



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
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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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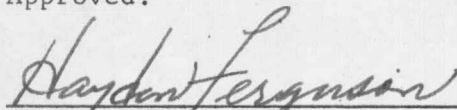
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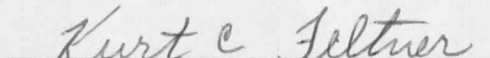
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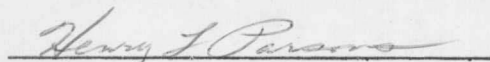
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Approved:


Chairman, Examining Committee


Head, Major Department


Graduate Dean

MONTANA STATE UNIVERSITY
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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 $\text{NO}_3\text{-N}$ and Na leaching under the manure treatments was present. However, no changes in the $\text{NO}_3\text{-N}$ or $\text{PO}_4\text{-P}$ 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 $\text{NO}_3\text{-N}$, $\text{PO}_4\text{-P}$, 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 $\text{PO}_4\text{-P}$ 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 $\text{NO}_3\text{-N}$.

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 $\text{NO}_3\text{-N}$, toward ground water supplies and quality of surface runoff waters. Since adverse health effects were noted when water containing more than 10 ppm $\text{NO}_3\text{-N}$ 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 $\text{NO}_3\text{-N}$ in the ground water exceeded 10 ppm, but no significant differences were found between the control and treatments. Researchers in California (1) studied $\text{NO}_3\text{-N}$ levels in soil profiles under intensive dairy use. They found average $\text{NO}_3\text{-N}$ 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 $\text{NO}_3\text{-N}$ 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 $\text{NO}_3\text{-N}$ loads, but decreased the downstream $\text{PO}_4\text{-P}$ 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 $\text{NO}_3\text{-N}$ 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 $\text{NO}_3\text{-N}$ 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 $\text{NO}_3\text{-N}$. Also measured in runoff was total N and $\text{NH}_3\text{-N}$ where check plot runoff averaged 8 ppm and 2.8 ppm, respectively. The proportionate increase in runoff total N and $\text{NH}_3\text{-N}$ due to manure applications was similar to that measured for $\text{NO}_3\text{-N}$. 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

$$F = -K \Delta \phi \quad \{1\}$$

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

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

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 dynamometers. 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 Bayer (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

FIELD SITE

VANANDA

CLAY

HUNTLEY IRRIGATION CANAL

CONTROL



- 1 CHECK
- 2 MANURE
- 3 GYPSUM 10T/A
- 4 GYPSUM 5T/A
- 5 GYPSUM 2.5 T/A

(PLOTS 150 FT. X 33 FT.)

- WATER TABLE PIPES
- * WATER FLOW METERS
- * TENSIO METERS-NEUTRON TUBES



*	*		*	
3	1	4	2	5
	●		●	

REP 3

		*	*	*
4	5	2	1	3
		●	●	

REP 2

*	*	*		
2	3	1	5	4
●		●		

REP 1

Figure 1. Experimental plot description and general location of some field instrumentation.

in the spring which caused a soil compaction effect from machinery tracking. This tracking effect of spring tillage and amendment application on soil structure was evaluated with the above treatments. In 1972 the 10 T/A gypsum and check treatments remained unchanged. An additional 90 T/A manure was applied over the initial 90 T/A manure. Also, two gypsum treatments, 2.5- and 5-T/A, were added.

Sugar beets were grown all three years of the study. All plots received spring fertilizer applications of 66-0-0 pounds per acre 1971, 100-40-0 pounds per acre 1972, and 100-40-0 pounds per acre 1973.

Soil Hydraulic Properties

Neutron access tubes and tensiometer systems were installed in the check, manure, and 10 T/A gypsum plots with three replications during summer of 1971-1973. Tensiometers were installed in one foot depth increments from .5- to 8.5-feet. Neutron moisture meter data were collected from .5- to 8.5-feet in one foot increments. During 1972 duplicate instrumentation as described above was set up in a check, manure, and 10 T/A gypsum treatment and covered with a 25- by 25-foot sheet of plastic, which prevented water loss to the atmosphere. Unsaturated soil water flow was calculated using Darcy's equation {1}

$$F = -K\Delta\phi \quad \{1\}$$

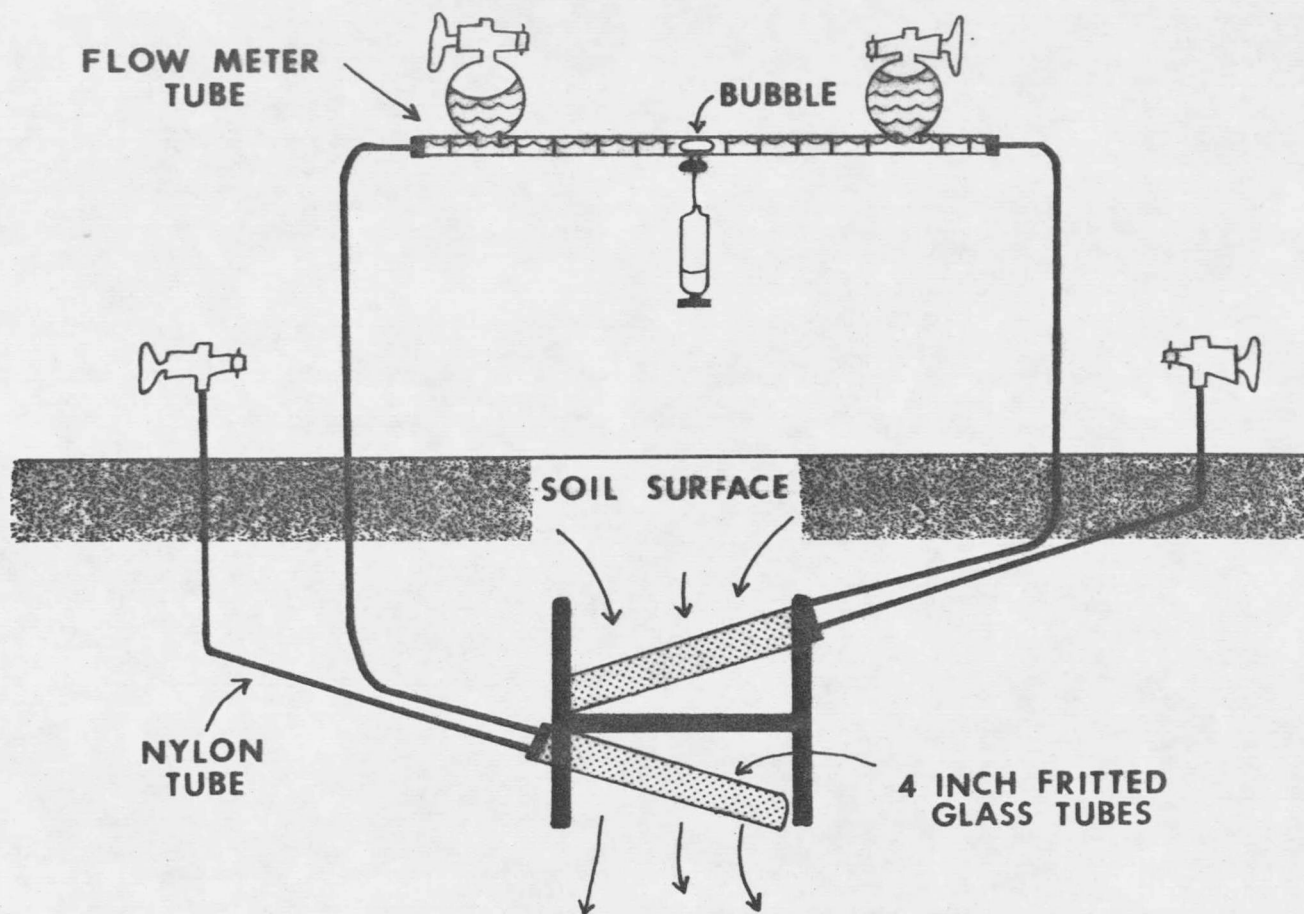
where F is the flux, K is the unsaturated soil hydraulic conductivity, and $\Delta\phi$ is the soil water potential gradient including both matric and gravitational components.

Soil desorption curve characteristics were determined at two sites in the experiment. Cores ten feet deep were collected and analyzed in one foot increments for .1-, .3-, 1-, 3-, and 15- bars tension on a pressure plate apparatus. Bulk density measurements were made at four sites in the experiment. Cores ten feet deep were collected and analyzed in six inch increments. Bulk density was determined directly by measuring the mass of a six inch soil core, then dividing this mass by the corresponding volume of the king tube.

Thus, matric potential measurements applied to desorption curves could give reliable estimates of soil water expressed on a weight basis. Percent soil water on a weight basis multiplied times the soil bulk density converts the soil water value to a volume basis, which served as a check on the neutron probe results.

Soil Water Flow Meter

Soil water flow meter construction (Figure 2) was similar to that described by Cary (17) except the surface resistance was eliminated. The transducer consisted of micro-fine porosity four inch fritted glass filter tubes separated and enclosed within a plexi-glass container (Figure 3). Field installation of the transducer required excavation of a pit (Figure 4). A tunnel parallel to the surface was made in the side of the pit just large enough to slide in the transducer. This resulted in minimum disturbance of soil on five of the six sides around the transducer. The pit was refilled and packed to a uniform bulk



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Figure 2. Cross section diagram of a flow meter installed in the soil. Arrows denote direction of water flow.

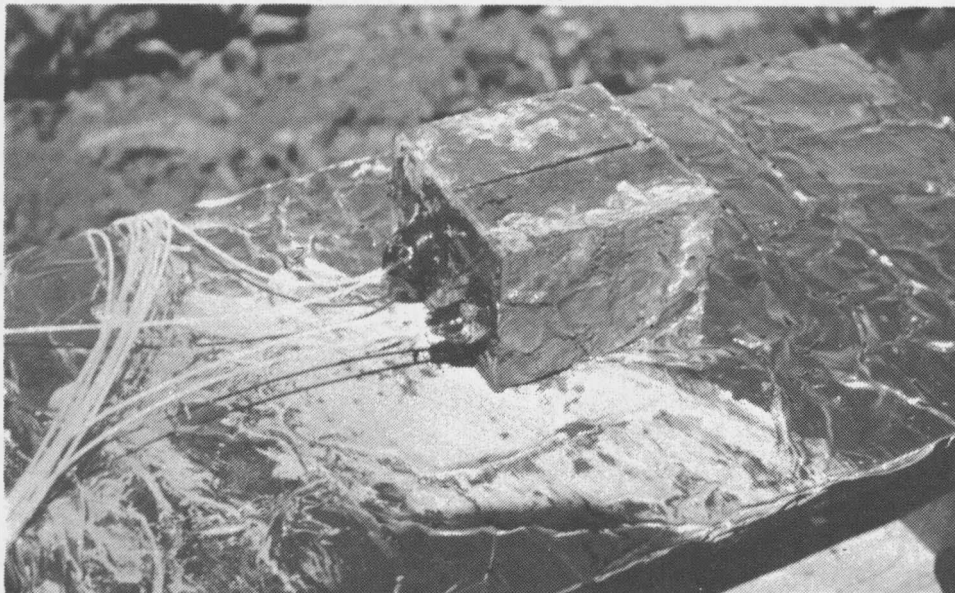


Figure 3. Plexi-glass soil water flow transducer packed with soil and ready for installation.

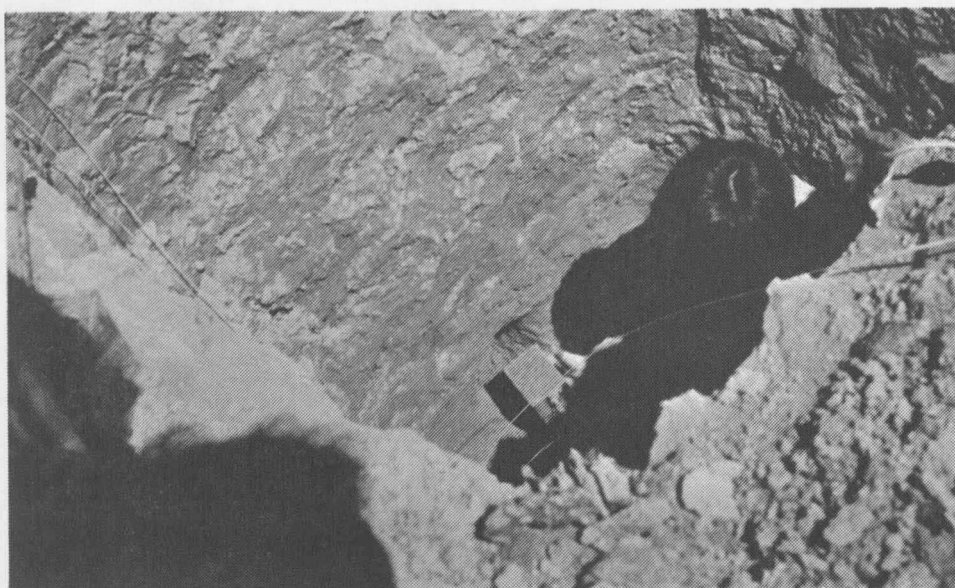


Figure 4. Soil water flow transducer being installed at the six foot soil depth.

density. Saran tubing was used to connect the transducer to the surface flow meter readout device which consisted of a modified one-milliliter pipett (Figure 5). An air bubble was introduced into the flow line with a hypodermic syringe. Water which had most of the air removed by boiling was used to fill the system. During the 1972 summer, flow meters were installed in the check, manure, and 10 T/A gypsum treatments of replication two at soil depths 1.5- and 6.0- feet (see Figures 1 and 6). The experiment was expanded during the 1973 summer to include flow meters at the 3.5-foot depth.

The validity of equation {2} as applied to soil water flow meters was evaluated by Cary (14, 15, 16) and results were satisfactory. It was hypothesized that error associated with soil water convergence was non-significant provided hydraulic properties of soil within the flow-meter were equivalent to the surrounding soil. If this were true components n and m could be ignored resulting in equation {3}

$$F = fA \quad \{3\}$$

where F is the true soil water flux (cm/day), f is water flow through the flow meter (cm³/day); and A is the inverse of the flowmeter cross sectional area (cm²). Equation {3} requires measurement of water flow through only one flowmeter (f) and eliminates all calibration work.

Laboratory tests indicated average flow meter flux, without soil, was 204-cm³ per day with a 3-cm water hydraulic gradient. This easily exceeds the conductivity of the soil system so divergent flow was

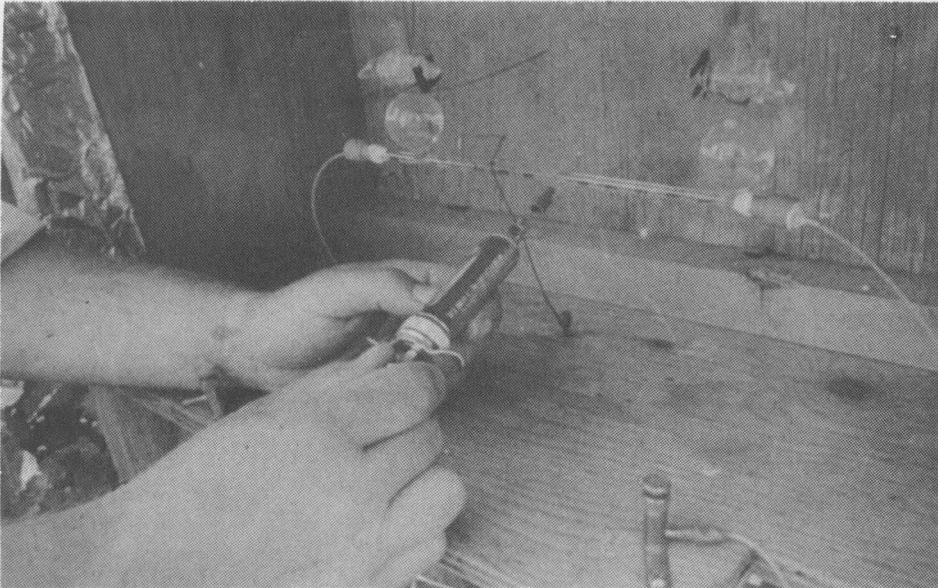


Figure 5. A hypodermic syringe was used to enter an air bubble into the flow line.



Figure 6. In 1972 flow meters were installed in the check, manure, and 10 T/A gypsum treatments at the 1.5- and 6.0- foot soil depths.

eliminated.

Infiltration

Using two Parshall flumes to measure input and outflow from plots, the quantity of water infiltration into each plot was determined. This value divided by the irrigation time period gave total plot infiltration rate. Infiltration was measured for each plot during all irrigations through 1971-1973.

Runoff Chemistry

Quality of runoff has little meaning unless quality of that water prior to use is known. Therefore, surface water chemistry was monitored at four sites including the main Huntley Canal, head ditch, plot runoff, and from a surface drain approximately 300-feet from the plots (Figures 7, 8, 9, and 10, respectively). The plot runoff site was sampled at two different times. The first water sample constituted the initial volume of water running off the plot, while the second sample was taken approximately twenty minutes later. These sites were sampled during irrigation of check, manure, and 10 T/A gypsum plots in all three replications. There were 3 to 4 irrigations each summer from 1971 to 1973. Samples were refrigerated and analysed as soon as possible for $\text{NO}_3\text{-N}$, $\text{PO}_4\text{-P}$, Ca, Mg, Na, electrical conductivity, pH, total carbon, turbidity, and total suspended solids (see Appendix Table 23 for procedures).

Water Table Depth and Chemistry

Eight .75-inch outside diameter steel piezometers, installed in



Figure 7. Surface water sampling site for quality analyses in the main Huntley Canal.

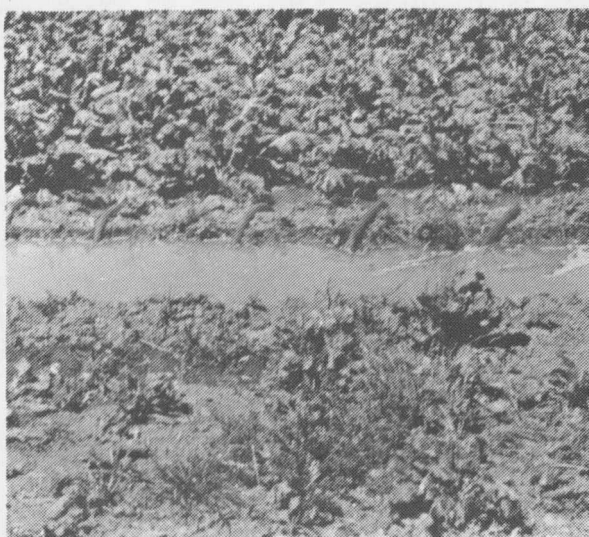


Figure 8. Surface water sampling site for quality analyses in the head ditch.

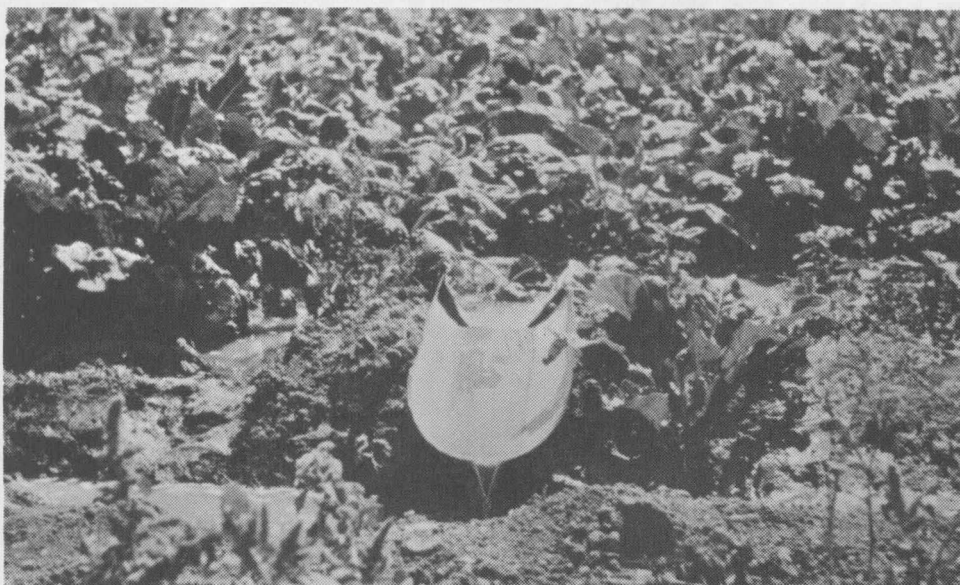


Figure 9. Surface water sampling site for quality analyses in the plot runoff.



Figure 10. Surface water sampling site for quality analyses in the surface drain approximately 300-feet from the plots.

one foot increments at soil depths 4- to 11-feet, were used to measure water depth (Figure 11). Also these piezometers served as a access for sampling the ground water for chemical analyses. During 1972 and 1973 two sites were located immediately north and south of the experiment, and together these were called the test area. In 1973 a control site was included approximately 600-feet from the experiment (Figure 1).

During 1973 additional piezometers were inserted into the water table directly under all manure and check plots (Figure 1). These piezometers were used to collect water samples out of the ground water system.

Depth to the water table measurements and collection of ground-water samples was done on a weekly basis for all piezometers. Water samples were analysed for $\text{NO}_3\text{-N}$, $\text{PO}_4\text{-P}$, Ca, Mg, Na, and electrical conductivity.

Soil $\text{NO}_3\text{-N}$, $\text{PO}_4\text{-P}$, and Salt Movement

Soil samples were taken every spring and fall from 1971 to 1973 in one foot increments from 1- to 10-feet deep. Only the check, manure, and 10 T/A gypsum treatments in all reps were sampled. Soil samples were analysed for $\text{NO}_3\text{-N}$, $\text{PO}_4\text{-P}$, Ca, Mg, Na, and electrical conductivity.

Tillage Power Requirement Tests

Strain gauges mounted on an extended ring transducer (Figure 12)



Figure 11. Eight .75-inch outside diameter steel piezometers, installed in one foot increments at soil depths 4- to 11-feet, were used to measure water table depth.

served as the force sensing device. Four strain gauges* were glued* to the transducer and wired according to Figure 13. A 10 K - 20 turn potentiometer functioned to zero out any output voltage associated with an unbalanced situation among the strain gauges. A 6 VDC battery powered all strain gauges. An integrator (25) with 4-digit lighting display readout integrated the voltage output over time (Figure 12 and 14).

A trailer type tool-bar with hydraulic soil depth controlled chisel shanks was bolted to the transducer in holes A - B, and the tractor was bolted to holes C - D (Figures 13, 15, and 16). Calibration was accomplished with a truck scale where a known force was applied to the transducer and the resultant voltage output integrated over time. Calibration results are shown in Table 2. The relationship between force and counts

Table 2. Transducer calibration for tillage power requirement test.
Southern Montana Agriculture Research Center, September 17,
1973.

Force in Pounds	Digital Counts Per Minute
0	0
800	2373
1400	4138
2210	6464
3000	8790

* Strain gauges were purchased from BLH electronics, Waltham, Mass. type FAP-25-1256 and were mounted using BLH strain gauge cement type SR4.

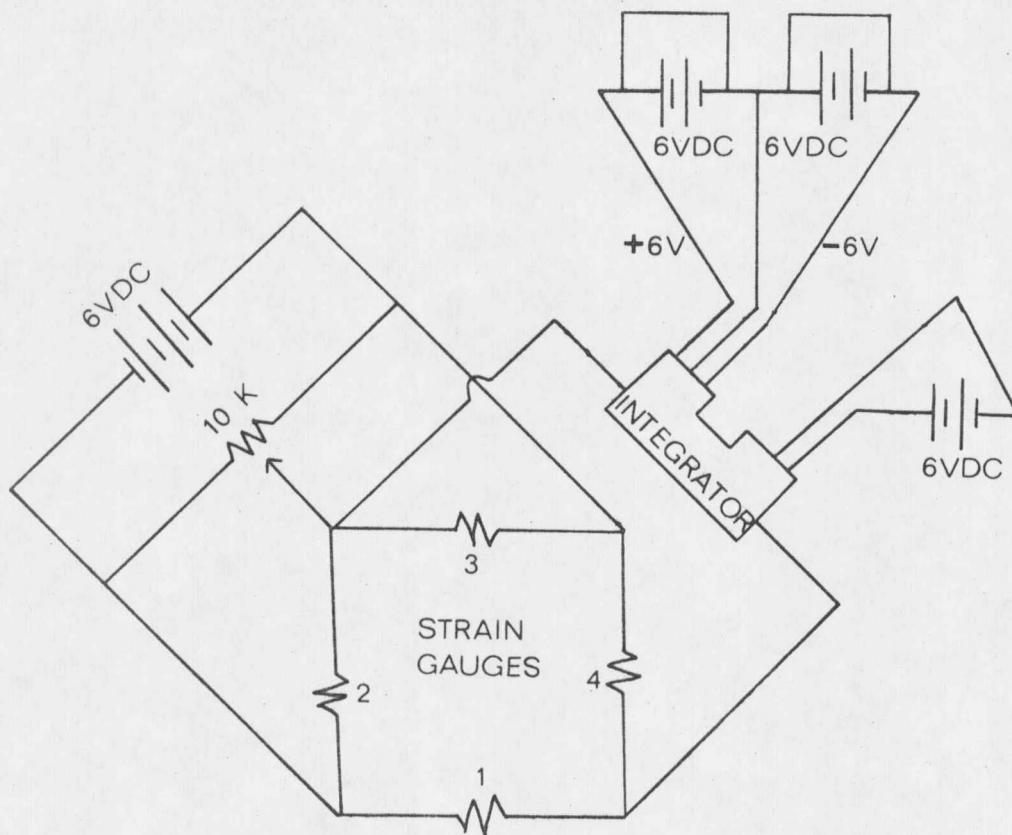


Figure 12. Wiring diagram for one transducer with four strain gauges connected to power supply, potentiometer, and digital integrator.

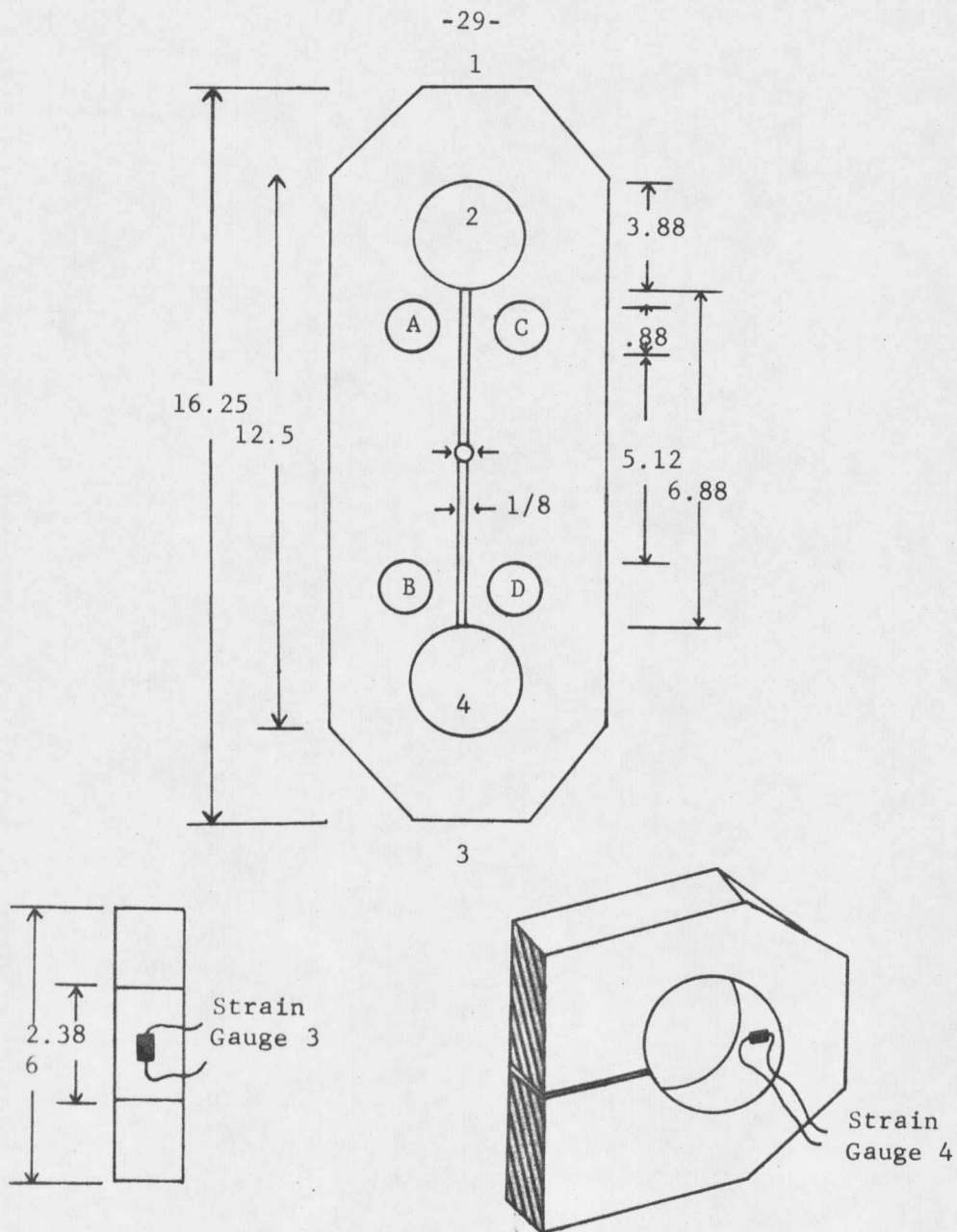


Figure 13. Extended ring transducer dimensions and stain gauge locations. All dimensions are given in inches.

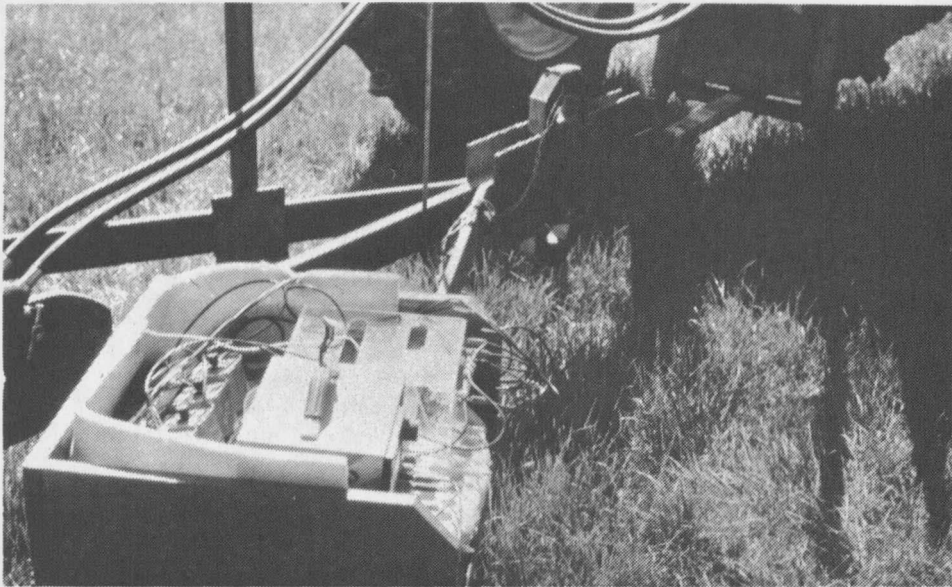


Figure 14. An integrator, mounted on the tool bar, with a 4-digit lighting display readout integrated the voltage output from the strain gauges over time.

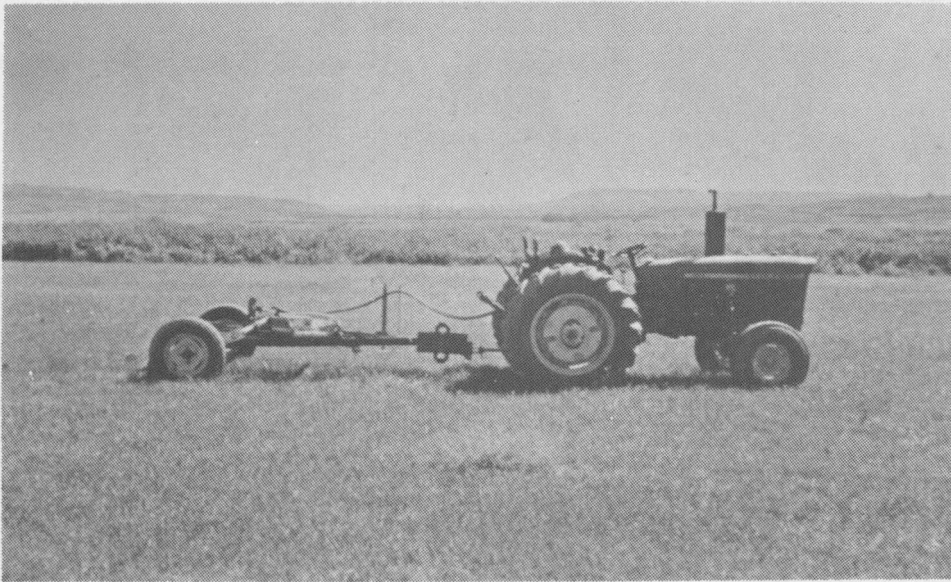


Figure 15. This tractor and tool bar apparatus was used for tillage force measurements in 1973.

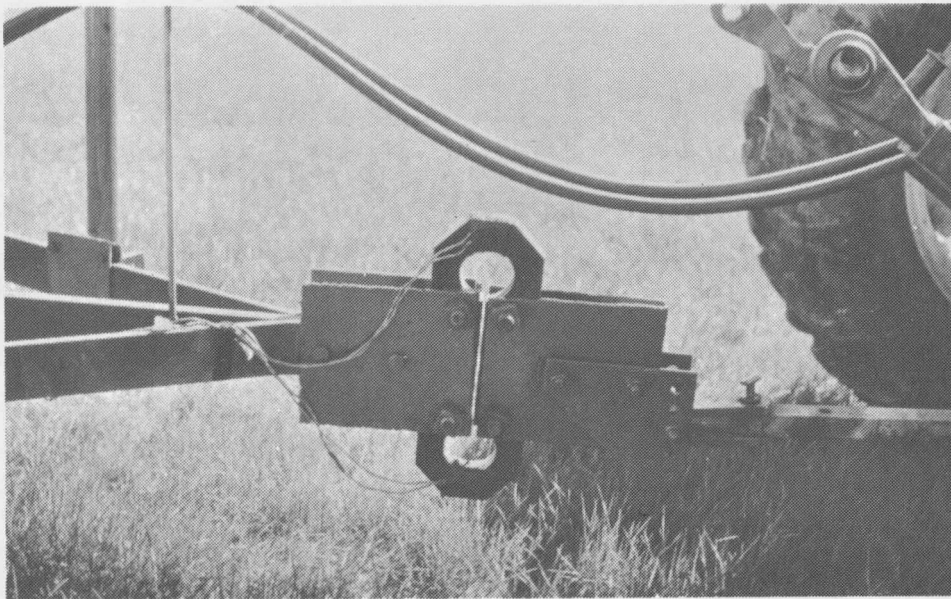


Figure 16. The tool bar and tractor were connected to each other via an extended ring strain gauge transducer.

per minute results in the linear Equation {4}

$$F = K \frac{c}{t} \quad \{4\}$$

where F is force in pounds, K is the graphical slope constant, c is digital counts, and t is time in minutes. For valid comparison between plots the same distance should be travelled and time needed to transverse that distance kept as equivalent as possible.

Particle Size and Aggregate Analyses

Soil samples from the 0- to 4-inch depth were taken from all plots and sieved through a 2-millimeter mesh screen. Particle size analyses was determined by pipette method with the settling time calculated according to Stokes Law. Textural size separations were: sand > .05mm, silt .002-.05mm, clay <.002mm.

Aggregate analysis was made by the procedure of Middleton (55). This procedure is similar to the pipette method but the aggregates are not dispersed with calgon and mixing. Thus a faster settling rate is measured which is proportional to how well the soil is aggregated.

Modulus of Rupture

Modulus of rupture is a measure of the breaking strength of materials, and is defined as the maximum fiber stress, i.e., force per unit area, that a material will withstand without breaking. The effects of field treatments upon soil crust strength was evaluated by means of the modulus of rupture technique (Figure 17) as reported by Richards (24) with one modification. The modification consisted of finer soil sieving,

1- versus 2-millimeters. It was reported by Moe, et al., (62) that the use of the finer sieve increased modulus of rupture values slightly, but decreased variation due to replication. The equation used was

$$M = \frac{3 F L}{2 b d^2} \quad \{5\}$$

where M is the modulus of rupture in dynes per cm^2 , F is the breaking force in dynes (the breaking force in grams weight $\times 980$); L is the distance between the two lower supports of the apparatus (cm), b is the width of the briquet, and d is the depth or thickness of the briquet (cm). The bar is a CGS unit of pressure and is equal to 1,000,000 dynes per cm^2 ; H is the accepted unit in expressing modulus of rupture for soils.

Samples from the 0- to 4- and 0- to 8-inch soil depth from all plots were analysed in June and again in September for years 1971-1973.

Sugar Beet Harvest

During 1971 to 1973 harvest measurements of root yield, percent sugar, sugar yield, root and top chemical analyses ($\text{NO}_3\text{-N}$, P, protein), and beet/top weight ratio were made on all plots. Also included were five tare measurements. "Field tare" represented the soil mass dislodged during transfer of beets from hopper to truck. "Dump tare" was the soil dislodged from transfer of beets from truck to pile at the beet dump. Soil "factory tare" represented soil still attached to the beet at the sugar factory. "Total tare" is the sum of these three soil tares. "Trash factory tare" is the unused top portion of the beet root.

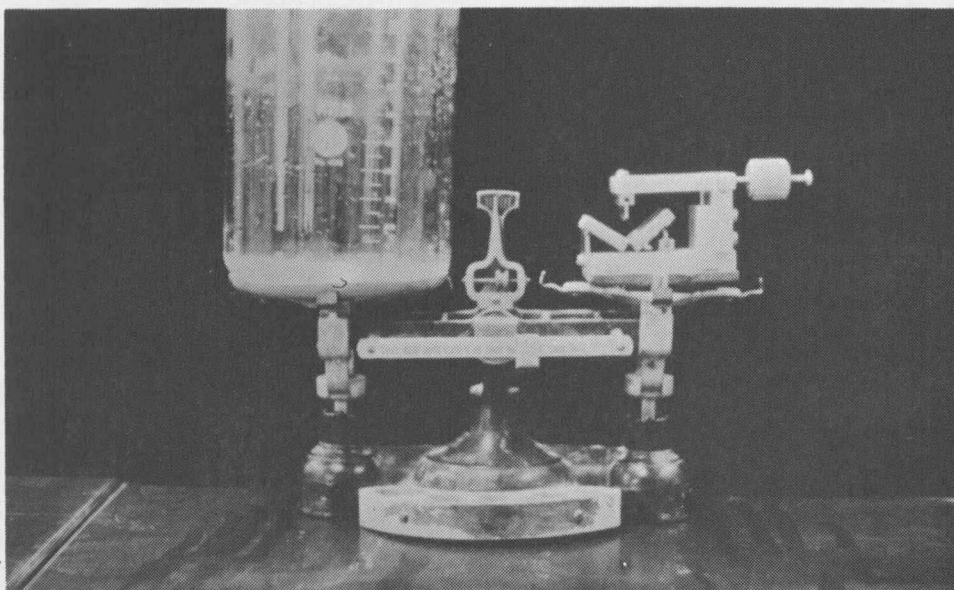


Figure 17. Modulus of rupture apparatus shown with fractured soil sample.

Percent soil moisture in each plot at harvest was measured.

Sequence of Field Operations

Spring 1971

- 1) soil samples taken to the 10 foot depth
- 2) initial field treatments applied
- 3) field planted to sugar beets

Summer 1971

- 1) soil samples taken for modulus of rupture analyses
- 2) tensiometers, soil solution extraction tube, neutron access tube, parshall flume, and water table pipe equipment installed
- 3) runoff chemistry monitored through 4 irrigations

Fall 1971

- 1) soil samples taken for modulus of rupture analyses
- 2) all field instrumentation removed
- 3) following harvest, tillage power requirement tests made
- 4) soil samples taken to the 10 foot depth

Spring 1972

- 1) soil samples taken to the 10 foot depth
- 2) second and final set of field treatments applied
- 3) field planted to sugar beets.

Summer 1972

- 1) soil samples taken for modulus of rupture analyses
- 2) tensiometer, soil solution extraction tube, soil water flow

meter, neutron access tube, parshall flume, and water table pipe equipment installed

- 3) three additional tensiometer - neutron access tube systems installed under black plastic covering
- 4) runoff chemistry monitored through 3 irrigations

Fall 1972

- 1) soil samples taken for modulus of rupture analyses
- 2) all field instrumentation removed
- 3) following harvest, tillage power requirement tests made
- 4) soil samples taken to the 10 foot depth
- 5) soil samples taken for aggregate analysis

Spring 1973

- 1) soil samples taken to the 10 foot depth
- 2) field planted to sugar beets

Summer 1973

- 1) soil samples taken for modulus of rupture analyses
- 2) tensiometer, soil water flow meter, neutron access tube, parshall flume, and water table pipe equipment installed
- 3) runoff chemistry monitored through 4 irrigations

Fall 1973

- 1) soil samples taken for modulus of rupture analyses
- 2) all field instrumentation removed
- 3) harvest

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4) soil samples taken to the 10 foot depth

Spring 1974

1) tillage power requirement tests made

RESULTS AND DISCUSSION

Results and discussion from this study are divided into six major headings. They are: soil structure, soil water movement, solute movement, groundwater quality, surface runoff water quality, and crop production aspects. These six sections are both interdependent and inter-related and will be presented in the above mentioned order. All statistical tests are given at the 5% level (Multiple Range Test) unless indicated differently.

Section I. Soil Structure

To initiate discussion on some soil structure relationships the mechanical analyses results and field distribution are shown in Table 3. These samples are from the 0- to 4-inch soil depth. The texture varied between clay and silty clay loam.

The extent to which the finer mechanical separates are aggregated into coarser fractions was determined as a function of treatments (Table 4). Both manure and 10 T/A gypsum significantly increased soil aggregation compared to the check and two lower rates of gypsum. The manure treatment was most effective in promoting aggregation. The two lower rates of gypsum, 2.5- and 5-T/A, had little or no effect on increasing soil aggregation.

The ability of a soil to fracture due to an applied force is an important soil physical characteristic. Soils which fracture easily are generally more productive. Table 5 presents modulus of rupture (MOR) results as a function of treatments. Both manure and 10 T/A gypsum had

Table 3. Soil mechanical analyses results from 0- to 4-inch depth samples taken at the research site in 1973.

Location Treatment	Replication	% Sand	% Silt	% Clay	Textural Class
check	1	10.5	39.4	50.1	clay
	2	13.0	38.0	49.0	clay
	3	9.9	42.0	48.1	silty clay
2.5 T/A Gypsum	1	9.3	44.1	46.6	silty clay
	2	16.4	39.1	44.5	clay
	3	12.7	35.7	51.6	clay
5.0 T/A Gypsum	1	10.2	42.4	47.4	silty clay
	2	17.3	41.6	41.1	silty clay
	3	12.5	48.9	38.6	silty clay loam
10.0 T/A Gypsum	1	18.2	40.1	41.7	silty clay
	2	12.7	39.4	47.9	clay
	3	14.2	43.2	42.6	silty clay
180 T/A Manure	1	17.6	39.8	42.6	clay
	2	14.3	51.2	34.5	silty clay loam
	3	10.0	41.0	49.0	silty clay

Table 4. Percent soil aggregates greater than .002mm in 1973 as a function of five treatments.

Treatment	REP I	REP II	REP III	MEAN
Check	69.4	68.1	72.2	69.9b
Manure 180 T/A	82.6	90.6	87.7	87.0a
Gypsum 10 T/A	85.1	82.9	83.3	83.8a
Gypsum 5 T/A	74.8	72.9	68.6	72.1b
Gypsum 2.5 T/A	69.7	70.3	66.7	68.9b

Table 5. Modulus of rupture values as a function of treatments from 1971 to 1973. Values are presented in units of bars.

Year	Check	Manure	Gypsum T/A		
			10	5	2.5
Soil Depth 0-3 inches*+					
1971	1.83a	1.53a	1.66a		
1972	3.02a	2.16abc	1.45c	1.60bc	2.52ab
1973	<u>2.81a</u>	<u>2.27b</u>	<u>2.36b</u>	<u>2.86a</u>	<u>2.56ab</u>
Mean	2.55	1.99	1.82	2.23	2.54
Soil Depth 0-8 inches*+					
1971	4.17a	2.60b	2.23b		
1972	3.15a	2.07a	2.09a	2.72a	2.86a
1973	<u>3.96a</u>	<u>2.67b</u>	<u>2.80b</u>	<u>3.98a</u>	<u>3.90a</u>
Mean	3.76	2.45	2.37	3.35	3.38

* Each datum is a mean of 6 values (3-reps and 2 samples per year).

+ Statistical results presented apply to the single year shown. No comparison between years is made.

the effect of decreasing MOR, and statistically significant differences were generally achieved. Statistical differences between the lower rates of gypsum and the check were not generally achieved, although these rates did decrease the modulus of rupture.

Tillage power requirements are described by the forces involved in compression, shear, and soil metal friction which contribute to draft of the tillage tool. Table 6 shows tillage power requirements as a function of treatments from 1971 to 1974.

The technique required innovative instrumentation techniques which resulted in large variation in data from year to year. Apparently using different tractors, tool bars, etc., led to the yearly variances.

Comparisons within years are valid. In 1971, the manure treatment had no effect, but 10 T/A gypsum significantly decreased tillage forces. In 1972, only the manure treatment significantly decreased tillage forces. However, the gypsum force values were less than the check plot. In 1974, all treatments decreased tillage forces significantly. These

Table 6. Tillage force data from all fifteen sugar beet plots during 1971 to 1974. Tool bar soil depth was 4-inches and data are in horse power hours per acre.

Rep	Check	Manure	Gypsum T/A		
			10	5	2.5
<u>Fall 1971</u>					
I	5.46	5.30	5.15		
II	5.28	5.34	4.94		
III	<u>5.20</u>	<u>5.24</u>	<u>4.89</u>		
Mean	5.31a	5.30a	4.99b		
<u>Fall 1972⁺</u>					
I	14.52	12.90	14.00	13.92	13.92
II	14.63	14.09	14.78	13.93	15.03
III	<u>15.28</u>	<u>14.80</u>	<u>13.74</u>	<u>15.28</u>	<u>15.12</u>
Mean	14.81a	13.93b	14.17ab	14.37ab	14.69a
<u>Spring 1974*</u>					
I	3.12	2.44	2.65	2.66	2.81
II	3.17	2.71	2.77	2.99	2.87
III	<u>3.41</u>	<u>2.96</u>	<u>2.77</u>	<u>3.14</u>	<u>3.16</u>
Mean	3.23a	2.71c	2.73c	2.93b	2.95b

* Each datum is a mean of 2 runs

+ Each datum is a mean of 4 runs

results indicate it takes a full year following manure and low rates of gypsum application before the soil tillage characteristics are altered. Manure (180 T/A) and gypsum (10 T/A) reduced tillage forces 8% and 6%, respectively.

Tillage force, soil aggregation, and modulus of rupture results all indicated significant changes in the inherent soil structure occurred due to manure and gypsum treatments. Although these soil tests are different the results of each can be attributed to similar reaction mechanisms.

It could be expected that treatment with manure and gypsum changed the soil equilibrium state towards one favoring stable aggregation. The cation exchange equilibrium with the soil solution could have been altered by gypsum application. The increase of calcium cations in solution may have resulted in a greater percentage of calcium on the cation exchange sites. Since calcium tends to cause a thin double diffuse layer, as described by Gouy-Chapman (32) diffuse double layer theory, increased flocculation of the clay system can be expected. A well flocculated clay system promotes increased soil aggregation.

Manure has no effect on the forces of flocculation. However, manure stabilizes soil aggregates by chemical and physical means. Summer wet-dry cycles and winter freeze-thaw action on soil with manure treatment could result in increased aggregation and increased stability. The data in Table 4 were collected two seasons after the initial manure treatment.

Both modulus of rupture and tillage force measurements are a direct reflection of soil shear strength. Shear can be described by

$$S = C + P \tan \phi$$

Eq. 6

where S is shear strength, C is related to cohesive forces, P is normal stress, and $\tan \phi$ is a function of the coefficient of friction and is described as the tangent of the angle between normal and resultant forces. A change in soil aggregation characteristics would have an effect on the cohesion and frictional components of Equation 6. Consider a sand and a clay system both at the same moisture level. The cohesive force in the sand is small but the frictional force is great relative to the clay. Conversely, in the clay the cohesive force is large but the frictional force is small relative to the sand. Increased soil aggregation had the effect of decreasing soil shear. As in the sandy soil example one could predict that frictional forces were increased, but the accompanying decrease in cohesive forces of this predominately silty clay soil resulted in a net decrease in soil shear. This phenomenon was demonstrated by the decreased soil modulus of rupture and tillage power requirement tests.

It can be concluded that these manure and 10 T/A gypsum treatments were observed to have beneficial effects on soil structure and tillage practices in the Yellowstone Valley.

Section II. Soil Water Movement

Section I demonstrated that gypsum and manure had beneficial effects on soil structure. The effect of this improvement on infiltration and soil water flow is described within this section.

Table 7 shows infiltration rates averaged over replications during 1971 to 1973. No statistically significant differences were attained but trends were present in these data. Manure and 10 T/A gypsum increased infiltration compared to the check. The lower rates of gypsum showed inconsistent results during 1972 and 1973.

A greater infiltration rate in these silty clay soils is desirable. Proper soil water recharge during irrigation is important and is not easily attained since the heavy texture creates a low hydraulic

Table 7. Infiltration rates averaged over replications and irrigations during 1971 to 1973. Values are centimeters per hour. Tests of significance should not be made between years.

Year	Check	Manure	Gypsum T/A		
			10	5	2.5
1971*	7.77a	8.74a	8.46a		
1972 ⁺	8.30a	8.62a	8.70a	7.36a	7.75a
1973 ^x	<u>8.25a</u>	<u>8.98a</u>	<u>9.14a</u>	<u>8.40a</u>	<u>8.34a</u>
Mean	8.11	8.78	8.77	7.88	8.04

* Each datum is a mean of 12 values.

+ Each datum is a mean of 9 values.

x Each datum is a mean of 12 values.

conductivity. Section I demonstrated that manure and gypsum treatments increased soil aggregation. This corresponds to a change in the

transmissivity characteristics of the surface soil which resulted in increased infiltration. It is highly likely, then, that application of high rates of feedlot manure or 10 T/A gypsum will result in a greater infiltration rate.

The effects of gypsum and manure treatments on soil water flux properties were evaluated. Neutron scattering equipment used in conjunction with tensiometers constituted one instrumentation approach for measuring soil water flow. Soil water flow meters were a second approach.

Appendix Tables 4 to 11 show time distribution of soil water content under check, manure, and 10 T/A gypsum treatments during 1971 to 1973. The corresponding soil matric potential values are given in Appendix Tables 12 to 20. As described in Methods and Materials, these water content and potential data permit solution of Darcy's Flow Equation 1. Thus, calculation of hydraulic conductivity (K) is possible. This silty clay soil is somewhat poorly drained and detection of hydraulic conductivity changes as a function of treatments was an objective.

Following the 1971 summer, it became obvious that the field soil-water flow system was complicated by a shallow water table and actively growing crop. Discontinuities in soil water content changes with time could not be reconciled with evapotranspiration losses and precipitation plus irrigation gains. It was concluded some water was moving from

the water table towards the root zone. This lack of continuity eliminated opportunity for a mathematical modeling approach in describing the soil hydraulic properties using the data obtained.

An indirect solution for measuring changes in soil water content was also attempted. These soil matric potential data were applied to desorption curves (Appendix Table 3) giving corresponding results in % water by weight. Similar unexplainable discontinuities, as those experienced with the neutron equipment, were still present in these soil water content data.

Following the 1971 summer it was decided to continue use of neutron equipment and tensiometers but an alternate method for measuring soil water flow would be included during 1972 and 1973. Soil water flow meters were included since they give a direct measurement of soil water flux and direction of flow, thus are applicable in very complicated flow systems.

During 1972 and 1973 neutron equipment and tensiometers continued to exhibit data discontinuities similar to those experienced during 1971. Therefore, no conclusions were formulated from these measurements and the remainder of this discussion on soil water flow pertains to data obtained with soil water flow meters.

Figure 5 shows depth and time distribution of soil water flux as measured with soil water flow meters. This figure shows several important phenomena. First, the soil water flow at the 6-foot depth was

from the groundwater towards the surface, with magnitude increasing as the summer progressed. Depth to the water table varied from 5- to 7- feet under these plots during the summer months. Consequently, the evapotranspirational demand set up a potential gradient favoring water movement from the water table to the root zone. This demand increased as the sugar beet crop matured. From this we would expect tensiometric values to show a definite and consistent matric potential gradient favoring water movement from the 6-foot level to some shallower depth. Appendix Tables 12 to 20 are inconclusive in showing the presence of such a matric potential gradient. Such inconsistencies hint that the matric potential gradient may not be the main force controlling movement of water. This phenomenon demonstrates the difficulty in using neutron equipment and tensiometers in complicated flow systems.

Flow meters at the 1.5-foot depth indicated downward fluxes, the magnitude of these fluxes being a function of water gained by precipitation and irrigation. Even though evapotranspiration was taking place I believe the continuous downward flux at the 1.5-foot depth was not out of the ordinary. This was an irrigated site and the soil was kept quite wet even though the surface few inches dried and cracked.

In 1973, flow meters were installed at the 3.5-foot depth in an attempt to resolve where the equilibrium interface between downward and upward fluxes was located. A small but consistent downward flux was present at the 3.5-foot depth. Thus, the equilibrium interface

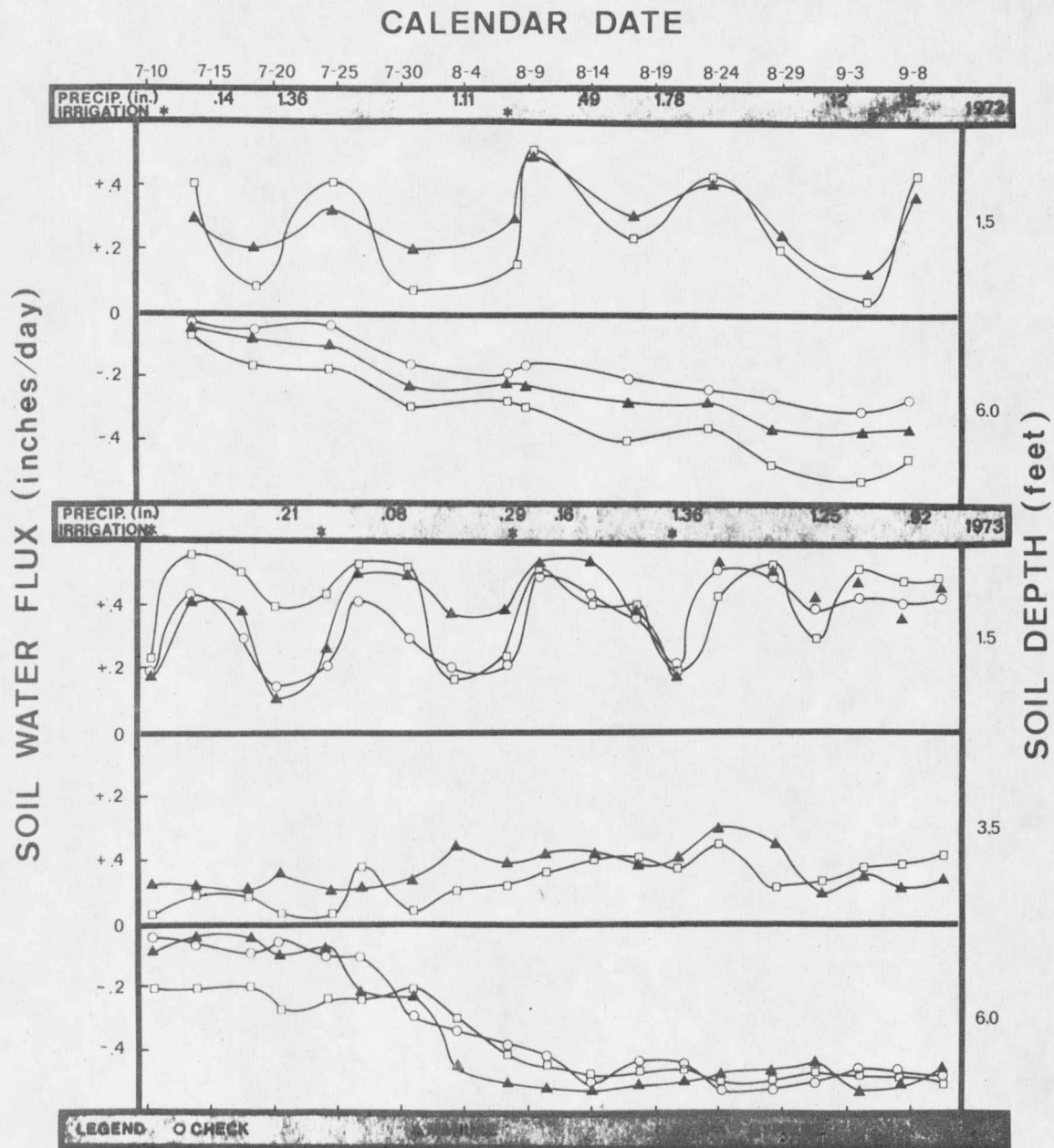


Figure 18. Depth and time distribution of soil water flux as measured with soil water flow meters. Negative flux means flow was toward the surface versus downward or positive flux.

was below 3.5-feet, but above 6.0-feet.

These flow direction phenomena imply active water uptake by the roots occurred largely near the 4-foot depth in the vicinity of the equilibrium interface. This had the overall effect of pulling water up from the shallow water table and downward from some superficial zone. This was the case under all treatments.

Differences in soil water flux between treatments were present (Table 8). Explanation of the technique used to determine values in Table 8 is necessary. The time based curves in Figure 18 were integrated employing the trapezoidal rule of numerical analysis (Gerald 29). Essentially, the area under each curve from some initial time (t_0) to some final time (t_1) was solved for by the definite integral;

$$\int_{t_0}^{t_1} f(t)dt \quad \text{Eq. 7}$$

where $f(t)$ is the curve function defined by the data points. Thus the integrated sum is the total soil water flux between t_0 and t_1 for a flow meter.

Some reliability in comparing check to treatments was lost since two flow meters in the check plot failed to function. Both 10 T/A gypsum and manure had the effect of increasing soil water flux compared to the check. Established soil physical principles attribute this phenomena to improved soil flocculation and aggregate stability. Soil analyses results in Figure 23 show application of 10 T/A gypsum had the

Table 8. Total soil water flux during 1972 and 1973 summers measured with soil water flow meters. Negative flux means flow was toward the surface versus downward or positive flux. Values are inches per unit time*#.

Year	Depth in feet								
	1.5	3.5	6.0	1.5	3.5	6.0	1.5	3.5	6.0
	Check			Manure			10 T/A Gypsum		
*1972	X	N	-9.88	+14.09	N	-13.82	+11.93	N	-18.42
#1973	+20.55	X	-19.92	+23.15	+9.76	-20.55	+24.17	+8.23	-22.48

* Represents 56 days of flux measurements

Represents 62 days of flux measurements

X Flow meter failed to function

N No flow meter installed at this depth

effect of increasing soil calcium in the surface 3-feet. Gouy double layer theory predicts, and numerous laboratory observations show, that calcium tends to flocculate soil materials. This is due, in part, to the double positive valence and the apparently small hydrated radius of the calcium ion. In these silty clay textured soils the water transmitting pores tend to swell closed upon wetting which retards soil water flux. Calcium tends to reduce this swelling and promote flocculation.

As previously discussed, the data of Table 4 demonstrated that manure significantly increased aggregation by acting as a cementing agent in soil aggregates. Thus, when the soil aggregates are subjected to a disruptive force, such as irrigation, the tendency to disperse is retarded. This phenomenon results in the soil pores remaining open during irrigation, consequently soil water flux remains large.

The difference in soil water flux between 10 T/A gypsum and manure

treated plots was small. Generally, the gypsum plot had the greatest soil water flux.

The magnitude of the flow meter values in Table 8 seem reasonable. Table 9 gives inches of precipitation and irrigation water applied to

Table 9. Inches of precipitation and irrigation water applied to plots with flow meters.

Treatment	1972			1973		
	Precip.	Irrig.*	Total	Precip.	Irrig.+	Total
Check	5.15	13.36	18.51	4.25	17.40	21.65
10 T/A Gypsum	5.15	14.00	19.15	4.25	20.40	24.65
Manure	5.15	14.36	19.51	4.25	18.15	22.40

* 3 Irrigations

+ 4 Irrigations

plots with flow meters. There was one major discrepancy. During 1973 the 1.5-foot depth flow meter in the manure plot measured a downward flux of 23.15 inches, but total water added to the system as precipitation and irrigation was only 22.40 inches. The difference was probably due to a greater irrigation water intake over the flow transducer than what was actually measured. The irrigation intake values are an average from over the entire 33 by 150 foot plot. However, the pit and tunnel dug for flow meter installation had a somewhat larger ability to conduct water since it was not possible to fill in the pit with the original high soil bulk density. Thus, a flow sink effect occurred in this pit area. My conclusion is that the flow meters gave accurate measurements of soil water flux and any discrepancies were due to uncontrollable

boundary conditions. Examples of such boundary conditions would be the loose soil in the access pit and row irrigation rather than the more uniform cover experienced during flood irrigation.

Section III. Solute Movement

The discussion in Section II indicated treatment with manure and gypsum increased the ability of this soil profile to transmit water. The effect of the increased flux of water on soil cation-anion displacement is presented in this section.

Attempts to collect in-situ soil water samples with extraction tubes at various depths and times were unsuccessful. The identical porous cups used for tensiometric measurements were used for soil water extractions. It was learned recently that the conductivity of these porous cups is very low and not suitable for soil water extractions. Rather, special porous cups of greater conductivity should have been used. Therefore, the following discussion on solute movement is based solely on soil analyses work during 1971 to 1973. The discussion is based on analyses of $\text{NO}_3\text{-N}$, $\text{PO}_4\text{-P}$, electrical conductivity, Na, Ca, and Mg.

Figure 19 depicts the soil profile $\text{NO}_3\text{-N}$ status from 1971 to 1973. Each datum is a mean of three replications. Commercial fertilizer was applied to all plots in the spring at 66-0-0(NH_4NO_3) pounds per acre in 1971, 100-40-0 pounds per acre in 1972, and 100-40-0 pounds per acre in 1973. An ammoniated phosphate fertilizer was added in 1972 and 1973.

It should be noted that the gypsum plots had the lowest $\text{NO}_3\text{-N}$ concentration in the surface one foot during 1972 and 1973. This phenomenon may have caused a crop yield loss as discussed in Section VI.

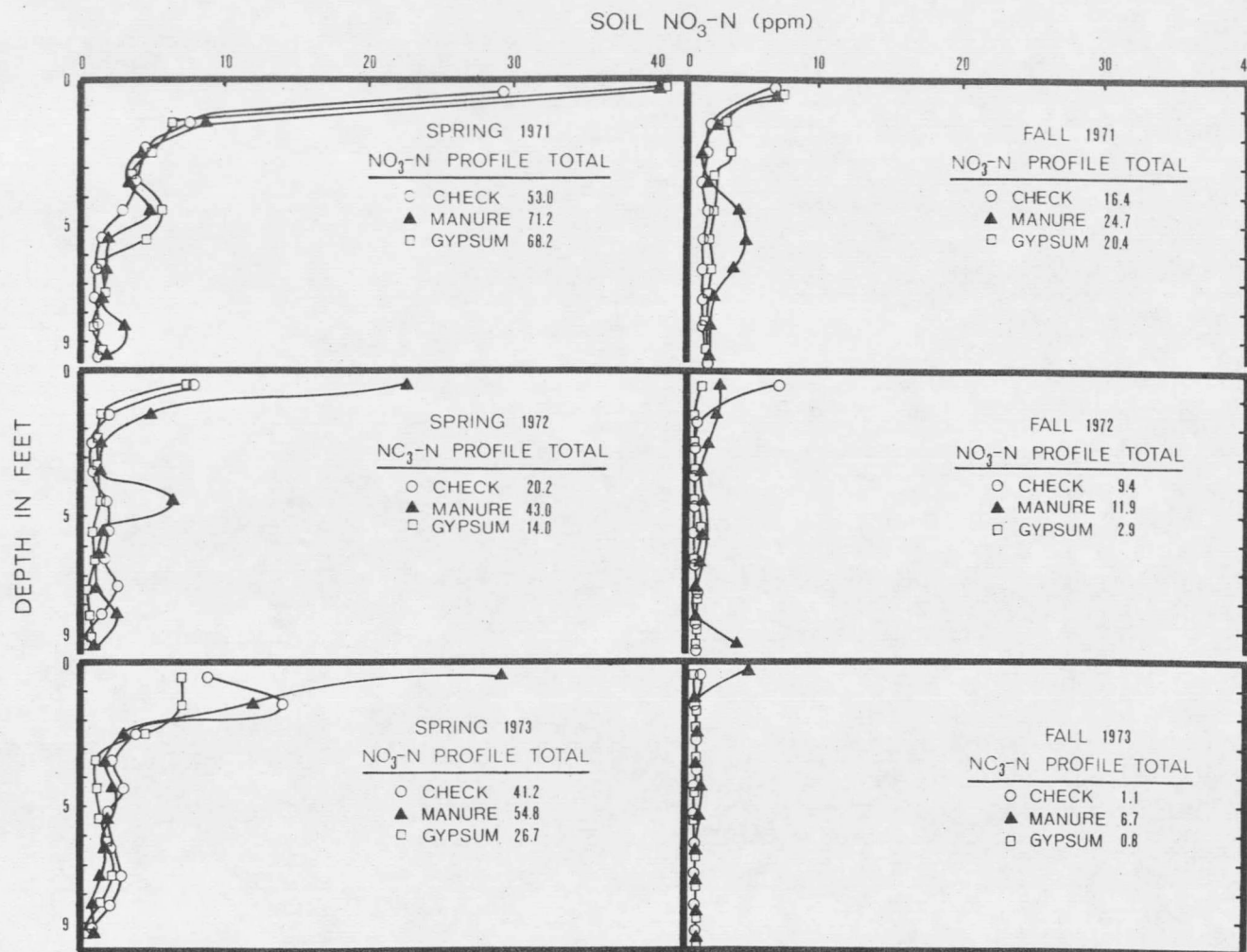


Figure 19. Soil profile distribution of $\text{NO}_3\text{-N}$ from 1971 to 1973. Each datum is a mean of three replications.

Displacement of $\text{NO}_3\text{-N}$ from the surface two feet of soil on a yearly cycle was prominent. The greatest displacement occurred in the manure plots. This displacement was due to either crop utilization or leaching. Only the manure plots demonstrated the effects of $\text{NO}_3\text{-N}$ leaching. In these plots some accumulation occurred at the 4- to 5-foot depths after one year of irrigation. After two irrigation seasons a small accumulation was present at the 10-foot depth. After the third irrigation season these accumulations under the manure plots were not detectable, and this disappearance could be attributed to deep leaching into the groundwater system which was located at the 4- to 7-foot level. However, Meek et al. (52, 53) has shown that disappearance of $\text{NO}_3\text{-N}$ in deep saturated zones can be attributed to denitrification. For denitrification to occur in soil it is necessary to have a low oxygen status, as found in a saturated soil system, and a readily available energy source. Carbon from the manure applications could serve as the energy source. Results to be presented in Section IV indicate no change occurred in the $\text{NO}_3\text{-N}$ status of the groundwater under these plots. Apparently, this leached nitrate underwent denitrification in the groundwater which resulted in no $\text{NO}_3\text{-N}$ buildup.

There seemed to be no $\text{NO}_3\text{-N}$ leaching attributable to the increased soil water flux in gypsum plots. Consider a comparison between the check and gypsum plots which received identical surface nitrogen applications. The time sequence $\text{NO}_3\text{-N}$ status in the check and gypsum plots

are nearly identical. Therefore, it is very likely that application of 100 pounds-acre-year nitrogen on irrigated soils in the Yellowstone Valley will not result in increased $\text{NO}_3\text{-N}$ leaching.

Soil profile $\text{PO}_4\text{-P}$ status from 1971 to 1973 is presented in Figure 20. Commercial phosphorus was applied in the spring at 40 pounds per acre in 1972 and 40 pounds per acre in 1973. During 1971 no $\text{PO}_4\text{-P}$ concentration changes occurred in the soil profile from spring to fall. Obviously the crop used phosphorus or it would not have produced. Therefore, the available $\text{PO}_4\text{-P}$ must have been in a dynamic equilibrium with phosphate minerals in the soil. Any crop utilization of $\text{PO}_4\text{-P}$ probably resulted in the $\text{PO}_4\text{-P}$ being replenished by phosphate from the solid state.

In 1972 fertilizer phosphorus seemed to boost the entire soil profile status of $\text{PO}_4\text{-P}$ to the 10 foot depth, yet no leaching or crop utilization occurred from spring to fall. These data imply heavy leaching of phosphate occurred during the 1971-1972 winter. The unlikelihood of this event warrants a different interpretation. Flow meter results in Section II indicated the soil water flux was from some lower depths towards the 4-foot soil depth. Therefore, some potential exists for $\text{PO}_4\text{-P}$ transport from the groundwater into the soil profile. However, the $\text{PO}_4\text{-P}$ content of the groundwater was very low (Section V), so this was an unlikely mechanism. In 1971, this writer personally analyzed these 1971 soil samples for $\text{PO}_4\text{-P}$ using the sodium bicarbonate technique

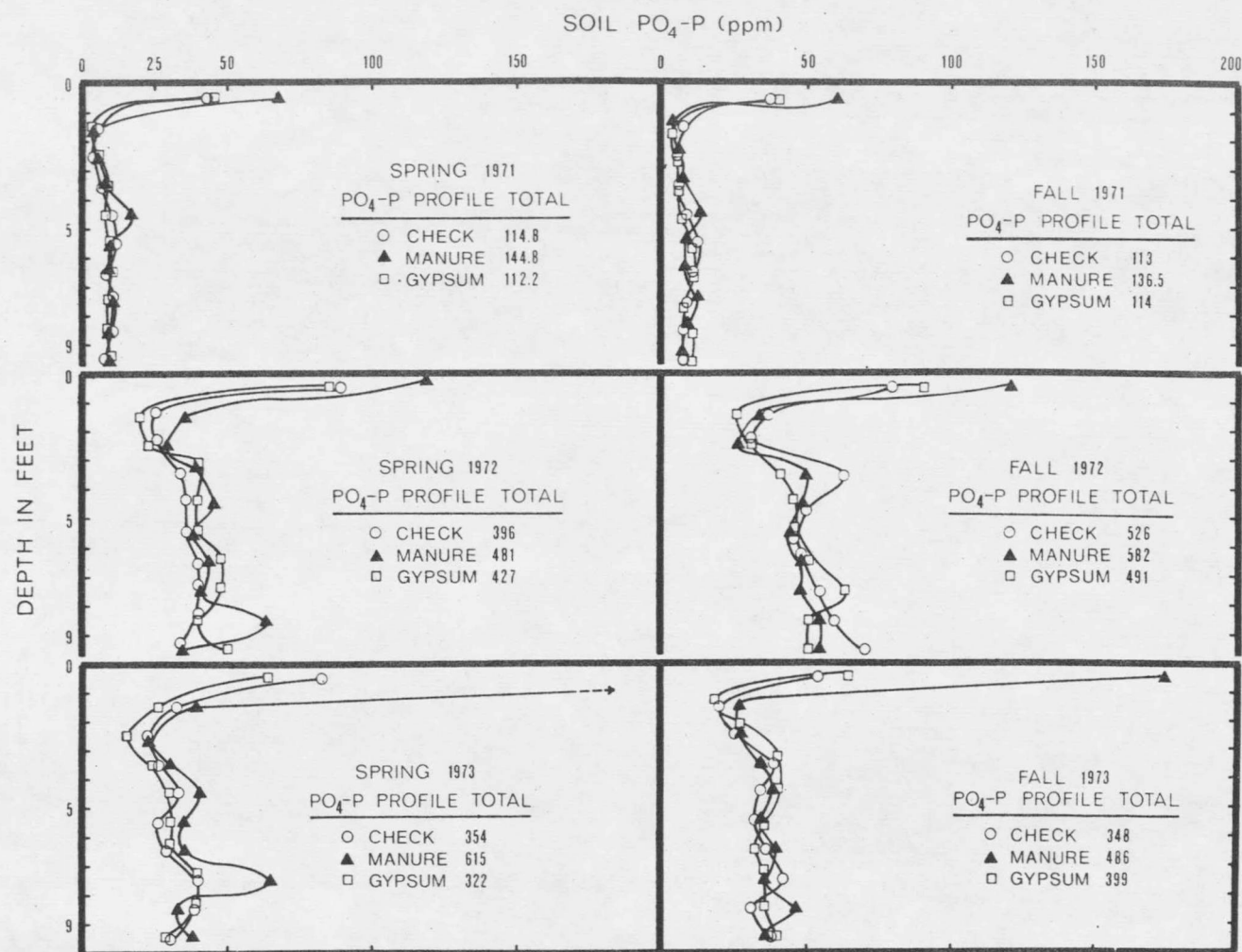


Figure 20. Soil profile distribution of $\text{PO}_4\text{-P}$ from 1971 to 1973. Each datum is a mean of three replications.

(see Appendix Table 22). The 1972 and 1973 soil samples were analyzed for $\text{PO}_4\text{-P}$ by the MSU Soil Testing Laboratory using the Bray (see Appendix Table 22) method. The extracting agent used in the Bray method tends to extract more phosphorus than the sodium bicarbonate method*. Thus, the increased $\text{PO}_4\text{-P}$ content measured through the entire 1972 soil profiles can probably be attributed to a change in the soil analysis procedure.

Differences between these spring and fall data for 1972 and 1973 are difficult to explain. In 1972 the fall soil profile contained more $\text{PO}_4\text{-P}$ than in the spring. Such a phenomenon can only be explained with speculation. It was possible that irrigation water could have contributed phosphorus to the soil, but Section IV presents data showing more $\text{PO}_4\text{-P}$ left the field in runoff water than was applied. Therefore, a net loss of soil $\text{PO}_4\text{-P}$ resulted. Also, the surface two feet of the profile changed very little in $\text{PO}_4\text{-P}$ content while the 2- to 10-foot depth was actually responsible for the gains. Since $\text{PO}_4\text{-P}$ is readily absorbed by soils the likelihood of irrigation water contributing $\text{PO}_4\text{-P}$ to the 2- to 10-foot soil depths was remote. These 1973 data show the first evidence of significant phosphorus utilization by the crop. This statement applies only to the manure treated plots where significant amounts

* This reasoning resulted from discussions with Dr. Jim Sims.

of $\text{PO}_4\text{-P}$ were extracted from the surface one-foot.

These data indicated this soil could readily replace most of the $\text{PO}_4\text{-P}$ utilized by the crop. The $\text{PO}_4\text{-P}$ concentrations seemed to be in equilibrium with the phosphate minerals in the soil. The manure plots always had the highest $\text{PO}_4\text{-P}$ content at the surface compared to both the check and gypsum plots.

Soil profile salt status from 1972 and 1973 is presented in Figure 21. These data indicate a salt buildup with depth in all plots. There were no consistent significant differences between any treatments. Generally, below the 4-foot depth the soil was above 4 mmhos/cm, or saline, in all plots. The source of this salinity was the groundwater. The groundwater, located at about the 6-foot depth, was saline (Section V) in nature with average conductivities greater than 8 mmhos/cm, and the soil water flux from water table towards the 4-foot depth (Section II) contributed to salinization of the profile.

It should be noted that the gypsum and manure plots had the greatest salt concentration in the surface one foot during three of the four seasons described in Figure 21. In these cases the check plots were below 2 mmhos/cm conductivity while check and gypsum plots ranged from 2- to 4-mmhos/cm. This phenomena may have caused a crop yield loss as discussed in Section VI since young sugar beet plants are sensitive to salt concentrations in the 2- to 4-mmhos/cm range. At deeper soil depths, for example four feet, where the salinity level averages about

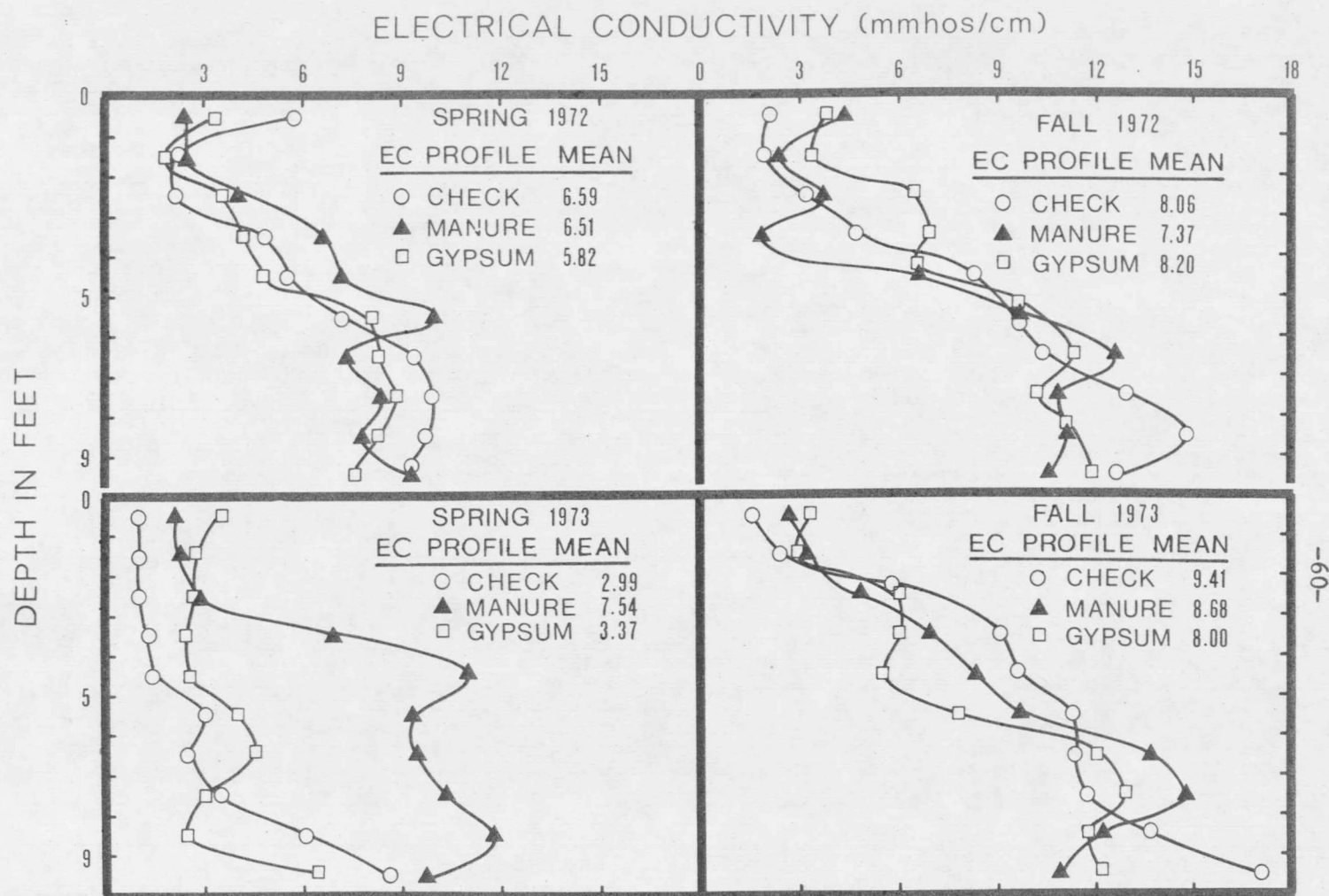


Figure 21. Soil profile distribution of salt from 1972 and 1973. Each datum is a mean of three replications.

5 mmhos/cm, there were no obvious differences between treatments so the effects of these salts upon crop production were nearly the same over all plots.

Figures 22, 23, and 24 show the contributions of sodium, calcium, and magnesium to the soil salt status. The distribution of sodium (Figure 22) increases with depth in accordance with the electrical conductivity data of Figure 8. Generally, the profile under the manure treatment was higher in sodium compared to both the check and gypsum plots. Over the three year period the manure profile averaged 88.9 meq/L compared to 81.3 meq/L for the check and 72.5 meq/L for the gypsum plot. Little difference existed between the check and gypsum plots with respect to their sodium distribution patterns. Figure 23 shows very little difference between treatments regarding soil calcium content. The only variation occurred in spring 1973 when the 3- to 10-foot depth under the manure treatment was much greater in calcium content compared to both the check and manure plots. This variance has to be attributed to experimental error. Figure 24 shows very little difference between treatments regarding soil magnesium content.

Sodium adsorption ratios (Equation 8) ranged from 1 to 3 in the 10-foot profile under all plots. Therefore, no alkali problem existed. A saline situation was present at depths greater than 4-feet under all plots, and the surface one foot was moderately saline under manure and gypsum treatments. It appeared calcium was the dominant cation

contributing to the soil electrical conductivity values.

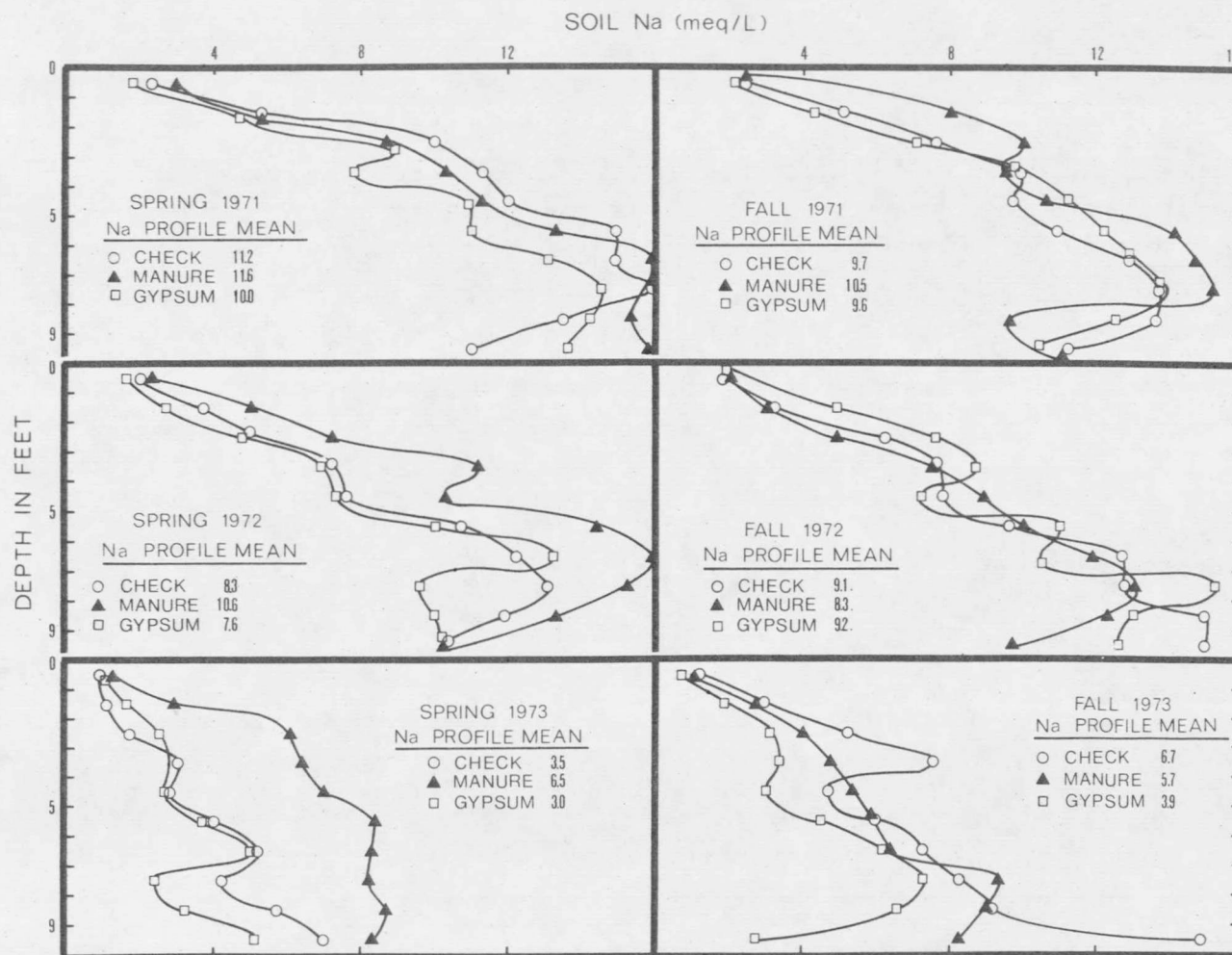


Figure 22. Soil profile distribution of sodium from 1971 to 1973. Each datum is a mean of three replications.

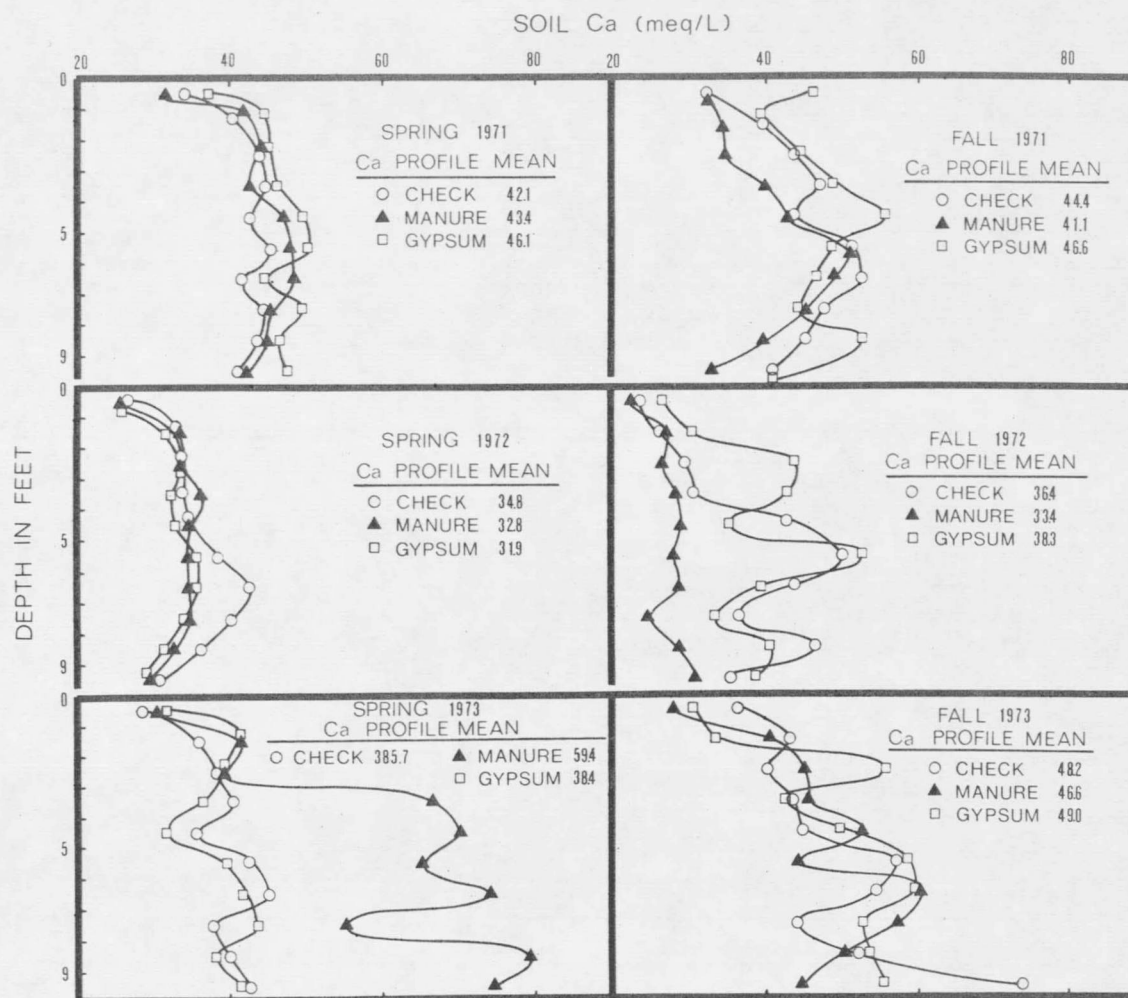


Figure 23. Soil profile distribution of calcium from 1971 to 1973. Each datum is a mean of three replications.

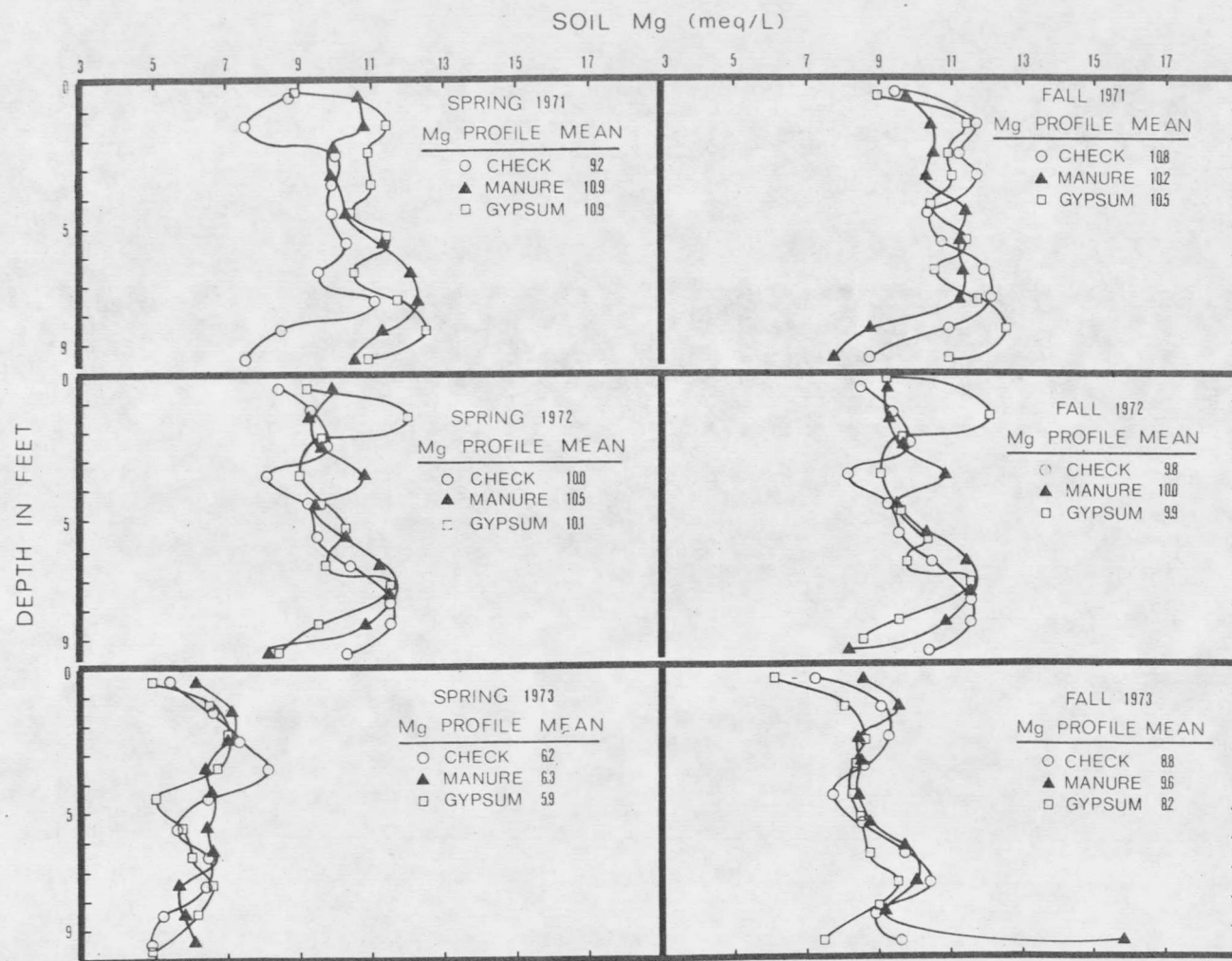


Figure 24. Soil profile distribution of magnesium from 1971 to 1973. Each datum is a mean of three replications.

Section IV. Groundwater Quality

Section two demonstrated that the soil water flux was from ground-water towards the 4-foot depth during the summer. This was in all plots. Therefore, the likelihood of solute leaching into the groundwater was small. However, it was possible that a net downward flux occurred at other times of the year resulting in some groundwater quality change from solute leaching. The quality of this groundwater was monitored at numerous sites in and around the experimental plot area during 1972 and 1973.

Table 10 describes the depth in feet to the water table at various locations. The water table was generally between 4- and 7-feet in depth. A conspicuous water table gradient existed from south of the plots (4 feet deep) to north of the plots (6 feet deep).

Figure 25 shows groundwater quality data at two locations. As described in Methods and Materials the test area site represents two test holes in the near vicinity of the plots whereas the control site was located about 200 yards from the plots. These data indicate $\text{NO}_3\text{-N}$ and $\text{PO}_4\text{-P}$ were present at both sites in very low concentrations. Apparently, the surface treatments had no effect on the $\text{NO}_3\text{-N}$ or $\text{PO}_4\text{-P}$ status of the groundwater.

The salt status of the groundwater under the test area was high but that of the control site was relatively low (Figure 25). These data are evidence indicating salt buildup in the groundwater occurred and could

Table 10. Depth in feet to the water table. Site location is shown in Figure 1.

Date	North Site	South Site	Check Site
<u>1972</u>			
6-20	6.5	4.0	-
6-28	6.0	4.0	-
7-7	6.0	4.0	-
*			
7-15	6.0	4.0	-
7-20	5.0	4.0	-
7-26	4.5	4.0	-
8-1	7.0	4.0	-
8-4	6.0	4.0	-
*			
8-9	6.0	4.0	-
8-17	6.0	4.0	-
8-24	4.5	4.0	-
9-1	5.0	4.0	-
*			
9-8	5.0	4.0	-
<u>1973</u>			
6-20	6.0	4.0	6.0
7-3	6.0	4.0	6.0
*			
7-13	6.0	4.0	5.0
7-22	6.0	4.0	6.0
*			
8-3	6.0	4.0	6.0
*			
8-10	6.0	4.0	6.0
8-17	6.0	4.0	6.0
*			
8-24	6.0	4.0	6.0
8-31	6.0	4.0	6.0
9-7	5.0	4.0	6.0

* Irrigation

be attributable to surface applied salts from gypsum and/or manure treatments. Table 11 shows comparative levels of sodium, calcium, and

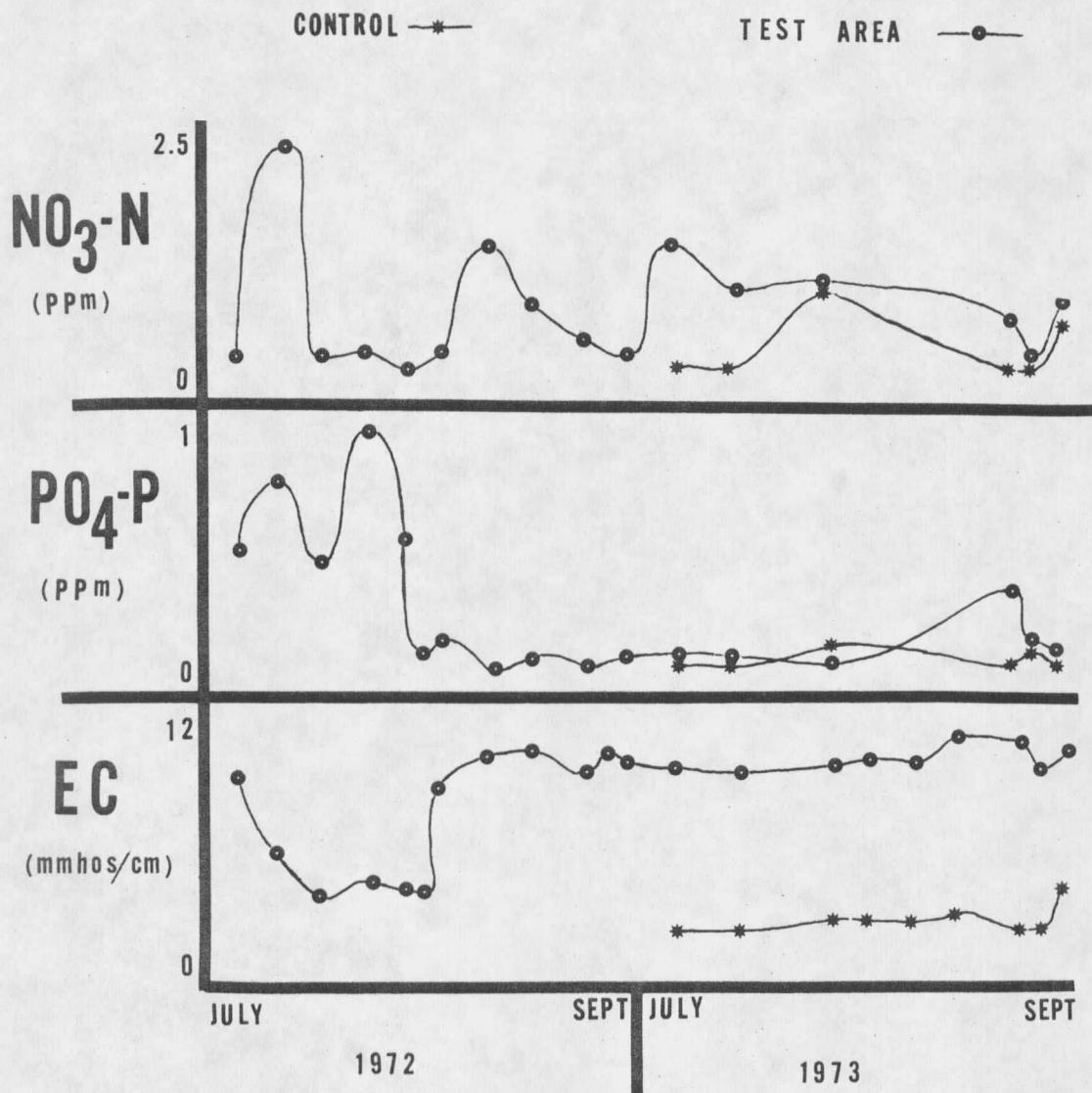


Figure 25. Groundwater quality at two locations during the 1972 and 1973 summers.

magnesium which contributed to the total electrical conductivity shown in Figure 25. The groundwater under the plot area was alkali during 1972 and 1973 with an average SAR of 34. Water with an SAR of 15 or greater is considered¹ alkali. The groundwater at the control site was essentially non-alkali with a median SAR of about 9.0 and a mean of 14.3. These data indicate the manure treatment may have contributed sodium to the groundwater. Section III discussed solute movement and Figure 22 described the distribution of soil sodium with time. The buildup of soil sodium under the manure treatment was definitely larger compared to the check and gypsum plots, and these groundwater quality data indicate sodium leaching occurred.

To measure this phenomenon more carefully additional access pipes were placed into the groundwater during 1973. Reference to Figure 1 shows access pipes were placed within individual manure and check plots. Figure 26 and Table 12 present these results. Again the $\text{NO}_3\text{-N}$ and $\text{PO}_4\text{-P}$ concentrations were very low and the salt status was both saline and alkali at these groundwater locations. Essentially, no difference existed between the manure and check plots. However, it should be noted that the magnesium concentrations under the manure plots averaged about 3 meq/L higher than the check. Also, the $\text{NO}_3\text{-N}$ concentration under the

1 U.S. Salinity Laboratory Staff. 1954. Saline and alkali soils. Agri. Handbook 60. U.S.D.A.

manure plots was higher than the check five of the six times sampled, even though these differences were extremely small.

Table 11. Comparative groundwater concentration of calcium, magnesium and sodium during the 1972 and 1973 summers. All data are meq/L.

1972					1973				
Date	Ca	Mg	Na	SAR	Date	Ca	Mg	Na	SAR
<u>Integrated Sample*</u>					<u>Integrated Sample*</u>				
7-1	9.2	19.1	94.3	25.0	7-3	9.2	17.8	95.8	25.1
7-7	5.8	20.5	68.2	18.8	7-13	16.0	22.7	123.9	27.5
7-14	12.9	16.1	138.0	36.2	7-27	1.3	20.9	141.8	57.4
7-20	5.2	21.5	124.4	34.0	8-3	6.8	16.4	139.3	36.0
7-26	8.1	5.12	111.2	43.2	8-10	10.3	17.9	123.6	34.0
8-1	7.2	13.3	106.5	33.3	8-17	7.4	15.8	107.5	27.2
8-4	14.2	18.9	114.8	20.0	8-24	3.1	20.8	144.0	41.5
8-10	9.7	8.1	148.0	49.6	8-31	8.6	18.2	124.0	33.5
8-17	6.5	21.4	114.6	30.7	9-7	15.3	19.0	135.6	<u>33.6</u>
8-24	3.9	15.0	125.0	40.7	Mean				35.0
9-1	6.4	22.3	134.8	35.6					
9-8	5.4	21.1	132.0	<u>36.3</u>					
Mean				33.6	<u>Control Site</u>				
					7-3	4.5	2.9	14.1	7.4
					7-13	4.5	3.0	13.9	7.2
					7-27	0.5	2.9	18.7	14.4
					8-3	3.2	2.0	13.7	8.6
					8-10	2.7	2.2	10.4	6.7
					8-17	0.9	2.0	66.7	55.9
					8-24	2.5	1.3	13.7	9.9
					8-31	2.1	1.2	12.6	9.8
					9-7	17.6	11.4	33.9	<u>8.9</u>
					Mean				14.3

* Average of north and south sites immediately adjacent to the research plots (See Figure 1).

If it can be assumed the control site, located 200-yards from research plots, was indeed a valid check on the native groundwater quality, then the results of this section show these heavy applications of

manure can salinize a shallow groundwater system. Sodium seemed to be the most leachable cation. Some reassurance in these statements was lost when access pipes located within each check and manure plot in 1973 showed no difference in groundwater quality. However, one could attribute this to complete masking by the manure plots. Leaching of the manure treatment had been going on for two years prior to 1973. During this period salts leaching into the groundwater from each manure plot

Table 12. Comparative groundwater concentrations of calcium, magnesium, and sodium under check and manure plots during 1973. Each datum is a mean of three replications.

Date	Meq/L		Na	SAR
	Ca	Mg		
		<u>Check Plot</u>		
7-3	22.3	19.0	110.9	24.2
7-13	19.5	16.8	62.7	15.0
7-27	1.4	13.5	109.1	39.7
8-3	15.9	14.2	95.3	24.0
8-10	15.0	13.5	106.6	27.9
8-17	15.0	13.6	98.8	25.7
8-24	9.1	12.1	91.9	28.7
8-31	8.4	12.0	95.0	29.7
9-7	9.6	12.0	92.2	<u>28.4</u>
Mean				27.0
		<u>Manure Plot</u>		
7-3	12.8	17.4	112.0	17.9
7-13	18.4	42.4	101.8	20.6
7-27	1.4	15.6	120.6	41.6
8-3	9.8	14.7	113.9	32.5
8-10	13.4	15.1	111.8	29.6
8-17	10.6	16.1	112.9	30.7
8-24	9.4	14.5	95.6	28.7
8-31	12.4	13.8	98.4	27.0
9-7	16.5	13.6	106.5	<u>27.3</u>
Mean				28.4

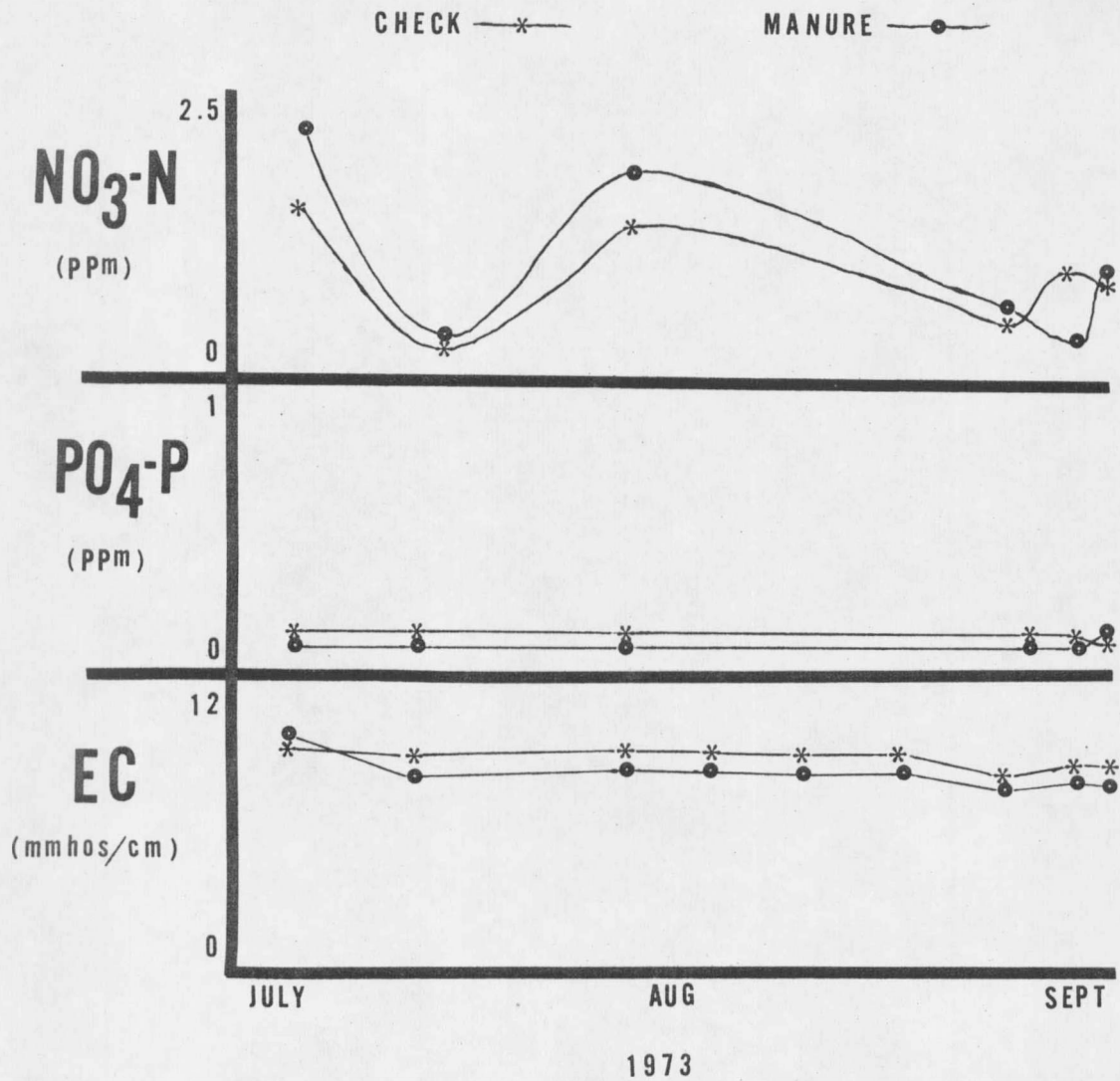


Figure 26. Groundwater quality immediately under check and manure plots during 1973. Each datum is a mean of three replications.

could have dispersed over the entire groundwater zone beneath the plots. Therefore, in 1973 no difference in groundwater quality could be detected immediately under individual plots. These data seem to support other studies (47) which measured salt buildups under heavy manure applications. However, unlike other studies (31, 57, 71, 73, 74) no $\text{NO}_3\text{-N}$ buildup in the groundwater resulted from these heavy manure applications in the Yellowstone Valley, probably because of denitrification processes in the saturated zone as discussed in Section III.

Section V. Surface Runoff Quality

The Yellowstone Valley in Montana is an intensely irrigated agricultural area. This valley is typical of the semiarid northwest where maximum production is sought adjacent to a river water source. A portion of the river flow is sliced off into a diversion canal which distributes water to the croplands. Unused irrigation water and/or drainage water is returned to the river downstream. The effects of such diversionary practices on downstream water quality has been the topic of much controversy.

Table 13 shows averaged water quality results from the Huntley irrigation project in the Yellowstone Valley during a 3-year period. The concentration of $\text{NO}_3\text{-N}$, $\text{PO}_4\text{-P}$, salts and suspended solids was greater in drainage water flowing off agricultural lands than in the irrigation water applied. The reverse was true for total carbon where the drainage water had a lower concentration than in irrigation water applied.

The largest city in Montana (Billings, population 70,000) is located on the Yellowstone River approximately 15 miles upstream from this experimental site. The potential exists where such a geographical setting of an irrigation project downstream from a large city could serve as a means of extracting carbon compounds out of surface waters.

Although $\text{NO}_3\text{-N}$ concentrations are at higher levels in drainage waters off these soils, it is still below 10 ppm $\text{NO}_3\text{-N}$, which is the value adopted by the U.S. Public Health Service as the safe upper limit

for water consumed by humans. Concentrations of $\text{PO}_4\text{-P}$ ranging from .02 to .05 ppm have been reported (4, 76) as minimal for supporting algal blooms. Applying this criterion, the $\text{PO}_4\text{-P}$ levels measured at this site in the Yellowstone Valley (Table 13) were very high. Although salt concentration was greater flowing off this agricultural site than irrigation water applied, the increase was small and still below 2 mmhos/cm conductivity, the value used to distinguish saline from non-saline water. The concentration of suspended solids (Table 13) increased as the water left the canal and traveled via a ditch to the field, across the field and out a drain ditch. Dirt ditches were used and results are as expected.

Table 13 also demonstrates runoff from the manured plots generally contained higher concentrations of $\text{NO}_3\text{-N}$, $\text{PO}_4\text{-P}$, salts, carbon materials, and suspended solids compared to the check and gypsum plots. The objective of the manure treatment was to determine the quantity of feedlot manure which could be applied to agricultural soils without detrimental effects upon crops or the environment. Although manure increased all nutrient concentrations in runoff, the increase was small.

Runoff concentrations of calcium were substantially higher from plots treated with 10 T/A gypsum compared to both the check and manure plots. Apparently, the gypsum mineral itself was physically eroded from the surface. This evidence demonstrates the importance of incorporating gypsum applications into the soil to insure maximum reactivity

Table 13. Water quality results from a large irrigation project in the Yellowstone Valley during 1971 through 1973.

Treatment	Diversion Canal	Head Ditch	Field Runoff 1	Field Runoff 2	Surface Drain
<u>*NO₃-N (ppm)</u>					
Check	.47	.55	1.20	2.11	1.72
Gypsum	.47	.55	1.75	1.47	2.01
Manure	.47	.55	2.65	4.75	3.79
<u>*PO₄-P (ppm)</u>					
Check	.04	.04	.33	.17	.22
Gypsum	.04	.04	.28	.13	.18
Manure	.04	.04	1.04	.62	.58
<u>*Ca (ppm)</u>					
Check	22.9	22.3	26.6	25.1	28.2
Gypsum	22.9	22.3	40.5	36.6	36.9
Manure	22.9	22.3	31.6	28.6	30.8
<u>*Mg (ppm)</u>					
Check	7.33	7.39	9.05	8.07	9.12
Gypsum	7.33	7.39	9.88	10.12	10.40
Manure	7.33	7.39	9.92	9.83	9.48
<u>*Na (ppm)</u>					
Check	41.47	47.93	52.34	46.65	48.46
Gypsum	41.47	47.93	50.78	44.02	51.61
Manure	41.47	47.93	65.93	57.91	60.07
<u>*Electrical Conductivity (mmhos/cm)</u>					
Check	.26	.28	.33	.30	.36
Gypsum	.26	.28	.38	.36	.36
Manure	.26	.28	.38	.36	.36
<u>▣ Suspended Solids (g/L)</u>					
Check	.08	.26	1.11	.64	1.58
Gypsum	.08	.26	1.68	.56	1.42
Manure	.08	.26	1.38	.61	1.82
<u>○ Total Carbon (mg/L)</u>					
Check	77.1	47.2	43.2	36.9	53.1
Gypsum	77.1	47.2	40.2	40.8	47.2
Manure	77.1	47.2	47.1	60.3	45.8

* Values are means from 33 observations (11 irrigations - 3 replications)

▣ Values are means from 21 observations (7 irrigations - 3 replications)

○ Values are means from 12 observations (4 irrigations - 3 replications)

and prevent loss from erosion.

Thus far, these data have been presented in terms of concentration with the general conclusion that surface water quality can be reduced by agricultural irrigation use. However, these same data take

Table 14. Dissolved and suspended load results from a large irrigation project in the Yellowstone Valley during 1971 through 1973.

Treatment	<u>H₂O - Ft³</u>		<u>Concentration (ppm)</u>		<u>Load (grams)</u>	
	Applied	Runoff	Applied	Runoff	Applied	Runoff

on a different appearance when the actual dissolved and suspended load translocation budget is solved. Table 14 presents both cubic-feet of irrigation water applied and field runoff along with the respective

concentration data of Table 13. The concentration multiplied by volume of water permits calculation of the mass load. The runoff load contained only a fraction of the applied load of $\text{NO}_3\text{-N}$ and Ca, but a greater load of phosphates were transported off the field than were applied except for gypsum plots. Apparently, a sediment-phosphate relationship was present which extracted phosphates from the soil surface. This phenomenon has been observed by other investigators (46, 38).

The interpretation of Table 14 should not be that soils can clean the nitrates, salts, and suspended solids out of surface waters. It just depicts the distribution of the salt load in an irrigation project. The Yellowstone River downstream from the Huntley Project will have higher concentrations of nitrates, phosphates, salts, and suspended solids as a result of irrigation. However, it is interesting to hypothesize that if anions and cations could be attracted from the main stream into the intake point of an irrigation canal that agriculture soils could improve the quality of surface waters.

Section VI. Crop Production Aspects

The concept of using agriculture soils as a feedlot waste disposal medium will not have general acceptance if crop quality or quantity is diminished. Likewise, the use of gypsum on non-alkali heavy textured soils must result in beneficial effects upon crop production. The results of these amendments on production and ease of harvest is discussed below.

Table 15 presents sugar beet yield data from 1971 to 1973. In 1971, the check plot had a significantly greater yield compared to manure or gypsum plots. This was attributable to spring application of amendments. Repeated trips over the plots in order to apply the amendments resulted in soil compaction which led to seedling emergence problems. Attempts to transplant beets into the barren areas were only partially successful. However, in the check plots emergence was normal. This unforeseen accident resulted in the check plot having the greatest mass yield and sugar production in 1971.

In 1972 the manure plots had a significantly greater yield compared to the check and gypsum plots. There was no difference between the gypsum and check plots. Although the beet yield was greatest on the manure plots the percent sugar was significantly lower and the sugar yield was the lowest of all treatments. Therefore, the manure treatment created a significantly greater beet yield but at the expense of a decrease in sugar content. The 2.5- and 5-T/A gypsum treatments

seemed to increase sugar yield, but not significantly.

Table 15*. Sugar beet yield data from 1971 to 1973 harvests.

Year	Check	Manure	Gypsum T/A		
			10	5	2.5
		<u>Yield T/A</u>			
1971	22.0a	19.16b	18.06b		
1972	18.06b	20.3a	17.6b	18.86b	18.26b
1973	18.8a	20.7a	15.2a	15.2a	17.2a
Mean	19.6	20.0	16.9	17.0	17.7
		<u>% Sugar</u>			
1971	15.8a	15.6a	16.5a		
1972	16.8a	14.5b	17.2a	17.1a	17.3a
1973	17.8a	15.5b	17.6a	17.4a	18.7a
Mean	16.8	15.2	17.1	17.2	18.0
		<u>Sugar Yield (lbs/A)</u>			
1971	6981a	5952b	5955b		
1972	6078a	5899a	6047a	6446a	6267a
1973	6657a	6377a	5333a	5322a	6403a
Mean	6572	6076	5778	5884	6335

* Tests of significance should be made only within the same year.
Each datum is a mean of three replications.

No statistical differences were present in 1973. The means indicated the gypsum treated plots had a low mass yield, an equivalent percent sugar, and lower sugar yield compared to the check plots. The manure plots again had the highest mass yield, lowest percent sugar, and lower sugar yield compared to the check plots.

Although statistical significance was not consistently attained, three years data demonstrated some trends. It appears gypsum and heavy manure applications will decrease total sugar production about 8%. Also, there was some indication that the 10 T/A gypsum rate

decreased yield more than the 2.5 T/A gypsum rate.

It appears these amendments decreased sugar yield. To help explain this phenomenon top/root ratios and plant analyses data were collected. Table 16 presents top/root ratios from the 1972 and 1973 harvests. In 1972 the two lower gypsum rates had a significantly smaller top/root ratio compared to all other treatments. This corresponded to the greatest sugar yields across all treatments for that harvest year (Table 15). Plants from manure plots had a large top/root ratio. The top growth on these manure plots were observed visually to be much greater during all three crop years (Figures 27 and 28). No consistent relationship between top/root ratio and yield was apparent or could be found.

Table 16*. Sugar beet top/root ratios from the 1972 and 1973 harvests.

Year	Check	Manure	Gypsum T/A		
			10	5	2.5
1972	.34a	.32a	.32a	.23b	.25b
1973	.50a	1.05a	.50a	.49a	.44a
Mean	.42	.68	.41	.36	.34

* Tests of significance should be made only within the same year.
Each datum is a mean of three replications.

Table 17 presents sugar beet top protein, $\text{NO}_3\text{-N}$, and phosphorus content during the 1971 to 1973 harvests. The tops from the manure plots had significantly more protein compared to other treatments, except 5 T/A gypsum in 1973. The tops from the manure plots also had greater $\text{NO}_3\text{-N}$ content compared to other treatments. Apparently, the



Figure 27. Sugar beet plot showing top growth on a check plot.



Figure 28. Sugar beet plot showing profuse top growth on a manure plot.

manure treatment created a situation which permitted luxury consumption of $\text{NO}_3\text{-N}$ by the sugar beet plant resulting in excessive top and root growth compared to the other treatments. Table 18 shows the classification of forages containing nitrates. When the % nitrate is greater than 0.3, controlled feeding is recommended. If greater than 1.2% then

Table 17⁺. Sugar beet top protein, $\text{NO}_3\text{-N}$, and phosphorus content during the 1971 to 1973 harvests.

Year	Check	Manure	Gypsum T/A		
			10	5	2.5
<u>% Protein</u>					
1971					
1972	11.5b	14.0a	10.8b	11.0b	11.7b
1973*	8.6b	12.4a	8.7b	9.9ab	8.0b
Mean	10.0	13.2	9.8	10.4	9.8
<u>% NO₃-N</u>					
1971	.17	.70	.13		
1972	.34	1.13	.33	.12	.19
1973	.12	.74	.21	.17	.10
<u>% Phosphorus</u>					
1971					
1972	.26a	.31a	.25a	.26a	.28a
1973	.22a	.24a	.21a	.20a	.21a
Mean	.24	.28	.23	.23	.24

* Means followed by different letters are significantly different at the 10% level.

+ Tests of significance should be made only within the same year. Each datum is a mean of three replications.

the forage should not be used for feeding. This indicates tops from the manure plots contained hazardous amounts of nitrates. Therefore, livestock should not be turned out into the sugar beet field following harvest. The alternative would be to pick up the tops and mix with low

nitrate feed. It should be noted that these tops approached 15% protein, which is the level considered useful as a protein feed supplement.

Table 18*. Classification of forages containing measurable amounts of nitrate.

% Nitrate (dry matter basis)	Use as feed for livestock
0-.30	generally safe
.30-1.20	controlled feeding plan suggested
1.20 and above	do not recommend feeding

* Table from: Dept. of Chem., Mont. Agr. Exp. Sta.

No significant difference existed in phosphorous content of the tops across all treatments.

Table 19 presents protein, $\text{NO}_3\text{-N}$, and phosphorous content of the sugar beet root during the 1972 and 1973 harvests. Again the beet roots from the manure plots had a significantly greater percent protein and a much greater $\text{NO}_3\text{-N}$ content compared to all other treatments. Also, in 1972 beet roots from the manure plots contained significantly more phosphorous compared to all other treatments. It is difficult to state what, if any, effect this higher protein, $\text{NO}_3\text{-N}$, and phosphorous content in the beet had on production. Table 15 demonstrated the beets from manure plots always had the lowest % sugar. Apparently, plant energy normally used for sugar production was used for protein production.

The measured decrease in sugar yield due to gypsum is difficult to explain and one can only speculate regarding the cause of this phenomenon. The data in this thesis regarding gypsum applications and

Table 19⁺. Sugar beet root protein, NO₃-N, and phosphorus content during 1972 and 1973 harvests.

Year	Check	Manure	Gypsum T/A		
			10	5	2.5
<u>% Protein</u>					
1972	4.4b	7.2a	4.3b	4.2b	4.2b
1973	3.5b	5.6a	4.0b	4.1b	3.4b
Mean	4.0	6.4	4.2	4.2	3.8
<u>% NO₃-N</u>					
1972	.11	.58	.10	.10	.12
1973	.10	.18	.10	.10	.10
<u>% Phosphorus</u>					
1972	.17b	.20a	.17b	.15b	.17b
1973*	.14b	.17a	.17a	.16a	.16a
Mean	.16	.18	.17	.16	.16

* Means followed by different letters are significantly different at the 10% level.

+ Each datum is a mean of three replications. Tests of significance should be made only within the same year.

sugar beet production indicate a need for soil fertility and plant nutrition research in conjunction with gypsum applications. The beneficial effects of gypsum on soil physical characteristics cannot be an accepted soil management tool until these gypsum soil fertility interactions are more clearly understood.

The heavy textured soils of Yellowstone Valley often make the beet digging process a difficult task for man and machine. Not only does the machinery require more power to dig the beets, but the heavy textured soil tends to stick to the beets all the way to the factory. The effect of these soil amendments on decreasing tare was measured.

Table 20 presents soil tare values at three locations during the

1971 to 1973 sugar beet harvest. Description of the various tare locations is given in the Methods and Materials. Figure 29 shows the field tare soil being caught on a tarp. The data of Table 20 demonstrate all gypsum rates were very effective in reducing tare weights. Gypsum plots had significantly lower field tare weights in 1971 and 1973 compared to the check. In 1972, no significant differences were present, but the gypsum plot tares were much lower relative to the check plot. Figures 30, 31 and 32 show field tare piles from check, gypsum and manure plots. Statistical significance was not consistently attained between check and gypsum plots for dump and factory tares. However, the gypsum plot dump and factory tares were consistently 15- to 50-percent lower compared to the check (Figures 33 and 34). The sum of the field, dump, and factory tares represents the total tare in Table 20. Gypsum treated plots had a significantly lower total tare compared to the check in 1971 and 1973, and in 1972 the total tare from gypsum plots was still much lower than the check plot.

One could have predicted this decreased tare with gypsum treatment from the results of Section I of this thesis. Gypsum was shown to improve soil aggregation, decrease modulus of rupture, and decrease tillage forces. All these measurements are related to the ease of digging beets out of the ground. Treatment with gypsum made this heavy textured soil more friable resulting in decreased tare. Undoubtably, part of the decreased soil tare from gypsum plots was due to a lower beet



Figure 29. Single row beet digging apparatus. Soil dislodged during transfer of beets into the truck constituted the field tare.



Figure 30. Typical field tare of 1156 pounds from a check plot in 1971.



Figure 31. Typical field tare of 512 pounds from a 10 T/A gypsum plot in 1971.



Figure 32. Typical field tare of 748 pounds from a 90 T/A manure treatment in 1971.



Figure 33. Soil returned to the truck at the beet dump. This was a typical quantity from a check plot.

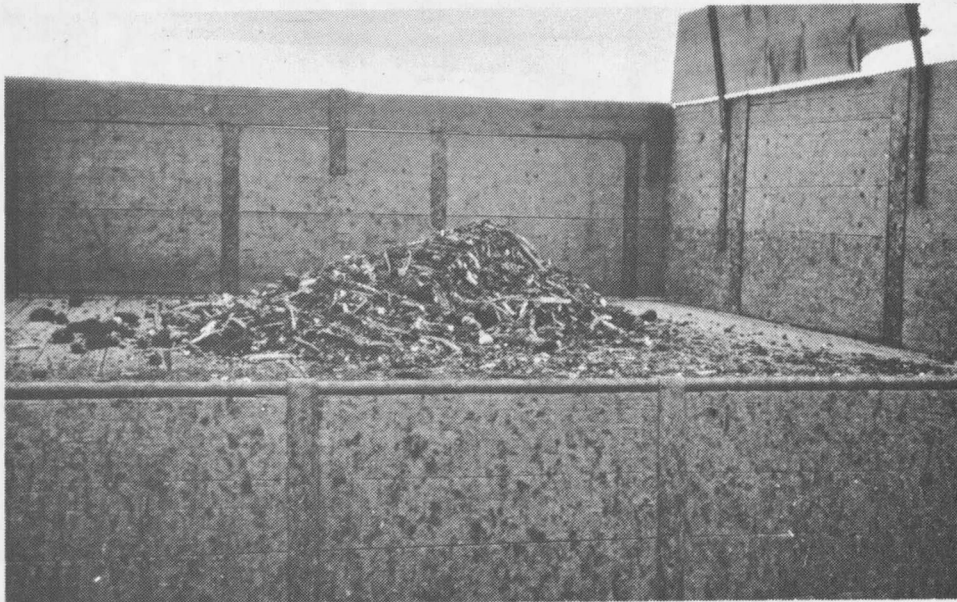


Figure 34. Typical quantity of dump tare from a 10 T/A gypsum plot.

Table 20*. Soil tare values at three locations during the 1971 to 1973 sugar beet harvest. Values are tons per acre.

Year	Check	Manure	Gypsum T/A		
			10	5	2.5
<u>Field Tare</u>					
1971	5.30a	3.01ab	1.60b		
1972	2.88b	5.16a	1.83b	1.82b	1.61b
1973	7.46b	9.02a	3.67c	3.48c	4.56c
Mean	5.21	5.73	2.37	2.65	3.08
<u>Dump Tare</u>					
1971	.97a	.94a	.63b		
1972	1.45ab	1.98a	1.14b	.92b	.71b
1973	3.65a	4.09a	1.76a	2.60a	2.46a
Mean	2.02	2.34	1.18	1.76	1.58
<u>Factory Tare</u>					
1971	.90a	.44b	.40b		
1972	1.10ab	1.46a	.78ab	.55b	.66b
1973	1.95a	1.97a	.76a	.54a	2.36a
Mean	1.32	1.29	.65	.54	1.51
<u>Total Tare</u>					
1971	6.66a	4.85ab	2.65b		
1972	5.43b	8.61a	3.75b	3.29b	2.98b
1973	13.70a	15.08a	6.19b	6.62b	9.39b
Mean	8.60	9.51	4.20	4.96	6.18

* Statistical comparison of means between years should not be made. Each datum is a mean of three replications.

yield in the field. It follows that if there was less beet volume there would be less area for soil to adhere. However, the yield was about 8% lower than the check and the tare was about 40% lower. So the lower tare cannot be completely attributed to a lower beet yield. Rather, a change in inherent soil physical properties was responsible.

In 1971 there was 90 T/A manure on the plots. Table 20 shows that field, dump, and factory tares were all less than the check. However, in 1972 and 1973, when the plots had 180 T/A manure on them, the

field and total tare values were significantly greater compared to the check. The second 90 T/A applied in 1972 (180 T/A total) was apparently too much to cause a further decrease in tare weight. Table 21 helps explain the reason for this high tare on manure plots. Soil moisture

Table 21. Soil moisture conditions at harvest time. Samples represent the 0-8 inch soil mass and values are % H₂O on a weight basis.

Year	Check	Manure	Gypsum T/A		
			10	5	2.5
1971					
1972*	19.32c	26.35a	20.39bc	21.83b	20.82bc
1973*	<u>20.91bc</u>	<u>28.07a</u>	<u>21.13bc</u>	<u>22.41b</u>	<u>20.60c</u>
Mean	20.12	27.21	20.76	22.12	20.71

* Statistical comparison can only be made within the same year. Each datum is a mean of three replications.

content in the manure plots during 1972 and 1973 was significantly higher compared to all other treatments. Apparently, the higher moisture level associated with the soil organic matter created a paste-like mixture which adhered to the beets resulting in a large soil tare.

Three years data demonstrated that gypsum can be very effective in reducing soil tare during the sugar beet harvest. The 2.5-, 5.0-, and 10-T/A gypsum rates were equally effective. The 90 T/A manure treatment had the effect of reducing soil tare, but 180 T/A manure resulted in significantly greater tare weights compared to the check.

No monetary assessment was made in this thesis regarding the value of a decreased soil tare. The farm manager could expect less wear and

tear on his beet digging machinery. Also, since less soil mass is hauled off to the beet dump, the operator may be able to haul a greater mass of sugar beets per load, and thus save gasoline during the harvest. Since it is a common practice to dispose of the dump tare soil at the unloading site, the operator may save time if the dump tare in the truck bed was only 200 pounds versus 400 pounds, for example. Also, the operator would be removing less of his valuable top soil from the sugar beet field, thus retaining nutrients and probably making the soil leveling job for the next seeding much easier.

SUMMARY AND CONCLUSIONS

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, and ease of farm operation were investigated.

Both 180 T/A manure and 10 T/A gypsum significantly increased percent aggregation of this silty clay soil. The soil modulus of rupture was decreased with manure and gypsum treatment. These changes in the soil structure resulted in decreased force required for tillage. Manure (180 T/A) and gypsum (10 T/A) reduced tillage forces 8% and 6%, respectively.

The rate of infiltration of water was increased with manure and 10 T/A gypsum treatments. Soil water flowmeters were used successfully to measure unsaturated flow. The soil water flux was found to be greatest under 10 T/A gypsum followed by 180 T/A manure compared to the check.

There was some indication of $\text{NO}_3\text{-N}$ leaching under the manure treatment. However, no changes in the $\text{NO}_3\text{-N}$ or $\text{PO}_4\text{-P}$ concentrations of the shallow groundwater were measured. The soil profile deeper than four feet was saline under all plots. Soil sodium content was slightly greater under the manure plot compared to the check but calcium was the dominant cation under all plots. The salt content of the groundwater beneath the plot area was saline-alkali while an adjacent check site was nonsaline-nonalkali. It was concluded that the manure treatment

contributed to salinization of the groundwater.

With one exception, it was concluded the concentration of $\text{NO}_3\text{-N}$, $\text{PO}_4\text{-P}$, salts and suspended solids was greater in surface water flowing off all plots than in the irrigation water applied. The reverse was true for total carbon where drainage water had a lower concentration compared to irrigation water applied. The chemical concentrations in runoff waters from the manure plots were greater compared to the check. However, these same data took on a different appearance when the actual dissolved and suspended load translocation budget was solved. Then, the runoff load contained only a fraction of the applied load, except for $\text{PO}_4\text{-P}$ which was still greater in the runoff load.

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

Both manure and gypsum treatments decreased sugar production about 8%. Sugar beet tops from manure plots contained nearly 15% protein, the level considered useful as a protein feed, but also contained hazardous levels of $\text{NO}_3\text{-N}$.

APPENDICES

Appendix Table 1. Recorded precipitation from the Southern Montana Agriculture Research Center weather station. Values are inches.

Month	DAY OF THE MONTH																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1971																																
June	.03	.30	-	-	-	-	.01	-	.20	.06	.07	-	-	-	.07	-	.18	-	-	-	-	-	-	-	-	-	-	.07	-	-	-	-
July	-	-	.09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.01	-	-	.11	-	-	.06	-	-	-	-
Aug	-	-	-	.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.02	1.06	.01	
Sept	.21	-	.54	.19	-	-	.16	-	-	-	-	-	-	-	-	.30	.15	-	-	.12	-	-	-	-	-	.07	-	-	-	.18	-	-
1972																																
June	-	.13	.06	-	-	-	-	-	-	-	-	-	-	-	-	.17	.06	.03	-	-	.20	-	.08	.66	-	-	-	-	-	-	-	-
July	-	.15	.06	-	-	-	-	-	-	-	-	-	-	-	-	-	.14	-	1.14	.13	.09	-	-	-	-	-	-	-	-	-	-	-
Aug	-	.43	.68	-	-	-	-	-	.23	-	.05	-	.42	.02	-	-	-	-	-	.12	1.55	-	.11	-	-	-	-	-	-	-	-	.10
Sept	.02	-	-	-	-	.11	.04	-	-	.19	.09	-	.04	-	-	-	-	-	-	.10	-	-	-	-	.38	-	.13	.02	-	-	-	-
1973																																
June	-	.53	.31	-	-	-	-	-	-	-	-	-	-	.05	.23	-	-	.05	.10	-	-	-	-	-	-	-	-	-	.13	-	-	
July	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.02	-	.19	-	-	-	-	.02	.06	-	-	
Aug	-	-	-	-	.20	.04	.05	-	-	-	-	.16	-	-	-	-	-	-	-	-	.33	.21	.80	.02	-	-	-	-	-	-	-	-
Sept	1.22	.03	-	-	-	-	.92	-	-	-	-	-	-	.12	.40	-	-	-	.02	-	-	-	.02	-	.17	.02	.23	-	-	-	-	-

Appendix Table 2. Soil bulk density (g/cm^3) values at four locations from the experimental site.

Soil Depth (feet)	LOCATION				Mean
	A	B	C	D	
0-.5	1.61	1.54	1.59	1.59	1.58
.5-1	-	1.60	1.46	1.71	1.59
1-1.5	1.84	1.35	1.56	1.62	1.59
1.5-2	-	1.76	1.66	1.50	1.64
2-2.5	-	1.72	1.55	1.53	1.60
2.5-3	-	1.64	2.08	1.69	1.80
3-3.5	-	1.14	1.60	1.86	1.54
3.5-4	1.53	1.59	1.67	1.77	1.64
4-4.5	1.58	1.61	1.67	1.78	1.66
4.5-5	1.70	1.62	1.58	-	1.63
5-5.5	1.77	1.69	-	1.69	1.72
5.5-6	1.55	1.79	1.77	-	1.70
6-6.5	1.67	1.65	1.76	1.65	1.68
6.5-7	1.56	1.67	1.73	1.64	1.65
7-7.5	1.54	1.60	1.70	-	1.62
7.5-8	-	1.58	1.63	1.65	1.62
8-8.5	1.63	1.43	1.53	1.67	1.57
8.5-9	-	1.65	1.62	1.69	1.65
9-9.5	-	-	-	1.63	1.63
9.5-10	-	1.61	-	1.89	1.75
Population Mean					1.64

Appendix Table 3. Desorption characteristics at two sites from the experimental site. Values are % H₂O by weight.

Soil Depth (feet)	SOIL WATER TENSION (BAR)				
	.1	.3	1	3	15
			<u>Site A</u>		
1	46.59	35.92	28.51	23.57	18.79
2	51.90	44.35	39.83	27.50	21.12
3	52.82	41.98	36.99	28.48	21.46
4	49.96	40.84	36.89	27.79	19.64
5	48.12	38.78	32.23	25.56	17.89
6	44.60	38.15	30.49	28.12	18.74
7	65.93	48.83	41.75	28.93	20.18
8	64.70	51.01	46.08	28.84	21.21
9	42.08	31.85	24.71	25.61	13.78
10	65.52	24.80	17.60	14.28	10.59
			<u>Site B</u>		
1	49.41	36.53	33.35	23.26	21.88
2	39.48	27.14	26.90	14.07	7.48
3	40.91	32.25	31.44	17.94	12.84
4	47.30	34.88	31.40	22.40	18.93
5	57.11	46.85	37.49	23.69	23.19
6	48.54	37.49	31.65	25.47	17.72
7	56.63	44.36	37.21	22.50	15.15
8	57.82	50.26	36.40	23.46	15.07
9	57.37	41.78	35.38	25.08	18.69
10	53.15	42.07	36.75	27.44	26.94

Appendix Table 4. Time distribution of soil water during 1971 in replication one. Values are inches of water per foot of soil.

		Calendar And Irrigation Date*																	
		7-11-71	7-14-71	7-16-71	7-21-71	7-23-71	7-28-71	7-29-71	8-3-71	8-6-71	8-10-71	8-11-71	8-13-71	8-20-71	8-25-71	8-26-71	9-2-71	9-6-71	9-10-71
Soil	Check	*					*					*			*				
Depth	Gypsum	*					*					*			*				
Feet	Manure	*				*						*			*				
CHECK REP 1																			
.5		2.39	2.74	2.79	2.26	1.81	-	2.78	2.39	1.82	1.47	2.70	2.32	1.30	1.28	2.78	2.66	2.74	2.45
1.5		3.71	4.10	4.60	4.52	4.40	-	4.58	4.30	3.91	3.34	4.26	4.11	3.20	3.15	4.51	4.45	4.40	4.27
2.5		4.23	4.42	4.26	4.57	4.41	-	4.33	4.51	4.25	4.38	4.39	4.38	4.05	4.00	4.21	4.17	4.12	4.04
3.5		4.50	4.30	4.55	4.71	4.52	-	4.53	4.63	4.57	4.65	4.70	4.47	4.44	4.40	4.74	4.56	4.48	4.48
4.5		4.73	4.66	4.82	4.83	4.59	-	4.90	4.87	4.68	4.73	4.76	4.60	4.74	4.70	4.80	4.82	4.90	4.66
5.5		4.63	4.83	4.65	4.81	4.58	-	4.79	4.85	4.67	4.73	4.81	4.76	4.75	4.87	4.86	4.78	4.78	4.78
6.5		4.83	4.83	4.93	5.00	4.80	-	5.05	4.86	4.80	4.70	4.89	4.85	4.74	4.92	4.85	4.78	4.88	4.84
7.5		4.99	5.06	5.01	4.96	4.81	-	5.09	5.02	4.86	4.88	4.95	5.06	4.77	4.98	5.03	4.98	5.07	4.87
8.5		4.50	4.42	4.48	4.58	4.44	-	4.66	4.43	5.00	4.47	4.67	4.58	4.48	4.60	4.59	4.65	4.63	4.63
Totals		38.51	39.36	40.09	40.24	38.36	-	40.71	39.86	38.56	37.35	40.13	39.13	36.47	36.90	40.37	39.85	40.00	39.02
10 T/A GYPSUM REP 1																			
.5		2.16	2.70	2.68	2.26	2.07	1.79	2.96	2.34	1.96	1.67	2.82	2.60	1.74	1.38	2.96	2.78	2.89	2.78
1.5		3.88	4.60	4.48	4.48	4.34	4.19	4.58	4.50	4.20	4.14	4.54	4.64	3.90	3.33	4.68	4.56	4.64	4.63
2.5		4.54	4.69	4.64	4.75	4.45	4.54	4.88	4.89	4.80	4.73	4.81	4.81	4.69	4.57	4.75	4.79	4.75	4.82
3.5		4.67	4.63	4.66	4.82	4.56	4.76	4.71	4.82	4.71	4.65	4.74	4.77	4.77	4.82	4.78	4.83	4.81	4.72
4.5		4.33	4.31	4.35	4.31	4.23	4.51	4.58	4.35	4.43	4.52	4.60	4.54	4.50	4.58	4.65	4.69	4.73	4.55
5.5		4.57	4.83	4.64	4.72	4.45	4.66	4.91	4.88	4.79	4.97	4.90	4.84	4.98	4.92	4.78	4.90	4.87	4.91
6.5		4.86	4.86	4.86	4.90	4.57	4.68	4.85	5.00	4.87	4.94	4.95	4.88	4.92	4.98	5.07	4.92	4.94	4.87
7.5		4.67	4.63	4.41	4.49	4.39	4.65	4.70	4.72	4.58	4.53	4.50	4.67	4.65	4.88	4.93	4.75	4.78	4.76
8.5		4.34	4.43	4.15	4.47	4.21	4.52	4.56	4.64	4.41	4.57	4.51	4.44	4.47	4.52	4.68	4.59	4.49	4.55
Totals		38.12	39.68	38.87	39.20	37.27	38.30	40.73	40.14	38.75	38.72	40.37	40.19	38.62	37.98	41.28	40.81	40.90	40.59
MANURE REP 1																			
.5		2.27	2.77	2.73	2.28	1.98	-	3.33	2.46	2.04	1.55	2.86	2.68	1.76	1.51	3.00	2.82	2.82	2.46
1.5		3.08	4.33	3.86	4.05	3.79	-	4.59	4.27	4.01	3.33	4.40	4.36	3.59	3.10	4.43	4.46	4.40	4.27
2.5		3.35	4.60	4.19	4.57	4.19	-	4.56	4.69	4.56	4.62	4.62	4.66	4.53	4.56	4.66	4.72	4.62	4.04
3.5		4.20	4.48	4.27	4.47	4.18	-	4.53	4.72	4.66	4.53	4.69	4.66	4.56	4.72	4.69	4.66	4.62	4.49
4.5		4.33	4.44	4.12	4.40	4.16	-	4.62	4.59	4.62	4.49	4.66	4.56	4.49	4.62	4.66	4.66	4.56	4.66
5.5		4.40	4.49	4.45	4.41	4.26	-	4.66	4.69	4.66	4.49	4.69	4.82	4.66	4.72	4.75	4.75	4.62	4.79
6.5		4.80	4.93	4.58	4.70	4.54	-	5.01	4.92	4.79	4.88	4.79	4.95	4.79	4.85	4.82	4.92	4.92	4.85
7.5		4.83	4.88	4.56	4.83	4.47	-	4.88	4.88	4.82	4.95	4.98	4.95	4.85	4.88	5.04	4.98	4.92	4.88
8.5		4.67	4.50	4.34	4.38	4.18	-	4.62	4.56	4.40	4.43	4.46	4.56	4.46	4.46	4.72	4.56	4.53	4.62
Totals		35.93	39.42	37.10	38.09	35.75	-	40.80	39.78	38.56	37.27	40.15	40.20	37.69	37.42	40.77	40.53	40.01	39.06

* Irrigation immediately followed this set of moisture readings.

Appendix Table 5. Time distribution of soil water during 1971 in replication two. Values are inches of water per foot of soil.

Soil Depth Feet	Check Gypsum Manure	Calendar And Irrigation Date *																		
		7-10	7-14	7-16	7-21	7-23	7-27	7-28	7-29	8-3	8-6	8-9	8-10	8-13	8-20	8-24	8-25	9-2	9-6	9-10
		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
		CHECK REP 2																		
.5		1.90	2.92	2.91	2.74	2.49	2.24	2.98	3.11	2.74	2.31	2.16	3.03	2.83	2.03	1.88	2.89	2.93	2.95	2.86
1.5		4.09	4.72	4.52	4.84	4.73	4.59	4.56	4.75	4.78	3.49	4.49	4.79	4.66	3.85	3.62	4.72	4.78	4.83	4.77
2.5		4.69	4.56	4.34	4.70	4.61	4.70	4.60	4.80	4.67	4.80	4.75	4.80	4.72	4.19	3.98	4.69	4.73	4.67	4.68
3.5		4.90	4.72	4.63	4.79	4.67	4.76	4.59	4.79	4.76	4.77	4.85	4.85	4.71	4.13	4.07	4.69	4.67	4.56	4.76
4.5		4.67	4.56	4.44	4.77	4.63	4.52	4.34	4.52	4.64	4.60	4.73	4.70	4.62	4.67	4.61	4.63	4.56	4.74	4.56
5.5		4.87	4.75	4.56	4.80	4.66	4.78	4.62	4.82	4.66	4.78	4.85	4.79	4.79	4.62	4.79	4.84	4.85	4.70	4.81
6.5		5.24	4.93	4.77	5.08	4.89	4.96	4.78	4.98	5.03	4.85	4.98	5.06	4.99	4.83	5.00	5.07	5.06	4.95	4.95
7.5		5.09	4.76	4.81	5.00	4.77	4.78	4.50	4.69	4.99	4.75	4.92	4.87	4.94	4.77	4.92	5.04	4.84	4.84	4.89
8.5		4.99	4.76	4.63	4.20	4.61	4.89	4.54	4.73	4.89	4.84	4.91	4.73	4.77	4.71	4.91	4.88	4.72	4.70	4.78
Totals		40.44	40.68	39.61	40.92	40.06	40.22	39.51	41.19	41.16	39.19	40.64	41.62	41.03	37.80	37.78	41.45	41.14	40.94	41.06
10 T/A GYPSUM REP 2																				
.5		1.97	3.24	2.88	2.77	2.51	-	2.46	3.37	2.92	2.61	2.32	3.35	2.98	2.22	1.94	3.28	2.21	3.15	2.97
1.5		3.65	4.60	3.91	4.15	4.07	-	4.14	4.64	4.38	4.13	4.16	4.71	4.30	4.02	3.61	4.54	3.93	4.42	4.35
2.5		4.55	4.75	4.16	4.40	4.39	-	4.59	4.68	4.58	4.56	4.47	4.67	4.58	4.02	3.90	4.56	4.11	4.73	4.68
3.5		4.61	5.04	4.56	4.51	4.43	-	4.55	4.69	4.92	4.67	4.56	5.01	4.85	4.57	4.55	4.90	4.31	4.82	4.92
4.5		4.84	5.09	4.44	4.68	4.58	-	4.84	5.03	4.86	4.91	4.85	4.48	4.83	4.68	4.70	4.90	4.33	4.79	4.88
5.5		4.95	5.04	4.49	4.72	4.60	-	4.91	4.84	4.91	4.87	4.92	4.58	4.95	4.41	4.92	4.85	4.64	4.83	4.91
6.5		5.11	5.25	4.91	4.90	4.71	-	5.26	5.19	5.26	5.16	5.20	5.16	5.12	5.12	5.13	5.20	5.15	5.11	5.16
7.5		4.94	5.18	4.77	4.76	4.60	-	5.06	5.17	5.00	4.86	5.08	5.07	5.04	4.91	4.98	5.14	4.66	5.14	5.13
8.5		4.81	5.08	4.67	4.74	4.51	-	5.00	4.81	4.88	4.84	4.82	5.02	4.98	4.84	4.87	5.14	4.58	4.98	5.09
Totals		39.43	43.27	38.79	39.63	38.40	-	40.81	42.42	41.71	40.61	40.38	41.95	41.63	38.79	38.60	42.51	37.92	41.97	42.09
MANURE REP 2																				
.5		2.13	2.90	2.74	2.31	2.27	-	1.85		2.76	2.56	2.18	3.15	2.90	2.26	2.03	3.23	3.06	3.05	3.00
1.5		4.12	4.74	4.28	4.67	4.52	-	3.54		4.57	4.57	4.23	4.66	4.59	4.15	3.96	4.70	4.65	4.71	4.67
2.5		4.60	4.64	4.30	4.61	4.39	-	4.20		4.59	4.65	4.35	4.67	4.67	4.52	4.50	4.84	4.75	4.74	4.71
3.5		4.72	4.39	4.18	4.31	4.33	-	3.60		4.77	4.60	4.61	4.75	4.74	4.51	4.49	4.75	4.74	4.72	4.71
4.5		4.85	4.72	4.54	4.78	4.60	-			4.82	4.75	4.82	4.78	4.71	4.59	4.51	4.74	4.84	4.71	4.77
5.5		4.90	4.74	4.40	4.63	4.55	-			4.90	4.81	4.85	4.83	4.90	4.71	4.86	4.93	4.86	4.92	4.92
6.5		5.07	5.04	4.77	5.09	4.91	-			5.07	5.11	5.09	5.05	5.22	5.10	4.95	5.23	5.02	5.07	5.06
7.5		5.09	4.83	4.60	4.83	4.67	-			4.83	4.82	4.76	4.85	4.79	4.73	4.94	4.86	4.93	4.89	4.76
8.5		4.86	4.60	4.40	4.58	4.57	-			4.69	4.69	4.63	4.70	4.69	4.61	4.79	4.74	4.76	4.66	4.73
Totals		40.34	40.60	38.21	39.81	38.81	-	Probe Quit	No Data	41.00	40.56	39.52	41.44	41.21	39.18	39.03	42.02	41.61	41.47	41.33

* Irrigation immediately followed this set of moisture readings.

Appendix Table 6 Time distribution of soil water during 1971 in replication three. Values are inches of water per foot of soil.

		Calendar And Irrigation Date *																		
		7-12	7-14	7-16	7-21	7-23	7-26	7-27	7-28	8-3	8-6	8-9	8-10	8-13	8-20	8-24	8-25	9-2	9-6	9-10
Soil	Check	*					*					*				*				
Depth	Gypsum	*						*				*				*				
Feet	Manure	*						*				*				*				
CHECK REP 3																				
.5		2.14	2.93	2.97	2.44	2.56	2.05	3.25	-	2.42	2.32	1.89	3.10	2.68	1.76	1.44	3.16	3.01	3.06	2.86
1.5		4.15	4.94	4.85	4.94	4.54	5.03	4.89	-	4.93	4.86	4.68	4.84	4.81	4.34	4.20	4.88	4.86	4.84	4.90
2.5		4.10	4.72	4.70	4.47	3.60	4.33	4.79	-	4.55	4.43	4.41	4.97	4.51	4.15	4.06	4.93	4.53	4.83	4.54
3.5		4.80	5.18	4.92	4.88	4.90	5.17	5.12	-	5.09	4.67	5.11	5.12	5.19	4.74	4.85	5.32	5.19	5.16	5.12
4.5		4.92	4.91	4.66	4.63	4.74	5.10	4.85	-	4.91	4.90	4.96	4.84	4.90	4.86	4.92	4.88	4.86	4.96	4.81
5.5		4.79	4.91	4.62	4.79	4.67	5.08	4.84	-	4.95	4.73	4.87	4.95	4.90	4.83	4.84	4.89	4.81	4.89	4.79
6.5		4.87	4.99	4.63	4.93	4.71	5.09	4.97	-	5.02	4.77	4.94	4.88	4.85	4.78	5.00	4.87	4.90	4.98	4.85
7.5		4.89	4.96	4.58	4.88	4.75	5.03	5.04	-	4.97	4.87	5.15	5.06	5.01	4.90	4.95	4.88	5.00	4.93	4.98
8.5		4.80	4.87	4.47	4.77	4.75	4.94	4.77	-	4.86	4.76	4.77	4.80	4.86	4.71	4.85	4.89	4.86	4.77	4.95
Totals		39.46	42.41	40.40	40.73	39.22	41.82	42.52	-	41.70	40.31	40.78	42.56	41.71	39.07	39.11	42.70	42.02	42.42	41.80
10 T/A GYPSUM REP 3																				
.5		2.14	3.13	2.41	2.20	2.02	-	1.72	3.19	2.32	1.92	1.60	3.07	2.44	1.63	1.44	3.22	2.86	2.98	2.70
1.5		3.43	4.15	3.89	4.29	4.36	-	4.17	4.49	4.29	4.21	4.13	4.55	4.18	3.67	3.41	4.13	4.45	4.52	4.36
2.5		3.25	4.44	4.00	4.62	4.52	-	4.38	4.57	4.52	4.49	4.57	4.63	4.45	4.39	3.28	4.51	4.47	4.61	4.60
3.5		4.57	5.09	4.42	5.35	5.29	-	5.05	4.88	5.23	5.18	5.16	5.24	4.92	4.92	4.69	5.34	5.31	5.14	5.14
4.5		4.62	4.63	4.25	4.62	4.79	-	4.66	4.61	4.69	4.68	4.62	4.76	4.67	4.61	4.70	4.71	4.73	4.74	4.72
5.5		4.90	4.91	4.57	4.94	4.92	-	4.76	4.88	4.90	4.91	4.92	4.93	4.82	4.72	4.84	5.32	4.92	4.88	4.96
6.5		5.02	4.91	4.58	5.10	5.00	-	4.91	5.09	5.09	5.04	5.22	5.06	5.06	4.90	5.11	5.11	5.22	5.16	5.10
7.5		5.02	4.83	4.54	5.04	5.07	-	4.68	4.80	4.96	4.86	4.89	4.88	4.99	4.74	5.09	4.94	5.05	5.04	4.91
8.5		4.89	4.90	4.53	4.90	4.88	-	4.81	4.81	5.02	4.89	5.00	4.92	4.94	4.82	4.89	4.84	4.94	5.01	4.93
Totals		37.84	40.99	37.19	41.06	40.85	-	39.14	41.32	41.02	40.18	40.11	42.04	40.47	38.40	37.45	42.12	41.95	42.08	41.42
MANURE REP 3																				
.5		2.69	3.27	2.98	3.00	2.86	-	2.61	3.43	2.78	2.44	2.23	3.24	2.94	2.06	1.81	3.32	3.11	3.16	2.94
1.5		4.60	4.83	4.43	4.67	4.50	-	4.55	4.85	4.86	4.82	4.74	4.96	4.95	4.67	4.51	4.74	4.78	4.77	4.90
2.5		4.35	4.96	4.37	5.03	4.81	-	4.52	5.03	5.07	4.58	4.59	4.99	5.06	4.34	4.31	5.08	5.11	5.08	4.67
3.5		4.90	5.08	4.60	5.15	5.13	-	4.94	5.02	5.04	5.14	5.03	5.09	4.95	4.92	4.94	5.15	5.15	5.16	5.04
4.5		4.42	4.38	4.08	4.52	4.39	-	4.55	4.50	4.57	4.52	4.66	4.67	4.56	4.47	4.47	4.53	4.55	4.58	4.67
5.5		4.69	4.81	4.34	4.82	4.80	-	4.72	4.87	4.87	4.65	4.82	4.77	4.87	4.64	4.89	4.90	4.93	4.77	4.98
6.5		4.82	4.83	4.43	4.76	4.71	-	4.79	4.80	4.86	4.86	4.89	4.94	4.93	4.78	4.93	4.86	4.86	4.88	5.03
7.5		5.19	5.04	4.37	5.07	5.09	-	4.99	5.07	5.28	5.15	5.11	5.30	5.14	5.18	5.20	5.26	5.24	5.27	5.14
8.5		4.90	4.93	4.41	4.77	4.87	-	4.85	4.84	4.90	4.85	4.78	4.82	4.83	4.69	4.89	5.05	4.91	4.79	5.00
Totals		40.56	42.13	38.01	41.79	41.16	-	40.52	42.42	42.23	41.01	40.85	42.78	42.23	39.75	39.95	42.89	42.64	42.46	42.37

* Irrigation immediately followed this set of moisture readings.

Appendix Table 10. Time distribution of soil water during 1972 in replication three. Values are inches of water per foot of soil.

		Calendar And Irrigation Date [*]																
		6-15-72	6-23-72	6-29-72	7-6-72	7-13-72	7-14-72	7-18-72	7-25-72	7-28-72	8-4-72	8-8-72	8-9-72	8-17-72	8-24-72	9-1-72	9-6-72	9-8-72
Soil Depth Feet	Check Gypsum Manure					*	*					*	*				*	*
		CHECK REP 3																
.5		4.30	3.69	3.10	2.97	2.52	4.98	4.53	4.27	4.08	3.78	3.43	4.82	3.91	4.14	3.46	3.01	4.73
1.5		4.42	4.27	3.97	4.43	3.53	4.56	4.40	4.24	4.21	3.78	3.85	4.43	4.17	4.27	3.85	3.65	4.37
2.5		4.60	4.61	4.35	4.73	4.47	4.66	4.63	4.43	4.60	4.43	4.73	4.79	4.60	4.66	4.63	4.40	4.66
3.5		4.80	4.81	4.59	4.95	4.85	4.92	4.73	4.63	4.92	4.73	5.08	5.14	4.92	4.79	4.89	4.92	4.82
4.5		4.57	4.51	4.39	4.65	4.66	4.63	4.67	4.43	4.73	4.53	4.79	4.73	4.69	4.63	4.69	4.56	4.53
5.5		4.81	4.69	4.57	4.85	4.76	4.73	4.73	4.56	4.79	4.79	5.08	4.98	4.92	4.76	4.85	4.92	4.76
6.5		4.92	4.93	4.54	5.08	5.02	5.05	5.02	4.73	5.02	4.92	5.31	5.08	4.98	4.85	5.05	5.02	5.02
7.5		4.93	4.91	4.59	5.08	4.89	4.98	5.02	4.76	5.11	4.95	5.28	5.11	5.08	5.02	5.11	4.98	4.92
8.5		4.83	4.91	4.58	5.02	4.85	4.92	4.92	4.69	4.89	4.76	5.02	5.02	4.95	4.76	4.82	4.89	4.85
Totals		42.18	41.33	38.68	41.76	39.55	43.43	42.67	40.74	42.35	40.67	42.57	44.10	42.22	41.88	41.35	40.35	42.66
		10 T/A GYPSUM REP 3																
.5		4.02	3.63	3.46	3.36	2.91	4.76	4.21	4.30	4.04	3.40	3.23	4.98	3.95	4.08	3.07	2.81	4.76
1.5		4.17	4.09	4.09	4.30	3.78	4.79	4.47	4.60	4.21	4.14	4.24	5.08	4.47	4.50	4.24	3.98	4.85
2.5		4.53	4.64	4.51	4.76	4.53	5.05	4.98	4.89	4.85	4.66	4.98	5.18	5.02	4.98	4.82	4.79	4.98
3.5		4.83	4.72	4.26	4.69	4.56	4.73	4.63	4.60	4.66	4.50	4.85	4.95	4.73	4.73	4.63	4.73	4.63
4.5		4.62	4.42	4.26	4.56	4.53	4.73	4.53	4.47	4.53	4.53	4.79	4.89	4.63	4.56	4.69	4.53	4.60
5.5		4.91	4.83	4.52	4.89	4.79	5.11	5.02	4.82	5.02	4.85	5.14	5.02	5.08	5.05	4.95	4.92	4.89
6.5		4.89	4.83	4.62	4.92	4.92	4.98	4.98	4.85	4.98	4.82	5.31	5.28	5.14	5.11	4.98	5.11	4.98
7.5		4.89	4.80	4.46	4.73	4.69	4.85	4.85	4.63	4.89	4.82	5.02	5.11	5.05	4.82	4.98	4.89	4.89
8.5		4.83	4.72	4.35	4.73	4.80	4.82	4.85	4.66	4.89	4.73	5.11	5.14	4.89	4.92	4.79	4.92	4.79
Totals		41.69	40.68	38.53	40.94	39.51	43.82	42.52	41.81	42.07	40.45	42.67	45.63	42.96	42.74	41.15	40.68	43.37
		MANURE REP 3																
.5		4.48	4.05	3.42	2.91	2.23	4.79	4.21	3.75	3.23	3.07	2.65	4.89	3.40	3.78	2.78	2.52	4.89
1.5		4.78	4.75	4.44	4.76	4.04	4.83	4.69	4.43	4.66	4.30	4.30	4.89	4.66	4.69	4.53	4.17	4.76
2.5		4.88	4.83	4.44	4.47	4.37	4.73	4.47	4.53	4.60	4.43	4.76	4.89	4.53	4.79	4.53	4.40	4.76
3.5		4.77	4.75	4.37	4.79	4.63	4.73	4.63	4.47	4.79	4.69	4.89	4.89	4.69	4.82	4.89	4.73	4.76
4.5		4.54	4.61	4.13	4.63	4.50	4.63	4.50	4.34	4.53	4.37	4.82	4.73	4.63	4.53	4.63	4.63	4.56
5.5		4.66	4.62	4.30	4.69	4.47	4.66	4.63	4.40	4.60	4.56	4.89	4.79	4.76	4.63	4.69	4.53	4.73
6.5		4.74	4.65	4.32	4.73	4.56	4.53	4.73	4.47	4.79	4.50	5.02	4.89	4.76	4.66	4.69	4.69	4.73
7.5		4.76	4.83	4.60	4.82	4.79	4.95	4.92	4.56	4.85	4.76	4.53	5.02	4.79	4.89	4.85	4.82	4.85
8.5		4.79	4.81	4.48	4.92	4.69	4.89	4.85	4.66	4.92	4.82	5.05	4.98	4.92	4.95	4.98	4.79	4.89
Totals		42.40	41.90	38.50	40.72	38.28	42.76	41.63	39.61	40.97	39.50	40.91	43.97	41.14	41.74	40.57	39.28	42.98

* Irrigation immediately followed this set of moisture readings.

Appendix Table 11. Time distribution of soil water during 1973. Values are inches of water per foot of soil.

		Calendar And Irrigation Date *													
		7-10-73	7-11-73	7-16-73	7-18-73	7-24-73	7-26-73	7-31-73	8-3-73	8-8-73	8-10-73	8-16-73	8-23-73	8-24-73	9-7-73
Soil	Check	*				*	*			*			*		
Depth	Gypsum	*				*				*			*		
Feet	Manure	*				*				*			*		
CHECK REP 2															
.5		4.21	4.60	4.04	3.65	3.26	4.43	3.78	3.33	3.10	4.34	3.46	4.04	4.63	4.08
1.5		4.63	4.24	4.60	4.43	4.34	4.43	4.27	4.34	3.59	4.27	4.01	3.98	4.24	3.95
2.5		4.82	4.73	4.76	4.69	4.56	4.73	4.92	4.79	4.73	4.66	4.21	4.60	4.66	4.50
3.5		5.08	5.08	5.21	4.98	4.98	5.02	5.02	4.92	5.11	5.05	4.63	4.89	4.95	4.98
4.5		4.53	4.66	4.60	4.43	4.43	4.43	4.60	4.50	4.56	4.47	4.17	4.53	4.37	4.34
5.5		4.92	4.85	4.73	4.63	4.43	4.63	4.85	4.60	4.76	4.63	4.40	4.56	4.60	4.24
6.5		4.85	5.05	4.98	4.95	4.85	4.82	5.02	4.95	5.08	4.79	4.69	4.79	4.82	4.82
7.5		4.92	4.63	4.92	4.82	4.69	4.82	5.08	4.85	4.92	4.79	4.24	4.79	4.82	4.60
8.5		4.74	4.74	4.79	4.76	4.53	4.73	4.85	4.79	4.89	4.73	4.56	4.69	4.73	4.66
Totals		42.43	42.58	42.63	41.34	40.07	42.04	42.39	41.07	40.74	41.73	38.37	40.87	41.82	40.17
10 T/A GYPSUM REP 2															
.5		4.60	4.89	4.37	3.53	2.97	4.50	4.34	3.56	2.46	4.63	3.72	4.11	4.56	4.24
1.5		4.66	4.76	4.79	4.76	4.56	4.66	4.82	4.27	4.56	4.63	4.27	4.40	4.69	4.43
2.5		4.82	4.56	4.89	4.89	4.73	4.79	5.05	4.92	4.89	4.98	3.98	4.63	4.98	4.69
3.5		5.02	5.11	4.98	5.02	4.82	4.82	5.05	5.02	4.79	4.82	4.60	4.76	4.85	4.82
4.5		4.63	5.14	4.63	4.60	1.92	4.40	4.63	4.60	4.53	4.50	4.21	4.37	4.43	4.37
5.5		4.92	4.63	4.66	4.69	4.66	4.56	4.89	4.85	4.66	4.66	4.40	4.66	4.60	4.56
6.5		5.05	5.02	4.92	4.95	4.85	4.50	5.14	5.02	4.30	4.95	4.53	4.73	4.85	4.79
7.5		4.85	5.02	4.98	4.95	4.89	4.79	4.95	5.08	5.05	4.98	4.60	4.76	4.85	4.82
8.5		4.63	4.63	4.79	4.66	4.47	4.40	4.60	4.85	4.79	4.69	4.40	4.53	4.66	4.63
Totals		43.18	43.76	43.01	42.05	37.87	41.42	43.56	42.17	42.49	42.75	38.71	40.95	42.47	41.35
MANURE REP 2															
.5		4.43	5.02	4.76	4.60	4.01	4.89	4.69	4.43	4.08	4.85	4.60	4.63	5.11	4.37
1.5		4.47	5.08	4.85	4.66	4.66	4.82	4.73	4.66	4.30	4.92	4.69	4.73	4.92	4.66
2.5		4.50	4.82	5.05	4.63	4.56	4.95	4.82	4.47	4.69	4.95	4.43	4.53	4.82	4.66
3.5		4.56	5.14	4.85	4.89	4.47	4.85	4.69	4.69	4.89	4.79	4.76	4.82	4.79	4.76
4.5		4.60	5.05	4.73	4.50	4.69	4.56	4.53	4.50	4.69	4.60	4.60	4.69	4.56	4.69
5.5		4.79	5.14	4.82	4.79	4.82	4.76	4.76	4.66	4.95	4.89	4.69	4.82	4.76	4.79
6.5		4.76	5.24	5.02	4.89	4.82	4.92	4.82	4.76	4.89	4.85	4.76	4.89	4.92	4.82
7.5		4.79	5.21	5.08	5.08	4.69	5.05	4.89	4.92	5.18	5.11	4.89	5.02	5.05	4.98
8.5		4.87	4.87	4.92	4.98	4.95	4.98	4.66	4.73	4.82	4.82	4.56	4.85	4.85	4.79
Totals		41.77	44.57	44.08	43.02	41.67	43.78	42.59	41.82	42.49	43.78	41.98	42.98	43.78	42.52

* Irrigation immediately followed this set of moisture readings.

Appendix Table 12 Time distribution of soil matric potential during four irrigations in replication one 1971. Values⁺ are centimeters of mercury.

CHECK REP 1									10 T/A GYPSUM REP 1									MANURE REP 1											
Date/Hours	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	Date/Hours	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	Date/Hours	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5			
IRR 1									IRR 1									IRR 1											
7-11	0	*	13.4	18.2	15.1	16.0	14.5	12.5	7-11	0	*	48.0	15.5	13.7	10.1	15.7	15.3	15.0	7-11	0	*	36.0	33.2	34.3	19.2	9.9	*	15.0	*
.25	*		14.5	19.8	15.2	16.7	15.1	13.3	.33	22.4	14.9	13.9	10.7	16.3	15.6	15.2	*	.25	28.2	34.7	34.5	18.7	11.6	1.8	14.6	*			
.66	*		14.6	20.4	15.5	17.1	15.1	13.7	.58	6.9	14.9	14.2	11.0	16.6	15.7	15.3	*	.66	7.1	31.6	24.5	18.7	11.7	1.7	15.0	*			
.92	*		14.1	20.7	14.2	17.1	14.6	13.7	1.00	3.7	15.0	15.0	11.6	17.2	16.2	15.9	*	1.17	1.0	27.3	17.7	18.7	11.5	1.9	14.8	*			
1.25	*		13.1	21.0	15.2	16.1	14.2	13.5	1.42	3.2	14.8	15.3	11.7	17.2	15.3	16.1	*	7-14			3.8	6.0	5.6	12.0	11.1	*	11.2	*	
7-14	*		6.3	15.2	10.2	9.2	7.3	9.6	7-14			7.2	4.8	10.8	10.2	10.2	8.3	9.2	7-16			4.6	6.4	5.8	13.2	6.2	*	11.0	*
7-16	*		7.5	16.6	12.0	11.3	8.1	10.1	7-16			12.1	4.9	11.8	12.7	12.5	8.8	9.5	7-21			24.4	9.8	8.6	17.2	*	*	12.9	13.5
7-21			57.8	30.4	19.4	14.1	15.2	11.5	7-21			58.1	8.1	14.4	16.4	16.8	11.6	15.7	7-23			34.4	11.0	8.1	15.8	12.8	11.1	11.8	13.2
7-23			60.5	45.8	16.2	11.4	10.9	8.7	7-23			57.4	7.3	11.2	13.3	13.2	10.4	13.7	J-28			62.0	42.0	25.4	20.4	13.2	14.3	14.1	18.2
7-28			63.4	60.0	21.6	14.9	16.1	13.0	7-28			64.4	32.6	17.8	21.0	20.1	13.3	18.7											
IRR 2									IRR 2									IRR 2											
.25			63.7	60.0	22.0	15.3	15.8	13.8	.25			64.2	32.1	19.0	21.1	20.2	13.7	18.9	.25			58.0	16.1	13.1	20.4	13.2	14.3	14.1	13.3
.50			63.7	60.0	22.1	15.6	17.0	14.0	.58			63.2	31.1	18.1	21.3	20.5	13.9	19.1	.58			58.4	14.0	10.7	20.5	13.7	14.8	14.9	18.4
.75			62.5	60.0	22.4	15.6	17.2	14.1	.75			59.9	29.7	18.0	20.5	21.2	13.8	19.2	.92			18.3	9.3	3.9	20.6	10.5	14.5	14.2	18.7
1.00			60.6	59.9	22.5	15.8	17.3	14.3	1.00			48.2	28.6	18.0	21.2	20.5	13.4	19.3	1.08			1.6	5.5	1.0	20.4	9.9	11.0	14.3	18.7
23.70			4.4	55.3	15.2	4.9	6.7	3.3	26.00			3.0	4.0	8.8	12.3	7.9	3.0	9.3	1.42			1.0	3.0	*	20.3	4.7	13.4	14.4	18.6
7-30			36.4	38.9	11.8	9.0	9.6	8.3	7-30			21.1	10.9	8.8	11.3	10.1	8.3	9.3	23.50	*		3.3	3.7	11.0	3.9	2.4	3.5	11.9	
8-6			58.8	47.8	13.1	9.3	10.3	8.4	8-6			49.1	25.5	8.0	*	10.8	9.9	10.4	7-30			18.2	9.1	7.5	9.7	10.3	9.3	10.1	12.5
8-10			61.3	59.2	22.2	11.4	12.4	10.0	8-10			64.7	53.9	12.2	14.9	14.6	10.5	13.1	8-6			45.5	*	9.2	11.1	11.4	10.3	11.5	13.1
IRR 3									IRR 3									IRR 3											
.25			61.2	59.6	22.4	12.2	13.3	10.5	.25			52.3	53.7	13.4	16.2	16.5	11.9	14.8	.25			59.3	*	16.2	14.4	12.1	11.5	12.5	16.1
.50			61.0	59.5	23.1	12.9	14.6	11.3	.50			1.2	53.7	14.3	17.1	17.7	12.6	15.9	.50			1.0	*	10.5	15.6	10.8	12.6	13.4	17.4
.83			60.9	59.2	23.5	13.2	15.0	12.0	.75			1.2	53.5	14.6	17.5	18.1	12.6	16.4	.75			1.0	*	6.5	16.3	5.2	13.1	13.7	18.1
1.00			60.9	59.2	14.0	13.6	15.3	12.3	1.00			1.2	53.2	15.0	17.9	18.7	12.6	16.9	1.08			1.0	*	3.6	17.0	2.9	13.1	13.7	18.7
2.17			60.3	59.2	25.7	14.2	16.4	13.2	3.25			1.5	52.0	15.9	18.5	19.4	12.0	8.1	23.75			3.3	*	4.2	7.5	5.8	4.6	5.9	13.9
24.00			59.6	58.5	16.6	9.5	10.6	8.0	25.50			5.1	33.2	9.8	13.8	11.0	7.6	12.4	8-13			10.6	*	7.3	8.5	9.8	9.2	10.2	12.3
8-13			59.7	58.0	18.5	9.1	9.8	8.5	8-13			13.1	15.7	9.5	12.2	10.0	9.1	9.4	8-20			55.9	3.3	13.4	11.8	11.1	10.7	11.1	13.1
8-20	*		50.5	40.4	11.3	11.4	9.0	10.3	8-20			58.6	51.0	12.6	12.7	10.5	12.4	10.9	8-25			62.0							
8-25	*		1.8	25.8	13.8	15.0	13.2	15.1	8-25			62.2	60.5	22.4	17.0	10.8	13.7	12.4											
IRR 4									IRR 4									IRR 4											
.25	*		2.0	21.9	12.3	16.0	14.4	15.8	.25	*		62.0	60.5	23.5	18.9	12.5	16.2	15.2	.25	*		61.4	3.6	24.8	14.0	11.8	12.1	11.3	14.6
.75	*		2.2	21.8	12.3	16.7	14.9	16.3	.58	*		44.5	60.6	24.3	19.3	12.8	16.9	16.0	.50	*		42.0	3.6	24.8	14.7	9.5	12.7	11.8	15.0
1.00	*		2.3	22.0	12.5	16.8	15.0	17.5	.83	*		2.1	60.3	25.0	29.8	12.9	17.4	16.4	.75	*		1.1	3.6	24.0	15.2	7.0	13.4	12.2	15.7
1.15	2.0		2.4	22.2	12.7	17.0	15.2	16.6	1.08	*		1.3	60.2	25.4	20.0	13.0	17.7	16.7	1.00	*		1.1	3.6	23.0	15.5	5.2	13.7	12.5	16.1
3.25	2.7		2.5	23.0	13.3	17.0	24.8	16.8	2.67	*		1.4	60.1	26.7	20.5	12.4	19.9	7.5	1.42	*		1.1	3.7	21.7	15.9	3.9	14.0	13.8	15.9
21.00	3.8		0.9	28.5	14.6	14.7	11.6	15.9	20.25	*		3.3	60.4	21.1	18.7	9.7	15.6	15.3	19.25	*		3.5	4.1	6.8	10.7	6.1	7.2	7.1	16.4
9-2	*		15.0	34.8	18.7	14.0	13.4	13.9	9-2	*		11.6	10.3	11.3	14.4	13.6	13.0	13.1	9-2	*		10.0	8.4	10.9	10.5	13.0	12.3	13.4	14.3
9-6	*		18.9	35.6	19.5	15.0	14.4	14.8	9-6	*		11.1	9.5	10.5	14.2	14.0	13.9	14.0	9-6	*		9.7	8.5	10.3	11.4	13.8	13.7	14.2	15.4
9-10	5.4		22.8	39.9	21.0	15.9	15.1	16.0	9-10			18.2	15.3	14.0	16.5	15.9	15.0	15.5	9-10			14.1	8.5	11.9	14.0	15.3	15.1	15.5	17.2

* No reading due to malfunction or soil matric potential exceeded tensiometer capabilities.

+ These data are from the .5- to 7.5-foot soil depths.

Appendix Table 13 Time distribution of soil matric potential during four irrigations in replication two 1971. Values range from the .5- to 7.5-foot soil depths and units are centimeters of mercury.

CHECK REP 2										10 T/A GYPSUM REP 2										MANURE REP 2									
Date/Hours	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		Date/Hours	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		Date/Hours	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	
7-10	50.0	49.0	22.0	18.6	18.0	18.4	15.8	*		7-10	62.0	24.0	59.0	16.1	17.5	13.4	13.3	*		7-10	18.0	61.0	29.0	15.0	5.3	12.0	12.1	*	
IRR 1										IRR 1										IRR 1									
.33	2.0	4.3	18.8	18.7	19.8	18.6	15.9	*		.25	3.0	5.6	11.4	16.0	17.7	13.5	13.3	*		.25	3.0	7.5	7.6	14.8	5.4	12.0	12.2	*	
.58	1.0	4.5	19.2	19.0	20.0	18.9	16.0	*		.66	1.0	4.0	12.0	16.5	18.3	14.0	13.8	*		.83	1.4	7.9	9.9	9.2	6.5	14.3	14.0	*	
.92	1.0	4.3	19.2	19.0	19.9	18.8	16.3	*		1.08	1.0	3.3	12.9	16.5	18.8	14.5	14.0	*		1.08	1.5	7.9	10.3	7.1	6.9	13.1	14.1	*	
1.25	1.0	4.4	19.0	19.1	19.6	18.7	16.3	*		7-14	5.4	5.8	5.0	6.9	7.3	8.0	7.1	*		1.25	1.0	7.9	10.6	6.5	7.1	12.9	14.3	*	
7-14	5.1	2.8	6.5	5.5	5.1	7.2	8.5	*		7-16	12.6	7.5	6.5	8.7	11.0	11.1	10.5	*		1.50	1.0	7.8	10.7	5.5	7.0	12.7	14.1	*	
7-16	7.0	3.7	4.5	5.3	5.2	4.9	6.6	*		7-21	51.5	8.2	8.1	*	9.9	14.0	12.6	11.3		7-14	8.2	4.7	5.7	6.0	4.9	4.9	5.3	*	
7-21	13.5	10.5	10.8	11.2	11.0	12.8	14.2	12.2		7-23	56.6	9.3	5.9	7.1	7.5	10.5	10.2	8.3		7-16	10.5	4.6	5.9	7.4	5.8	4.5	3.4	*	
7-23	40.1	8.7	7.2	7.5	7.4	9.3	11.4	8.3		7-28	*	31.2	12.6	12.9	14.4	18.0	15.4	12.9		7-21	18.2	9.3	10.4	9.1	9.8	11.2	11.4	11.9	
7-27	57.2	31.3	12.0	12.5	12.0	14.2	16.0	12.7												7-23	23.8	8.8	7.3	9.7	8.5	10.8	8.8	8.2	
																				7-27	*	31.8	12.6	10.5	14.0	11.3	10.8	12.8	
IRR 2										IRR 2										IRR 2									
.50	*	15.0	15.9	17.9	19.5	18.1	21.4	17.8		.25	*	7.8	13.3	13.5	15.5	18.4	16.1	13.8		.25	*	28.5	13.0	9.2	14.2	12.0	14.2	13.4	
.75	*	34.7	17.2	18.0	17.9	19.5	21.7	18.2		.50	*	1.7	12.9	13.3	14.8	18.5	16.2	13.9		1.08	*	13.8	1.9	13.5	14.0	15.0	13.1	15.2	
1.00	*	34.2	17.2	18.1	18.0	19.6	21.9	18.3		.75	*	*	12.6	13.2	14.7	18.6	16.3	13.9		2.33	*	13.0	1.5	15.3	13.8	15.5	12.7	15.3	
1.25	*	20.6	11.9	13.6	11.5	15.8	18.7	15.0		1.08	*	*	12.4	12.9	14.6	18.7	16.3	13.9		8-3	*	11.3	7.1	6.6	7.5	7.0	6.4	6.8	
24.00	1.9	4.7	7.3	8.8	5.5	12.8	10.6	16.9		29.25	*	2.9	1.6	1.6	1.4	7.5	4.2	1.7		8-6	16.5	23.4	8.3	8.1	7.6	7.2	7.0	7.8	
8-3	17.9	10.5	5.0	4.8	4.7	6.7	6.8	6.3		8-3	*	10.5	5.7	6.4	6.6	6.0	5.3	5.5		8-9	17.0	46.3	10.5	9.0	9.1	7.9	8.8	8.3	
8-6	43.1	26.6	5.3	5.2	6.2	7.7	7.8	5.1		8-6	16.5	23.4	8.3	8.1	7.6	7.2	7.0	7.8											
8-9	61.6	52.4	13.8	13.0	11.1	13.9	16.2	12.2		8-9	60.3	51.4	9.5	7.4	7.9	9.5	7.9	7.3											
IRR 3										IRR 3										IRR 3									
.25	61.4	52.4	13.4	12.2	11.3	14.0	15.9	11.9		.25	45.2	24.8	11.7	9.2	10.5	12.0	10.8	10.6		.25	16.7	44.2	11.4	8.0	9.5	9.1	10.0	*	
.50	*	52.0	14.0	12.7	12.2	14.7	16.5	12.5		.50	*	7.1	12.8	12.5	11.1	13.8	13.1	12.9		.50	10.1	34.4	12.9	5.6	11.6	10.3	11.5	*	
.75	*	51.3	14.3	13.2	12.7	15.0	16.6	12.7		.75	*	2.2	12.2	11.2	13.0	13.7	13.0	12.9		.75	5.9	30.9	13.6	4.2	12.6	10.9	12.2	*	
1.08	*	50.1	14.3	13.5	13.1	15.2	16.1	13.0		1.00	*	1.6	12.3	11.2	13.8	14.0	13.4	13.0		16.75	1.8	3.4	3.4	2.3	8.9	5.0	10.7	*	
4.00	*	43.8	11.1	11.8	10.7	13.8	15.5	12.0		1.92	*	1.6	12.5	10.7	14.4	15.7	14.8	13.3		8-13	10.5	8.6	6.7	6.7	6.2	5.7	5.9	*	
6.33	5.4	40.6	9.4	10.3	8.7	13.4	15.0	11.4		18.00	2.4	2.9	5.4	3.8	6.4	13.4	10.2	6.4		8-20	22.5	42.7	14.4	8.6	9.5	7.9	8.4	*	
28.75	3.9	12.2	3.4	3.1	3.2	5.3	9.5	4.4		8-13	21.4	11.1	7.3	7.0	5.5	7.5	6.2	6.0		8-24	17.5	61.4	33.1	10.4	13.0	10.6	12.8	*	
8-13	9.9	10.2	5.4	5.3	5.1	5.4	6.7	4.3		8-20	60.5	25.2	53.4	7.4	9.6	10.0	7.6	7.5											
8-20	42.5	45.0	9.8	6.5	8.2	8.7	7.7	7.0		8-24	61.1	25.4	60.7	9.6	9.6	11.0	9.4	8.0											
8-24	49.5	62.0	23.7	13.1	11.8	13.0	15.4	12.1																					
IRR 4										IRR 4										IRR 4									
.25	1.0	61.6	23.5	13.2	12.9	13.9	15.4	13.1		.25	60.9	27.7	58.8	10.3	10.2	12.4	11.2	9.9		.25	14.9	50.4	22.1	8.2	14.3	11.8	13.8	*	
1.25	1.0	61.4	23.2	13.6	13.6	14.5	15.7	13.6		.50	60.2	28.1	56.7	11.0	11.4	13.7	12.5	11.2		.50	12.4	34.2	13.2	5.5	14.9	12.8	14.3	*	
1.67	1.0	60.5	23.0	13.5	13.5	14.5	15.7	13.8		.75	10.5	28.5	51.9	11.7	12.3	14.5	13.4	12.3		.75	10.2	8.4	16.7	3.8	15.2	13.3	14.7	*	
4.50	1.1	58.4	18.9	11.3	10.7	12.7	14.5	12.7		1.08	1.8	17.5	44.8	12.1	12.7	14.9	14.0	12.9		1.00	8.7	7.9	6.2	2.9	15.3	13.4	14.9	*	
6.50	1.6	57.9	17.7	11.2	9.3	12.0	5.1	14.5		3.08	*	27.0	5.2	9.2	14.2	16.2	15.8	13.6		4.08	5.7	3.0	4.9	1.9	13.2	11.5	14.1	*	
23.50	3.2	54.7	11.5	8.8	7.0	10.1	15.3	10.4		20.25	2.9	9.6	3.0	3.0	4.0	9.7	7.3	4.2		6.33	5.8	3.9	6.5	1.9	11.0	9.0	12.0	*	
9-2	10.4	9.5	8.1	7.2	7.0	7.2	9.3	7.3		9-2	8.0	9.2	10.5	9.0	7.6	8.4	9.0	8.7		24.50	7.5	6.2	11.4	4.5	7.9	5.3	8.3	*	
9-6	9.6	8.5	7.3	6.5	7.0	7.1	7.7	7.1		9-6	8.0	9.1	10.2	9.1	8.3	8.3	9.2	8.9		9-2	13.5	8.8	9.5	8.7	7.5	7.7	7.4	*	
9-10	15.0	12.6	10.6	9.9	10.4	11.2	10.8	10.2		9-10	18.5	11.6	13.4	11.7	12.8	12.7	13.4	12.4		9-6	13.0	8.6	9.5	8.5	8.1	7.8	7.9	*	
																				9-10	17.7	12.3	13.5	11.5	11.9	11.0	11.7	*	

* No reading due to malfunction or soil matric potential exceeded tensiometer capabilities.

IRR = Irrigation

Appendix Table 14. Time distribution of soil matric potential during four irrigations in replication three 1971. Values range from the .5- to 7.5-foot soil depths and units are centimeters of mercury.

CHECK REP 3									10 T/A GYPSUM REP 3									MANURE REP 3								
Date/Hours	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	Date/Hours	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	Date/Hours	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5
7-12	20.6	14.3	*	10.4	13.2	14.6	12.6	*	7-12	56.0	22.0	11.9	12.2	13.4	16.6	12.7	*	7-12	60.7	37.0	8.2	11.4	14.0	17.2	11.6	*
IRR 1									IRR 1									IRR 1								
.25	15.0	15.1	*	10.4	13.1	14.7	12.7	*	.75	6.7	9.5	12.2	12.5	13.9	16.6	13.7	*	.33	1.0	14.3	8.5	10.1	14.7	17.3	11.8	*
.66	1.0	15.1	*	10.4	13.4	14.4	12.5	*	1.05	2.3	9.0	12.9	13.0	15.0	17.1	14.1	*	.75	1.5	14.6	9.2	12.2	15.3	17.6	12.2	*
.92	1.0	15.2	*	10.4	13.6	14.4	12.6	*	1.33	1.0	7.7	12.9	13.0	15.3	17.1	14.4	*	1.17	1.5	15.2	7.3	10.6	5.9	18.1	12.6	*
1.33	1.0	15.2	*	10.0	13.3	14.3	13.6	*	7-14	4.0	4.4	4.2	3.9	4.5	6.2	5.0	*	2.08	1.5	15.2	3.0	9.2	16.0	18.4	12.9	*
1.75	1.0	15.1	*	9.6	13.0	14.2	12.6	*	7-16	10.2	5.8	4.9	4.9	5.3	5.2	4.8	*	7-14	15.0	3.0	3.0	2.0	4.6	8.3	5.7	*
7-14	4.0	4.0	*	2.8	3.8	5.7	5.3	*	7-21	47.5	7.5	7.2	7.4	8.6	8.9	8.1	8.6	7-16	25.0	6.4	2.1	3.7	4.5	5.6	3.0	*
7-16	9.3	4.4	*	4.2	3.8	4.8	4.8	*	7-23	55.0	6.9	5.3	5.2	6.0	6.9	5.4	5.7	7-21	38.0	7.5	6.1	6.2	9.3	11.3	13.8	*
7-21	7.6	6.0	*	7.5	9.2	9.9	8.7	*	7-27	60.9	9.2	9.4	9.3	10.0	10.7	10.1	10.1	7-23	43.3	5.2	5.6	5.2	5.9	8.7	5.3	12.5
7-23	12.6	5.0	*	4.0	4.6	6.6	7.8	4.5										7-27	60.1	12.3	7.0	8.2	11.2	13.4	10.1	15.4
7-26	*	8.9	*	4.2	4.4	6.1	6.8	4.7																		
IRR 2									IRR 2									IRR 2								
.25	*	7.0	*	6.5	6.7	7.9	7.8	6.6	.25	60.7	8.9	9.4	9.3	10.4	10.6	10.2	10.7	.25	58.8	12.0	6.9	8.0	10.9	12.3	9.5	15.2
.50	*	8.0	*	7.0	7.6	8.2	8.6	7.6	.50	50.2	7.0	9.7	10.0	11.4	11.1	10.7	11.2	.50	50.8	9.6	5.8	8.2	11.4	13.2	9.8	15.2
16.50	*	10.5	*	7.5	9.7	14.9	17.2	12.6	.78	6.8	5.2	9.5	9.7	11.7	11.2	10.6	10.9	.75	36.2	11.1	4.4	8.2	11.7	13.3	9.8	15.2
8-3	31.5	6.0	*	4.5	5.2	5.5	4.8	4.5	1.12	3.0	3.5	8.8	9.1	11.7	11.3	10.6	10.9	1.00	14.7	10.6	3.6	8.1	12.1	13.5	10.3	15.2
8-6	45.8	9.0	*	5.4	1.0	1.0	6.5	4.7	4.58	1.3	4.3	1.6	4.8	12.0	15.5	12.1	17.0	6.92	3.0	1.9	5.4	6.0	8.2	11.3	11.9	11.6
8-9	60.8	23.2	*	9.4	11.6	13.2	13.1	10.6	23.50	3.3	4.2	4.0	4.3	4.8	8.8	8.4	7.6	24.33	2.0	3.1	2.1	3.7	8.6	14.7	11.7	17.7
									8-3	13.3	6.3	5.2	5.1	5.7	4.7	5.1	5.5	8-3	34.7	5.3	5.2	5.1	6.1	7.0	4.7	10.1
									8-6	34.9	7.9	6.7	6.8	7.0	6.7	6.8	6.8	8-6	31.2	10.0	6.3	6.0	7.1	8.0	4.3	10.8
									8-9	51.5	10.8	8.6	9.3	9.8	10.5	10.2	9.6	8-9	59.5	20.9	7.5	7.4	9.5	10.8	6.4	12.5
IRR 3									IRR 3									IRR 3								
.25	60.6	22.6	*	9.2	11.2	12.6	12.7	10.2	.25	44.4	10.8	8.5	9.0	9.8	9.8	9.7	9.9	.25	57.0	10.0	7.5	7.3	9.7	11.1	7.1	12.9
.50	17.2	21.2	*	9.8	11.7	12.8	13.2	11.0	.58	1.0	8.5	9.1	9.8	11.5	10.6	10.4	10.5	.50	41.5	19.9	5.3	7.1	10.6	11.5	8.1	13.2
.75	1.0	20.8	*	10.0	11.8	13.0	13.4	11.2	.83	1.0	6.5	9.0	9.8	11.9	10.8	10.6	10.7	.75	9.2	19.3	3.4	6.0	11.3	12.0	8.8	13.6
1.00	1.0	20.2	*	9.6	11.9	13.1	13.4	11.3	1.08	1.0	4.9	8.8	9.5	11.9	10.9	10.5	10.8	2.75	1.0	13.4	1.3	2.3	11.4	12.2	9.6	14.0
3.00	1.0	13.5	*	5.9	10.1	12.0	12.0	10.1	3.67	1.8	1.5	4.3	5.0	8.8	9.6	9.3	9.9	4.83	1.0	10.7	1.7	2.2	11.2	13.1	11.2	14.7
6.50	1.0	9.1	*	4.8	7.9	10.6	11.0	9.3	5.75	2.2	2.3	4.4	4.5	7.5	9.4	10.3		23.17	3.0	5.8	3.0	3.3	8.4	12.3	9.3	15.2
8.50	1.0	8.8	*	4.8	8.3	11.2	10.3	8.9	24.15	3.2	3.0	3.6	4.0	4.5	6.8	7.6	7.0	8-13	24.8	7.2	6.0	5.6	6.0	7.1	5.2	9.4
25.50	3.6	6.2	*	5.0	7.0	10.6	11.5	8.0	8-13	10.8	6.2	5.9	5.5	5.8	4.9	4.9	4.8	8-20	58.1	38.3	8.6	8.4	9.0	9.0	5.8	11.1
8-13	20.8	11.5	*	5.6	5.3	5.7	5.5	4.1	8-20	49.2	13.4	8.0	8.0	7.3	7.3	*	7.7	8-24	61.6	38.0	11.4	10.1	12.0	12.2	8.4	13.4
8-20	49.3	41.2	*	6.3	7.0	7.0	7.8	5.8	8-24	57.7	24.2	12.0	10.4	10.6	10.9	*	10.8									
8-24	13.5	27.1	*	11.6	13.2	13.9	13.5	11.4																		
IRR 4									IRR 4									IRR 4								
.25	6.0	23.0	*	12.0	13.2	14.3	13.9	12.2	.25	54.2	21.2	11.1	10.0	9.8	10.0	*	10.4	.25	61.4	20.2	9.9	10.0	11.6	10.8	9.8	13.3
.50	3.7	19.6	*	12.0	13.6	14.5	14.2	12.2	.50	1.8	17.5	11.4	10.5	11.1	10.9	*	11.0	.58	54.9	5.6	6.6	10.9	12.8	12.4	11.1	14.2
.75	2.4	17.0	*	11.9	13.6	14.6	14.4	12.4	1.08	1.7	11.0	10.7	10.3	11.9	11.0	*	11.8	1.00	17.7	2.8	3.8	10.9	13.6	13.5	11.9	14.3
1.00	1.7	15.0	*	11.7	13.7	14.3	14.5	12.6	1.33	1.7	9.0	10.3	9.9	11.9	10.8	*	11.9	1.25	2.9	2.5	2.7	10.5	13.8	14.0	12.2	15.0
3.00	1.0	6.5	*	7.7	12.0	13.5	14.4	12.1	4.00	1.7	2.8	4.8	6.7	9.8	11.5	*	12.1	3.25	1.0	1.9	1.8	7.5	13.1	15.2	13.2	15.9
5.00	1.0	4.5	*	5.8	10.5	13.0	12.5	12.4	5.42	2.0	2.6	5.0	6.0	9.0	11.5	*	12.0	4.25	1.0	2.2	1.8	6.4	13.5	15.8	13.7	16.4
7.00	1.0	4.4	*	5.3	9.8	12.5	12.3	11.3	25.58	2.8	2.8	3.4	4.0	3.8	6.4	*	6.4	20.58	2.7	3.5	3.5	3.8	8.4	12.4	8.3	15.4
25.00	1.5	4.4	*	7.0	5.8	10.5	11.1	7.5	9-2	9.0	8.2	7.0	6.8	6.0	6.9	*	6.1	9-2	11.2	9.2	9.8	9.2	8.7	9.0	9.0	12.5
9-2	*	9.8	*	10.0	8.6	9.5	9.5	7.9	9-6	8.7	7.8	6.9	7.0	7.3	7.7	*	7.6	9-6	10.6	8.5	8.9	8.5	8.9	8.7	9.0	12.4
9-6	5.5	6.6	*	8.8	7.8	9.0	8.8	8.4	9-10	10.3	9.8	9.4	9.7	10.0	10.2	*	9.7	9-10	32.1	11.8	10.7	10.9	11.5	12.1	11.5	14.5
9-10	10.3	13.0	13.9	11.0	11.0	11.2	12.0	11.0																		

* No reading due to malfunction or soil matric potential exceeded tensiometer capabilities.

IRR = Irrigation

Appendix Table 15. Time distribution of soil matric potential during three irrigations in replication one 1972. Values range from the .5- to 7.5-foot soil depths and units are centimeters of mercury.

	CHECK REP 1								10 T/A GYPSUM REP 1								MANURE REP 1							
Date/Hours	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5
7-12	*	*	*	*	*	*	*	*	16.5	34.1	19.4	18.3	17.2	18.3	20.2	20.5	34.9	32.7	14.1	14.3	16.7	17.6	16.5	15.5
IRR 1																								
.17	12.0								5.7								24.0							
.20	8.2								5.5								6.7							
7-13	11.9	12.6	25.2	26.3	14.9	29.8	18.3	8.6	9.3	15.3	17.1	17.9	15.6	18.3	19.5	20.2	11.6	49.3	12.2	12.3	13.5	15.5	13.9	15.0
7-18	37.5	20.6	22.5	22.5	14.7	19.2	15.8	9.2	7.0	17.1	15.7	17.2	14.0	16.0	16.1	16.0	26.1	37.4	12.4	13.3	14.0	16.0	13.8	14.9
7-26	43.6	22.3	16.2	15.6	16.8	18.2	17.3	9.7	21.4	16.7	13.1	11.2	11.8	11.4	14.6	14.5	36.9	40.6	10.8	8.3	10.5	11.5	*	9.3
7-28	56.7	35.2	25.0	18.3	16.4	10.0	15.8	9.6	32.3	22.7	15.7	15.8	16.1	15.8	18.3	17.4	43.9	25.5	15.4	11.0	13.3	15.9	10.5	12.9
8-4	64.5	51.6	25.8	22.3	16.3	13.2	17.0	13.2	*	42.3	19.5	18.7	17.8	18.9	19.8	18.2	41.7	25.5	26.0	14.6	15.5	18.8	14.3	16.1
8-7	65.2	55.0	17.2	23.0	16.9	13.0	17.0	15.6	*	27.9	21.5	19.1	18.3	18.5	19.4	18.1	28.1	12.7	32.8	15.7	16.3	19.7	16.1	16.1
IRR 2																								
.2	64.0								4.8								22.1							
1.12	62.0								4.3								10.6							
8-9	17.9	16.2	13.9	22.5	16.0	14.3	18.0	18.1	7.9	12.5	18.2	18.5	18.5	20.0	21.1	18.8	9.5	11.1	12.0	14.2	13.5	17.0	16.5	15.8
8-17	50.2	26.5	22.1	19.3	15.4	11.6	15.3	12.7	7.4	21.7	16.9	16.5	16.1	16.5	18.3	16.8	14.8	13.0	15.5	13.2	13.8	17.2	15.4	14.0
8-24	59.5	42.8	30.4	21.7	16.3	14.2	16.5	15.7	8.0	31.4	19.3	17.7	16.9	17.7	18.7	17.4	11.6	11.7	13.0	11.9	12.1	15.6	16.8	15.4
9-1	22.7	11.4	17.8	14.9	15.1	18.9	17.6	16.0	*	45.0	22.0	18.9	17.5	18.2	19.0	18.7	64.7	52.6	16.8	26.8	17.0	14.5	17.5	19.3
9-7	8.2	44.4	9.7	31.1	19.5	14.6	17.2	12.8	33.8	40.9	31.4	17.5	20.3	21.1	21.3	19.3	34.4	39.5	19.7	17.8	18.4	21.2	18.7	19.2
IRR 3																								
9-8	8.2	15.3	28.3	28.5	14.7	14.8	15.9	12.1	10.6	11.4	21.6	15.5	15.9	17.5	18.6	18.5	9.8	14.0	10.5	12.3	15.4	7.9	16.3	14.8

* No reading due to malfunction or soil matric potential exceeded tensiometer capabilities.

IRR → Irrigation

Appendix Table 16, Time distribution of soil matric potential during three irrigations in replication two 1972. Values range from the .5- to 7.5-foot soil depths and units are centimeters of mercury.

Date/Hours	CHECK REP 2								10 T/A GYPSUM REP 2								MANURE REP 2							
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5
7-14	64.6	56.3	22.6	18.6	18.7	22.5	20.2	20.9	56.7	47.1	18.8	15.0	16.5	19.7	16.5	21.2	*	*	*	*	*	*	*	*
IRR 1																								
.17	63.5								20.5								*							
.20	60.0								8.1								*							
1.00	7.5								6.2								*							
7-15	9.7	54.4	9.5	13.1	13.5	17.0	16.8	20.0	9.5	10.5	8.1	7.9	9.9	17.4	11.4	18.2	*	*	*	*	*	*	*	*
7-18	16.9	28.8	11.1	12.0	12.1	13.4	13.2	13.7	14.8	12.1	10.2	9.4	9.7	10.6	8.8	14.4	*	*	*	*	*	*	*	*
7-25	15.3	12.9	9.5	9.5	9.8	13.1	13.3	13.5	12.8	10.2	8.8	*	5.9	*	*	*	10.9	10.5	10.7	*	*	9.3	8.6	8.2
7-28	30.2	18.2	12.1	12.3	12.3	19.0	18.8	18.7	27.0	13.4	11.7	11.9	12.2	14.2	12.0	13.4	18.6	14.3	12.0	10.4	*	13.8	13.6	12.8
8-4	66.8	20.9	14.3	12.0	11.9	18.2	18.0	17.9	12.9	17.8	12.4	10.4	11.1	12.0	11.3	11.5	57.5	25.7	14.2	10.4	5.0	12.2	12.1	11.6
8-8	66.8	28.0	17.2	13.1	12.7	19.3	19.0	18.7	7.1	26.6	14.2	12.1	12.5	14.6	12.7	13.0	69.1	41.3	17.5	14.0	*	15.0	15.2	13.4
IRR 2																								
8-9	6.2	9.6	7.8	6.5	6.5	14.5	14.5	16.9	5.0	7.8	6.2	5.6	6.0	9.8	5.9	6.9	6.5	9.0	5.9	5.8	*	7.5	7.0	8.8
8-17	14.4	14.8	11.3	10.2	10.4	16.4	16.2	16.0	*	14.1	11.5	9.8	10.5	11.0	10.3	10.8	17.4	12.4	11.2	*	*	12.0	11.0	11.6
8-24	9.8	12.1	9.7	9.0	9.0	15.2	15.2	15.6	*	11.6	9.9	9.5	9.3	10.4	9.3	9.7	10.2	9.2	9.3	*	*	9.2	9.8	8.9
9-1	38.8	17.1	13.0	11.1	11.1	17.7	17.4	17.8	*	20.7	12.5	11.4	11.4	13.2	11.1	12.0	60.1	19.2	11.7	*	10.0	11.8	12.2	10.3
9-6	56.2	19.9	15.0	12.3	12.4	19.0	18.8	18.7	39.6	36.4	14.4	12.1	12.7	14.6	12.5	13.0	61.8	43.3	13.6	15.7	*	11.8	13.1	12.3
IRR 3																								
9-8	5.5	10.7	6.7	5.9	11.3	5.7	11.5	14.0	11.9	7.5	6.3	5.5	5.8	7.0	6.0	6.0	6.1	6.1	5.4	9.5	6.0	*	6.0	6.8

* No reading due to malfunction or soil matric potential exceeded tensiometer capabilities.

IRR → Irrigation

Appendix Table 17. Time distribution of soil matric potential during three irrigations in replication two 1972. These plots were covered with black plastic preventing evapotranspiration. Values range from the .5- to 7.5-foot depths and units are centimeters of mercury.

	CHECK ⁺ REP 2								10 T/A GYPSUM ⁺ REP 2								MANURE ⁺ REP 2							
Date/Hours	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5
7-14	20.7	20.5	20.3	*	20.4	24.0	18.2	25.6	25.1	17.1	16.9	24.5	6.9	15.8	18.5	18.4	16.2	19.7	19.7	19.4	20.3	22.8	*	24.2
IRR 1																								
.17	17.4								4.1								5.0							
1.60	8.8								1.0								4.1							
7-15	11.5	12.7	16.4	*	13.0	18.7	8.5	26.7	5.3	9.0	12.8	16.1	13.3	*	17.4	18.2	6.9	10.0	18.0	13.4	14.4	19.3	8.5	41.8
7-18	10.8	10.8	11.2	*	10.4	11.4	6.1	14.1	6.9	5.0	5.0	7.2	4.5	*	5.0	6.4	7.2	10.7	9.5	10.0	10.1	11.2	8.2	18.1
7-25	14.8	14.0	14.5	7.0	14.6	10.9	9.2	13.7	7.8	6.4	*	8.6	*	8.7	6.0	5.4	7.2	11.0	11.2	13.0	12.1	8.3	10.3	*
7-28	15.1	12.8	14.9	10.3	14.2	6.9	7.0	16.7	8.4	5.5	7.0	9.7	6.6	11.3	7.3	8.1	*	11.5	10.8	12.6	11.4	5.5	9.5	*
8-4	14.7	13.0	14.5	10.7	14.5	7.1	8.1	18.9	8.0	*	5.8	8.3	5.0	9.5	5.8	7.0	5.2	10.7	10.5	12.5	11.5	5.5	*	13.7
8-8	18.9	13.6	15.8	12.2	15.7	10.0	9.7	20.8	9.2	*	9.4	11.6	9.8	10.0	10.7	10.9	*	12.3	13.5	14.6	13.9	7.8	*	16.4
IRR 2																								
8-9	12.3	11.4	14.8	*	12.7	7.7	5.5	23.4	5.2	*	7.8	5.6	7.7	11.2	10.2	11.0	*	9.5	12.9	11.8	11.0	7.4	*	17.5
8-17	14.9	12.1	14.5	10.9	14.0	6.5	7.1	17.2	8.4	*	6.2	9.3	5.5	8.9	6.4	17.6	*	11.0	9.7	11.8	10.9	*	6.5	11.6
8-24	15.0	13.5	16.7	6.9	15.1	9.9	8.3	21.7	*	*	9.8	8.3	10.1	11.6	10.2	11.0	*	10.9	12.3	13.0	12.5	7.2	10.3	15.3
9-1	16.5	13.8	16.5	10.9	12.0	16.4	10.8	21.3	9.5	*	9.4	12.4	10.9	8.8	11.5	11.7	*	12.8	13.0	14.8	14.0	8.9	12.4	15.2
9-6	16.6	14.5	17.4	11.4	16.9	10.7	10.2	20.3	9.9	13.8	11.0	12.5	12.2	13.0	12.8	12.5	*	12.5	14.2	15.6	15.1	10.8	*	17.0
IRR 3																								
9-8	12.8	9.8	10.9	5.8	10.7	*	*	14.8	*	*	10.3	*	*	*	*	9.0	*	10.3	8.8	10.0	*	9.3	*	10.3

+ Plots covered with black plastic.

* No reading due to malfunction or soil matric potential exceeded tensiometer capabilities.

IRR + Irrigation

Appendix Table 18. Time distribution of soil matric potential during three irrigations in replication three 1972. Values range from the .5- to 7.5-foot soil depths and units are centimeters of mercury.

Date/Hours	CHECK REP 3								10 T/A GYPSUM REP 3								MANURE REP 3							
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5
7-13	64.7	13.7	15.6	14.8	14.7	15.4	16.3	*	66.7	17.6	17.8	*	*	*	12.9	*	67.5	15.9	*	*	*	*	17.6	*
IRR 1																								
.12	2.4								6.1								11.9							
.50	1.1								1.6								2.6							
7-14	7.8	7.0	8.0	8.0	10.3	9.5	17.1	15.5	6.6	6.7	6.9	*	*	*	8.4	*	7.1	12.3	*	*	*	*	7.9	*
7-18	11.9	17.4	10.1	10.0	8.0	9.2	12.2	12.4	13.8	10.7	10.5	*	*	*	8.5	*	26.0	9.1	*	*	*	*	11.0	*
7-25	14.0	10.9	10.3	10.0	11.3	9.9	12.8	12.2	13.9	11.8	9.7	9.0	5.8	*	9.5	6.1	17.1	11.5	9.3	12.5	*	*	*	9.2
7-28	36.9	12.3	11.4	11.6	11.0	12.1	16.3	16.1	17.1	12.6	11.1	10.9	11.3	12.4	12.2	11.6	40.3	13.5	11.6	16.4	13.4	11.7	13.1	9.0
8-4	21.7	15.3	12.6	12.5	10.4	11.3	15.1	14.6	36.4	13.5	13.5	9.8	9.1	8.5	10.5	8.1	29.4	14.8	13.0	14.7	11.4	10.3	12.0	7.8
8-8	49.6	17.3	13.4	15.0	15.4	14.8	17.4	10.1	43.7	14.6	15.3	12.4	12.8	13.8	14.4	13.5	42.6	18.0	15.1	18.8	17.7	16.4	15.5	13.3
IRR 2																								
.17	4.1								11.2								8.1							
.33	1.0								8.7								5.8							
8-9	7.0	8.1	7.9	9.0	8.1	7.2	14.4	10.0	10.5	8.8	7.2	6.7	6.7	6.9	6.5	8.3	9.0	9.0	7.4	10.1	7.7	8.6	11.8	9.3
8-17	31.4	12.7	11.4	11.5	10.8	10.3	13.7	9.3	16.3	11.7	11.6	11.3	10.3	10.9	9.4	10.5	31.7	12.8	12.1	13.9	11.5	11.4	7.8	10.4
8-24	14.1	10.7	10.2	10.2	9.8	9.5	14.0	14.6	12.2	11.0	9.8	*	7.7	8.0	8.3	7.4	16.3	12.7	10.2	12.5	9.5	8.9	7.6	8.7
9-1	43.5	14.4	12.3	13.3	12.0	11.8	15.5	9.5	37.7	13.2	13.0	*	9.7	9.3	10.5	8.3	45.1	14.7	12.8	9.7	*	*	8.7	10.2
9-6	56.0	16.6	13.9	15.0	14.7	14.3	17.1	9.7	33.7	15.7	15.0	*	13.7	13.9	13.7	11.8	29.3	18.0	15.0	9.4	*	*	8.0	12.5
IRR 3																								
9-8	7.5	8.2	7.8	7.8	7.7	7.4	13.7	9.7	14.8	9.3	7.1	*	*	4.8	6.3	5.5	13.0	9.3	7.2	9.3	*	*	8.0	7.6

* No reading due to malfunction or soil matric potential exceeded tensiometer capabilities.

IRR = Irrigation

Appendix Table 19. Time distribution of soil matric potential during four irrigations in replication two 1973. Units are centimeters of mercury measured at the 1.5, 3.5, and 6.0 soil depths.

	CHECK REP 2			10 T/A GYPSUM REP 2			MANURE REP 2		
Date	1.5	3.5	6.0	1.5	3.5	6.0	1.5	3.5	6.0
7-10	10.8	12.6	6.2	13.9	10.9	11.9	12.2	10.7	14.0
IRR 1									
7-11	7.3	8.1	0.0	8.7	7.6	7.9	7.9	8.2	9.1
7-16	8.4	9.7	4.5	11.5	8.4	8.2	10.1	9.0	9.4
7-18	6.0	10.7	6.3	13.2	10.2	10.2	10.7	9.7	10.7
7-24	10.3	13.4	7.0	16.7	10.8	11.3	11.4	10.6	12.0
IRR 2									
7-26	7.0	8.5	*	9.0	6.1	9.0	7.8	6.4	8.0
7-31	6.0	12.1	*	12.1	6.9	6.7	10.4	8.5	8.7
8-3	7.6	14.0	*	16.5	7.2	7.2	12.0	9.5	8.1
8-8	9.8	18.3	7.4	26.1	11.5	9.2	13.4	10.3	8.5
IRR 3									
8-10	8.4	8.6	5.6	10.7	7.2	7.7	7.6	7.1	6.6
8-16	7.9	12.6	*	13.2	7.3	6.2	12.1	8.5	5.9
8-23	9.7	15.5	5.9	22.7	10.2	8.5	13.2	10.5	9.7
IRR 4									
8-24	9.7	8.2	7.2	16.4	9.5	9.2	8.3	7.2	8.6
9-7	10.8	11.6	*	12.5	10.5	8.9	11.8	11.4	9.0

* No reading due to malfunction or soil matric potential exceeded tensiometer capabilities.

IRR → Irrigation

Appendix Table 20. Soil Conservation Service classification and profile description of the soil system used in this thesis.

The Vananda series is a member of the fine, montmorillonitic (calcareous), mesic family of Ustic Torriorthents. Typically, Vananda soils have fragile, massive, vesicular, clear silt-coated surface crust and they have indistinct horizonation below this crust in grayish brown grading to olive gray slightly calcareous clay.

Typifying Pedon: Vananda clay - native grass
(Colors are for dry soil unless otherwise noted.)

- A11 0-1/4" --Grayish brown (2.5Y 5/2) clay, dark grayish brown (2.5Y 4/2) moist; massive crust in hexagonal shapes 2 to 4 inches in diameter; light brownish gray on top side with many clear silt grains; grayish brown on underside with clusters of granules and very fine plates adhering; hard, friable, very sticky, very plastic; noncalcareous; abrupt boundary. (1/8 to 1 inch thick)
- A12 1/4-4" --Grayish brown (2.5Y 5/2) clay, dark grayish brown (2.5Y 4/2) moist; moderate grading to strong thin platy structure, plates crumble to moderate very fine subangular blocks; hard, firm, very sticky, very plastic; slightly calcareous; many very fine roots; moderately alkaline; (pH 8.3); clear smooth boundary. (2 to 6 inches thick)
- B2 4-20" --Grayish brown (2.5Y 5/2) clay, dark grayish brown (2.5Y 4/2) moist; moderate medium to fine angular blocky structure; extremely hard, very firm, very sticky, very plastic; faces on all ped surfaces have a light reflecting sheen without difference in color from inside of ped; few very fine pores; common grading to few very fine roots; strongly alkaline (pH 8.8); clear irregular boundary. (10 to 20 inches thick)
- Ccs 20-26" --Olive gray (5Y 5/2) clay, olive gray (5Y 4/2) moist; weak medium angular blocky structure; very hard, very firm, very sticky, very plastic; few roots; many medium to large white nests of gypsum crystals; moderately alkaline (pH 8.0) gradual boundary. (0 to 20 inches thick)
- C2 26-60" --Olive gray (5Y 5/2) clay, olive gray (5Y 4/2) moist; weak medium angular blocky structure; extremely hard, very

Appendix Table 20
(continued)

firm, very sticky, very plastic; common clusters of gypsum crystals decreasing with depth in horizon; moderately alkaline (pH 8.0); slightly calcareous.

Range in Characteristics: Vanada soils are usually dry when not frozen, unless irrigated, and they have a mean annual soil temperature of 48° to 52°F. The continuous surface crust is 1/8 to 1/2 inch thick under sparse grass cover, and 1/2 to 1 inch thick under greasewood and saltbush plants, in animal hoof tracks and in cultivated fields. The thicker crust under greasewood and saltbush is contrasting in appearance in its lighter color of the dry soil surface with more abundant clear silt covering in the crust. Beneath the crust the A12 horizon ranges in structure from moderate to strong fine to medium plates to strong very fine granules. It differs in color from the underlying horizons by less than 1 unit in Munsell value. The soil below the A12 horizon has hue of 2.5Y or yellower, value of 6 or 5 dry and 5 or 4 moist, and chroma of 2 or 3. It ranges from moderate medium blocky to massive with widely spaced (6 to 10 inches) vertical cracks appearing in the dry soil. It has 45 to 60 percent clay. Quantities of gypsum crystals range from many to very few. The exchangeable sodium percentage is greater than 7 and increases to more than 15 at about 20 inches, and the electrical conductivity is greater than 7 and increases to more than 15 at about 20 inches, and the electrical conductivity exceeds 2 mhs per cm. The soil profile ranges from very slightly to moderately calcareous with a few (less than 1 percent) fine or medium segregations of lime below the A12 horizon.

Setting: Nearly level to sloping or gently rolling upland or valley plains on residual or transported clay surfaces. Local relief ranges up to 20 feet with long smooth slopes 300 to more than 1,000 feet long. Slopes are short (50 to 200 feet) where associated with the Lismas soils on hilly terrain. The climate is cool semiarid with mean annual temperature of 45° to 47°F., mean summer temperature more than 60° F. and mean winter temperature between 18° and 28°F. Mean annual precipitation is 10 to 14 inches.

Principal Associated Soils: Well-drained; slow to rapid runoff; very slow permeability.

Use and Vegetation: Use is mainly for range with limited use for irrigated crop production. Principal vegetation is greasewood, Gardner saltbush, big sagebrush, and plains pricklypear cacti with plants

Appendix Table 20
(continued)

having 5- to 2-foot spacing and with a sparse (5 percent) cover of grasses between shrubs, mainly of western wheatgrass, Sandberg bluegrass and some green needlegrass.

Distribution Extent: Southeastern Montana, where the soils are extensive.

Series Established: Big Horn County (Big Horn Area), Montana, 1970.

Remarks: Vananda soils were formerly classified as an alkali phase of Brown soils.

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Appendix Table 21. Analyses* of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) material supplied by the Wyo-Ben Company, Billings, Montana.

Si	15.44%	Co	0.0%
Ca	25.17%	Pb	6.1 ug/g
Mg	1.62%	Ba	<200 ug/g
Na	.24%	B	0.0%
Mn	111 ppm	Se	1.7 ug/g
Cu	8 ppm	F	8.7 ppm
K	.05%	SO ₃	33.45%
Fe	.24%		
P ₂ O ₅	.03%		
As	0.0%		
Zn	11 ppm		

* Performed by Wyoming Department of Agriculture, P.O. Box 3228, Laramie, Wyoming.

Appendix Table 22. Procedures used for soil analyses in this thesis.

NO ₃ -N	Pheneldisulfonic Technique Jackson, M.L. 1958. Soil chemical analyses. Prentice Hall, Inc. 498 pages. Nitrate determination p. 197.
PO ₄ -P	
1971	Olsen, S. R., et al. 1954. Sodium bicarbonate extractable phosphorus. USDA Circular No. 99, March.
1972-1973	Bray number-one method as modified by Smith, F. W., et al. SSSAP 21:400-404.
Ca, Mg, Na	Saturated soil extract made to 1% strontium solution and analysed on an atomic absorption spectrophotometer. Perkins-Elmer. 1973. Analytical methods for atomic absorption spectrophotometry. Perkins-Elmer Corp. P.O. Box 21085, Salt Lake City, Utah.
Electrical Conductivity	Saturated soil extraction measured with a conductivity bridge.

Appendix Table 23. Procedures used for water analyses in this thesis.

NO ₃ -N	Chromotropic Acid Technique West, P. A. and G. L. Lyles. 1960. A new method for the determination of nitrates. <i>Analytica Chemica Acta</i> . p. 227-232.
PO ₄ -P	Olsen, S. R., et al. 1954. Sodium bicarbonate extractable phosphorus. USDA Circular No. 99, March.
Ca, Mg, Na	Saturated soil extract made to 1% strontium solution and analysed on an atomic absorption spectrophotometer. Perkins-Elmer. 1973. Analytical methods for atomic absorption spectrophotometry. Perkins-Elmer Corp. P.O. Box 21085, Salt Lake City, Utah.
Electrical Conductivity	Analysed on a conductivity bridge.
Suspended Solids.	A known volume of sample was centrifuged, then decanting the liquid, the mass of the residue was determined.
Turbidity	Analyses with a Jackson Turbidity Unit (4)
Total Carbon	Performed by the Botany Dept., Montana State University on a total carbon analyser.

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