Soil and water relationships with gypsum and land disposed feedlot waste
by Douglas John Dollhopf

A thesis submitted in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Crops and Soil Science
Montana State University

Abstract:
The effects of 2.5-, 5-, and 10-T/A gypsum and 90- to 180- T/A manure on physical and chemical properties of soil, quality of surface and groundwaters, crop production, tillage forces, and soil tares during sugar beet harvest were investigated.

Both 180 T/A manure and 10 T/A gypsum significantly increased % aggregation and decreased modulus of rupture of this silty clay soil. These changes in the soil structure resulted in a 8% and 6% decrease in tillage forces associated with these manure and gypsum plots, respectively.

Infiltration was increased with manure and 10 T/A gypsum treatments. Soil water flow meters were used successfully to measure in-situ unsaturated flow. Flux under 10 T/A gypsum was greatest while the smallest flux was recorded under the check.

Indication of both NO3-N and Na leaching under the manure treatments was present. However, no changes in the NO3-N or PO4-P concentrations of the shallow groundwater were measured. Evidence showed the manure treatments caused the groundwater immediately under the plot area to become saline-alkali.

The concentration of NO3-N, PO4-P, salts and suspended solids was greater in drainage water flowing off all plots than in the irrigation water applied. This scheme was reversed for total carbon in that drainage water had a lower concentration compared to the irrigation water applied. Runoff from the manure treatments had the greatest concentration of dissolved and suspended constituents. These data took on a different appearance when the actual dissolved and suspended load translocation budget was solved. Then, the runoff contained only a fraction of the applied load, except for PO4-P which was still greater in the runoff.

All rates of gypsum were very effective in reducing soil tare weights about 40% during harvest. When 90 T/A manure was applied the soil tare was decreased, but 180 T/A manure increased soil tare.

Both manure and gypsum treatments decreased sugar production about 8%. Sugar beet tops from manure plots contained nearly 15% protein but also contained hazardous levels of NO3-N.

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TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

LIST OF TABLES

LIST OF TABLES
(continued)

LIST OF FIGURES

LIST OF FIGURES
(continued)

LIST OF FIGURES
(continued)

LIST OF APPENDICES

LIST OF APPENDICES
(continued)

LIST OF EQUATIONS

ABSTRACT

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INTRODUCTION

The irrigated soils of the Yellowstone Valley present management problems due to the heavy silty clay texture. Although these soils are not excessively salty, they have a tendency to crust during a wet-dry cycle often making seedbed preparation a problem. The large energy consumption during seasonal tillage practices and slowness with which these heavy soils conduct soil water are other problems which plague farm operators.

Gypsum has been used extensively for reclamation of saline-alkali soils, but its use for improvement of non-saline, non-sodic heavy textured soils is not well documented. In this latter case, gypsum has the potential of decreasing tillage energy requirements while increasing soil aggregation, infiltration, and soil water movement. Such soil physical changes may result in increased crop production.

The growing feedlot business is faced with a livestock waste disposal problem. One potential solution to this problem would be to apply the manure to agricultural soils in the vicinity of the feedlot. However, the farm operator will want to know how much feedlot manure can be applied to his soils before crop or environmental considerations suffer. Such a situation exists in the Yellowstone Valley near Billings, Montana. A relatively new 30,000 head capacity feedlot has a solid waste disposal program destined for the irrigated crop lands of the adjacent Yellowstone Valley. The water table under this area is shallow, thus the potential exists for nitrate and salt leaching from heavy manure applications into the groundwater system. Irrigation field runoff water from soils treated with large tonages of manure may contain excessive nitrates, phosphates and salts which may eventually be transported back into the Yellowstone River. Solute movement through the soil may cause salinization of soils. These types of events need to be measured before the farm operator initiates a program of heavy feedlot manure applications to his crop producing soils.

The objectives of this study were to investigate the effects of 2.5-, 5-, and 10-T/A gypsum and 90- to 180-T/A manure on:

1) selected physical and chemical characteristics of the soil profile.
2) the quality of surface and groundwaters.
3) sugar beet production and quality.
4) ease of tillage operation.

This three-year study was conducted on the Southern Montana Agriculture Research Center near Huntley, Montana.

REVIEW OF LITERATURE

Environmental Quality and Agriculture

Much public attention has been focused recently on environmental quality as influenced by agricultural practices. Considerable interest has centered around solute movement, particularly NO_3-N, toward ground water supplies and quality of surface runoff waters. Since adverse health effects were noted when water containing more than 10 ppm NO_3-N was consumed by infants (21), the U.S. Public Health Service adopted this value as the safe upper limit for water consumed by humans. Soluble N compounds and other essential plant nutrients are also related to the undesirable growth of aquatic vegetation and eventual oxygen depletion in lakes (27).

Groundwater Quality Under Agriculture

Researchers (18, 26, 36, 39, 59, 63, 64, 66, and 73) have shown that N from commercial fertilizers can move into groundwater supplies, often in excessive amounts. This phenomena has been attributed to leaching of residual N not recovered by crops. Similarly, investigators (31, 57, 71, 73, and 74) have shown nitrate build-up problems under feedlots due to the stockpile of livestock manure. Application of animal wastes to agricultural soils is a potential solution to the feedlot waste disposal problem (43, 45). However, the criterion of how much waste material might be placed on various types of soils without causing crop production or environmental problems is not well defined. Some attention has been given to the physical problem of applying great quantities of manure to agricultural lands. Weber, et al. (81) estimated a minimum of 50 acres of land per 100 cattle would be required to insure that excessive N did not reduce corn yield or cause water pollution. Using deep plow techniques, Reddell, et al. (68) concluded rates of manure up to 900 T/A can be plowed into agricultural soils at costs ranging from 2.1 cents to 62 cents per ton.

Several investigators have studied the effects of animal wastes applied to agricultural lands. In Ontario, researchers (7) applied poultry manure at rates of .25, .5, and .75 T/A to a sandy loam soil. Using lysimeters they found average concentration of nitrates in percolates from all treatments exceeded 10 ppm. Researchers (22) in New Jersey studied the effects of 0, 15, 30, and 45 T/A dry poultry solids applied on soils. Concentrations of NO_3-N in the ground water exceeded 10 ppm, but no significant differences were found between the control and treatments. Researchers in California (1) studied NO_3-N levels in soil profiles under intensive dairy use. They found average NO_3-N concentrations of 92, 74, and 66 ppm in soil solutions at the 10- to 19-foot depth for corrals, pastures and croplands, respectively. This nitrogen would be expected to eventually reach the underlying ground water which had lower NO_3-N concentrations. In Texas, Mathers and Stewart (47) applied cattle feedlot manure at rates of 0, 10, 30, 60, 120, and 240 T/A to a clay loam soil. In addition, the irrigated area received an annual NPK application of 480-50-50 pound per acre. They found that yields of grain sorghum were reduced when 120 T/A or more manure was applied, and that plant NO_3 concentration was excessive. Nitrates and salts accumulated in the profiles of plots treated with high rates of manure. Also, it was suggested that if sugar beets were grown, the high nitrate level of the soil might result in low sugar content of the beets produced. They concluded nitrate pollution hazards were eliminated only when the crop used most of the nitrogen applied.

Runoff Quality From Agriculture

Large streams draining intensive agricultural areas have been monitored for quality for at least 30 years (8, 35, 69, 85). These data indicate no significant change in water quality even though fertilizer use has increased several fold in the area. However, in Idaho, Carter et al. (13) concluded a large irrigation area of the Snake River increased the downstream total soluble salt and NO_3-N loads, but decreased the downstream PO_4-P load by about 70%.

Other researchers (60, 61, 83) have focused their studies of runoff chemistry to specific N-P-K fertilized fields or plots. Their results indicate N fertilizers can be surface water pollutants under certain soil and surface cover conditions which retard infiltration. Moe (60, 61) and White (83) reported fertilizer runoff was greatest on moist and sodded soils.

The argument of agriculture fertilizers as surface water pollutants becomes more intense when livestock manures are considered. Runoff from some feedlots (42, 82) has been shown to be excessive in N, but in an Ohio feedlot Edwards et al. (30) reported runoff waters never exceeded 6 ppm NO_3-N although phosphorus went as high as 14 ppm. In Wisconsin, researchers (56, 84) measured excessive runoff pollution of N from manure applied to frozen soils. Therefore, to use agricultural soils as media for livestock waste disposal requires caution, particularly at extremely large rates. In Alabama, researchers (50) evaluated the quality of runoff from grassland to which dairy cow manure was applied at various rates up to 145 T/A. Runoff NO_3-N from check plots averaged 1.8 ppm whereas from manure treated plots it ranged between 2.8 to 18.1 ppm. Only one treatment, 145 T/A, had runoff which exceeded 8 ppm NO_3-N. Also measured in runoff was total N and NH_3-N where check plot runoff averaged 8 ppm and 2.8 ppm, respectively. The proportionate increase in runoff total N and NH_3-N due to manure applications was similar to that measured for NO_3-N. Runoff PO_4 from check plots averaged 4.6 ppm whereas manure plot runoff ranged from 3.6 ppm to 34.5 ppm.

Sediment and Its Nutrient Load

The physical, chemical, and biological effects of sediment on water makes it a primary hazard, if not the primary hazard, to water quality. Wadleigh (80) estimated that four billion tons of sediment wash into the United States' waterways each year and each ton contains 2 pounds of N and 1.3 pounds of P.

It has been well established (37, 54, 75) that eroded soil contains higher concentrations of nutrients than the soil that remains. For example, in Wisconsin Massey and Jackson (46) found that eroded material contained 2.7 times as much N, 3.4 times as much P, and 19.3 times as much exchangeable K as the soil that remained. Available evidence indicates that little fertilizer P leaches through the soil or runs off as inorganic phosphate in solution, but can wash off as phosphorus adsorbed on sediment (38, 72, 76).

Sediment acts as a scavenger with the ability to adsorb or desorb elements on its chemically active surface (33, 51). Therefore sediment, as a pollutant, has a two fold effect on the environment. It depletes the land resource from which it comes and often impairs the quality of the water resource in which it is deposited.

Unsaturated Flow: Soil Water Flow Meter

Accurate measurement of soil water transfer in the field is one of the major problems confronting soil scientists. Calculations of unsaturated soil water flow have, in general, been inferred from Darcy's equation

$$F = -K\Delta \Phi \qquad \{1\}$$

where F is the flux, K is the unsaturated soil hydraulic conductivity, and $\Delta \Phi$ is the soil water potential gradient including both matric and gravitational components. Using tensiometers to measure $\Delta \Phi$, it is possible to calculate F provided one knows the value of K. Since K decreases sharply as the moisture content drops, it is difficult to apply equation {1} to field problems with any confidence in accuracy unless the researcher performs a great deal of calibration work. This calibration work requires knowledge of the relationship between K and the soil water potential. Even with this knowledge, uncertainties arise when the field site is complicated with a growing crop, rainfall, and a shallow water table.

Cary (14, 15, 16) developed a unsaturated soil water flow transducer with which K can be measured directly. The intercepting-type transducer consists of an impermeable barrier between two porous plates. The flux into one plate is routed to the surface, through a flow meter, and back into the other plate. A known flow resistance is placed in series with the flow at the surface. Cary used the equation

$$F = fA(n-1)/(n-m) \qquad \{2\}$$

where F is the true soil water flux, f is water flow through one meter, A is a constant dependent only on the shape of the meter, m is the ratio of water flux through one meter to the water flux through the other, and n is the constant ratio of the conductivity, without soil, of one meter to the conductivity of the other. Solution of equation 2 requires two flowmeters. Here, Cary employed the flow resister at the surface, creating, in essence, two flowmeters each with different conductivities by alternately using and bypassing the resistance.

The principle problem associated with using such a transducer is the uncertainty of divergence or convergence of water flow associated with the buried device. Divergence can be eliminated if the flowmeter has a greater hydraulic conductivity than the surrounding soil. The n and m components of equation 2 are correction factors associated with convergent water flow. The transducer is limited to flux measurements in soils with potentials greater than -1 bar. However, this is the range in which the bulk of moisture flows.

Cary (17) tested several flowmeters in field situations and results were encouraging. Transducers worked satisfactorily in a sandy soil, under a ditch, and were found to be very responsive to additions of water during the course of a summer.

Tillage Power Requirements

Clyde (20) pioneered much of the early research in the United States regarding the force required to pull tillage tools. Recently Gill (30) reviewed literature in which researchers employed various types of dynomometers. The objectives in these investigations dealt with tool design, not effects of various soil parameters on tillage tool power requirements.

The principles of soil physics in relation to tillage has been reviewed by several researchers (3, 10, 11, 41, 70). Relatively few studies have made actual field measurements of tillage power requirements as a function of soil chemical or soil physical characteristics or management practices. In view of the current energy shortage such information is relevant.

In North Dakota (28), dynamometer tests were made on plots subjected to different tillage practices. No significant differences were present at the 5% level using a 4-16" bottom plow at the 4-inch soil depth. In Canada (12), a vacuum gauge recorder attached to the tractor manifold, calibrated with a dynamometer, was used to measure power requirements of various tool bar devices across treatments. Treatments consisted of sod or corn stubble within two different soil textures. Conclusions regarding tool bar design were made, but no significant statements were made concerning effect of soil properties on tillage forces. A USDA project in Israel (79) made long-term tillage power tests as a function of management practices. All measurements were made with a recording hydraulic dynamometer. Again, conclusions regarding tool bar design were made, but no significant statements were made concerning effects of soil properties on tillage forces. It is apparent that tillage power requirement research has been conducted by agricultural engineers with better machinery design as the main objective. The effects of soil chemical and physical properties on tillage forces has been largely ignored.

Aggregate Stability

The ability of soil aggregates to withstand some arbitrary disintegrating force, such as water or wind, is an important soil property.

Soils with low aggregate stabilities are typically plagued by high erosion, low infiltration, and low crop yield problems. Aggregate stability has been shown to be affected by a variety of soil constituents.

Clay content and aggregate stability were observed to be positively correlated by Baver (6) and Chesters et al. (19). Mazurak (48) studied the role of different clay minerals in aggregation. High surface area clays (i.e. bentonites) seemed to cause greater aggregation than equal quantities of low surface area clays (i.e. kaolinite).

Demolon and Henin (23) found colloidal organic matter to be more effective than equal amounts of colloidal clay in stabilizing aggregates. McCalla (49) and Martin (44) attributed increased aggregation of soil after an addition of fresh organic matter to polysaccharides formed during microbial decomposition of the fresh organic matter. Chesters et al., (19) found microbial gums to be an important aggregating factor. Peerlkamp (65) and Miller (58) found the increased stability resulting from added organic matter to be transient and to decrease to the original level after a few months. However, the temporary increase in stability was large, and Anderson and Kemper (5) concluded that if the soil is cultivated and wetted when the stability is high, the resulting large pores may persist even after the aggregate stability has returned to normal levels. Kemper (40) also presented results showing soil N was positively correlated to aggregate stability.

The deleterious effect on soil structure of replacing divalent with monovalent ions has been well documented (9).

Gypsum As A Soil Amendment

The use of gypsum for reclamation of alkali soils has been well documented in the literature (24). The use of gypsum on non-alkali soils with poor physical condition has received little attention.

In New Jersey, Rinehart (67) reported gypsum modified the soil physical properties successfully in field wet spots which enabled better drainage. A two ton per acre gypsum treatment proved more effective in draining field wet spots when combined with manure. Aldrich (2) observed improved soil physical structure when gypsum was applied to fine textured soils in the laboratory, but field results did not show similar benefits.

Animal Wastes As A Soil Amendment

Generally, animal wastes have beneficial effects on soil physical condition. Organic matter tends to stabilize soil aggregates, thus when the soil is subjected to disruptive forces such as wetting the tendency of aggregates to slake or disperse is retarded. Following manure applications Guttay et al., (34) observed improved granular structure.

Some investigators who have applied waste materials to soils reported negative results regarding soil physical condition. Thomas et al., (77) applied domestic sewage to soils which resulted in a reduced infiltration rate. He stated an organic mat formed which was a physical barrier to water infiltration. Travis et al., (78) also observed reduced infiltration rates when feedlot lagoon water was applied to soils. He measured a 200% increase in soil electrical conductivity and concluded the soil salt balance was significantly disrupted resulting in soil pores swelling closed upon wetting.

METHODS AND MATERIALS

The experimental site was located on the Southern Montana Agricultural Research Center. The soil is classified in the Ustic Torriorthent family and Vananda series (see Appendix Table 20 for description).

Experimental Design and Treatments

The experimental design (Figure 1) was a randomized block with three replications of five treatments. Each of the 15 plots was 33 by 150 feet in size. Table 1 shows analysis of cattle feedlot material taken from Miller Feedlot, Shepherd, Montana and applied to plots.

Table 1. Analysis* of oven dried cattle feedlot material taken from Miller Feedlot, Shepherd, Montana and applied to plots. Move the decimal four places right to convert percent to ppm.

Potassium	1.77%
Calcium	1.53%
Magnesium	.99%
Sodium	.70%
Total Phosphorus	.86%
Nitrate	.10%
Crude Protein (N x 6.25)	5.40%
pH (1:10 dilution)	8.2
Ash (salts & minerals)	47.00%
Field moisture content	61.00%

*Conducted by the Chemistry Station, Montana State University.

In 1971 initial treatments were 10 T/A gypsum (see Appendix Table 21 for analyses) + tracked, 90 T/A manure wet weight + tracked, check + tracked, disked + harrowed, and check. Amendments had to be applied