



Studies of nitrogen losses from fertilized Bowdoin clay soil
by Gilbert Schumaker

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree
of Master of Science in Soils

Montana State University

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Abstract:

Nitrogen losses from Bowdoin clay were studied in the greenhouse. Nitrogen uptake in barley was used as an indicator of nitrogen loss in ammonium and nitrate forms by applying these sources to the clay soil and allowing the barley to mature.

Two greenhouse experiments were conducted applying nitrogen sources to Bowdoin clay. Nitrogen materials were applied on the soil surface at four rates with two levels of moisture in the first experiment. More than 50% of the applied nitrogen was recovered from the nitrate source treatment. Nitrogen recovery from the ammonium-treated pots was much less—15 to 20%. Differences were noted in the application of nitrogen at different rates; no differences were noted between moisture treatments.

The nitrogen materials were mixed with the soil in a second experiment to observe the effect of placement on nitrogen uptake, again assuming nitrogen uptake to be an indicator of nitrogen loss. Results showed a recovery of 80 to 90% of the applied nitrogen.

Nitrogen loss in the ammoniacal form was measured from Bowdoin clay in the laboratory. The clay soil has the ammonium-fixing capacity of 8 meq. per 100 gm. of soil, much larger than in most soils. Some volatilization of ammonia was measured; however, the amounts measured were small, with the largest loss being 7% of the nitrogen applied.

These determinations do not necessarily account for all the ammonium source loss measured in the greenhouse experiment with nitrogen application on the soil surface. It is possible that some of the ammonium nitrogen became positionally unavailable.

It was shown in these studies that losses from the surface application of the ammonia source of nitrogen can be overcome by the surface application of the nitrate source or by deeper placement of any of the fertilizer materials studied.

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FERTILIZED BOWDOIN CLAY SOIL

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GILBERT SCHUMAKER

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ABSTRACT

Nitrogen losses from Bowdoin clay were studied in the greenhouse. Nitrogen uptake in barley was used as an indicator of nitrogen loss in ammonium and nitrate forms by applying these sources to the clay soil and allowing the barley to mature.

Two greenhouse experiments were conducted applying nitrogen sources to Bowdoin clay. Nitrogen materials were applied on the soil surface at four rates with two levels of moisture in the first experiment. More than 50% of the applied nitrogen was recovered from the nitrate source treatment. Nitrogen recovery from the ammonium-treated pots was much less--15 to 20%. Differences were noted in the application of nitrogen at different rates; no differences were noted between moisture treatments.

The nitrogen materials were mixed with the soil in a second experiment to observe the effect of placement on nitrogen uptake, again assuming nitrogen uptake to be an indicator of nitrogen loss. Results showed a recovery of 80 to 90% of the applied nitrogen.

Nitrogen loss in the ammoniacal form was measured from Bowdoin clay in the laboratory. The clay soil has the ammonium-fixing capacity of 8 meq. per 100 gm. of soil, much larger than in most soils. Some volatilization of ammonia was measured; however, the amounts measured were small, with the largest loss being 7% of the nitrogen applied.

These determinations do not necessarily account for all the ammonium source loss measured in the greenhouse experiment with nitrogen application on the soil surface. It is possible that some of the ammonium nitrogen became positionally unavailable.

It was shown in these studies that losses from the surface application of the ammonia source of nitrogen can be overcome by the surface application of the nitrate source or by deeper placement of any of the fertilizer materials studied.

INTRODUCTION

The purpose of this dissertation is to discuss the type of nitrogen loss or losses which occur in Bowdoin clay as investigated in the laboratory and greenhouse.

Nitrogen recovery data from native hay experiments on Bowdoin clay¹ have indicated that only a small portion of the nitrogen applied is recovered by the hay crop. While crops respond very favorably to nitrogen application on the Bowdoin clay soil, not more than 30% of the nitrogen applied is recovered the year of application. Experiments have shown that only a small percentage of the nitrogen not utilized the year of application is taken up by the crop in following years. Thus it appears that the nitrogen not recovered in plant material is lost or becomes unavailable for crop use. Losses of volatile forms of nitrogen and the fixation of ammonium are possible causes.

With the increased use of nitrogen fertilizers and with applications at higher rates becoming more common, attention must be given to the factors responsible for these losses which impair the efficiency of nitrogen use.

Since nitrogen losses, believed to occur here, are either in the form of ammoniacal or nitrate nitrogen, one approach used in this investigation was to measure the nitrogen uptake by plants treated with these sources of nitrogen under greenhouse conditions. The form of nitrogen loss occurring could then be determined, since a reduction of the nitrogen supply

¹U. S. Department of Agriculture, Agricultural Research Service, Western Soil and Water Management Research Branch, Milk River Annual Report, 1957.

in the soil due to loss would be reflected in a reduction of nitrogen uptake by the plant.

Greenhouse experiments with barley were conducted in two phases. Nitrogen applications were on the surface in the first greenhouse experiment. Following this experiment, a comparison of nitrogen uptake by barley was made when various sources of nitrogen were mixed with the soil.

In order to verify conclusions drawn from greenhouse experiments, quantitative measurements of nitrogen loss by ammonia volatilization and ammonium fixation were then made in the laboratory to determine the importance of these forms of nitrogen losses.

Studies of the types of nitrogen losses which occur from Bowdoin clay will be helpful in finding a means of reducing nitrogen loss, resulting in greater nitrogen economy and increased productivity.

REVIEW OF LITERATURE

From the reservoir of soil nitrogen, there is a continual removal and return of nitrogen during the course of the nitrogen cycle. Black (1957) has explained the addition and removal of nitrogen from this reservoir quite fittingly: "Over each annual cycle, some nitrogen is mineralized, and some is immobilized. Some is removed by plants, and some is returned in the form of plant residues. Some is lost to the atmosphere, and some is returned. Some may be lost by leaching and some added by fertilization. Some may be lost by erosion or added by deposition."

This addition and removal of nitrogen from the soil has been discussed by Allison (1955). He refers to the nitrogen balance sheets of a number of long-term experiments and shows the total nitrogen additions and losses during the course of these experiments. Even when an account was made of nitrogen lost by leaching and erosion, all the nitrogen added could not be accounted for. It appears that the only adequate explanation of these negative balances is nitrogen loss by the volatilization of various forms of nitrogen and by the fixation of the ammonium ion, rendering it unavailable in the soil.

Early investigations indicated that some of the nitrogen applied to the soil was lost in some form; however, nitrogen fertilizers were not applied in large quantities. At that time, refined methods of measuring small losses occurring at slow rates had not been developed. Since these losses, which were believed to occur, could not be measured, it was concluded that they did not reach significant proportions.

It is, however, recognized today that these previously unexplored losses can reach significant proportions, particularly where nitrogen is applied in large quantities.

It is not likely that nitrogen is leached from Bowdoin clay since the depth of water penetration in this soil is about 30 inches. This form of loss will not be reviewed.

Forms of nitrogen loss which will be reviewed are: the fixation of ammonium, the volatilization of ammonia, and the loss of elemental nitrogen through denitrification. While the fixation of ammonium is not a loss in a strict sense, it is difficult to reclaim and is not immediately available for crop growth.

Nitrogen Loss by Ammonium Fixation

The property of certain soils to change added ammonium into a non-exchangeable state is termed ammonium fixation. Leggett² describes fixed ammonium as "ammonium which is entrapped between two adjacent mineral plates, presumably in the voids formed by the hexagonal oxygen rings in the oxygen layers of some silicate minerals. The entrapment 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. It is assumed that fixed NH_4 is present in minerals in a position similar to that of K in micas."

McBeth (1917) was one of the earlier workers who noted the occurrence of ammonium fixation. He observed that ammonium salts added to soils could

²Leggett, Glen E. Ammonium fixation in soils and minerals. Doctor of Philosophy thesis, State College of Washington, Pullman, p. 2. 1958.

not always be reclaimed from the soil in the same quantity that had been added. In studies reported in 1917, he treated several soils with ammonium salts but was able to reclaim no more than 95% of the amount added. He described this loss as ammonium fixation.

Allison et al. (1953a and 1953b), in their work on ammonium fixation, reported values of less than 1.0 meq. per 100 gm. of soil for non-kaolinitic soils. Kaolinitic soils do not have the capacity to fix ammonium. It was also shown that, on drying the ammonium treated soils, the amount of ammonium fixed was almost doubled. Leggett³ determined the ammonium-fixing capacities of 30 surface soils and found that eight of these soils had ammonium-fixing capacities greater than 0.5 meq. per 100 gm. of soil under moist conditions. Ammonium fixation in New York soils was studied by Sohn and Peech (1958). They found the capacity of most of these soils to fix ammonium to be below 1.0 meq. per 100 gm. However, values as high as 5.0 meq. per 100 gm. of soil were measured in some soils containing average amounts of organic matter. It was also noted that about half of the ammonium fixed was due to soil organic matter. They investigated the ammonium-fixing capacity of several soils high in organic matter and found considerably larger ammonium-fixing capacities in these soils. They suggest that the ammonium combines chemically with certain organic fractions in the soil. Allison et al. (1953b), on the other hand, estimate that subsoils fix about four times as much ammonium as do surface soils. This would indicate that subsoils contain a larger

³Ibid., p. 52.

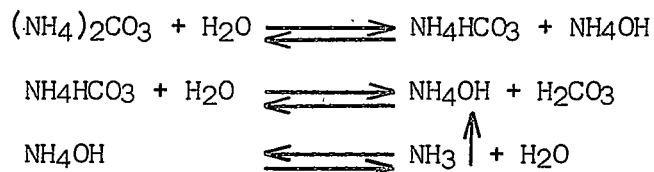
quantity of ammonium-fixing clay minerals or the ammonium-fixing capacity of the soil surface has been neutralized as a result of ammonium release by decomposing organic matter. They also compared ammonium fixation of soils high in certain clay minerals under both moist and dry treatments. Their data shows that both illite and vermiculite clay minerals fix ammonium under moist conditions, while montmorillonite fixes ammonium upon drying. This explains the increased ammonium fixation following the drying of some ammonium-treated soils.

The findings of these workers can be summarized. The ammonium ion is fixed by certain clay minerals present in soils. The amount of ammonium fixed depends on the amount of clay minerals present in the soil that have the ability to fix ammonium ions. The amount of fixation is also dependent on the moisture condition to which the soil is subjected when montmorillonitic clay minerals are present. Some of the ammonium added to soils also becomes unavailable due to its combination with certain organic substances in the soil.

Volatilization of Ammonia

Loss of ammonia through the volatilization of this gas is another type of nitrogen loss from the soil.

Wahhab (1957) proposes that the loss occurs as a result of the evaporation of ammonia and water vapor together. It is known that, in an alkaline soil, ammonia is present in the following forms which are readily changed to free ammonia which is subject to loss as a gas:



He proposes that the above equilibrium exists in the soil solution between these compounds as shown. Ammonium ions continue to exist in the soil solution as long as there are ammonium ions on the exchange complex. Then the ammonium ion supplied to the soil solution by the exchange complex becomes a part of these equilibrium reactions, and free ammonia can be evolved as long as there are ammonium ions on the exchange complex. Wahhab (1957) explains that ammonia and water vapor exert their own partial pressures and evaporate together in proportions which depend upon their molar concentrations. As the concentration of ammonia is increased, larger amounts of ammonia will be volatilized.

Work by Jewitt (1942) gives evidence that the cation exchange capacity is also a factor influencing the loss of ammonia into the air. Loss of ammonia occurs more rapidly in soils low in exchange capacity. He explains the relation of cation exchange to ammonia loss: "The base exchange tends to maintain the concentration of ammonia in solution at a constant level". Soils high in cation exchange can build up a high reserve of ammonium ions and maintain a constant concentration in the soil solution for a considerable length of time. Soils low in cation exchange capacity cannot hold a large reserve of ammonium ions and the rate of loss is not maintained at a constant level. Such soils would be comparable to a dilute solution of ammonium hydroxide, in which the ammonium content declines progressively as evaporation occurs.

Jewitt (1942) and Wahhab (1957) have reported volatile losses of ammonia from ammonium sulfate applications. Losses were found to vary with the soil pH. Both observed considerable losses from alkaline soils. Wahhab (1957) showed that a reduction of the soil pH from 8.4 to 7.3 greatly reduced the ammonia volatilized, while a further lowering of the soil pH to 5.4 resulted in no loss of ammonia.

Martin and Chapman (1951) also measured substantial losses of ammonia from alkaline soils. In this connection, they found that nitrogen applications which raised the soil pH permitted volatile losses of ammonia to occur. They concluded that losses from alkaline soils could be reduced by the use of neutral or acid ammonium fertilizers. A solution of ammonium sulfate has an acid pH. The alkaline forms of ammonia are anhydrous ammonia, aqueous ammonia, and ammonium carbonate, a product of the hydrolysis of urea. This occurs by the reaction of urea and water in the presence of urease, an enzyme produced by soil bacteria. This is discussed by Conrad (1940).

Gibson (1930) investigated the decomposition of urea in soils of a wide range of characteristics. Since none of the soils was slow to transform urea into ammonium, it was concluded that the hydrolysis was due to the enzyme activity of urease.

Jewitt (1942) and Wahhab (1957) both showed that nitrogen loss, as ammonia, increases with an increase in the concentration of ammonium salts. Wahhab (1957) found that 6.8% of a 25-mgm. application to a sandy loam soil was lost as ammonia, while 13.4% of a 100-mgm. application was lost.

Measurements of ammonia loss by volatilization on Putman silt loam were conducted by Wagner and Smith (1958). They found that the loss of ammonia from urea applications was most rapid at the time when the ammonium ion was at its maximum concentration. The rate of loss increased as more urea was transformed into ammoniacal nitrogen, then decreased as more of the ammonium was nitrified into nitrate nitrogen.

Wahhab (1957) demonstrated that larger losses of ammonia occurred from a sandy soil than from a sandy loam. This emphasizes the effect of texture on losses by volatilization of ammonia.

Wahhab (1957) and Jackson and Chang (1947) both report that ammonia losses can be reduced or eliminated by the placement of the ammonium salt below the soil surface.

The relationship of ammonia loss to moisture loss was investigated by Jewitt (1942). He found that ammonia continued to be volatilized as long as evaporation occurred.

Losses by Denitrification

The loss of nitrogen in the elemental form from the soil through the reduction of nitrate nitrogen is termed denitrification. Bremner and Shaw (1958) define denitrification as "the microbial process whereby nitrate is reduced to gaseous compounds such as nitrous oxide and nitrogen".

Denitrification has not been considered a serious loss or thought to be responsible for the loss of significant amounts of nitrogen in well-drained soils, since denitrification is usually thought to occur only under anaerobic conditions. However, Broadbent (1951) published results which showed serious nitrogen losses under aerobic conditions. He found

that a sandy loam soil containing 1,290 p.p.m. of total nitrogen and 64 p.p.m. of nitrate nitrogen lost 250 p.p.m. of nitrogen in 7 days under incubation.

The work of Lowenstein et al. (1957) showed that denitrification takes place in soils under conditions similar to those found in the field. Their greenhouse studies with cropped and uncropped soils resulted in large losses under different nitrogen source treatments. The possibility of denitrification occurring under anaerobic conditions was not ruled out, however. It was pointed out that, despite the fact that these experiments were carried out under good aeration, a soil may possess oxygen-poor areas which could result in denitrification.

In a study of the denitrification in eight Missouri soils, Wagner and Smith (1958) found that the largest losses occurred in the Weldon silt loam, while the Sharkey clay showed losses most consistently from the different nitrogen sources applied. They attributed these losses to denitrification.

Regarding the effect of soil pH on denitrification, the work of Bremner and Shaw (1958) showed that pH does have an effect. Significant losses of nitrogen occurred in soils above pH 5.0. They also showed that soil temperature was a factor affecting denitrification. The results showed that denitrification increased rapidly with a rise in temperature up to 25° C. It was found that nitrogen loss occurred most rapidly at 60° C. but that denitrification was inhibited at a temperature of 70° C.

Losses from Nitrite Nitrogen

In addition to the loss of nitrogen gas by means of denitrification, Wahhab and Uddin (1954) studied the possible occurrence of nitrogen loss

as a result of the interaction of the ammonium (NH_4^+) ion with the nitrite (NO_2^-) ion. An interaction was found at higher concentrations of these two ions under desiccation with the resulting loss of nitrogen gas. Without high concentrations, loss occurred through the volatilization of the individual compounds of these two ions. Loss through the interaction of these two ions was significant in highly alkaline soils of pH 10; however, the direct loss of ammonia gas and the loss from spontaneous decomposition of the nitrous ion were of greater significance in the lower alkaline range than was the interaction of the two compounds.

Nitrogen loss measured from the decomposition of the nitrite ion on desiccation is of interest, however. Madhok and Uddin (1946) also report this type of loss. It may be of significance in some soils. Caster et al. (1942) report that ammoniacal nitrogen applied to certain alkaline desert soils was oxidized only to the nitrite stage. Waksman (1952), in his discussion of nitrification, lists the oxidation of ammonium to nitrite as the first link in the formation of nitrate by certain autotrophic bacteria. With incomplete nitrification, losses could occur from the nitrite formed if conditions were ideal for the spontaneous decomposition of nitrite. Wahhab and Uddin (1954) felt that loss through this mechanism might be important in some soils. Morrill and Dawson⁴ studied the nitrification pattern when soils were perfused with ammonium sulfate. Above pH 7.2, it was found that Nitrobacter, the

⁴Morrill, L. G., and Dawson, J. E. An explanation of the nitrification patterns observed when soils are perfused with ammonium sulfate. *Agronomy Abstracts*, 1958, p. 15.

organism which completes the nitrification of ammonia to nitrate, goes through a lag phase, while Nitrosomonas, the nitrite-producing bacteria, proliferate rapidly. The lag was attributed to soil pH.

The discussion of the work of others presented in the foregoing review gives evidence that nitrogen losses can occur in soils in a significant proportion to warrant steps which will reduce losses.

MATERIALS AND METHODS

Greenhouse Experiments

A bulk sample of Bowdoin clay was taken from the surface at a selected site and brought into the greenhouse, where it was crushed finely enough to pass through a 4-mm. sieve. After thoroughly mixing the sieved soil, pots measuring $6\frac{1}{2}$ inches in diameter and $9\frac{1}{2}$ inches in height were filled with 4 kgm. of air-dry soil.

A treatment of 570 mgm. of treble superphosphate was mixed with the soil. This was equivalent to 100 pounds of P_2O_5 per acre based on the surface area of the pot.

Each pot was seeded with 20 kernels of barley, the pots being thinned to 10 plants per pot on emergence of the seedlings. The pots were seeded previous to the application of the nitrogen and watering of the pots since the clay soil is very difficult to handle when it is wet. One-half of the water required to bring the soil to field capacity was then added. The various concentrations of nitrogen sources were added at the soil surface in solution form as measured by a 25-cc. volumetric pipette. These treatments are listed in table I. Following the nitrogen treatment, the remaining water required to bring the soil to field capacity was added. Urea was used as the ammonium source since ammonia would not be lost into the air during application.

Two moisture levels were maintained--the minimum moisture contents being 50 and 75% of the total available moisture. Each pot was weighed individually during the period of growth, and when the minimum moisture level was reached, sufficient water was added to bring the soil back to

Table I. Nitrogen rates and sources used for greenhouse experiment on Bowdoin clay.

Nitrogen source	Gm. of fertilizer added for each rate			Equivalent mgm. of nitrogen added		
	100 lbs./A	200 lbs./A	300 lbs./A	100 lbs./A	200 lbs./A	300 lbs./A
Check	0	0	0	0	0	0
CaNO ₃ (hydrate)	1.98	3.96	5.94	265	530	795
NH ₄ NO ₃	.72	1.44	2.15	241	481	722
Urea (NH ₄)	.52	1.04	1.56	234	469	703

field capacity.

The pots were arranged in a completely randomized block design. A system of pot rotation within each replication was established so that none of the pots was on the outer edges of the bench during the full course of the experiment.

Plant height measurements were made at maturity. The heads were then removed, and the remaining plant material was clipped. The heads and straw were dried at 70° C. and weighed to determine the total plant material weight. The heads were then threshed and, after cleaning, the weight of the grain was determined. The barley grain was ground in a laboratory mill for the determination of nitrogen content, as was the straw to which the chaff had been added. Nitrogen was determined by the Kjeldahl method.

The second greenhouse experiment was conducted in the same manner as the previous experiment except that potassium nitrate was included as a nitrate source. Applications at the rate of 300 pounds of nitrogen per acre were omitted, as was the 75% moisture treatment. The minimum moisture was maintained at 50% of the total available moisture. This experiment was cared for and harvested as discussed previously. After threshing and weighing the grain, it was combined with the straw and chaff, then ground. Nitrogen content was then determined on the total plant.

Aggregation Measurements

Since the addition of calcium nitrate to the Bowdoin clay caused an apparent change in soil structure, a measurement of the dispersion

ratio of the soil taken from the surface inch of the 300 pounds N per acre calcium nitrate pots, 300 pounds N per acre urea pots, and the corresponding check pots was made. Dispersion ratio was measured by determining the amount of silt plus clay in the nondispersed sample compared to the total silt plus clay in the sample when dispersed. The grams of silt plus clay in the dispersed and nondispersed samples were measured by the pipette method as described by Middleton (1930).

Ammonia Volatilization

Measurement of the ammonia volatilized from Bowdoin clay was determined by placing 100 gm. of the soil in 500-cc. erlenmeyer suction flasks. After bringing the sample to a moisture content approximating field capacity, a urea or ammonium nitrate solution was distributed over the surface of the soil. Ammonia-free air, dried with calcium chloride, was then drawn by means of a vacuum over the soil surface through gas dispersion tubes, and any volatile ammonia was collected in a .02 N sulphuric acid solution. At the end of 1 week of incubation, the sulphuric acid was titrated with standard sodium hydroxide. The amount of ammonia volatilized was determined by the difference in milliequivalents of acid remaining after ammonia collection and that present at the start of the experiment. The suction flasks containing the soil and the acid traps were connected in a train; treatments were run in duplicate and included a blank soil treatment.

The amount and sources of nitrogen applied to Bowdoin clay are listed in table II.

Table II. Nitrogen salts applied to Bowdoin clay for the measurement of ammonia volatilization (milligrams applied to 100 gm. of soil).

	Source	
	Urea	Ammonium nitrate*
Nitrogen equivalent in milligrams	88	176
Milligrams of material	196	526

*These rates should provide the same amount of ammonium as the urea application.

Fixation of Ammonium

The procedure followed for the determination of ammonium fixation was that outlined by Leggett⁵ with adaptations for the measurement of ammonium fixed under air-dry conditions. Both ammonium-chloride-treated soil samples and blank soil samples treated with a volume of water equivalent to the ammonium chloride solution were aerated until the soil was air dry. Ammonia evolved during the aeration and drying was collected in acid traps. The procedure of Leggett⁶ was then followed with the addition of potassium carbonate and collection of ammonia in the acid traps for 16 hours by the aeration recovery method he describes. Samples were run in duplicate.

Soil Analyses

The procedure of Jackson (1958) was followed in the determination of the cation exchange capacity of Bowdoin clay, using a centrifuge washing procedure with calcium as the replacing ion. The calcium was then replaced by the ammonium ion. Calcium was determined by the versene titration.

The particle size distribution of the clay soil was determined by the pipette procedure outlined in USDA Handbook No. 60 (1954), after dispersing the soil in 2% calcium meta-phosphate solution.

Internal and external surface area of Bowdoin clay was determined by the total and external ethylene glycol retention method described in USDA Handbook No. 60 (1954).

⁵Leggett, op. cit., p. 23.

⁶Ibid.

Extractable sodium, potassium, and calcium plus magnesium as well as conductivity were determined from the saturation extract. These procedures and the determination of soil pH from the saturation paste were followed as described in the section, "Methods for Soil Characterization" of USDA Handbook No. 60 (1954).

The determination of soil organic matter was by the Walkley-Black method (Jackson, 1958). Nitrifiable nitrogen was determined after incubation of the soil-vermiculite mixture for 2 weeks as described by Stanford and Hanway (1955).

Procedures of Richards (USDA Handbook No. 60, 1954) were followed in obtaining the 1/10- to 15-atmospheres moisture extraction data. The pressure plate was used at tensions of 1/10 to 1 atmosphere. The pressure membrane was used for tensions of 5 and 15 atmospheres.

Statistical Procedures

The analysis of the data collected from the greenhouse experiments was by the method outlined by Kempthorne (1952) for partially factorial experiments. The multiple range test of Duncan was used for mean separation as described by LeClerc (1957) where more than three means were involved. The L.S.D. was used where three means were being compared.

EXPERIMENTAL RESULTS

Soil Analyses

The results of the measurement of particle size distribution show that the texture is a clay (table III).

A measurement of specific surface differentiates between expanding and nonexpanding types of clay minerals. The results reported in table IV show a large internal surface area, indicating the presence of a large proportion of expanding-type clay minerals.

Various saline and alkali characteristics of Bowdoin clay and other soil characteristics are shown in table V.

The measurement of pH shows that this surface soil is slightly alkaline. The percent exchangeable sodium is above 15%, commonly given as the lower limit of the alkali classification. The conductivity is not high enough to produce saline effects detrimental to most plants. While the conductivity and pH of this soil are low, it might be classed as a degraded alkali soil due to its high percent exchangeable sodium. These results are in agreement with Frahm (1948).

The cation exchange capacity is high. This is to be expected in view of the high clay content and the presence of a large internal surface area. This gives evidence that this soil is high in montmorillonitic clay. The organic matter is quite low for a surface soil. The nitrifiable nitrogen is correspondingly low.

Moisture retention data at various tensions are shown in table VI, while figure 1 gives the moisture retention curve for the Bowdoin clay. The ability of this soil to retain a large amount of moisture at low

Table III. Particle size distribution of Bowdoin clay surface soil as determined by the pipette method.

Sample	% Sand	% Silt	% Clay
1	3.9	21.5	74.5
2	0.6	24.3	75.0
Average	2.2	22.9	74.7

Table IV. Specific surface of Bowdoin clay as measured by the ethylene glycol retention method.

Sample No.	Surface area--square meters per gm. of soil		
	Total external + internal	External	Internal
1	368	155	213
2	363	138	224
3	375	139	236
Average	369	144	224

Table V. Measurement of various soil characteristics of Bowdoin clay.

Characteristic	Value determined	
pH	7.7	
Cation exchange capacity	48.25	meq./100 gm. of soil
Electrical conductivity	3.0	mmhos/cm.
Organic matter	1.75	percent
Nitrifiable nitrogen	33.2	parts per million
Soluble cations		
Sodium	2.9	meq./100 gm. of soil
Potassium	0.03	meq./100 gm. of soil
Calcium + magnesium	0.43	meq./100 gm. of soil
Exchangeable cations		
Sodium	12.5	meq./100 gm. of soil
Potassium	2.3	meq./100 gm. of soil
Exchangeable sodium percentage	20.0	percent

Table VI. Percent moisture retained by Bowdoin clay under various tensions.

Tension-- atmospheres	Percent moisture
1/10	89.2
1/3	62.2
1	53.6
5	38.2
15	32.4

