A Study Of:

SOIL STRUCTURE IN RED RIVER SOIL ASSOCIATES

And Of:

MODIFICATION UNDER CULTURE

A THESIS

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TABLE OF CONTENTS

Page

INDEX OF TABLES.

INDEX OF FIGURES

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I. INTRODUCTION:

In the naturally fertile soils of the semi-arid regions of North America, especially those of clay and sandy texture, the physical properties are highly significant and have a profound effect upon the productive capacity of the soil.

Favorable soil structure is essential in the maintenance of soil productivity. Under a system of intensive cultivation deterioration of soil structure occurs. In the Red River Valley the maintenance of desirable structural characteristics is essential if maximum crop yields are to be obtained.

A natural degradation process similar to the classical "solonchak-solonetz-solod" series occurs in the Red River Valley. Structure in the "solonetz" of Europe and North America has been correlated with the existing physical and chemical conditions. The morphological conditions characteristic of "solonetz" as typified by European investigators are known to exist in the "valley".

Under arable culture, deterioration of soil tilth has become a problem throughout much of the Red River Valley. In the alkalinized and degraded alkalinized phases of the Morris Soil associate, dispersion of the colloidal material of the soil apparently occurs. A massive structural condition has been developed, under which plough draft is doubled (8) and the soil made impervious to water. Both natural degradation processes and cultural practices have been involved in the formation of undesirable physical properties in the heavy textured valley soils.

The investigation of this problem herein presented has been along three lines.

(1) A study of the physical and chemical properties of virgin soils exhibiting both favorable and unfavorable structural conditions.

(2) A study of the chemical and physical modifications in the soil resulting from cultural practices.

(3) An investigation of methods of physical amelioration.

II. OUTLINE OF FACTORS AFFECTING SOIL STRUCTURE

Definition

Soil structure is usually defined as the arrangement of soil particles. The word "particle" refers to any unit which is part of the soil make up, irrespective of its being a primary (sand, silt or clay fraction) or a secondary (flocculation) particle. The term"soil structure" consequently implies an arrangement of primary and secondary particles into a structural pattern.

Structural arrangement as seen in a soil by the naked eye of an observer is generally considered the macro-structure of a soil. The macro-structure is however dependent upon the arrangement of micro-structures within the dimensions of a single macro-structural unit. This micro-structure markedly influences the macro-structure.

Genesis of Soil Structure

Baver (4) gives an excellent review of the genesis of soil structure. A summary of this work is presented here.

Most of the present day theories of aggregation are based on the phenomena of flocculation in dilute suspension. However, flocculation and stable aggregate formation are not synonymous. Floccules are formed when the zeta potential is lowered sufficiently to allow flocculation. Stable aggregate formation requires that the primary particles be so held together that they do not disperse in water. A cementation or binding together of the flocculated particles is necessary in aggregate formation. Flocculation may be a necessary step in the aggregate process but it is not aggregation itself.

The nature of the base exchange complex has long been recognized as being associated with structural conditions of the soil. The replacement of the sodium in alkali soils by calcium and the resulting favourable physical properties exemplify cation effects on physical properties. Permeability studies also show distinctly different effects of cations. Lutz (37) reported H > Ca > K > Na in producing permeability in a colloidal clay membrane.

Factors affecting cementation in aggregate formation include cohesion between colloidal clay particles, the cohesive effect of organic matter, and the presence of irreversible iron colloids. The soil colloidal material may be divided into at least three main groups as far as cementation effect is concerned. They are: (1) clay particles themselves

(2) irreversible or slowly reversible inorganic colloids

(3) organic colloids.

As the percentage of clay increases in a soil, the degree of correlation between organic matter and aggregation decreases. In the study of a large group of soils, clay and organic matter were found to be equally significant in causing granulation. In so called "lateritic" soils the irreversible iron colloids and possibly irreversible colloids of alumina are mainly responsible for cementation.

Certain physical processes are associated with the formation of soil structure. Rupture is caused in a massive soil complex when unequal strains arise. The action of alternate wetting and drying is two-fold, <u>first</u>, unequal strains due to expansion and contraction arise; <u>second</u>, virtual explosions may occur when the pressure of the entrapped air in a wetted soil clod exceeds the degree of cohesion of the soil particles. Conditions of unequal stress also may be caused by freezing and thawing of a soil. An optimum amount of moisture is necessary to achieve maximum effectiveness of this action. If the soil is excessively wet this process, in combination with spring rainfall, may cause dispersion. These effects on aggregation are more or less temporary.

Sod crops promote soil granulation. Several theories have been advanced in explanation, such as;-

(a) Roots create pressures when growing in a clod, thus forming granules.

(b) Changes in moisture content caused by the uptake of water by the roots, result in unequal stress, and cause granulation.

(c) Root secretions may have some cementing or coagulating effect upon soil particles.

(d) Decomposition of roots by micro-organisms produces sticky decomposition products.

The action of roots in granulation is accepted as being as important as any other factor in producing stable aggregation.

Summarizing, it would appear that aggregate formation in soils depends upon:

(a) the presence of primary particles that are sufficiently small in size

(b) the coagulation or flocculation of these particles and

(c) the cementation of the coagulated material into stable aggregates.

III. STUDIES OF RED RIVER SOILS IN VIRGIN CONDITION

A. LITERATURE REVIEW

Gedroiz (23) recognized three main divisions in alkali soils, "solonchak", "solonetz", and "solod". The general inference, based mainly on Russian investigators and supported by Gedroiz and de Sigmond (15), is that alkali soils pass through these three stages, one leading inevitably to the next. Rost and Maehl (5) report finding these morphological stages in the Red River association. They suggest that these three stages represent progressive steps in solodization.

Sodium has been generally agreed upon as being responsible for the dispersed condition found in solonetz soils. A. J. de Sigmond (15) characterizes the solonetz soil as having "an A B C profile, a stable colloid dispersion, a pH of 6.5 to more than 10.0, and an exchangeable sodium content of more than 12 to 15% of the exchangeable bases or a sodium salt content of more than 0.15%." In alkali soils studied in the Red River association by Rost and Chang (50), Rost and Maehl (51), and Ellis and Caldwell (20), the exchangeable sodium in no instance approaches the limits set by de Sigmond.

High exchangeable magnesium has been found in solonetzic soils containing little sodium by Mitchell and Riecken (42), Kelly (34), Rost and Chang (50), and Ellis and Caldwell (20). This absence of sodium and the relatively high amount of magnesium in the base exchange complex has led to the belief that magnesium also is responsible for the formation of solonetzic soils. In investigating the alkalinized soils of the Red River association, Ellis and Caldwell (20) in Manitoba and Rost and Maehl (51) in Minnesota have suggested it is the magnesium cation which is responsible for the dispersion of these soils. Rost and Associates, Ellis and Caldwell (20) and Mitchell and Riecken (42) concurred in the finding that if magnesium is not the dominant ion in the exchange complex of the A horizon of Red River solonetz, it becomes dominant with increasing depth. These solonetzic soils have been termed "magnesium solonetz" by Ellis and Caldwell (20) on the basis that the term "solonetz" referred only to the structure of these soil and did not correspond to the classical idea that "solonetz" is synonymous with sodium soil.

The characteristic structure of these solonetzic soil types appears to be clearly connected with their physical and chemical properties. A. J. de Sigmond (15) describes the impermeability of the solonetz soil to be due to the closing of the soil pores which takes place when the colloids swell. A deflocculated condition exists which causes the soil to become hard and to crack deeply on drying. He notes that these conditions are most apparent in leached alkali soils. In the Red River soil association, physical conditions similar to those described by de Sigmond have been reported by Caldwell (11).

Glinka (26) classified the Russian "Salzboden" into two groups on morphological differences alone;- soils with structure, solonetz soils; soils without structure, saline soils. A. J. de Sigmond (15) observed that alkali soils offer the best illustration of the close connection between the physical properties of a soil and the chemical composition of the absorbing complex.

A review of the literature on alkalinization present in soils of the Red River Association indicates the following:-

1. Three stages of development exist which represent steps in solodization.

2. The sodium content of soils is not high enough for the alkali soils to be classified as "sodium solonetz".

3. The exchangeable magnesium cation is the factor responsible for the solonetzic structure in the alkali soils of the Red River Association.

B. MORPHOLOGICAL DESCRIPTIONS OF RED RIVER VALLEY SOIL TYPES STUDIED.

The Red River Valley is a vast lacustrine clay plain stretching from Stony Mountain in Manitoba southward into the states of North Dakota and Minnesota. This area was formerly the central basin of glacial Lake Agassiz. It is drained by the Red River flowing northward and emptying into Lake Winnipeg.

A reconnaisance soil survey of the valley was conducted by the co-operative efforts of Dominion and Provincial Soil Specialists with Professor J. H. Ellis of the Soils Department, University of Manitoba, in charge. The soils occurring in the Red River Valley area were classified according to the Nikiforoff system of soil classification (19), those developed on the lacustrine sediments were classified as the Red River Soil Association.

The morphological descriptions of the dominant associates in this association are as follows;

<u>Red River Phytomorphic Associate -- Red River Clay;</u>

<u>Horizon Depth:</u>

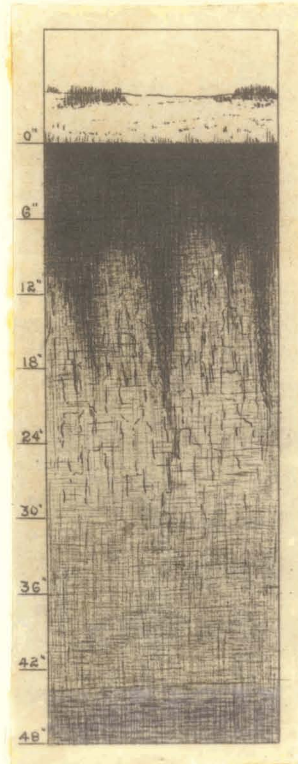
0-13" ------Color:-		Black (10YR 2/1), (54).*
	Texture:-	Clay.
	Structure:-	Moderately granular, may appear weakly coarse columnar when dry because of shrinkage cracks.

*Literature reference.

Consistence:- Firm when dry, slightly sticky and moderately plastic when moist.

Intrusions and Concretions:- The horizon is highly interspersed with grass roots.

Reaction:- Neutral to slightly alkaline.



13-18" Color:- Between very dark grey (2.5 Y 3/0) and dark grey brown (2.5 Y 3/2).

Texture:- Clay.

Structure:- Weakly medium columnar structure which breaks down to granular aggregates under moderate pressure.

Consistence:- Hard when dry; moderately sticky and very plastic when moist.

Intrusions:- With dark tongued intrusions from above.

Reaction:- Alkaline, effervesces slightly.

18-24" Color:- Dark grey brown to greyish brown (2.5 Y 4/2).

Texture:- Clay.

Structure:- Amorphous.

Consistence:- Extremely hard when dry; very sticky and very plastic when moist.

Reaction:- Alkaline, effervesces strongly.

24"+ Color:- Greyish brown (2.5 Y 5/2).

Texture:- Clay.

Structure:- Amorphous.

Consistence:- Extremely hard when dry; very sticky and very plastic when moist.

Intrusions and Concretions:- Small calcium carbonate concretions are present.

Reaction:- Alkaline, effervesces strongly.

Geological Parent Material:- Lacustrine clay.

Topography:- Smooth level terrain with less than 0.5 percent slope. A_1 (44)

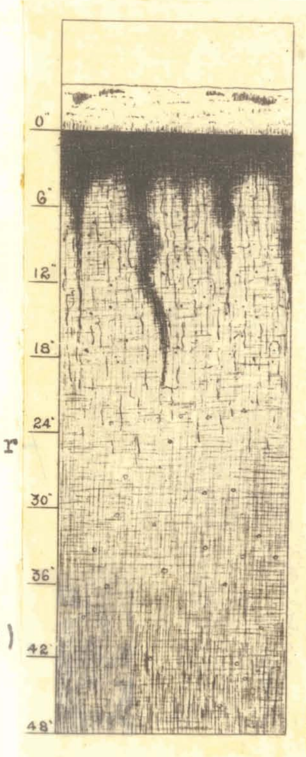
Drainage:- Well drained.

Stone:- None.

Native Vegetation:- Andropogon spp., Agropyron spp., Poa spp., golden rod, sunflower, yarrow, vetch, rose, etc.

Red River Hydromorphic Associate--Osborne Clay:

Horizon Depth



0-4.5" Color:- Very dark grey, (10YR 3/1)

Texture:- Clay.

Structure:- Moderately granular.

Consistence:- Hard when dry; moderately plastic and moderately sticky when moist.

Intrusions and Concretions:- The horizon is highly inter spersed with grass roots.

Reaction:- Slightly alkaline.

4.5-13" Color:- Dark grey brown (2.5Y 4/2) to greyish brown (2.5Y 5/2)

Texture:- Clay.

Structure:- Amorphous.

Consistence:- Very hard when dry; very sticky and very plastic when moist.

Intrusions and Concretions:- Calcium carbonate concretions, iron stains and a few gypsum crystals are found in the horizon.

Reaction:- Alkaline, effervesces freely.

13" + Color:- Greyish brown (2.5Y 4/2).

Texture:- Clay

Structure:- Amorphous.

Consistence:- Very hard when dry; very sticky and very plastic when moist.

Intrusions and Concretions:- Iron stains and calcium carbonate concretions present.

Reaction:- Alkaline, effervesces strongly.

Geological Parent Material:- Lacustrine clay.

Topography:- Smooth, basin like. Depressional terrain with 0 slope. A_0.

Drainage:- Poorly drained.

Stone:- None.

Native Vegetation:- Swale and tall prairie grasses, golden rod, asters, plantain, etc.

<u>Red River Halomorphic Associate--Morris Clay (alkalinized phase)</u>.

<u>Horizon Depth</u>

0-10" Color:- Very dark grey (10 YR 3/1).

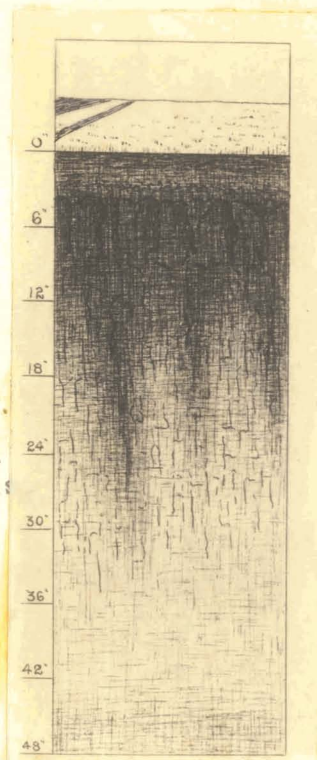
Texture:- Clay

Structure:- Strongly coarsely granular.

Consistence:- Very hard when dry; very sticky and very plastic when moist.

Intrusions and Concretions:- The horizon is highly interspersed with grass roots. Material from this horizon is tongued into underlying horizons

Reaction:- Neutral.



10-23" Color:- Dark grey brown (2.5 Y 3/0)

Texture:- Clay.

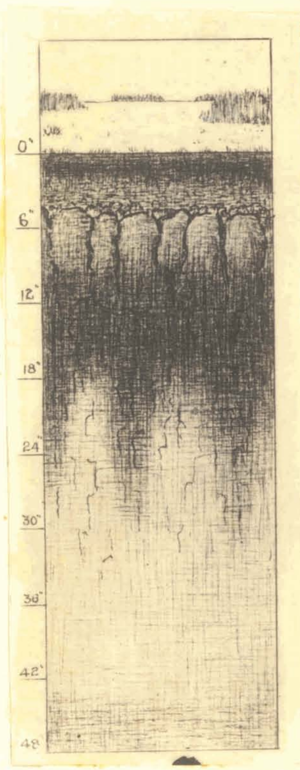
Structure:- Very coarsely columnar, (clodlike).

	Consistence:-	Extremely hard when dry; very sticky and very plastic when moist.
	Reaction:-	Neutral at the top of the horizon gradually changing to alkaline at the bottom of the horizon.
23"+	Color:-	Dark grey brown (2.5 Y 3/2)
	Texture:-	Clay.
	Structure:-	Amorphous.
	Consistence:-	Extremely hard when dry; very sticky and very plastic when moist.
	Intrusions and Concretions:-	Calcium carbonate concretions are present.
	Reaction:-	Alkaline, effervesces strongly.
	Geological Parent Material:-	Lacustrine clay.
	Topography:-	Smooth level terrain with less than 0.5 percent slope. A_1.
	Drainage:-	Intermediately drained.
	Stone:-	None.
	Native Vegetation:-	Dominantly grasses. Herbs such as yarrow, gumweed, and golden rod are relatively few.

<u>Red River Halomorphic Associate--Morris Clay (degraded alkalinized phase)</u>

<u>Horizon Depth</u>

0-5"	Color:-	Very dark grey (10YR 3/1)
	Texture:-	Clay.
	Structure:-	Strongly coarse granular.
	Consistence:-	Very hard when dry; moderately sticky and moderately plastic when moist.
	Intrusions and Concretions:-	The horizon is highly interspersed with thickened grass roots. Soil material from this horizon is tongued into underlying horizons.



	Reaction:-	Neutral.
5-13"	Color:-	Grey (10YR 5/1).
	Texture:-	Clay
	Structure:-	Round-topped very coarsely columnar (clodlike).
	Consistence:-	Extremely hard when dry; very sticky and very plastic when moist.
	Reaction:-	Neutral to slightly acid.

Note:- An ashlike dust is found on the top of the round topped columns of this horizon.

13-24"	Color:-	Very dark grey (2.5 Y 3/0).
	Texture:-	Clay.
	Structure:-	Breaks into massive amorphous clods of very large proportions.
	Consistence:-	Extremely hard when dry; very sticky and very plastic when moist.
	Reaction:-	Neutral in the upper part to alkaline in the lower part of the horizon.
24" +	Color:-	Dark grey brown (2.5 Y 3/2).
	Texture:-	Clay.
	Structure:-	Amorphous.
	Consistence:-	Extremely hard when dry; very sticky and very plastic when moist.
	Intrusions and Concretions:-	Calcium carbonate concretions are present.
	Reaction:-	Alkaline, effervesces strongly.
	Geological Parent Material:-	Lacustrine clay.

Topography:- Smooth level terrain with less than 0.5 percent slope. A_1.

Drainage:- Intermediately drained.

Stone:- None

Native Vegetation:- Dominantly grasses, with a few herbs such as yarrow and golden rod.

The phytomorphic or better drained member of the Red River Soil Association is the most productive soil type and comprises about fifteen percent of the Association. A relatively high organic matter content and degree of friability characterize this soil. The objectionable structural characteristics of the alkalinized types do not occur. This associate is well adapted to field and forage crop culture and is also suitable for market gardening and the production of high acre - value row crops.

The hydromorphic member or the meadow type of the association is the dominant associate, comprising forty percent of the total area. Normally, this soil is under the influence of water due to the absence of relief and the flat topography. Drainage is therefore the chief proglem in this associate. Two phases occur:- the salinized phase, and the non-salinized phase.

Drainage, as accomplished by ditching, has been none too effective in improving this soil. When excessive amounts of rainfall occur, crop losses due to inundation are considerable. The present artificial drainage system is adequate to remove surface water quickly.

Together, the alkalinized and the degraded alkalinized phases of the halomorphic soil associate, constitute thirty-one percent of the association. The degraded alkalinized soil is considered to be a highly alkalinized soil that has undergone subsequent degradation. Many stages of alkalinization and degradation exist. The degraded alkalinized phase is always found as an island within a more extensive area of the alkalinized soil phase. Although the degraded phase at present comprises only a small portion of the total area, the degraded alkalinized soils appear to be increasing as the drainage is improved.

The alkalinized soils are characterized by "heaviness" and are difficult to till. These soils, under both the natural and the cultivated conditions, form hard massive clods which can only be broken up with difficulty.

The outstanding differences between the phytomorphic, and the alkalinized and degraded alkalinized phases of this soil association, are the relative friability, granular structure, and ease of tillage of the phytomorphic associate as contrasted to the hard, massive and intractible physical conditions of the alkalinized soil types.

C. ANALYTICAL DETERMINATIONS ON RED RIVER ASSOCIATES

The soils sampled for analytical studies in the laboratory were of the types previously described, (pages 9-14). Representative profiles of the associates were selected from various locations. The samples obtained included three phytomorphic associates-Red River Clay, three hydromorphic associates-Osborne Clay, one halomorphic associate-Morris Clay (alkalinized phase), and two halomorphic associates-Morris Clay, (degraded alkalinized phase).

1. METHOD OF SAMPLING

Soil samples for laboratory analysis were taken from each of a number of profiles representative of the association. A pit was dug in the field, and the samples were taken from a core of soil left standing in the central part of the pit. The soils were sampled by depths, corresponding to specific morphological horizons, down to the level of the lime carbonate accumulation. These samples were subjected to the following laboratory determinations.

2. ORGANIC CARBON: NITROGEN AND REACTION

(i) Methods.

The methods used in the determination of total carbon, inorganic carbon, nitrogen and reaction are as follows:-

The organic carbon was determined by analyzing the samples for total carbon by a wet combustion procedure and subtracting the inorganic carbon obtained by a dilute hydrochloric acid extract method. The wet combustion method was adapted from a combination of the methods of Adams (1) and Wayneck with some modifications. The soil is oxidized using a mixture of sulfuric acid and chromic trioxide. The carbon dioxide evolved is dried by passing it through a sulfuric acid bath and over calcium chloride and magnesium perchlorate crystals. Any chlorides present are removed by passing the gas over amalgamated zinc. The carbon dioxide is collected and weighed in a Nesbitt tube containing ascarite.

The inorganic carbon was determined by a similar system as described above. The carbon dioxide was extracted by means of hot dilute hydrochloric acid (1:9), and was handled in the same manner as in total carbon determinations except that no amalgamated zinc was present in the system.

The nitrogen present in the soil samples was determined by the Kjeldahl-Gunning-Arnold method which consists essentially of sulfuric acid digestion and alkali distillation. The ammonia is collected in standard acid, and the excess acid determined by acid - base titration.

The pH of the samples were determined by means of a Coleman Model 3 pH Electrometer. Solutions of soil and water were made up in the proportion of one of soil to two and one-half of water by weight. The pH was determined upon this mixture using the standard glass electrode.

(ii) Data.

The results obtained are given in Table No. 1.

(iii) Discussion of Results

An examination of the results shows several analytical differences in the amount, nature and depth of accumulation of organic and inorganic carbon in the various soil profiles.

The highest concentration of organic matter was observed in profile seven, which is the surface horizon of a hydromorphic associate. The surface horizons of the two degraded alkalinized soils profiles No. five and six, were found to be very high in organic carbon. The depth of the zone of accumulation, however, was relatively shallow in comparison to that of the phytomorphic associate. These horizons of high organic accumulation in the Morris soil profiles were also found to exhibit relatively good structure. The best structural conditions were observed in the phytomorphic associate. Although the organic carbon content of these soils is not as high as found in the surface horizon of the degraded alkalinized phase, the depth of accumulation is greater and no impervious B horizon exists beneath the A.

The inorganic carbon of the Red River phytomorphic associate, profiles No. one, two and three increased with depth in the successive horizons studied. This is the normal condition in well drained, black earth soils. In the degraded alkalinized soils, profiles No. five and six, an apparently different condition exists. There is a decrease in inorganic carbon with increasing soil depth until free carbonate is encountered as observed in morphological studies.

The reaction of the soil horizons also follow the same pattern. In the Morris associate, although the surface horizon is neutral, the B1 and B2 horizons are slightly acid. This is normally caused by a modification of the base exchange complex in which the exchangeable bases are replaced, to some extent, by hydrogen. The surface horizons of the phytomorphic profiles were found to be neutral with the degree of alkalinity increasing with depth. There is no acid horizon in the Red River profiles as was found in the Morris soil profiles.

The nitrogen content of the soil horizons usually is found to exist in a more or less definite ratio to the organic carbon content of the soil. In most soils this ratio is found to be about 10:1. There is, however, a very wide discrepancy in the B1 and B2 horizons, and the B horizon of the degraded alkalinized and the alkalinized soils, respectively. High carbon nitrogen ratios exist which suggest that the organic

TABLE NO. 1.

ORGANIC CARBON, INORGANIC CARBONATE, NITROGEN AND REACTION.

Soil Profile No.	Soil Associate	Horizon Designation	Depth in Inches	Percent Organic Carbon	Percent Inorganic Carbon	Percent Total Nitrogen	C/N Ratio	Reaction or pH
(1)	Red River phytomorphic	A	0- 8	6.00	.09	.598	10.0 : 1	7.0
		AB	8-16	1.20	.48	.038	31.6 : 1	7.2
(2)	Red River phytomorphic	A	0-13	6.59	.10	.523	12.4 : 1	6.9
		AB	13-18	1.80	.33	.084	21.4 : 1	7.2
(3)	Red River phytomorphic	A	0-11	5.44	.08	.526	10.3 : 1	7.1
		AB	11-16	1.96	.20	.098	20.0 : 1	7.2
(4)	Morris alkalinized phase	A	0- 9	4.31	.06	.370	11.6 : 1	7.0
		B	9-22	1.72	.20	.035	49.1 : 1	6.9
(5)	Morris alkalinized degraded phase	A	0- 5	9.93	.17	.694	14.3 : 1	7.1
		B_1	5-13	2.53	.16	.028	90.4 : 1	6.8
		B_2	13-24	1.55	.02	.028	55.4 : 1	6.9
(6)	Morris alkalinized degraded phase	A	0- 5	7.93	.17	.607	13.1 : 1	7.0
		B_1	5-12	1.40	.01	.056	25.0 : 1	6.8
		B_2	12-26	1.37	.05	.024	57.1 : 1	6.9
(7)	Osborne hydromorphic	A	0- 4	14.75	.16	.878	16.8 : 1	7.4
(8)	Osborne hydromorphic	A	0-4.5	5.20	.33	.565	9.2 : 1	7.2
(9)	Osborne hydromorphic	A	0- 5	4.84	.31	.376	12.9 : 1	7.0

material occurring in these horizons is different to the organic matter of the surface horizons. The high ratios might be due to the adverse conditions for biological activity, and, therefore, the slow decomposition rate occurring in the horizons of the Morris soils.

3. EXCHANGEABLE BASES AND REPLACEABLE HYDROGEN

The base exchange complex of a highly colloidal soil exerts a strong influence upon the physical conditions present in the soil.

Determinations of the total base exchange capacity and the base exchange status of the soils were conducted. It was necessary to adapt the methods used to the analysis of the heavy clay soils, as a small sample, and a minimum amount of filtering are desirable when dealing with highly colloidal material.

(i) Method.

The ammonium acetate method as outlined by Piper (47) was adapted for use in base exchange analysis of these soils. Ten grams of soil were used, as larger quantities would cause very slow, if not impossible filtering. The volume of leachate was reduced to four hundred milliliters to shorten the period of time required for filtering.

One hundred milliliters of ammonium acetate solution was shaken with ten grams of soil for fifteen minutes and the mixture allowed to stand over night. The solution was filtered through Whatman No. 40 filter paper and the soil residue washed with ammonium acetate solution until the volume of extract measured four hundred milliliters. If any turbidity was present in the leachates, they were refiltered through a dry Whatman No. 50 filter paper. Two milliliters of toluene were then added to prevent mould growth in the extracts.

An aliquot of the leachate was analyzed for calcium and magnesium using the A.O.A.C. (2) methods. The calcium was precipitated as the oxalate, ignited and then weighed as calcium oxide. Magnesium was precipitated by sodium ammonium phosphate, forming magnesium ammonium phosphate. It was then ignited to and weighed as magnesium pyro-phosphate.

The exchangeable potassium was determined by the method described by Dr. Volk (57). Potassium is precipitated, using sodium cobaltinitrite at a constant low temperature. The double salt sodium potassium cobaltinitrite precipitates out in a definite ratio of sodium to potassium, dependent upon temperature. A standard of known potassium concentration was carried during the determination to give a working calibration factor. The factor is derived by dividing the known weight of potassium precipitated from the standard by the weight of the precipitate of sodium potassium cobaltinitrite. This factor, when multiplied by the weight of precipitate obtained from a solution of unknown concentration, yields the amount of potassium present in the leachate.

Sodium was determined using an adaptation of Kahane's method as reported by Piper (47). The sodium is precipitated using a solution of uranyl magnesium acetate. The solution is filtered through a Gooch crucible and the precipitate dried and weighed in the form of the triple salt.

Total base exchange capacity was determined by a modification of the method of Chapman and Kelly (12). The excess ammon-

TABLE NO. 2.

EXCHANGEABLE BASES AND HYDROGEN IN RED RIVER SOILS
EXPRESSED AS MILLI-EQUIVALENTS.

Profile No.	Soil Associate	Horizon Designation	Depth in Inches	Ca	Mg	K	Na	H	Total Bases	NH_4 absorbed	Ca/Mg Ratio
(1)	Red River phytomorphic	A	0- 8	42.7	15.8	1.9	0	2.6	63.0	58.2	2.7:1
		AB	8-16	41.4	19.5	1.4	.1	0	62.4	37.9	2.1:1
(2)	Red River phytomorphic	A	0-13	50.0	18.5	2.1	.2	3.1	73.9	66.2	2.7:1
		AB	13-18	46.2	22.8	1.3	.1	0	70.4	41.7	2.0:1
(3)	Red River phytomorphic	A	0-11	39.4	17.6	2.1	0	.3	59.4	52.6	2.2:1
		AB	11-16	42.5	19.8	1.3	0	2.6	66.2	42.6	2.1:1
(4)	Morris alkalinized phase	A	0- 9	35.6	18.3	1.2	.6	1.0	56.7	57.9	1.9:1
		B	9-22	32.2	24.1	1.1	1.2	3.8	62.4	51.8	1.3:1
(5)	Morris alkalinized degraded phase	A	0- 5	55.8	22.2	2.7	.4	2.0	83.1	63.2	2.5:1
		B_1	5-13	31.6	20.4	1.7	1.0	5.0	59.7	68.3	1.5:1
		B_2	13-24	30.5	23.3	.6	2.0	5.0	61.4	66.6	1.3:1
(6)	Morris alkalinized degraded phase	A	0- 5	41.1	20.2	1.7	.4	1.6	65.0	61.4	2.0:1
		B_1	5-12	33.6	26.3	.9	.7	5.0	66.5	52.2	1.3:1
		B_2	12-26	31.1	26.8	1.0	1.0	2.0	61.9	58.5	1.2:1
(7)	Osborne hydromorphic	A	0- 4	53.4	30.4	2.0	2.2	2.6	90.6	75.3	1.8:1
(8)	Osborne hydromorphic	A	0-4.5	35.6	24.0	1.5	1.2	0	62.3	56.6	1.5:1
(9)	Osborne hydromorphic	A	0- 5	36.8	22.6	1.2	2.1	1.6	64.3	56.6	1.6:1

ium is removed from the soil residue by leaching with ninety-five percent ethyl alcohol. This process is discontinued after sufficient alcohol has been added to remove the free ammonia, or until colloidal material from the soil residue begins to pass through the filter paper. The ammonia remaining in the soil residue was then determined by distilling the ammonia into standard acid using the Kjeldahl distillation apparatus.

The method outlined by Brown (7) was used in the determination of the milliequivalents of exchangeable hydrogen. The hydrogen ion concentration of the ammonium acetate solution and of the leachate are determined using a glass electrode. Knowing the hydrogen ion concentration of the ammonium acetate solution before and after leaching, the milliequivalents of hydrogen present on the absorption complex of the soil are determinable.

(ii) Data.

The results obtained in this study are given in Table No. Two.

(iii) Discussion of Results.

An examination of the results from the base exchange determinations reveal certain important differences between soil types.

A discrepancy is noted between the total ammonium absorbed in the determination of absorption capacity and the sum of the total bases plus hydrogen. Theoretically, these figures should approximate to each other. Kelley and Brown (35) report that in soils containing calcium carbonate difficulties arise in the determination of replaceable calcium as the carbonate is soluble in solutions of all the common salts. Apparently erroneous results were obtained because of the calcium and possibly magnesium carbonate interfering with the total bases and hydrogen data. The soils that show the widest discrepancy between total bases plus hydrogen and ammonia absorbed were previously found to be those which have the highest inorganic carbonate content.

The dominant bases are the divalent calcium and magnesium cations. Baver (4) suggests that it is the magnesium ion which is responsible for the development of the bad structure present in "Magnesium solonetz" soils as it acts much as monovalent ions in its flocculating powers. Caldwell (11) reported an increase in magnesium content with depth in the halomorphic associates until it becomes dominant in lower horizons. Data presented here from analysis of profiles from the same association indicates the magnesium ion is proportionately higher in lower horizons of the Morris associate, but is not dominant.

Ellis and Caldwell (20) and Rost and Maehl (51) have presented data which agree with Baver's suggestion of magnesium solonetz formation. Investigators appear to be in agreement that in the Red River Association an increasing magnesium content is associated with deterioration of soil structure.

The amount of sodium found in these soils does not approach the limits set by de Sigmond (15) as necessary for the formation of the classical "solonetz" soil.

Potassium is present in the soils studied in small quantities which increase with depth. Although the quantities of the cation present are considerable in relation to soil fertility, its effect on the physical properties of the soil in this quantity are slight.

Hydrogen is present in the absorption complex of these soils only in small quantities. The degraded phase of the Morris soil shows a certain amount of replacement of the bases by hydrogen in the illuvial horizons. Hydrogen is reported by Baver (4) to be superior to calcium in its flocculating powers. Caldwell's (11) data, in which he studied the flocculating effect of the various ions in Red River clay, agree with Baver's statement. However, the effect of magnesium on soil structure appears to be dominant in the degraded alkalinized phase. The hydrogen cation is not present in large enough quantities to affect soil structure to any extent.

4. WATER STABLE AGGREGATION AND ATTERBERG CONSISTENCY CONSTANTS

An analytical measurement of the conditions of soil tilth seemed desirable. A high degree of water stability of aggregation is associated with favorable structural conditions in a soil. Baver has suggested the Atterberg consistency constants as being a measure of soil tilth. Determination of these two measures of the physical condition of a soil were undertaken.

(i) Methods -

The degree of water stable aggregation and the Atterberg consistency constants in all soil horizon samples were determined by the following methods.

A water stable aggregate analysis method was adopted from the methods of Rowles (52). This method was used by Rowles in the water stable aggregate analysis of heavy textured soils and, in itself, is an adaption of Yoder's (60) wet sieving technique. The soil was broken down into three to five milli-

TABLE NO. 3.

WATER STABLE SOIL AGGREGATES AND

THE ATTERBERG CONSISTENCY CONSTANTS OF RED RIVER SOILS.

Profile No.	Soil Associate	Horizon Designation	Depth in Inches	Percent Aggreg. .50mm	Upper Plastic Limit	Scouring Point	Lower Plastic Limit	Plasticity No.
(1)	Red River phytomorphic	A	0- 8	68.1	60.9	53.3	32.3	28.6
		AB	8-16	82.1	50.7	34.5	23.7	27.0
(2)	Red River phytomorphic	A	0-13	64.8	68.8	58.5	39.7	29.1
		AB	13-18	81.9	51.5	28.9	24.7	26.8
(3)	Red River phytomorphic	A	0-11	87.8	54.4	44.3	30.8	23.6
		AB	11-16	81.8	59.1	34.5	26.6	32.5
(4)	Morris alkalinized phase	A	0- 9	64.5	69.2	34.8	30.1	39.1
		B	9-22	64.9	63.4	32.1	28.4	35.0
(5)	Morris alkalinized degraded phase	A	0- 5	85.2	68.0	49.2	33.2	34.8
		B_1	5-13	42.2	72.9	38.1	30.7	42.2
		B_2	13-24	9.6	73.5	33.9	29.0	44.5
(6)	Morris alkalinized degraded phase	A	0- 5	91.3	63.3	47.6	31.8	31.5
		B_1	5-12	59.2	68.3	34.3	26.4	41.9
		B_2	12-26	59.2	69.0	34.3	26.9	42.1
(7)	Osborne hydromorphic	A	0- 4	81.8	76.6	67.5	37.4	39.2
(8)	Osborne hydromorphic	A	0-4.5	83.4	64.9	39.5	31.3	33.6
(9)	Osborne hydromorphic	A	0- 5	81.6	62.9	40.8	31.4	31.5

meter aggregatesby artificial pressure. Thirty grams of the aggregateswere placed in the bottom of a thousand milliliter beaker and covered with blotting paper. Wet cloths were placed on top of the blotting paper, the purpose being to maintain a saturated atmosphere about the aggregates. After twenty-four hours the cloths were removed and twenty-five milliliters of distilled water added to the beaker. The aggregates were left immersed in the water for a further twenty-four hours and were then transferred to the top of a series of sieves in a four liter beaker, the top sieve being just inundated by water. The process of transferring the aggregates to the top sieve was done by using a washing bottle to remove the aggregates from the beaker. (A vertical reciprocation of the sieves is necessary to agitate the water stable aggregates enough that they will pass through the sieves and be separated into the various sizes of aggregates.) After separation had been accomplished, the sieves were removed from the beaker and the segregated soil aggregates transferred carefully to beakers. These aggregate separates were then dried to constancy, weighed, and the weights calculated as a percentage value of the total aggregates.

The methods used in the determination of the Atterberg consistency constants were those outlined by Russel and Wehr (53). Determinations included the upper and the lower plastic limits, the plastic number and the scouring point of the soil samples.

(ii) Data

The results obtained from these determinations are enumerated in Table No. Three.

(iii) Discussion of Results

This study brings out several important differences between the upper and lower horizons of the profiles as well as between the association members. It would appear that with high organic matter content in the soil of the surface horizons, the lower plasticity limits are shifted to higher values. Baver (3) has suggested that this is the case but that organic matter content, although shifting the plastic limits to higher values, has no effect upon the plasticity number of the soil. This appears to be true in the case of the phytomorphic associate, but, in the halomorphic soil associates studied, the plasticity numbers increased with depth. The base exchange studies reported on pages 21 - 25 and shown in Table No. Two, show that magnesium in the base exchange complex of these soils also increased with depth.

An inverse relation seems to exist between the scouring point and the plasticity numbers. A high scouring point appears to correlate with a relatively low plasticity number. This suggests that the factors which affect the plasticity number of a soil may also be related to the scouring point.

Horizons of high organic matter content generally show a greater amount of water stable soil aggregation (see Table No. Four.) A very significant correlation between aggregation and organic matter content in the case of soils containing less than twenty five percent clay, and a lower, yet still significant correlation in soils containing more than thirty-five percent clay has been reported. The large degree of variability in water stable aggregation in the highly colloidal soils under

TABLE No. 4.

THE CALCIUM MAGNESIUM RATIO, PLASTICITY NO., AGGREGATE STABILITY AND PERCENT ORGANIC CARBON OF RED RIVER SOILS.

Profile No.	Soil Associate	Horizon Designation	Depth in Inches	Percent Ca	Percent Mg	Ca/Mg Ratio	Plasticity No.	Percentage Aggregates .50 mm	Organic Carbon
(1)	Red River phytomorphic	A	0- 8	67.8	25.1	2.7:1	28.6	68.1	6.00
		AB	8-16	66.3	31.2	2.1:1	27.0	82.1	1.20
(2)	Red River phytomorphic	A	0-13	67.7	25.0	2.7:1	29.1	64.8	6.59
		AB	13-18	65.6	32.4	2.0:1	26.8	81.9	1.80
(3)	Red River phytomorphic	A	0-11	66.3	29.6	2.2:1	23.6	87.8	5.44
		AB	11-16	64.2	29.9	2.1:1	32.5	81.8	1.96
(4)	Morris alkal-inized phase	A	0- 9	62.8	32.3	1.9:1	39.1	64.5	4.31
		B	9-22	51.6	38.6	1.3:1	35.0	64.9	1.72
(5)	Morris alkal-inized degrad-ed phase	A	0- 5	76.3	26.7	2.5:1	34.8	85.2	9.93
		B_1	5-13	52.9	34.2	1.5:1	42.2	42.2	2.53
		B_2	13-24	49.7	37.9	1.3:1	44.5	9.6	1.55
(6)	Morris alkal-inized degrad-ed phase	A	0- 5	63.2	31.1	2.0:1	31.5	91.3	7.93
		B_1	5-12	50.5	39.5	1.3:1	41.9	59.2	1.40
		B_2	12-26	50.2	43.3	1.2:1	42.1	59.2	1.37
(7)	Osborne hydromorphic	A	0- 4	58.9	33.6	1.8:1	39.2	81.8	14.75
(8)	Osborne hydromorphic	A	0-4.5	57.1	38.5	1.5:1	33.6	83.4	5.20
(9)	Osborne hydromorphic	A	0- 5	57.2	35.1	1.6:1	31.5	81.6	4.84

study, suggests that although organic matter is very important, other factors have a marked influence upon aggregate stability of the soil.

It has been shown that the dominant cations on the base exchange complex are calcium and magnesium. The flocculating effect of the cations are generally given as follows, "La^{+++} H^{+} Ca^{++} Sr^{++} Mg^{++} K^{+} Na^{+} = Li^{+}. The Mg ion acts more like the monovalent cations with respect to flocculation than like the other divalent cations. This effect is obviously important in connection with the formation of magnesium solonetz soils." Flocculation of colloidal material is recognized as the primary action in desirable aggregate formation. In the Morris soils the decrease in aggregation with depth, apparently correlates with a decreasing calcium magnesium ratio, as is shown in Table No. Four.

Gish and Browning (25) recognized that the moisture content of the soil at the time of sampling influences the amount and stability of soil aggregates. Dutt (18) states that the dehydration or drying process may affect the "intimate orientation" of particles resulting in an increased resistance of aggregates to disintegration. The action of grass roots as an effective aggregate stabilizing agent was considered by Kolodny and Neal (36) to be partly due to their dessicating action. The moisture content of a soil has been recognized as a factor affecting the aggregate stability of soils, especially those of heavy texture.

Baver (3) suggested that the Atterberg constants can be used as a measure of friability of the soil. The phytomorphic associates which were observed to be in good physical condition in the field, show lower plasticity numbers, higher plastic limits, and greater degree of water stable aggregation. The degraded halomorphic associates were recorded as having undesirable physical properties. Determinations on these soils reveal high plasticity numbers, low plastic limits and a relatively low degree of water stable aggregation.

Table No. Four gives a summary of analytical work and shows the relation of the plasticity numbers and degree of aggregate stability to other soil properties. Soils in unfavorable physical condition with low degree of aggregate stability and high plasticity numbers, also exhibit a narrow calcium magnesium ratio and low organic carbon content. Soils with favorable physical condition present show soil properties that are the converse of those associated with bad structure.

D. SUMMARY OF STUDIES ON VIRGIN SOILS:

Analysis of the virgin profiles of the Red River soil association has revealed to a large extent the chemical and physical characteristics of the soils which are naturally found in good physical condition and of the soils with undesirable structural characteristics. The results obtained were used as a basis for the correlation of the chemical and physical properties of the soil with the structural conditions observed in the soil profile.

The organic matter of the B horizons of the degraded phase of the Morris soil associate was found to differ in constitution or character from the organic material of the surface or A horizons. The extremely wide carbon nitrogen ratios which occur in the B horizons are probably due to a slower rate of decomposition as the result of poor aèration.

The analysis of the B_1 of the degraded Morris soil associates shows a lower water stability of aggregation than in the case of the AB horizon of the phytomorphic associates. Organic matter and aggregation are generally reported as being highly correlated. However, the organic carbon content of the B_1 of the Morris soils is as high or higher than the organic carbon content of AB of the phytomorphic associate. This discrepancy may be due to either the form of the organic matter present, or to the effect on aggregation of the specific bases in the exchange complex.

The amount of magnesium in the base exchange complex of the B horizons of the Morris or alkalinized soil profiles approaches the quantity of calcium present. Apparently this magnesium is responsible for the peptization of the colloidal content of the soil. In these soils the structural conditions are undesirable. It appears that a wide calcium magnesium ratio is necessary for the maintenance of granular structure in the soil.

The sodium content of these alkalinized soils is very low and does not approach the limits, defined by de Sigmond, necessary to designate soils as being of the "solonetz" type. However, the soils which fit de Sigmond's definition should be termed sodium solonetz. Soils which have "solonetz" morphology, but in which magnesium rather than sodium is the reactive base, should be termed "magnesium solonetz".

The potassium and exchangeable hydrogen content of the exchange complex in all Red River soils were found to be quite low and therefore they can exert little influence upon the physical condition of the soil.

A study of the water-stable aggregation and the Atterberg consistency constants also leads to the belief that the undesirable physical properties of the alkalinized and degraded alkalinized phases of the Morris associate are, in a large part, due to the effect of the base exchangeable magnesium content. Soils with a narrow calcium magnesium ratio show consistence conditions which are associated with undesirable structural arrangements, and also show a low stability of aggregation.

Red River clay soils having favorable physical properties exhibit a high content of organic carbon, and a high degree of aggregate stability; low carbon nitrogen ratios and low plasticity numbers; as well as wide calcium magnesium ratios. The associated degraded Morris soils which have undesirable physical properties exhibit the converse of these characteristics.

IV. STUDIES OF SOILS UNDER THE INFLUENCE OF CULTURE ON UNIVERSITY FARM.

A. LITERATURE REVIEW:

It is generally agreed that, under culture, changes in the physical and chemical characteristics of a soil are inevitable. Patterns of variation in organic matter content, nitrogen content, aggregation, base exchange capacity, have been recognized and reported.

Hudig (29) states that organic matter is "an essential material for producing and maintaining crumb structure in soil. The process is a dynamic one; organic matter in an aerated soil is destroyed and replenishment is necessary to keep the soil productive. Nature has provided stable products which maintain structure, but this condition may be disturbed by intensive cultivation or by monoculture."

Brown, Wyatt and Newton (8) reported an average decrease of organic matter of from 21 per cent to 27 per cent in a group of brown, dark brown, black and black transitional soils over a thirty year period. Daniel and Langham (13) found a decrease of 18 per cent in organic matter as a result of tillage. Myers, Hallstead, Kuska and Haas (43) reported in a study of soils from U.S.D.A., Dry Land Field Stations in Kansas, that the greatest decrease in organic matter occurred in the soils which were originally highest in that soil constituent.

A high correlation between organic matter and soil aggregation has been reported by many investigators. Browning and Milam (9) found that there is a significant increase in aggregation for each unit increase in organic matter. Puhr and Olsen (49) have stated that the importance of organic matter diminishes after the sod has acquired sufficient organic matter for structural development. Wilson and Fisher (58) go a step further in stating that a point of maximum aggregation can be reached past which increasing organic matter has no effect.

A decrease in nitrogen content of soils under culture is reported by many investigators. Myers, Hallstead, Kuska and Haas (43) reported the decrease in nitrogen content to be greatest in the first years following the breaking of the sod. They believe the nitrogen content of soils under arable culture to be approaching an equilibrium, but the general trend in Great Plains soil is still downward. Harper (27) believes that in time an equilibrium should occur in a soil under cultivation between losses and gains of nitrogen, but that this equilibrium may be too low for economical cultivation of the land.

McVickar, Batten and Shulkaen (40) analyzed the results of four years of green manuring on Onslow fine sandy loam soil. Five treatments were compared; fallow, rye grass, crimson clover, vetch and Austrian winter peas. They reported no significant change in soil nitrogen and that organic matter was not significantly increased in the soils under experiment. Metzger (41) in studying cropping systems reported continuous alfalfa increased the carbon and nitrogen content of the soils 0.43% and 0.73% annually respectively.

Several investigators have shown the beneficial action of grasses and legumes in increasing aggregation of a soil. Page and Willard (46), Wilson. Gish and Browning (59) and Elson Jesse (21) all report greater aggregation under grass than under other systems of culture. Elson Jesse found a sequence of aggregation under different culture systems. Corn and wheat plots showed the same percentage of macro-aggregates, clover showed an increase in aggregation over wheat and corn and grasses an increase over clover in the rotation. Tsyganov (56) found grasses to be more effective than legumes in causing stable aggregate formation, but stated that a legume should be included in the hay crop because of its powers to fix nitrogen. The importance of grasses in aggregation is emphasized by Olmstead (45) who reported an 80 per cent decrease in aggregation due to cultivation of a soil since 1902.

In a controlled experiment by Joffe and Zimmerman (30) the effect of varying ratios of base exchangeable calcium magnesium and sodium on the swelling properties of a soil were studied. They suggest that a high calcium magnesium ratio is far more effective than a low calcium magnesium ratio in reducing the swelling caused by sodium. They further suggest that either the magnesium acts similarly to sodium or there is not enough calcium present to antagonize the effect of the sodium.

B. OUTLINE OF FERTILITY FIELD EXPERIMENTS.

The fertility field plots on the University farm have been under a systematic rotation system for approximately thirty years. In this period of time these plots should exhibit modifications in soil properties caused by culture in its various forms. Therefore, certain plots were selected from which soil samples were taken in the hope that they would throw light on the problem under study.

Analytical determinations indicate that cultural systems have varying effects on soil properties. Although the results cannot be statistically analyzed because of the limited number

FIGURE NO. 1

DIAGRAM OF FERTILITY FIELD PROJECTS SAMPLED

of samples, the results obtained indicate certain points which are worthy of presentation.

1. DESCRIPTION OF ROTATIONS STUDIED AND THEIR HISTORY:

(i) Green Manure (sub-project 69).

A green manuring project was begun in 1919 and brought into its full four year rotation system in 1921. The details of this rotation are as follows:-

Location: Block 1, Ranges 26-29.

Rotation: Year 1. Fallow and Green Manure.

Year 2. Wheat.

Year 3. Corn.

Year 4. Wheat and seed down plots 8 and 9 as outlined.

Treatment: Plot 1. Check fallow only.

2. Weeds plow down when one and one-half feet high.

3. Buckwheat plowed down in bloom.

4. Spring rye plowed down in August.

5. Corn sowed in six inch drills, ploughed down in August.

6. Check fallow only.

7. Peas ploughed down in August.

8. Sweet clover ploughed down in bloom.

9. Red clover ploughed down in bloom.

10. Rotted barnyard manure, 10 tons, ploughed down at the same time as the plots.

11. Check, fallow only.

The rotation system was deviated from, in 1927, 1928 and 1929 because of exceptionally wet conditions and delayed seeding.

The rotations for these three years were as follows:-

1927	Barley, fallow, barley, corn;	) Green manure crops were
1928	Flax, fallow, oats, corn;	) carried on as usual with
1929	Barley, fallow, wheat, corn;	) fallow years during this period.

The forty-four plots in this experiment were sampled in the fall of 1930 and also in the fall of 1948 for comparison.

(ii) Frequency of Fallow (sub-project 70):

The same year as the green manuring sub-project was undertaken an experiment was begun to give data on the effect of (1) frequency of fallow, (2) continual wheat, (3) manure, (4) burning or returning straw to the plots. The project was set up in the following manner.

Location: Block 2, Ranges 26-29

Rotation: Range 26 No manure.

(a) Plot 1. Fallow every second year.

Plot 2. Wheat

(b) Plot 3. Fallow every third year.

Plot 4. Wheat.

Plot 5. Wheat.

Plot 6. Fallow every fourth year

Plot 7. Wheat.

Plot 8. Wheat

Plot 9. Wheat

Rotation Range 27 Manured.

(a) Plot 1. Fallow every second year, four tons of manure.

Plot 2. Wheat.

(b) Plot 3. Fallow every third year, four tons of manure.

Plot 4. Wheat, four tons of manure ploughed in in fall.

Plot 5. Wheat

(c) Plot 6. Fallow every fourth year. Four tons of manure.

Plot 7. Wheat. Four tons of manure ploughedin in the fall.

Plot 8. Wheat--Four tons of manure ploughed in in the fall.

Plot 9. Wheat.

Rotation: Range 28.

(a) Plot 1. Wheat continuous, no manure, stubble only returned.

(b) Plot 2. Wheat continuous, return all straw grown on the plot.

Rotation: Range 29.

(a) Plot 1. Wheat continuous, stubble only returned.

(b) Plot 2. Wheat continuous, burn straw and stubble.

In 1927 and 1928 barley was substituted for wheat in the rotation because wet conditions delayed seeding too late for wheat. Soil samples were obtained from these plots in the fall of 1948 for laboratory analysis.

(iii) The Effect of Fertilizers on Crops (sub-project 71):

Sub-project 71 was started in 1919 also, to ascertain the beneficial effect, if any, of fertilizers, and to compare commercial fertilizer with manure. The four year rotation used is as follows;

Location: Block A, Ranges 30-33.

Rotation: Year 1. Fallow

Year 2. Wheat amendment applied

Year 3. Corn.

Year 4. Barley.

The treatments which were sampled include:

Plot 5. Hydrated Lime applied at the rate of 70 pounds per acre.

Plot 7. Check (no fertilizer).

The rotation has been carried out in this manner with the exception that in 1928 barley replaced wheat in the rotation.

(iv) <u>The Effect of Fertilizers on Grasses (sub-project 72):</u>

The rotation in operation on sub-project 72 was started in 1919, and assumed its present establishment form in 1923. The details of this system of culture are as follows:

<u>Location</u>: Block B, Ranges 30-33.

<u>Rotation</u>: Year 1--Seed down to grassed (mixed) timothy, meadow fescue, alsike and alfalfa in the proportions by weight of 4:8:3:5.

Year 2--Hay.

Year 3--Hay and break.

Year 4--Corn.

The treatments which were sampled include:

Plot 5 Hydrated lime at the rate of 70 pounds per acre.

Plot 7 Check (no fertilizer).

In 1943 the corn plot was split. Wheat has been grown on the left half of the range since that year.

(v) <u>Sulfur Treatments</u>:

In May 1946 applications of sulfur were made on a block adjacent to sub-project no. 74 to determine the effect of sulfur on soil acidity.

The system of cropping on these plots has been uniform since the sulfur applications were made. The treatments used are as follows:

<u>Location</u>: Block 3, Range 29, Plots 7-11

Treatments: Plot 7 Check

Plot 8 500 lbs.

Plot 9 1000 lbs.

Plot 10 2000 lbs.

Plot 11 Check.

The sulfur was applied broadcast and incorporated into the surface soil by cultivation.

(vi) Continuous Fallow (Roadways).

The 20 foot roadways, between the fertility plots, have been under a system approximating continuous fallow since 1919 when the plots were laid out. Continuous cultivation of the roads has been followed to prevent weeds and grain from becoming established. As no plants were permitted to develop in the cultivated roadways, virtually little or no organic matter has been incorporated into this soil. Four of these cultivated roadway strips were sampled for analysis, these included:

Roadway between Block B Range 30,
Block B Range 31;

Roadway between Block 1 Range 27,
Block 1 Range 28;

Roadway between Block 2 Range 28,
Block 2 Range 29;

Roadway between Block 2 Range 26,
Block 2 Range 27.

C. EFFECT OF CULTURE ON THE CLAY TEXTURED SOILS OF THE UNIVERSITY FARM:

The rotations previously described have been in operation in their present form, with the exception of the sulfur experiment, for from twenty-five to twenty-eight years. The purpose of the following investigations was to study the degree and nature of some modifications that have taken place in the soils on these plots.

1. METHOD OF SAMPLING

Soil samples were obtained using a core sampling tube of three inch diameter. Four cores, six inches in length were obtained from each plot. After thorough mixing a portion of the sample was retained for analytical determinations, the size of sample being reduced by the method of quartering.

2. ORGANIC MATTER (ORGANIC CARBON) AND NITROGEN AS AFFECTED BY CULTURE.

The organic matter content of a soil has long been recognized as associated with soil tilth. In virgin soils brought under culture, a certain degree of depletion of organic matter is recognized as being inevitable. Relative effects of different culture systems on organic matter and nitrogen are noticeable in the analysis of the plot samples.

(a) The Effect of Continuous Fallow; Continuous Wheat; and Frequency of Fallow With and Without Manure.

(i) Method.

The organic carbon and nitrogen were determined on these plot samples using the same methods of carbon and nitrogen determination as were outlined in the study of virgin soils. The analytical data presented are the result of determinations on blocks 26 and 27, plots one to nine and the four continuous fallow (roadway) samples.

(ii) Data

The results of determinations on the soil samples are given in Tables No. Five and Six.

(iii) Discussion of Results.

The data in Table No. Five suggest that continuous fallow is less destructive of organic material than is a system of continuous wheat culture. There is a possibility that, under fallow and the subsequent relatively higher moisture content of the soil that micro-organisms such as algae function in a carbon fixing capacity, also that nonsymbiotic bacteria are fixing nitrogen in the soil. The converse of this condition could also cause the same effect; that is, bacterial action under the cultural system of continuous wheat is greater than under fallow as root growth causes aggregation and subsequent aeration of soil. Not enough samples have been analyzed to outline the specific character of the variations occurring under these two cultural systems. The variation between individual plots in the same cropping system is too large to permit final conclusions to be drawn about the effect of continuous fallow in comparison to continuous wheat culture, but the values obtained are disturbing and not in agreement with prevailing opinions.

An inspection of the data of Table No. Six on the effect of frequency of fallow with and without manure appears to indicate a definite trend caused by these cultural systems. Three apparent trends are visible: (a) The more frequently fallow is carried out, the greater the destruction of organic material. (b) Under manure application larger amounts of organic carbon and nitrogen occur in the soil. (c) Under manure application the carbon nitrogen ratios are greater than with no application of manure.

The effect of frequency of fallow is illustrated both without and with manure application. The individual determinations on each plot within the rotations show a certain amount

TABLE NO. 5.

CARBON, NITROGEN AND C/N RATIOS IN SOILS

UNDER CONTINUOUS FALLOW AND CONTINUOUS WHEAT CULTURE.

Plot	Treatment	Organic Carbon	Average Organic Carbon	Nitrogen	Average Nitrogen	C/N Ratio	Average C/N Ratio
B-30/B-31	fallow continuous	3.02	3.47	.258	.313	11.7:1	11.1:1
1-27/1-28	" "	3.20		.312		10.3:1	
2-28/2-29	" "	4.15		.329		12.6:1	
2-26/2-27	" "	3.50		.355		9.9:1	
2-28-1	wheat continuous	2.51	3.17	.255	.305	9.8:1	10.7:1
2-29-1	" "	3.83		.335		11.4:1	

TABLE NO. 6.

CARBON, NITROGEN AND C/N RATIOS IN SOILS

UNDER FALLOW FREQUENCY WITH AND WITHOUT MANURE.

Plot	Treatment	Organic Carbon	Average Organic Carbon	Nitrogen	Average Nitrogen	C/N Ratio	Average C/N Ratio
2-26-1	fallow every second year	2.74	2.78	.228	.251	12.0:1	11.1:1
2-26-2	" " " "	2.82		.275		10.2:1	
2-26-3	fallow every third year	3.42	3.48	.349	.313	9.8:1	11.1:1
2-26-4	" " " "	3.70		.326		11.3:1	
2-26-5	" " " "	3.32		.265		12.5:1	
2-26-6	fallow every fourth year	3.77	3.54	.315	.309	12.0:1	11.5:1
2-26-7	" " " "	2.71		.312		8.7:1	
2-26-8	" " " "	3.63		.275		13.2:1	
2-26-9	" " " "	4.06		.335		12.1:1	
2-27-1	*fallow every second year	3.20	3.30	.248	.261	12.9:1	12.6:1
2-27-2	* " " " "	3.40		.275		12.4:1	
2-27-3	**fallow every third year	3.57	3.96	.302	.333	11.8:1	11.9:1
2-27-4	**" " " "	4.22		.375		11.3:1	
2-27-5	**" " " "	4.08		.322		12.7:1	
2-27-6	***fallow every fourth year	4.65	4.54	.355	.389	13.1:1	11.7:1
2-27-7	***fallow every fourth year	4.17		.355		11.8:1	
2-27-8	***fallow every fourth year	4.37		.399		10.9:1	
2-27-9	***fallow every fourth year	4.96		.449		11.1:1	

Application of manure = 4 tons--*1 year out of 2, **2 years out of 3, ***3 years out of 4.

of variability but not enough to refute the overall pattern of the rotations studied. Manure apparently maintains the organic carbon content of the soil at a relatively higher level than it does the nitrogen content, considering the values in comparison with no manure application. This effect is manifest in the wider carbon nitrogen ratios.

Apparently conflicting evidence has been found in this experiment. In the case of continuous fallow compared with continuous wheat, the second method of culture resulted in the lower organic carbon and nitrogen content of the soil. In a study of frequency of fallow, the more frequent the fallow year, the greater the destruction of organic matter. In the first case, with wheat continuous plots, the organic matter is lower than under continuous fallow, in the second case the more often wheat occurs in the frequency of fallow experiment, the higher is the organic matter content of the soil. As suggested previously, the apparent contradiction may be due to the activity of soil micro-organisms. Further investigation is required along these lines to determine the effect of fallow on soil properties.

(b) The Effect of Green Manure

(i) Methods.

The sub-project devoted to methods of green manuring was sampled in 1930 by members of the staff of the Soils division Department of Agronomy. The nitrogen content of the plots was determined by the Kjeldahl-Gunning-Arnold method and the carbon by oxidation of the organic matter using N/2 iodine solution and titration of the excess iodine with sodium thiosulphate $Na_2S_2O_3$. Sampling of the plots in the green manure were again carried out in 1948. Analytical determinations of carbon and nitrogen were

TABLE NO. 7.

NITROGEN CONTENT OF PLOTS UNDER VARIOUS GREEN MANURES AND MEAN VALUES OF NITROGEN AS PERCENT OF GENERAL MEAN IN 1930.

Plot No:	1	2	3	4	5	6
Green manure:	Fallow	Weeds	Buckwheat	S.Rye	Corn	Fallow
Range 26, % nitrogen in soil	.361	.373	.345	.319	.327	.349
Range 27, % nitrogen in soil	.383	.368	.294	.370	.414	.419
Range 28, % nitrogen in soil	.330	.307	.297	.291	.327	.361
Range 29, % nitrogen in soil	.396	.407	.369	.408	.376	.380
Mean nitrogen content	.3650	.3637	.3262	.3470	.3810	.3772
Mean nitrogen content as percentage of general mean	98.62	98.27	88.94	93.76	102.94	101.92

Plot No:	7	8	9	10	11	
Green manure:	Peas	Sweet Clover	Red Clover	B.Y. Manure	Fallow	General Mean
Range 26, % nitrogen in soil	.345	.373	.380	.393	.387	
Range 27, % nitrogen in soil	.343	.464	.354	.377	.407	
Range 28, % nitrogen in soil	.336	.379	.362	.369	.337	
Range 29, % nitrogen in soil	.401	.419	.423	.411	.384	
Mean nitrogen content	.3567	.4087	.3797	.3875	.3787	.3701
Mean nitrogen content as percentage of general mean	96.38	110.42	102.59	104.70	102.32	100.00

TABLE NO. 8.

NITROGEN CONTENT OF PLOTS UNDER VARIOUS GREEN MANURES AND MEAN VALUES OF NITROGEN AS PERCENT OF GENERAL MEAN IN 1948.

Plot No:	1	2	3	4	5	6
Green manure:	Fallow	Weeds	Buckwheat	S. Rye	Corn	Fallow
Range 26, % nitrogen in soil	.293	.309	.312	.285	.286	.295
Range 27, % nitrogen in soil	.328	.357	.363	.328	.302	.363
Range 28, % nitrogen in soil	.285	.272	.308	.262	.292	.379
Range 29, % nitrogen in soil	.335	.352	.305	.375	.335	.335
Mean nitrogen content	.3102	.3225	.3220	.3125	.3037	.3430
Mean nitrogen content as percentage of general mean	95.39	99.18	99.03	96.10	93.40	105.48

Plot No:	7	8	9	10	11	
Green manure:	Peas	Sweet Clover	Red Clover	B.Y. Manure	Fallow	General Mean
Range 26, % nitrogen in soil	.322	.342	.314	.312	.353	
Range 27, % nitrogen in soil	.315	.385	.315	.347	.308	
Range 28, % nitrogen in soil	.305	.312	.298	.308	.251	
Range 29, % nitrogen in soil	.359	.392	.379	.386	.349	
Mean nitrogen content	.3252	.3577	.3265	.3382	.3152	.3252
Mean nitrogen content as percentage of general mean	100.00	110.04	100.41	104.01	96.93	100.00

TABLE NO. 9.

ORGANIC CARBON CONTENT OF PLOTS UNDER VARIOUS GREEN MANURES

AND MEAN VALUES OF ORGANIC CARBON AS PERCENT OF GENERAL MEAN IN 1930.

Plot No:	1	2	3	4	5	6
Green manure:	Fallow	Weeds	Buckwheat	S. Rye	Corn	Fallow
Range 26,% organic carbon in soil	4.42	4.71	4.00	4.20	4.38	4.68
Range 27,% organic carbon in soil	4.70	4.21	4.06	4.18	5.43	4.92
Range 28,% organic carbon in soil	4.03	4.25	4.24	3.70	4.63	3.72
Range 29,% organic carbon in soil	4.46	4.83	4.29	4.69	4.78	4.52
Mean organic carbon	4.40	4.50	4.14	4.19	4.80	4.46
Mean organic carbon as percentage of general mean	96.91	99.18	91.18	92.29	105.72	98.23
Plot No:	7	8	9	10	11	
Green manure:	Peas	Sweet Clover	Red Clover	B.Y. Manure	Fallow	General Mean
Range 26,% organic carbon in soil	4.19	4.84	5.35	5.10	5.21	
Range 27,% organic carbon in soil	3.60	5.37	4.10	5.41	5.11	
Range 28,% organic carbon in soil	3.26	4.79	4.17	4.52	3.23	
Range 29,% organic carbon in soil	4.76	5.20	5.14	5.26	5.17	
Mean organic carbon	3.95	5.05	4.69	5.07	4.68	4.54
Mean organic carbon as percentage of general mean	87.00	111.23	103.30	111.67	103.08	100.00

TABLE NO. 10.

ORGANIC CARBON CONTENT OF PLOTS UNDER VARIOUS GREEN MANURES

AND MEAN VALUES OF ORGANIC CARBON AS PERCENT OF GENERAL MEAN IN 1948.

Plot No:	1	2	3	4	5	6
Green manure:	Fallow	Weeds	Buckwheat	S.Rye	Corn	Fallow
Range 26,% organic carbon in soil	3.15	3.50	3.80	3.32	3.30	3.54
Range 27,% organic carbon in soil	3.07	3.05	3.24	3.27	4.00	4.28
Range 28,% organic carbon in soil	3.02	3.12	3.10	3.02	3.65	4.00
Range 29,% organic carbon in soil	3.78	4.25	3.59	3.84	3.76	3.35
Mean organic carbon	3.25	3.48	3.43	3.49	3.68	3.79
Mean organic carbon as percentage of general mean	89.01	95.17	93.85	95.36	100.55	103.70

Plot No:	7	8	9	10	11	
Green manure:	Peas	Sweet Clover	Red Clover	B.Y. Manure	Fallow	General Mean
Range 26,% organic carbon in soil	3.48	3.97	4.15	4.23	3.97	
Range 27,% organic carbon in soil	3.14	3.80	3.59	4.03	3.83	
Range 28,%organic carbon in soil	3.68	4.20	3.62	4.08	2.73	
Range 29,% organic carbon in soil	4.30	3.97	4.17	4.19	3.77	
Mean organic carbon	3.65	3.98	3.88	4.13	3.58	3.66
Mean organic carbon as percentage of general mean	99.81	108.98	106.16	112.99	97.76	100.00

TABLE NO. 11.

APPARENT DECREASE IN NITROGEN AND ORGANIC CARBON OVER AN 18 YEAR PERIOD.

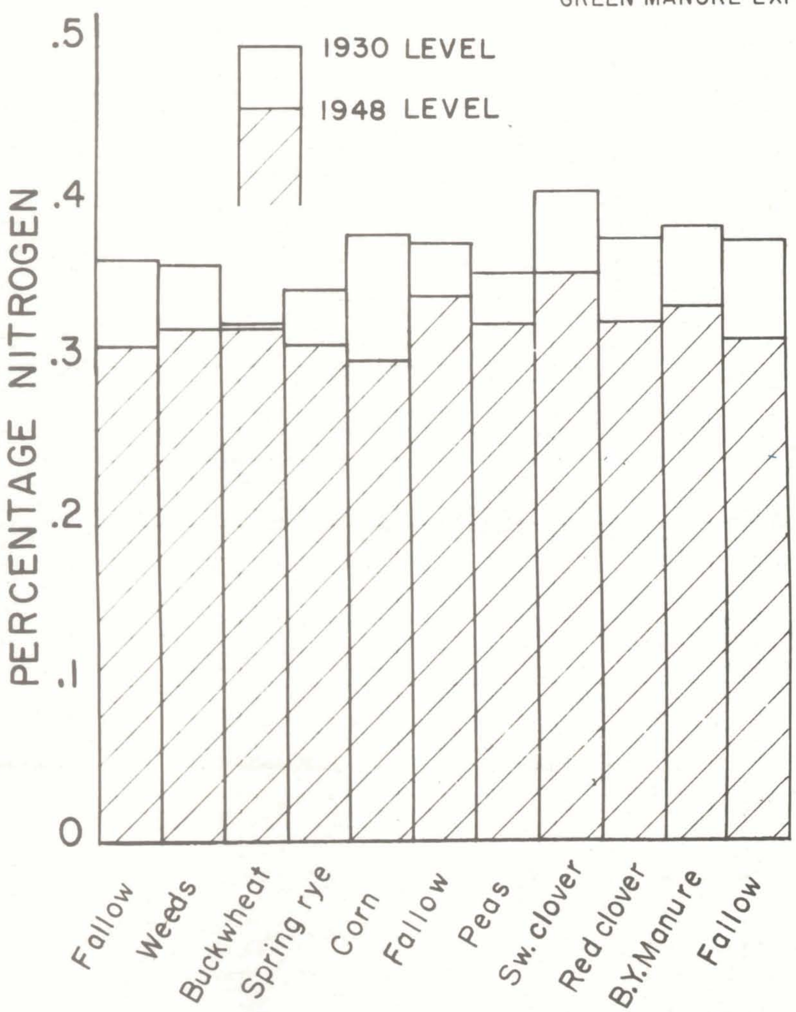
GREEN MANURE EXPERIMENT UNIVERSITY FARM.

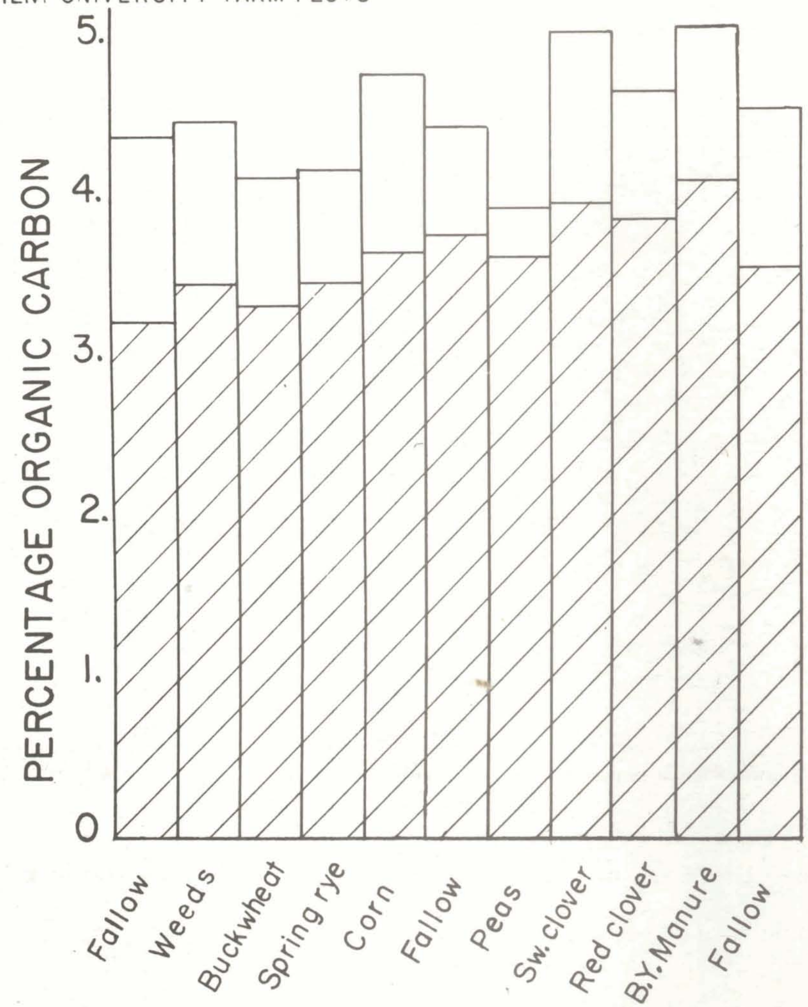
NITROGEN				CARBON			
Plot No.	Green Manure	Decrease in Nitrogen Percentage 1930 - 48 Mean Of Four Plots.	Percentage Decrease Since 1930	Plot No.	Green Manure	Decrease in Carbon Percentage 1930-48 Mean Of Four Plots.	Percentage Decrease Since 1930
5	Corn	.0773	20.29	1	Fallow	1.15	26.11
11	Fallow	.0635	16.77	2	Weeds	1.02	25.18
1	Fallow	.0548	15.01	5	Corn	1.12	23.33
9	Red Clover	.0532	14.02	11	Fallow	1.10	23.21
10	B.Y. Manure	.0493	12.72	8	Sweet Clover	1.07	21.29
2	Weeds	.0412	11.33	10	B.Y. Manure	0.94	18.53
8	Sweet Clover	.0510	10.47	3	Buckwheat	0.71	17.26
4	Spring Rye	.0345	10.09	9	Red Clover	0.81	17.23
6	Fallow	.0342	9.06	4	Spring Rye	0.70	17.06
7	Peas	.0315	8.83	6	Fallow	0.67	14.98
3	Buckwheat	.0042	1.29	7	Peas	0.30	7.64

FIGURE NO. 2

THE PERCENTAGES OF NITROGEN AND ORGANIC CARBON IN 1930 AND 1948

GREEN MANURE EXPERIMENT UNIVERSITY FARM PLOTS





made by means of the method described in the analysis of virgin soils.

(ii) Data

The results from the above determinations are reported in Tables No. Seven, Eight, Nine, 10 and 11, and Figure No. Two.

(iii) Discussion of Results

There has been a general decrease in both organic carbon content and nitrogen content of these soils. Over a period of eighteen years, green manuring has not maintained the organic matter content of the soil.

Depletion of organic matter due to cultivation of a virgin black earth soil is inevitable. Myers et al (43) reported the greatest losses of this constituent to take place in soils originally high in organic matter. The field on the University farm, from which the soil samples were procured, has been under cultivation for approximately thirty-five years. In this time, apparently, the soil has not as yet decreased to a point where an equilibrium between destruction of organic matter and its incorporation can be established using green manure crops. It would appear then that the use of green manuring crops does not prevent the decline of organic matter in black earth soils under the conditions of this experiment.

The carbon nitrogen ratio of the soil in the green manure experiment has been reduced considerably from values determined in 1930. Tables No. Seven and Eight show the percentage decreases in organic carbon over the 18 year period. It is apparent from the percentage values that carbon has decreased considerably more than has the nitrogen content of the corresponding green manure treatments. A general narrowing of the carbon ratio is the net result.

Legumes are known to have the ability to fix nitrogen, but, there was a large percentage loss of nitrogen where legumes were used as green manures. This may be caused by one of several factors. (a) The amount of nitrogen fixed by a legume is insignificant when compared with the amount of nitrogen already present in black earth soils. (b) The cereal crops grown in the rotation may deplete the soil of more nitrogen than is added by using a legume as a green manure. (c) A general reduction of nitrogen content is inevitable when virgin black earths are placed under cultivation. This inevitable lowering of the nitrogen content is greater than any nitrogen fixation that may be taking place. (d) If the supply of nitrogen is adequate for the needs of legume nitrogen fixation may not take place.

Apparently at the present high levels of organic matter in the soil of the fertility field, green manure does not maintain the organic matter content of the soil. Barnyard manure, at the rate of 10 tons per acre, used once in four years gives much the same results. However, although there is little effect on the upkeep of the carbon and nitrogen content, it cannot be concluded that the green manure crop has had no beneficial effect on the soil. Davis (14) found sweet clover green manure caused significant increases in the yields of corn and cereal crops on heavy Michigan soils. Lyon and Wilson (38) recognized the usefulness of legumes in fixing nitrogen and the resulting conservation of soil fertility when a legume is grown in the rotation. The effect of a green manure on the physical conditions of the soil cannot be overlooked. The incorporation of readily decomposable organic matter causes greater microbial activity. Geltzer (24) believed the main cementing substance in soils to be the colloidal products of bacteria. This effect along with the physical effects of roots, according to Geltzer (24) is, to a large degree, responsible for the aggregation of soils.

It is worthy of note that the treatments which were highest in organic matter in 1930 tend to show the greatest depletion of organic matter regardless of the treatment carried out. The treatments with the lowest organic carbon and nitrogen values in 1930 also show the lowest loss of organic matter. This suggests that the treatments on the plot are approaching an equilibrium in destruction and incorporation of organic matter.

Treatments which gave the greatest amounts of organic matter in 1930, although losing large quantities of organic matter, still show a tendency to be highest in 1948. This effect may be due to soil variation but it does occur under the treatments of Barnyard manure and clover which are known to return the greatest amounts of organic matter. It seems feasible that under these treatments an equilibrium in soil nitrogen and carbon may be established at a higher level than under the other green manure treatments.

Dodge and Jones (17) found that cropping systems have only slight influence on the trend of carbon and nitrogen, but may have some influence on the speed with which equilibrium is reached and also the ultimate level. A similar condition is apparent in the soils of the fertility field. Decrease in organic carbon content and nitrogen have occurred over the 18 year period between samplings. There are indications that an equilibrium is being approached. The level of this equilibrium when reached apparently will be affected by the method of green manuring.

3. WATER STABLE AGGREGATION UNDER VARIOUS CULTURAL METHODS

Soil structure has been considered the key to soil fertility by eminent soil scientists for a long time. Hilgard (28), Wollny, and also Williams[+] of Russia were among the earliest to realize the importance of a favorable soil structure. Many investigations have shown that under culture soil aggregation is, to a large degree, being destroyed. A study was made of the relative effects of culture on the water stable aggregation of the plots on the University farm.

(a) The Effect of Fallow Continuous; Wheat Continuous; a Grain Rotation; Clover in the Grain Rotation; Manure; Straw Burned and not Burned; and a Grass-Legume Mixture in the Rotation.

(i) Method.

The fertility field plots sampled for the study of the degree of water stable aggregation under different cultural systems included:- four roadways - continuous fallow; Block 2 Range 28 and 29 Plot 1 - continuous wheat; Block 1 Range 26 to 29 Plots 8 and 11 - the effect of clover in a grain rotation; Block 2 Range 28 and 29 Plots 1 and 2 - the effect of manure; Block 2 Range 28 and 29 Plot 2 - the effect of burning and incorporating straw; Block B Ranges 30 to 33 Plot 7 - the effect of a grass legume mixture in the rotation.

Analytical determinations conducted on these samples and herein reported include organic carbon, nitrogen and the degree

+ as reported in Baver (4)

TABLE NO. 12.

WATER STABLE AGGREGATION, ORGANIC CARBON AND NITROGEN

ON THE UNIVERSITY PLOTS UNDER SEVERAL SYSTEMS OF CULTURE.

Plot	Rotation	Aggreg. .25mm	Average Aggreg. .25mm	Organic Carbon	Average Organic Carbon	Nitrogen	Average Nitrogen	C/N Ratio	Ave. C/N Ratio
B-30/B-31	fallow continuous	40.60	34.51	3.02	3.47	.258	.314	11.7:1	11.0:1
1-28/1-27	fallow continuous	38.15		3.20		.312		10.3:1	
2-28/2-29	fallow continuous	30.52		4.15		.329		12.6:1	
2-26/2-27	fallow continuous	26.96		3.50		.355		9.9:1	
2-28-1	wheat continuous	52.51	57.06	2.51	3.17	.255	.295	9.8:1	10.7:1
2-29-1	wheat continuous	61.62		3.83		.335		11.4:1	
1-26-11	yr. 2--wheat	42.99	48.90	3.97	3.58	.353	.315	11.2:1	11.4:1
1-27-11	yr. 3--corn	55.55		3.83		.308		12.4:1	
1-28-11	yr. 4--wheat	49.24		2.73		.251		10.9:1	
1-29-11	yr. 1--fallow	47.84		3.77		.349		10.8:1	
1-26-8	yr. 2--wheat	55.96	51.42	3.97	3.98	.342	.358	11.6:1	11.1:1
1-27-8	yr. 3--corn	60.27		3.80		.385		9.9:1	
1-28-8	yr. 4--wheat sow sweet clover	46.75		4.20		.312		13.5:1	
1-29-8	yr. 1--fallow pd. sweet clover	42.71		3.97		.392		10.0:1	
2-26-1	yr. 2 --wheat	39.34	38.60	2.74	2.78	.228	.251	12.0:1	11.1:1
2-26-2	yr. 1--fallow	37.87		2.82		.275		10.2:1	
2-27-1	yr. 2--wheat	53.57	52.40	3.20	3.30	.248	.261	12.9:1	12.6:1
2-27-2	yr. 1--fallow apply 4 T. BYM.	51.24		3.40		.275		12.4:1	
2-28-2	wheat continuous return straw	58.51		4.21		.362		11.7:1	
2-29-2	wheat continuous burn straw	54.98		4.82		.376		12.8:1	
B-30-5	yr. 1--s.d. grasses and clover	62.84	67.09	4.00	4.06	.376	.380	10.6:1	10.7:1
B-31-5	yr. 2--hay	75.26		4.38		.426		10.3:1	
B-32-5	yr. 3--hay and break	71.49		4.19		.365		11.5:1	
B-33-5	yr. 4--wheat/Corn(plot split)	58.77		3.66		.355		10.3:1	

of water stable aggregation.

(ii) Data

The experimental data obtained from these determinations are given in Table No. 12.

(iii) Discussion of Results

Water stable aggregation studies indicate that under different rotation systems, soil aggregate stability shows a significant variation. This variation may be due partly to the effect of the different crops used in the rotations, or to the effect of the different rotations on the level of the organic matter.

The highest degree of water stable aggregation existed under a rotation having three years out of four devoted to the growing of a grass-legume mixture. According to Page and Willard (46) the longer the period a grass-legume mixture is in the rotation the better is the aggregation that will result. Geltser (24) believed that the stability of soil structure depended on the amount of stable aggregates accumulated during the lifetime of perennial grasses. The soils having the greater percentage of stable aggregates will show the least deterioration during the rotation. Grasses are considered by Tsyganov (56) to be more effective than legumes in aggregate stabilization. However, combinations of grass and legume are considered desirable because of nitrogen fixation by legumes and of greater hay yields obtained from mixtures.

Fallow, apparently, reduces aggregate stability. The lowest degree of aggregation was found to exist under continuous fallow. The average organic carbon content of these soil samples is considerably higher than of the soil under wheat continuous, yet the aggregation under continuous wheat is more favorable. This apparently suggests that the system of culture interferes with the correlation of aggregation with organic matter content.

Application of manure apparently favors aggregation stability. This agrees with the work of Elson (22) who found that manure significantly increased macro-aggregation; the greatest increases being noted when the soil was in a moist condition.

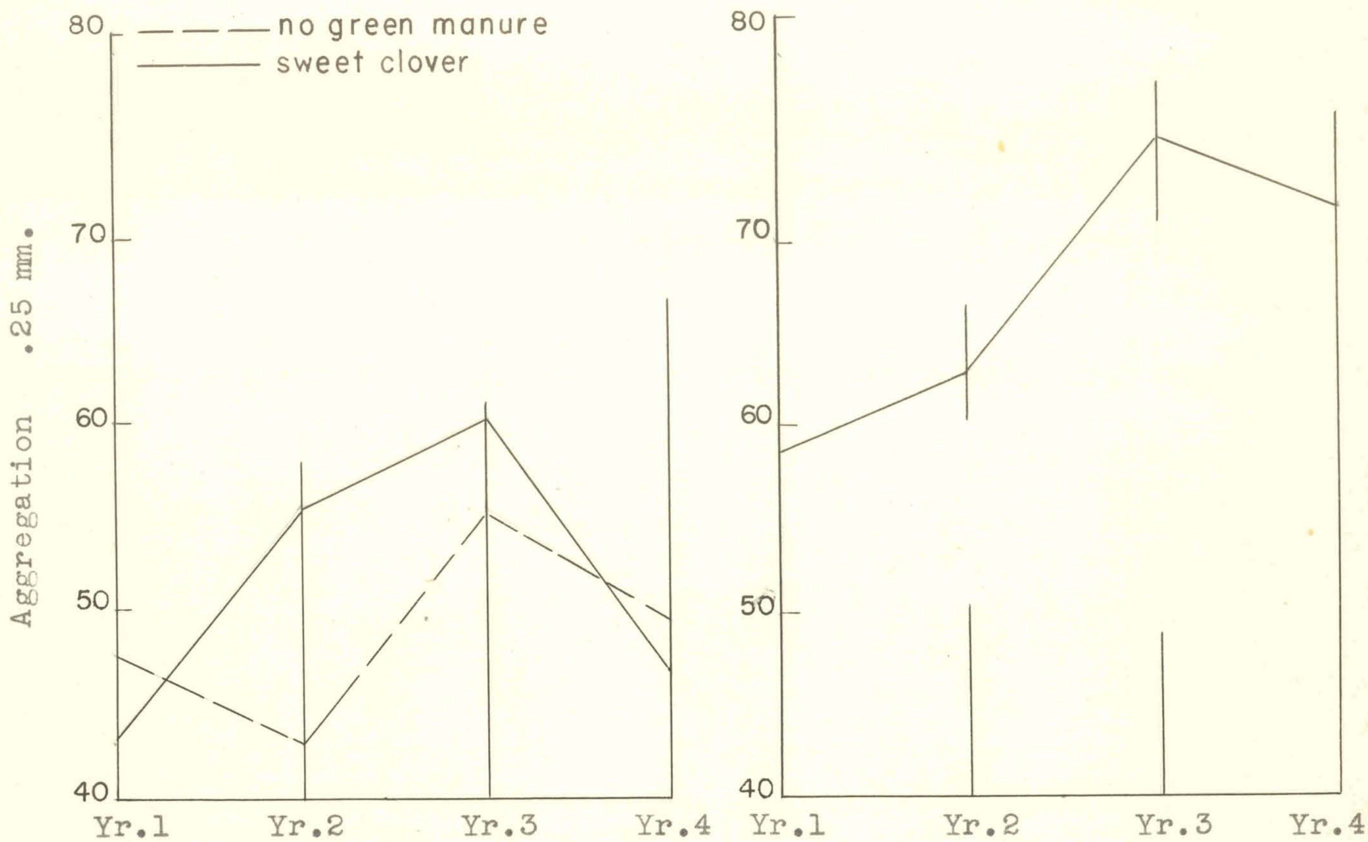
A study of the effect of incorporating and burning straw on the University farm plots indicates a slight beneficial effect of straw on soil aggregation. The level of organic carbon and nitrogen in the plot in which the straw was burned is higher than where straw has been returned. However, aggregation is greater in the plot in which straw has been returned. The problem of incorporating or burning of straw is an important one. Crop yields are reduced, due to the tie-up of nitrates by bacteria, when straw is incorporated in the soil. More work is required on this problem to determine what should be done with residual straw.

A comparison of soil under rotation with clover included as the green manure crop against soil under the same rotation without clover shows a slight increase of aggregation with clover present.

The accompanying figure shows the effect of clover on aggregation in the first year after green manuring is apparently significant. This graph also suggests the effect of the cultural treatment. Under corn, aggregate stability is greater than under wheat. This could be due to soil variation. Jesse Elson (22)

Figure No. 3

Aggregation with clover as the green manure and with a grass-legume crop three years out of four.



Rotation:

Year 1--Fallow plow down sweet clover;
Year 2--Wheat;
Year 3--Corn;
Year 4--Wheat sow sweet clover.

Rotation:

Year 1--Wheat and corn, (Range is split)
Year 2--Seed down grasses and legumes;
Year 3--Hay;
Year 4--Hay and break.

found that corn and wheat culture affected aggregation similarly; also that clover plots showed better aggregation than wheat and corn plots. The apparent increase in aggregation due to clover on the University fertility field agrees with literature data.

In the rotation of three years grass-legume mixture an increase in aggregation occurs with the length of time the mixture has been established. The results illustrated in Figure No. Three show a decrease in aggregation takes place after the grass-legume mixture is plowed up, and an increase in aggregation follows the establishment of a grass-legume mixture. The plots were sampled in the fall after the hay crop had been removed and the sod broken and backset. This decrease in aggregation illustrates the dynamic nature of soil aggregation.

It is impossible to draw conclusions from a single determination of soil aggregation on a rotation system. Variation in moisture conditions, stage of crop, maturity and cultivation methods all cause a variation in aggregation. A study of soil aggregation under different rotation schemes should be carried out over a period of time in which the rotation can complete a full cycle. Sampling of the plots should also be done several times each year.

The results of these determinations on soils under rotations indicate three apparent trends:

(1) Fallowing causes deterioration of water stable aggregation.

(2) Decomposable organic residues, such as manure, green manure crops, and straw, increase aggregation.

(3) A grass-legume mixture in the rotation results in a marked increase in aggregation.

(b) The Effect of Applications of Lime and Sulfur

(i) Method.

TABLE No. 13.

THE EFFECT OF SULPHUR ON WATER STABLE AGGREGATION, UNIVERSITY FARM PLOTS.

Plot	Treatment	Aggreg. .25 mm	Average Aggreg. .25 mm	Organic Carbon	Average Organic Carbon	Nitrogen	Average Nitrogen	Average C/N Ratio	pH.
3-29-7	Check	25.95	34.75	2.43	3.20	.241	.266	12.0:1	7.26
3-29-11	Check	43.55		3.98		.291			5.85
3-29-8	*500 lbs. sulphur	41.84	40.12	3.58	3.63	.320	.325	11.2:1	7.48
3-29-9	*1000 lbs. sulphur	38.13		3.29		.302			6.57
3-29-10	*2000 lbs. sulphur	40.40		4.02		.353			5.85

*Applied in the spring of 1946.

TABLE No. 14.

THE EFFECT OF LIME ON WATER STABLE AGGREGATION, UNIVERSITY FARM PLOTS.

Plot	Rotation	Aggreg. .25 mm	Average Aggreg. .25 mm	Organic Carbon	Average Organic Carbon	Nitrogen	Average Nitrogen	Average C/N Ratio
A-30-5	yr.3--corn	28.45	33.40	2.45	2.54	.327	.301	8.4:1
A-31-5	yr.4--barley	47.45		2.60		.346		
A-32-5	yr.1--fallow (limed)	32.31		2.52		.255		
A-33-5	yr.2--wheat	25.41		2.58		.277		
A-30-7	yr.3--corn	36.41	34.30	4.39	3.50	.335	.295	11.9:1
A-31-7	yr.4--barley	38.92		2.78		.269		
A-32-7	yr.1--fallow (no lime)	31.85		3.22		.338		
A-33-7	yr.2--wheat	30.01		3.63		.237		

Samples were taken from Block 3 Range 29, Plots 6-11 which is devoted to the effects of sulfur, and from Block A, Ranges 30-33, Plots 5 and 7, which have been under a liming experiment for twenty-nine years. The sampling was done in the late fall of 1949. The moisture content of the soil at the time was high. These samples were allowed to dry in the laboratory before aggregate analysis was determined upon them.

(ii) Data

The results of this investigation are enumerated in Tables No. 13 and 14.

(iii) Discussion of results.

The use of lime apparently does not increase aggregation to any extent. Sulfur may have some effect on the water stable aggregation of a soil.

Bradfield (6) has reported poor structural conditions in Ohio soils. One, a heavy glacial lake clay was not benefitted by applications of lime. Johnston and Hill (31), reporting on some highly colloidal rendzina soils in Texas, found dry weather cracking and cloddy conditions existing in these soils even though they show a high lime composition.

In the plot samples studied, free calcium carbonate is encountered either in the surface six inches of soil or immediately below this depth. The application of hydrated lime to these high lime soils has apparently shown no effect upon the physical properties of the soil as exemplified by water stable aggregation.

An application of sulfur in varying amounts was made in 1946 to three fertility field plots. Under these applications there may have been some increase in aggregation. The results given in Table No. 13 show one of the check plots having a very high comparative stability of aggregation, but it is noticed that the reaction of this plot has been reduced to a pH of 5.85. The surface drainage caused by micro-relief is in the direction of this check plot. This plot should probably be included with those of sulfur application, as much sulfur has been deposited on it by the movement of surface water.

The remaining check plot is very low in organic carbon, also the water stable aggregation of this plot is much less than the other four plots. It cannot be assumed that sulfur increases aggregation in the other plots as the low organic carbon content may be the cause of poor aggregate stability in this check.

Further investigation into the use of sulfur as an ameliorant and also as a fertilizer are required. As the cost of sulfur is high, a relatively large increase in aggregation of a rather permanent nature would be required to justify its use, but, as it has the effect of lowering the reaction of a soil; the value its action has in creating a soil medium more favorable for plant growth cannot be overlooked.

4. CALCIUM MAGNESIUM RATIO OF EXCHANGEABLE BASES IN SOILS UNDER DIFFERENT SYSTEMS OF CULTURE.

In the study of virgin profiles, it was established that there was a correlation between the exchangeable calcium magnesium ratio and the physical properties of the lacustrine clay soils of the Red River Valley. It also was shown that under the systems of culture used in this area, a decrease in nitrogen and organic matter, and a general dispersive soil action appears to be in progress.

The exchangeable calcium and magnesium were determined on several rotations from the experimental field to ascertain

TABLE NO. 15.

CALCIUM, MAGNESIUM, CA/MG RATIO, AMMONIUM ABSORBED, EXPRESSED IN MILLI-EQUIVALENTS;

AND PERCENTAGE ORGANIC CARBON IN SOILS ON THE UNIVERSITY PLOTS.

Plot	Rotation	Ca	Mg	Ca/Mg Ratio	Average Ca/Mg Ratio	Ammonium Absorbed	Average Ammonium Absorbed	Organic Carbon	Average Organic Carbon
B-30/B-31	fallow continuous (Roadways)	39.59	15.89	2.49:1	3.13:1	56.3	54.4	3.02	3.47
1-27/1-28	fallow continuous (")	39.81	14.98	2.66:1		53.4		3.20	
2-26/2-27	fallow continuous (")	51.57	12.02	4.29:1		54.2		4.15	
2-28/2-29	fallow continuous (")	55.00	18.05	3.05:1		53.5		3.50	
2-26-1	yr.2--wheat	52.43	13.31	3.94:1	3.89:1	47.8	48.7	2.74	2.78
2-26-2	yr.1--fallow	49.22	12.82	3.84:1		49.6		2.82	
2-27-1	yr.2--wheat	38.30	7.38	5.19:1	4.19:1	55.8	55.6	3.20	3.30
2-27-2	yr.1--fallow apply 4 T. BYM.	46.87	14.65	3.19:1		55.4		3.40	
2-28-1	wheat continuous	47.94	14.49	3.31:1	3.18:1	48.9	50.4	2.51	3.17
2-29-1	wheat continuous	50.51	16.54	3.05:1		51.0		3.83	
2-28-2	wheat continuous return straw	55.22	16.21	3.39:1		52.3		4.21	
2-29-2	wheat continuous burn straw	34.45	14.76	2.33:1		56.0		4.82	
1-26-8	yr.2--wheat	44.09	13.20	3.34:1	2.94:1	56.7	55.9	3.97	3.98
1-27-8	yr.3--corn	50.72	14.82	3.42:1		56.3		3.80	
1-28-8	yr.4--wheat s.d. sweet clover	40.02	16.00	2.50:1		53.0		4.20	
1-29-8	yr.1--fallow p.d. sweet clover	44.73	17.67	2.53:1		57.5		3.97	

whether or not the degradation effect that was apparent was accompanied by a narrowing of the calcium magnesium ratio.

(i) Method.

The samples analyzed were taken from four roadways, Blocks 2, Ranges 26 to 29, Plots 1 and 2; and Block 1, Ranges 26 - 29, Plots 8 and 11. Calcium, magnesium, total base exchange capacity and organic carbon were determined by the methods outlined under studies of virgin soils.

(ii) Data.

The data obtained are given in Table No. 15.

(iii) Discussion of Results.

The calcium magnesium ratio varied in the soils under the different rotations, but the variation within the rotations were greater than the variations between the treatments. Little significance is therefore attached to the variation in calcium magnesium ratio between the rotations.

The calcium magnesium ratio was found to be as high or higher than the ratios which were found to exist in the phytomorphic Red River soils. Apparently these soils have enough calcium present to mask any dispersive action of the magnesium ion if the studies on virgin Red River soils can be used as a standard.

There appears to be a wide discrepancy in some cases between the sum of the calcium and magnesium bases and the amount of ammonia absorbed, the sum of the milliequivalents of calcium and magnesium being greater than the milliequivalents of ammonia absorbed. In the soils under study, calcium carbonate and probably magnesium carbonate occur. These free carbonates quite definitely would effect the calcium and magnesium values as the carbonates of these two bases are to some extent soluble in the ammonium acetate solution used as an extracting agent.

Apparently, the calcium magnesium ratios do not differ sufficiently to warrant any differentiation among the rotational systems. The calcium magnesium ratios, when compared to Red River soils, are high enough that dispersion should not occur.

D. SUMMARY OF STUDIES ON SOILS UNDER CULTURE.

In the study of soils influenced by culture, several patterns or trends are apparent. The most striking effect of culture upon the soils on the University farm is the general decrease in organic carbon and nitrogen which has taken place.

Red River soils under virgin conditions accumulate large reserves of organic carbon and nitrogen. Tillage interferes with this natural soil building process.

Under culture, it is not possible to maintain the organic matter content of a soil at the level found under virgin conditions. Leaving the soil in virgin condition would be the only possible way of keeping any large area of soil at the high levels of fertility encountered in the virgin soils. A decrease towards a new equilibrium point is inevitable under culture. The soil of the fertility field studied, shows a relatively high decrease in nitrogen over the last eighteen years and a larger percentage decrease in organic carbon content. There is reason to believe an equilibrium is being approached but the trend is downward under the present systems of culture.

Although the carbon and nitrogen levels of the soil are falling under the systems of rotation in operation on the fertility field, it cannot be concluded that legumes, grasses or green manures should not be used in crop rotations. Fallow has been found to cause deterioration in the water stable aggregation of a soil. It was found that clover as a green manure crop and a grass-legume mixture increases the aggregate stability of a soil. In a rotation the longer the period devoted to growing grasses and legumes, the greater the development of stable aggregates.

Incorporation of decomposable organic matter causes an increment in water stable aggregation and apparently helps to maintain the organic carbon and nitrogen levels of the soil at relatively higher levels than if no organic matter is added. In a rotation of fallow every other year, with and without manure, the organic matter content of the soil and aggregate stability under application of manure were significantly greater. The application of straw was found to show a positive effect on aggregation of the soil.

The application of lime apparently caused no significant increase in aggregation in the plot studied, and the application of sulfur gave uncertain results. More experimentation is necessary to ascertain the effect of sulfur than is obtainable from the present sulfur experiment.

The calcium magnesium ratio is relatively high in the soils of the fertility plots in comparison to the ratios determined in virgin soils. No dispersion should result on these plots from the effect of the magnesium ion because there appears to be sufficient calcium present to counteract its influence.

III. STUDIES OF AMELIORATION PRACTICES

A. LITERATURE REVIEW.

According to de Sigmond (16) the first attempt at the improvement of alkali soils was recorded in the eighteenth century. The method of improvement of the solonetz structure outlined by early investigators was liming or marling. Hilgard (28) carried out extensive investigations using calcium sulphate as the ameliorant for so called "black alkali" soils. De Sigmond (16) refers to the relatively high cost of such operations and points out the need of knowing the sodium carbonate content of the soil so that neither too little nor too much gypsum will be applied. Kelley (23) states that difficulty is encountered in reclamation of heavy soils but that lighter textured soils may be reclaimed using gypsum or sulphur.

The use of aluminum sulphate and iron sulphate as an ameliorant has been attempted by Botkin (5) and other investigators. However, Powers (48) considers the application of these ameliorants too costly for farm use.

Sulfur in its elemental form and as sulfuric acid has been used as an ameliorant. Snyder and associates (55) report sulfur to be slightly more effective than gypsum in the reclamation process. According to Powers (48) "the elemental sulfur is oxidized by biological activity mainly, and combines with water to form sulfuric acid. This reacts with the calcium carbonate in the soil to form calcium sulfate and increases the calcium in the soil solution. This calcium then participates in base exchange freeing the absorbed sodium from the clay so it can be laundered out."

The effect or organic matter on permeability and aggregation of heavy soils has been given consideration by many investigators. Botkin (5) reports a thirty-three per cent increase in permeability in an alkali soil by the addition of organic matter. Browning and Milam (10) in studies of different organic materials report that those materials which rapidly decompose increase aggregation in a few days, while the slower decomposing materials take longer to exert their binding influence but remain effective over a greater period of time. The general opinion of Wilson and Fisher (58) and other investigators is that in a soil of low organic matter increasing the organic carbon content of the soil will cause increased aggregation.

Powers (48) reports a mixture of manure and sulfur as being the most effective method of improving the structure of alkali or "solonetz" soils. The manure in decomposing produces carbon dioxide and carbonic acid. It also adds micro-organisms which aid in the oxidation of sulphur. Two reasons for poor fertility in alkali land, he reports, are low organic matter and carbon dioxide content. Since manure retains some acid from the sulphur applications, the colloids are flocculated and stabilized. Magistad and Christiansen (39) suggest the use of sulfur with a green manure crop, as barnyard manure is not always readily available. As an advantage in this method, they site the value of the root action of the green manure crop in promoting good soil structure.

B. DESCRIPTION OF THE SOIL STUDIED IN THE AMELIORATION EXPERIMENT

The B_1 horizon of the degraded alkalinized phase of the Morris associate (Profile No. Five, description on Page No. 14) was selected for amelioration studies. This soil was relatively low in organic matter and nitrogen, had a low calcium magnesium ratio and a high plasticity number. The characteristic dispersed appearance of a "solonetz" soil was present and the water stability of aggregation relatively low.

C. SOIL AMENDMENT STUDIES.

Certain amelioration practices are suggested from a review of literature and from observation of the results obtained in previous experimentation. A controlled experiment was set up to determine the effects of both organic and inorganic ameliorants upon physical properties of the soil from the B_1 horizon of the Morris degraded soil.

1. THE EFFECT OF AMENDMENTS ON WATER STABILITY OF SOIL AGGREGATES

A review of literature indicated that several amendments have been used in the amelioration of the undesirable physical conditions of a "solonetz" soil. The use of similar improvement practices on the "magnesium solonetz" (11) soils of the Red River valley under laboratory conditions was attempted to determine their value on the magnesium type of "solonetz".

(i) Method

The B_1 horizon of the degraded alkalinized phase of the Morris associate was ground on a mortar board to pass through a two millimeter sieve. The rate of application of ameliorants was determined considering tillage depth of soil to be six inches. The amendments were thoroughly mixed with the soil prior to placing it in pots having a five inch diameter. The treatments included:

1. Check
2. Sulfur at the rate of one ton per acre
3. Gypsum ($CaSO_4 \cdot 2H_2O$) at the rate of five tons per acre.

4. Calcium carbonate at the rate of 3.34 tons per acre.

5. Calcium carbonate at the rate of five tons per acre.

6. Barnyard manure and calcium carbonate at the respective rates of thirty and five tons per acre.

7. Barnyard manure and gypsum at the respective rates of thirty and five tons per acre.

8. Barnyard manure and sulfur at the respective rates of thirty and one ton per acre.

9. Chopped alfalfa at the rate of four tons per acre.

10. Barnyard manure at the rate of 100 tons per acre.

The moisture equivalent of the soil was determined and the moisture content of the soil raised to this point every second day. Application of water was started on December 28, 1948, and continued until March 19, 1949. On March 25 the soils were removed from the containers. A water stable aggregate analysis was conducted using the wet sieving technique developed by Rowles (52) previously outlined under "Studies of Red River Soils in Virgin Condition".

(ii) Data.

The results obtained are presented in Table No. 16 and Figure No. Four.

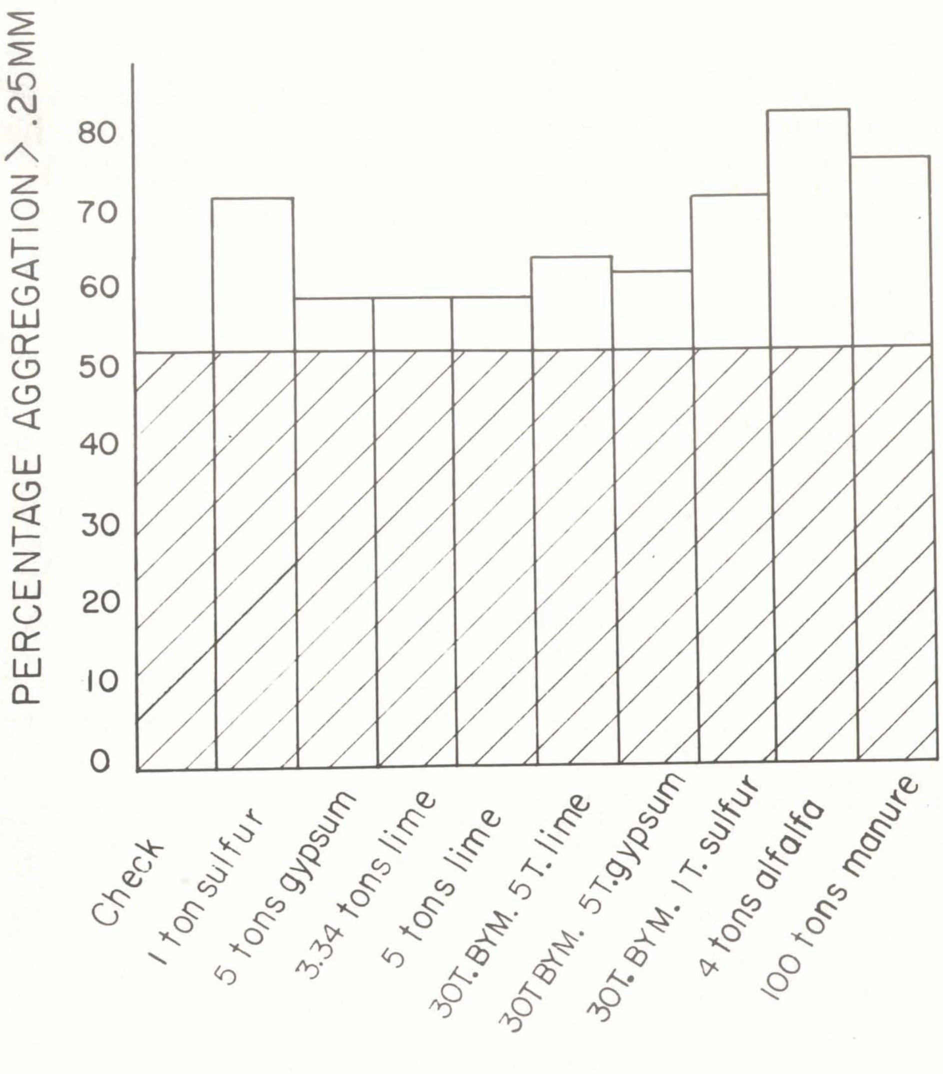
(iii) Discussion of Results.

The treatments used apparently differ in their effect on aggregate stability. All treatments resulted in an increase over the check pot.

A relatively large increase in aggregation from the use of sulfur is noted. Sulfur has been used in the reclamation of "solonetz" soils in its elemental form and as sulfuric acid. Snyder (55) reported sulfur superior to gypsum in amelioration of "solonetz" soils. Sulfur, in combination with manure, was

FIGURE NO. 4

THE EFFECT OF SOIL AMENDMENTS ON AGGREGATION



LEGEND :- Clear area = Increase in aggregation over check

TABLE NO. 16.

WATER STABLE AGGREGATION OF THE B_1 OF A MORRIS (DEGRADED) SOIL TREATED WITH VARIOUS AMELIORANTS.

Treatment	Percentage Aggregates 1 mm	Percentage Aggregates .25 mm	Percentage Moisture In Soil
Check	1.0	52.9	2.5
1 ton sulphur per acre	17.6	72.4	3.0
5 tons $CaSO_4.2H_2O$ per acre	2.7	59.8	2.7
3.34 tons $CaCO_3$ per acre	3.9	59.8	2.8
5 tons $CaCO_3$ per acre	3.8	59.9	2.8
30 tons manure + 5 tons $CaCO_3$	6.7	64.7	3.0
30 tons manure + 5 tons $CaSO_4.2H_2O$	5.5	62.9	3.0
30 tons manure + 1 ton sulphur	13.2	72.6	2.9
4 tons chopped alfalfa	35.0	83.5	2.9
100 tons manure	16.8	77.8	3.2

suggested by Powers (48) to be the most effective means of improving soil structure in these soils. The use of sulfur with manure, however, in the experiment herein reported, did not improve aggregation to any degree over the use of sulfur alone.

Gypsum and calcium carbonate caused comparative increase in aggregation. Both are relatively insoluble in water. In an experiment conducted over this period of time, they possibly do not show their maximum effect. A slight increase is noted with the use of combinations of calcium carbonate and gypsum with manure.

Alfalfa, which had been chopped up previous to its incorporation into the soil, gave the highest degree of aggregation. Manure at one hundred tons per acre caused an increase in aggregate stability of just slightly less than the chopped alfalfa. Alfalfa at the rate of four tons per acre caused greater aggregate stability than manure at the rate of 100 tons per acre. It may be that the physical and chemical characteristics of the organic matter may influence aggregate stability more than actual quantity.

Browning and Milam (10) found that organic materials, which decompose readily increase aggregation within a few days, come to a maximum effectiveness and gradually become ineffective with time. Slower decomposing materials require a longer time to exert a binding effect, but continue for a longer time. Differences in the effect of organic and inorganic materials are markedly influenced by time. More work is required on the alkalinized Red River soils with the use of inorganic and organic ameliorants.

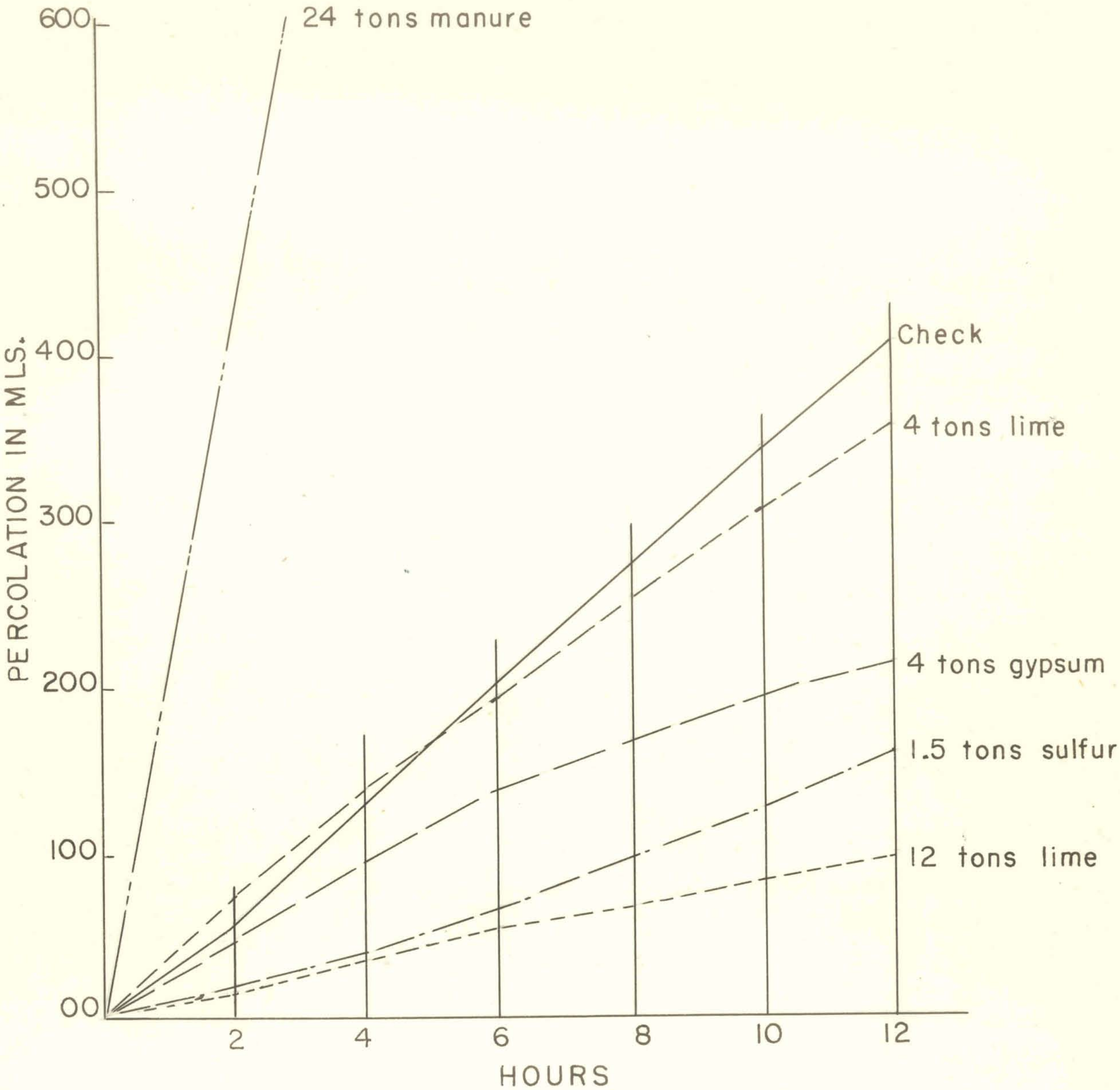


Figure No. 5.

The effect of organic and inorganic amendments on the porosity of the B_1 of a Morris soil.

TABLE NO. 17.

RATES OF PERCOLATION OF WATER THROUGH THE B_1 OF A MORRIS SOIL

UNDER TREATMENT WITH VARIOUS SOIL AMENDMENTS.

Treatment	0-2 hrs.	2-4 hrs.	4-6 hrs.	6-8 hrs.	8-10 hrs.	10-12 hrs.
	mls.	mls.	mls.	mls.	mls.	mls.
Sulphur 1.5 tons per acre	19.5*	19	25	28	31.5	34.5
Gypsum 4 tons per acre	46	47	42	29	28.5	27.5
Lime carbonate 4 tons per acre	72	64	58	56.5	55	50.5
Manure 24 tons per acre	419	393	366	362	365	363
Lime carbonate 12 tons per acre	18.5	18.5	16.5	14.0	15.0	13.5
Check	55	71	72	69	72	67

* Percolation through a core of soil four inches in length and two inches in diameter.

2. THE EFFECT OF SOIL AMENDMENTS ON PERMEABILITY

The Red River clay soils are highly impermeable to water--the alkalinized and degraded alkalinized phases of the Morris soil associate exhibit slower infiltration rates than the other soil associates (Caldwell (11)). An increase in soil porosity is of primary importance in the improvement of existing physical conditions. Applications of gypsum, lime or sulfur to ameliorate solonetzic conditions in "solonetz" soils have been suggested. These soil amendments were utilized in the treatment of a magnesium solonetz soil in an investigation of their relative effects on porosity.

(i) Method.

Soil from the same sample on which aggregate studies were conducted (see page no. 67) was used in this study. The rate of application of ameliorants was calculated on the basis of acre six inch depth of soil. The ameliorants were thoroughly mixed with the soil before the soil was placed in percolation tubes. Amendments used in this experiment included:

1. Sulfur at the rate of 1.5 tons per acre.
2. Gypsum ($CaSO_4 \cdot 2H_2O$) at the rate of four tons per acre.
3. Calcium carbonate $CaCO_3$ at the rate of four tons per acre.
4. Barnyard manure at the rate of 24 tons per acre.
5. Calcium carbonate at the rate of 12 tons per acre.
6. Check no treatment.

The dates and methods and period of water application were the same as those described in aggregation studies on page 68. At the end of this period the percolation tubes were placed in water for 18 hours previous to the permeability determinations, to allow the soil to swell. The experiment was carried on under a one inch head of water and continued over a twelve hour period. The amount of water passing through the soil was measured every two hours.

(ii) Data.

The results from this experiment are given in Table No. 17 and Figure No. Five.

(iii) Discussion of Results.

From the results obtained in this experiment, two general conclusions can be drawn. Organic matter increased the infiltration rate into a soil. Inorganic amendments showed no positive effect on permeability in this study.

The manure has increased infiltration of water in this soil to a rate several times as large as water percolation under the other treatments. The use of inorganic amendments retarded the rate of infiltration of water into the soil. The treatment of soil with 12 tons of lime and the check soil show a straight line relationship between percolation in milliliters and time in hours. The soil which was treated with four tons of lime and the soil treated with four tons of gypsum give a convex curve when the percolation in milliliters is plotted against time in hours. In the case of the sulfur treatment on soil, a concave curve with respect to the hours axis was obtained. The rate of percolation in this soil nearly doubled during the period of time elapsing between the 0-2 hour and the 10-12 hour measurements. It might be concluded from this experiment that soil permeability can be increased with time by sul ur application.

The most promising results in this study were obtained from the use of organic matter and sulfur. Further investigation about the effect of ameliorants on permeability is required.

SUMMARY OF AMELIORATION STUDIES

Poor physical condition in the Morris soils was found to be correlated with the character and amount of organic matter and the base exchange status of the absorption complex of the soil. A number of ameliorants were used experimentally in an attempt to improve the physical condition of this soil. The ameliorants used included chopped alfalfa, manure, sulfur, lime and gypsum.

Aggregation was favorably influenced by all the ameliorants used. Chopped alfalfa gave the greatest positive effect. Of the inorganic amendments sulfur gave the best results. The greater the amount of organic matter added in the form of manure, the larger was the increase in water stability of aggregation.

Infiltration of water was apparently adversely affected by the use of lime carbonate and gypsum. Organic material in the form of barnyard manure increased permeability to a very marked extent. Initially infiltration was much reduced when sulfur was used as the amendment, but the rate of percolation per hour increased with time.

It has been shown that the problems of the alkalinized and degraded alkalinized phases of the Morris associate are due to at least two factors:

(a) The narrow calcium magnesium ratio and the resulting dispersive action of magnesium on the colloidal complex of the soil; and

(b) the low organic content of the soil under this condition.

The dispersed condition of the soil is apparently due to the high content of magnesium in the base exchange complex.

Studies of soils under virgin condition and amelioration studies indicate two steps necessary in amelioration practices. The first step indicated is a modification of the base exchange complex. The second step indicated as necessary in amelioration is the addition of organic matter to the soil.

SYNOPSIS:

Agricultural practices and natural degradation processes have resulted in deterioration of soil structure, and of workability, over a large acreage in the Red River valley plain.

An investigation of this problem has been undertaken along three lines:

1. A study of the physical and chemical properties of typical virgin soils that respectively exhibit both favorable and unfavorable structural conditions.

11. A study of the chemical and physical modifications resulting from cultural practices on the fertility field of the University farm.

111. An investigation of methods of amelioration.

The heavy lacustrine soils studied in this investigation belong to the Red River Soil Association, and are located in the central basin of glacial Lake Agassiz.

1. The major soil associates occurring in the Red River association include the phytomorphic member (Red River clay), the hydromorphic member (Osborne clay), the halomorphic member (Morris clay). Two phases of the Morris clay exist, the alkalinized phase and the degraded alkalinized phase.

Nine virgin profiles, representative of the major soil associates were examined in the field and their morphological characteristics described. Soil samples from specific horizons of these profiles were transported to the laboratory where their respective physical and chemical properties were determined. Laboratory work on these soil samples included determinations of:

(a) Organic carbon, inorganic carbon, nitrogen and reaction.

(b) Exchangeable bases and replaceable hydrogen.

(c) Water stable aggregation and Atterberg consistency constants.

The results of these determinations revealed a number of important facts which may be summarized as follows:-

(a) The organic matter in the soils with unfavorable structure (halomorphic associate) was found to be lower in amount and to have a wider carbon nitrogen ratio than the organic matter in soils exhibiting favorable structure (phytomorphic associate). It is suggested that these differences in organic composition may be due to retarded decomposition resulting from inadequate aeration, but further investigation of this point should be undertaken. Inorganic carbon is low in the solum of all Red River soils studied, and it is almost negligible in the horizons of the Morris solum that exhibit unfavorable structure.

(b) A study of the base exchange status of "unfavorable-structured" alkalinized and degraded alkalinized soils showed a very low content of sodium; a high content of magnesium; and a narrow calcium magnesium ratio. Evidently the sodium content was not great enough to bring about the formation of sodium solonetz with their characteristic high alkalinity. It is apparent that magnesium rather than sodium in the base exchange complex of the "unfavorable-structured" soils studied has been responsible for the solonetz-like structural conditions existing. These poor structural soils with solonetzic character and high content of magnesium with only a trace of sodium in the exchange complex would be better termed "magnesium solonetz."

(c) The soils with favorable physical condition were found to have a low plasticity number; a high degree of water stable and a comparatively wide calcium magnesium ratio. Conversely, the soils with unfavorable structure had a narrow calcium magnesium ratio; a high plasticity number; and a low degree of water stable aggregation.

11. The fertility field plots on the University farm, which is situated on the clay deposits of the Red River plain, have been under systematic experiments for approximately thirty years. Analytical determinations were made on soil samples taken from plots selected to ascertain the effect of the different cultural treatments on the soil. The laboratory analysis included determinations of:-

(a) Organic carbon and nitrogen.

(b) Water stable aggregation.

(c) Base status and calcium magnesium ratio.

The results of these determinations may be summarized as follows;

(a) A general decrease was found in organic carbon and nitrogen due to the effect of arable culture. Over an eighteen year period in the case of the "green manuring" experiment there was a mean percentage decrease of 12.13 per cent and 19.38 per cent in the nitrogen and carbon content, respectively.

The effect of fallow frequency on nitrogen and carbon content of the soils gave conflicting evidence. On the one hand, where the plots were under fallow - grain rotations, it was evident that the carbon and nitrogen levels were lowered as the fallow frequency increased. On the other hand, where the land has been kept in continuous fallow the level of carbon and nitrogen in the soil was found to be at higher levels than under the various fallow-grain rotations. Investigation should be undertaken to ascertain if a different micro-biological regime prevails under continuous fallow which might affect the carbon and nitrogen levels in a different manner than under crop growth.

The general tendency of arable culture to reduce the carbon and nitrogen content in the soils of the fertility field has been retarded where barnyard manure has been applied.

(b) The results of the water stable aggregation studies showed that fallowing has caused a decrease in aggregate stability. Unlike the conflicting results obtained in the carbon nitrogen levels, both under conditions of fallow-grain and continuous fallow, the decrease in aggregate stability was evident.

Incorporation of decomposable organic matter, such as manure, straw and clover as a green manure, was found to increase aggregation. It was found that grass-legume mixture resulted in the greatest increase in aggregation.

Lime and sulfur applied to certain plots under field conditions were found to have little or no effect upon the aggregate stability of the soil.

(c) The results of base status studies showed that the ratio of calcium to magnesium in the base exchange complex of sixteen cultivated plots studied was wide in comparison with the calcium magnesium ratios in virgin Red River soils. Apparently sufficient calcium is present in the cultivated soils studied to inhibit the dispersive action of the magnesium ion.

<u>lll</u>. Certain amelioration methods were suggested from a review of literature and from the results of the initial studies undertaken. A controlled experiment was undertaken to determine the effect of organic and inorganic ameliorants on the B_1 horizon of a degraded Morris soil which exhibited unfavorable structural characteristics to a marked degree. In this experiment, chopped alfalfa, manure, lime-carbonate, gypsum and sulfur were mixed

with different portions of the soil. These soils were held in a moist state under the temperature conditions of the laboratory for a three month period. After this period, the effect of the treatments on the (a) water stable aggregation of soils under all treatments, and on (b) the porosity of the soils under all ameliorants except chopped alfalfa were determined. The results of these determinations indicated certain effects of the soil amendments which may be summarized as follows:

(a) All the ameliorants used increased aggregation. Chopped alfalfa gave the greatest positive effect on the water stability of aggregation. Sulfur gave the best results of the inorganic ameliorants. Lime and gypsum had approximately equal effect and gave the smallest increases in aggregation.

(b) The organic amendments used gave a very marked increase in soil permeability. The inorganic amendments used were found to affect soil permeability, adversely.

CONCLUSIONS

Deterioration of soil tilth, due to natural degradation processes and to cultural practices, occurs in the heavy textured soils of the Red River soil association. Virgin soils of this association and cultivated soils occurring on the clay deposits of the Red River valley were studied to ascertain the factors responsible for deterioration of soil tilth and to investigate amelioration practices. From these studies several conclusions may be enumerated.

1. The unfavorable solonetzic structure of the Morris soil associate is due to the dispersive action of the magnesium in the base exchange complex.

2. A general decrease in carbon and nitrogen content in Red River soils under arable culture appears to be inevitable. The rate of decrease and the final equilibrium point are influenced by the system of arable culture practiced. The decrease is accelerated by fallow, and is retarded by the addition of decomposable organic matter.

3. Water stable aggregation in the cultivated soils studied was found to be highest under a grass-legume mixture and lowest under fallow. A grass-legume mixture given a prominent place in the crop rotation is a good way of developing favorable soil structure.

4. The addition of decomposable organic residues increases aggregation, and greatly increases soil porosity.

5. Two distinct steps in the amelioration of the degraded soils of the Red River area are indicated,

(a) a modification of the base exchange status and

(b) an increase in the organic matter content.

(a) The magnesium ions of the base exchange complex should be replaced by calcium ions which have greater coagulating effect, and the replaced magnesium "laundered out" of the soil. Increased porosity by the addition of organic matter is required to facilitate the removal of the magnesium.

(b) The most effective way of adding organic matter to any extensive area of these soils is to give grass-legume mixtures an important place in a suitable systematic crop rotation.

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