and smooth; pH 5.2.
A ₁₂	9-17	Dark yellowish brown (10YR 3.5/4) moist; silt loam (but almost silty clay loam); moderate, medium prismatic breaking to strong, fine sub-angular blocky structure; friable, slightly sticky, slightly plastic; abundant roots; abundant, fine and tubular pores, few, medium and coarse tubular pores; coatings on peds and pores are dark yellowish brown (10YR 3/4); lower boundary, gradual and smooth; pH 5.4.
AC	17-36	Dark yellowish brown (10YR 3.5/4) moist; silty clay loam; moderate, coarse prismatic breaking to strong, medium sub-angular blocky structure; friable, plastic, sticky; common roots, abundant, fine tubular pores; lower boundary gradual and smooth; pH 5.6.
C ₃	36-54	Dark yellowish brown (10YR 3.5/4) moist; silty clay loam; weak, coarse prismatic breaking to moderate, fine and medium sub-angular blocky structure; friable, plastic, sticky; few roots; abundant, fine and very fine tubular pores, few, medium and coarse tubular pores; few, faint fine mottles; pH 5.6.

Steiner silt loam (Prairie or Gray-Brown Podzolic soil)

Location: NE 1/4, NW 1/4, section 33, T. 12S, R. 5W, 1/4 mile W of Corvallis near OSC turkey pens.

Description by: C. Bowsby and C. Olds, July 17, 1958.

Profile samples collected by: D. L. Carter, R. A. Cattani, L. H. Robinson, and J. L. Young, July 17, 1958.

Site: Oak, wildrose, grasses, and weeds; 15% slope, west exposure, and slight erosion; a well drained residual soil developed from shale.

<u>Horizon</u>	<u>Depth (in.)</u>	<u>Description</u>
A ₁	0-5	Pale brown (10YR 6/3) dry, brown (10YR 4/3) moist; silt loam; moderate, fine sub-angular blocky structure; friable, slightly hard; non sticky, non plastic; few, fine pores; gradual horizon boundary; pH 6.0.
A ₃	5-10	Pale brown (10YR 6/3) dry, brown (10YR 4/3) moist; silt loam; strong, fine sub-angular blocky structure; non sticky, non plastic, friable, slightly hard; few, fine and some large pores; diffuse smooth horizon boundary; pH 6.0.
B ₁	10-19	Dark yellowish brown (10YR 4/4) moist; silty clay loam; strong, medium sub-angular blocky structure; slightly sticky, slightly plastic, friable, hard; few, fine tubular pores; thin, patchy clay flows; clear and smooth horizon boundary; pH 5.8.
B ₃	19-32	Dark brown (7.5YR 4/4) moist; silty clay; strong, medium sub-angular blocky structure; sticky, plastic, firm, hard; few, large tubular pores; few, fine patchy clay flows; clear and wavy horizon boundary; pH 5.8.
D _r	32	Bedrock

Tillamook silt loam (Ando like)

Location: NW 1/4, SW 1/4, section 8, T. 2S, R. 9W; SW corner of the enclosure of the Tillamook soil fertility plots established on the Tillamook Naval Air Base, Tillamook County, Oregon by T. L. Jackson, E. Jenne and others.

Description by: E. G. Knox and L. H. Robinson, March 26, 1958.

Profile samples collected by: R. A. Cattani, L. H. Robinson, August 1958.

Site: Soil from silty alluvium on a broad terrace above the present flood plain. Well drained and level.

<u>Horizon</u>	<u>Depth</u> (in.)	<u>Description</u>
A _{1p}	0-7	Black (10YR 1/2) moist; silt loam; moderate, fine and very fine sub-angular blocky structure; friable, slightly sticky, slightly plastic; abundant roots; abundant, fine and very fine interstitial pores; lower boundary abrupt and smooth.
A ₁₂	7-16	Black (10YR 1/2) moist; silt loam; strong, medium and fine sub-angular blocky structure; friable, slightly plastic, slightly sticky; abundant roots; abundant, fine and very fine interstitial pores; lower boundary clear and wavy.
C	50-60	Dark yellowish brown (10YR 3/4) moist; silty clay loam; moderate, medium to very fine sub-angular blocky structure; friable, plastic, sticky; few roots; abundant, fine and very fine tubular pores, few, medium and coarse tubular pores; few rounded pebbles.

Walla Walla silt loam (Chestnut soil)Location: Section 20, T. 1S, R. 17E; 2 1/2 mi. S & E of Moro.Description by: L. H. Robinson, August 1958.Profile samples collected by: L. H. Robinson, R. A. Cattani, Aug. 1958.Site: Crested wheatgrass, cheat and blue-bunch grass. Soil from loess, 8% NE slope, gently sloping upland, moderate permeability, well drained; semiarid climate, 13"/yr. moisture, 1800' elevation. Reduced iron around root channels, mycelia shaped lime along root channels.

<u>Horizon</u>	<u>Depth (in.)</u>	<u>Description</u>
A _{1p}	0-7	Very dark grayish brown (10YR 3/2) moist; very fine sandy loam or loam; weak, medium platy structure; friable, slightly sticky, slightly plastic; abundant roots; abrupt, smooth lower boundary; pH 6.5.
A ₁₂	7-13	Very dark grayish brown (10YR 3/2) moist; very fine sandy loam or loam; weak, coarse prismatic structure; friable, slightly sticky, slightly plastic; abundant roots; abrupt, smooth lower boundary; pH 6.6.
AC	13-23	Dark brown (10YR 3.5/3) moist; silt loam; weak, coarse prismatic and weak, medium coarse sub-angular blocky structure; friable, slightly sticky, slightly plastic; plentiful roots; gradual, smooth lower boundary; pH 6.6.
AC ₂	23-47	Dark brown (10YR 4/3) moist; silt loam; same characteristics as AC except has many fine pores; pH 6.8.
Cca ₁	47-57	Dark brown (10YR 4/3) moist; silt loam; massive structure; friable, slightly sticky, slightly plastic; many fine pores; coarse, sand-size basalt fragments; diffuse, smooth lower boundary; pH 8.3.
Cca ₂	57	Dark brown (10YR 4/3) moist; silt loam; same characteristics as horizon above except pH 8.2.

Willamette silt loam (Prairie soil)

Location: NW 1/4, NW 1/4, NE 1/4, section 16, T. 13S, R. 4W; at an old farmstead about 1 1/2 miles E of Peoria, Linn County, Oregon.

Description by: E. G. Knox, May 21, 1959.

Profile samples collected by: E. G. Knox and J. L. Young, May 21, 1959.

Site: At edge of a cultivated field; level, well drained from old, silty, water-deposited material (Willamette silts).

<u>Horizon</u>	<u>Depth</u> (in.)	<u>Description</u>
A _p	0-6	Very dark brown (10YR 2.5/2) moist; silt loam; strong, medium and fine sub-angular blocky structure; friable, plastic, slightly sticky; abundant roots; abundant, coarse to very fine tubular and interstitial pores; lower boundary abrupt and smooth; pH 5.6.
B ₁₁	6-16	Very dark grayish brown (10YR 3/2) moist; silty clay loam with very dark brown coatings; moderate, medium and fine sub-angular blocky structure; friable, plastic, sticky; common roots; common, medium and coarse, and abundant, fine and very fine tubular pores between the peds; lower boundary clear and smooth; pH 6.0.
B ₁₂	16-30	Dark yellowish brown (10YR 3/4) moist; silty clay loam; moderate, medium sub-angular blocky breaking to weak, fine sub-angular blocky structure; friable, plastic, very sticky; common roots; abundant, fine and very fine tubular pores; abundant, thin clay skins (10YR 3/3); lower boundary clear and wavy; pH 5.8.
B ₂	30-46	Brown (10YR 4/3) moist; silty clay loam; moderate, coarse angular blocky structure; firm, plastic, sticky; few roots; abundant, fine and very fine tubular pores; abundant clay skins (10YR 3/3); lower boundary diffuse and smooth; pH 5.6.
C	46-56	Brown (10YR 4/3) moist; silty clay loam; weak, very coarse sub-angular blocky structure; firm and friable, plastic, sticky; few roots; few, medium and common, fine tubular pores; few, thin clay skins on peds and few, thick ones in vertical pores; few manganese dioxide coatings; pH 6.0.

Table 6

Lab Characterization of Soils Used

Soil	Horizon	Depth inches	Organic ¹ Matter %	Clay ² %	Silt ² %	Sand ² %	CEC ³ me/100g	Ex. Ca, ³ Mg, K, & Na me/100g	Moisture Air Dry %	pH 1:1
Aiken	A _p	0-6	6.11	63	28	9	23.9	9.4	4.3	5.3
	B ₁	6-15	4.33	66	26	8	24.0	9.3	4.6	5.4
	B ₂₁	15-26	2.82	70	23	7	21.4	8.8	4.5	5.2
	B ₂₂	26-40	0.94	75	20	5	19.8	8.1	4.6	5.3
	Deep	52-72	0.29	76	19	5	21.9	7.0	4.5	5.3
Amity	A ₁	0-12	4.58	29	48	23	16.1	7.6	2.8	4.9
	A ₂	12-20	0.90	29	47	24	20.2	9.4	2.4	5.1
	B ₁	20-29	0.15	28	53	19	18.0	15.9	2.9	5.4
	B ₂₁	29-37	0.33	26	50	24	22.7	22.4	4.0	5.5
	C _m	37-41	0.19	23	39	38	22.8	22.8	4.0	5.7
	C	41	0.19	20	55	25	23.9	25.3	4.2	6.1

¹ Walkley, A. and I. A. Black. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37:29-38. 1934.

² Kilmer, Victor J. and Lyle T. Alexander. Methods of making mechanical analyses of soils. Soil Science 68:15-24. 1949.

³ Schollenberger, C. J. and R. H. Simon. Determination of exchange capacity and exchangeable bases in soils - ammonium acetate method. Soil Science 59:13-24. 1945.

Table 6 (cont.)

Lab Characterization of Soils Used

Soil	Horizon	Depth inches	Organic Matter %	Clay %	Silt %	Sand %	CEC me/100g	Ex. Ca, Mg, K, & Na me/100	Moisture Air Dry %	pH 1:1
Cascade	A _p	0-8	4.35	20	52	28	16.4	5.7	2.6	5.4
	A ₃	8-18	1.27	23	49	28	11.6	4.7	2.6	5.4
	B ₁	18-27	0.31	21	55	24	11.6	6.3	2.3	4.9
	B ₂	27	0.17	23	56	21	15.0	12.0	2.7	5.0
Chehalis	A ₁	0-11	6.65	35	62	3	38.7	32.3	4.5	5.8
	A ₃	11-18	2.03	32	62	6	31.2	26.8	4.5	6.0
	C ₁	18-28	1.70	30	57	13	29.0	26.1	4.4	6.1
	C	28	1.38	27	60	13	28.1	26.1	4.2	5.9
Dayton	A ₁₁	0-3	6.60	19	78	3	16.1	7.5	2.0	4.8
	A ₁₂	3-9	2.16	21	76	3	12.7	6.0	1.7	4.9
	A ₂	9-18	0.70	25	72	3	12.6	7.7	1.8	5.0
	B ₂₁	18-30	0.70	52	47	1	33.7	28.0	5.3	5.2
	B ₂₂	30-40	0.40	43	54	3	33.5	31.5	5.4	5.9
	Deep	40	0.32	28	69	3	28.6	28.2	4.5	6.4
Nehalem	A _{1p}	0-9	8.34	38	57	5	53.7	35.0	7.2	5.3
	A ₁₂	9-17	3.68	38	57	5	50.6	37.5	7.4	5.5
	AC	17-36	3.52	35	58	7	48.7	35.7	7.3	5.5
	C ₃	36-54	2.19	32	59	9	50.5	38.1	7.3	5.6

Table 6 (cont.)

Lab Characterization of Soils Used

Soil	Horizon	Depth inches	Organic Matter %	Clay %	Silt %	Sand %	CEC me/100g	Ex. Ca, Mg, K, & Na me/100	Moisture Air Dry %	pH 1:1
Steiwer	A ₁	0-5	3.16	31	49	20	19.8	15.5	2.6	5.4
	A ₃	5-10	2.32	30	47	23	18.5	15.6	2.7	5.4
	B ₁	10-19	1.33	33	48	19	18.8	15.5	2.9	5.4
	B ₃	19-32	0.58	38	43	19	22.8	18.4	3.7	4.9
	D _r	32	0.17	45	43	12	32.6	23.7	5.6	4.6
Tillamook*	A _{1p}	0-7	20.80						8.1	4.7
	A ₁₂	7-16	15.29						7.6	4.7
	C	50-60	1.59						6.1	4.7
Walla Walla	A _{1p}	0-7	1.97	13	46	41	12.4	11.2	1.6	6.6
	A ₁₂	7-13	0.94	12	44	44	11.7	10.6	1.4	6.6
	AC	13-23	0.46	14	56	30	12.3	11.5	1.6	7.0
	AC ₂	23-47	0.22	10	58	32	13.3	13.5	1.6	7.4
	Cca ₁	47-57	0.11	8	59	33	14.1	18.6	1.8	8.1
	Cca ₂	57	0.11	6	62	32	14.7	20.9	1.9	8.1
Willamette	A _p	0-6	6.56	27	71	2	22.9	22.3	2.3	5.2
	B ₁₁	6-16	2.53	28	70	2	17.6	14.0	1.9	5.6
	B ₁₂	16-30	1.20	27	69	4	15.1	11.8	1.9	5.5
	B ₂	30-46	0.29	33	64	3	25.8	21.5	3.9	5.7
	C	46-56	0.25	28	69	3	23.9	22.3	3.8	5.7

* Missing analyses were not determined for the Tillamook profile samples.

Table 7
Relationships of Soils Used
with Respect to Parent Material and Annual Rainfall

	Annual Rainfall (inches)				
Soils formed from:	12	40	45	50	90
Recent silty alluvium		Chehalis			Nehalem
Water-deposited silts: well drained		Willamette			Tillamook
imperfectly drained		Amity			
poorly drained		Dayton			
Loess	Walla Walla			Cascade	
Residuum and colluvium from basalt			Aiken		
from sedimentary rock			Steiwer		