

EFFECTS OF BEEF FEEDLOT LAGOON WATER ON GROUNDWATER
QUALITY, SOIL CHEMICAL PROPERTIES, AND PLANT COMPOSITION

by

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INTRODUCTION

Food preferences in the United States have changed as the standard of living has improved. Consumption of meat products, including beef, has increased as the standard of living has increased. Loehr (56) states that per capita consumption in 1969 as compared to 1950 of poultry (broilers), beef and veal, pork, dairy products, and cereal products is 193.3, 148.4, 93.6, 90.3, and 87.3%, respectively. The shift in preference for beef over some other food products and an increase in population have greatly increased the demand for beef products. An example of the response by cattle producers to this increased demand was seen during the 12-month period prior to August 1, 1969 in which the six major cattle feeding states reported a 16% increase in numbers of cattle on feed.

The large increase in numbers of beef cattle on feed has resulted in the production of vast amounts of animal waste. Morrison (71) estimates that 10,000 steers on a high concentrate diet produce about 70,000 M tons of wet manure per year or about 193 M tons per day. Gray (36) stated to the Kansas Livestock Feeders Association that on a BOD basis one 20,000-head feedlot produces as much waste per day as does a city of population 175,000.

Animal waste disposal problems in the United States are magnified by a trend toward production of beef cattle in large commercial confinement type operations. An increasingly larger proportion of beef is produced in feedlots containing over 1000 head (Table 1). Some of the larger feedlots have capacities as high as 80,000 head. These large feedlots tend to concentrate animal wastes into small areas. Greater concentration of higher absolute quantities of animal wastes has been the net result of recent developments in the beef feedlot industry.

Table 1

Cattle marketed from feedlots of under 1000 head and over 1000 head (17).

Region	Under 1000 head		Over 1000 head	
	1962	1968	1962	1968
	1000 head			
Northern Great Plains	2,380	2,958	803	2,604
Southern Great Plains	200	193	742	2,196
Total	2,580	3,151	1,545	4,800

Certain problems have grown out of these developments. The pollution potential of runoff from beef cattle feedlots has been pointed out by several investigators (34, 35, 68, 69). One primary concern is the effect of feedlot runoff on lakes, streams, and waterways. According to Smith (80), of 27 fish kills in Kansas during 1964, fifteen were believed to be caused primarily by runoff from commercial livestock feedlot operations. Another primary concern arises from the effect of the leachate from feedlot areas and areas receiving feedlot wastes upon groundwater quality. A close relationship between the geographic location of nitrate found in groundwater and livestock populations has been indicated by Smith (79) and Metzler (66).

The Federal Water Quality Standards Act of 1967 and state legislation (50) requires disposal of animal wastes without polluting surface or groundwater. The construction and maintenance of runoff retention facilities is required to obtain these objectives. Also, the retention facilities must be emptied periodically to provide space for more runoff. The need exists for an environmentally acceptable method of disposing of the runoff held in retention facilities.

Land application of feedlot runoff contained in retention structures is one of the more practical and economically feasible methods of disposing of

feedlot runoff. Willrich (95) has indicated that stockpiling of manures for future use, the conversion of manures by dehydration, and composting to marketable products are not normally economically feasible. The quality of feedlot runoff can be improved by aerobic and/or anaerobic treatment but in many situations further treatment is necessary before release into surface waters (70).

It is widely recognized that feedlot wastes contain substantial amounts of plant nutrients (91, 76, 61). Accordingly, feedlot runoff is often applied as supplemental irrigation water with the dual objectives of disposing of the runoff and furnishing nutrients for plant growth.

This research project was undertaken to evaluate the effects of irrigating with feedlot runoff on the quality of water in a shallow aquifer beneath the application area, on smooth brome grass (Bromis inermis L.) yields and composition, and on some selected chemical properties of an alluvial soil. Cattle feedlot lagoon water was applied by border irrigation as diluted and non-diluted treatments. The soil profile was analyzed to determine the extent of movement and accumulation of salts applied in the lagoon water. Deep and shallow sampling wells (7.6 and 21.4 m in depth, respectively) placed in the application areas were used to monitor groundwater quality. Total yield and N, P, K composition of the brome grass were ascertained in the spring following application of feedlot runoff the previous summer and fall.

REVIEW OF LITERATURE

Water Pollution Potential of Cattle Feedlot Runoff

Agricultural wastes, being dependent upon natural occurrences, discharge into streams intermittantly and tend to be quite variable in quantity and quality. Following an intense precipitation event a slug of runoff water may enter a stream and move along with it, creating a moving zone of severely polluted water. In Kansas, pollution control authorities have reported that livestock feedlots are the most important single source of pollution (37). In contrast, the rate of release of industrial and urban wastes can be controlled more easily to provide a continuous discharge.

Oxygen is required during the stabilization of feedlot runoff and organic wastes in general. The BOD (biological oxygen demand) and COD (chemical oxygen demand) are used to characterize wastes. BOD is the quantity of oxygen required during the stabilization of decomposable organic matter and oxidizable inorganic matter. COD is the quantity of oxygen required by the nonbiological oxidation and stabilization of compounds (23).

Miner (68) found cattle feedlot runoff to be a high strength waste. The BOD of feedlot runoff from a concrete surfaced lot ranged from 300 to 1400 mg/l while that from an unsurfaced lot ranged from 150 to 750 mg/l. This compares with an approximate value of 200 mg/l for untreated domestic sewage (23). In a slow sluggish stream one might expect anaerobic conditions to be created by a BOD of 10 mg/l. Turbulent mountain streams have been observed to handle 50 mg/l BOD without showing significant oxygen depletion (63).

Smith and Miner (81) listed several severe water pollution incidents that resulted in septic conditions moving downstream in a slug, causing fish kills below cattle feedlots. They reported fish deaths due to a lack of dissolved

oxygen and/or high ammonium nitrogen concentrations. Fish require 5 to 6 mg/l of dissolved oxygen to sustain life (49).

Nitrogen is a second component of feedlot runoff which poses a potential water pollution problem. Feedlot runoff contains significant quantities of various forms of nitrogen. Nitrogen may be bound in organic forms or be present in inorganic forms such as ammonium (NH_4^+), nitrate (NO_3^-), or nitrite (NO_2^-). When considering the water quality implications of nitrogen in runoff, the total-N must be considered as a potential source of inorganic forms of nitrogen through the processes of ammonification and nitrification (68).

In a study of the chemical characteristics of cattle feedlot runoff from rainstorm activity the total-N averaged 916 mg/l and ranged from 11 to 8,593 mg/l (60). At Bushland, Texas total-N in cattle feedlot runoff ranged from 600 to 2,400 mg/l (14). Over a three-year period total-N from a small barnlot averaged 26.2 mg/l (24). Miner (69) found that during warm weather the organically bound nitrogen in feedlot runoff was continuously converted to ammonium. Only when aerobic conditions existed was the NH_4^+ further oxidized to NO_2^- and NO_3^- . Because of the amount of oxygen-demanding organic matter in feedlot runoff, aerobic conditions existed only in isolated areas for brief periods. In evaluating the potential inorganic-N content of feedlot runoff the total-N content should be considered.

Ammonium nitrogen in feedlot runoff poses a potential pollution problem by virtue of its toxicity to fish in low concentrations. The threshold value varies with the pH, hardness, and dissolved oxygen content of the water in question but concentrations of 0.3 to 15.0 mg/l NH_4^+ -N have been reported toxic to various species of fish (64). Toxicity from NH_4^+ increased quite markedly with increases in pH. Concentrations of NH_4^+ in feedlot runoff considerably higher than the toxic level for fish are common (24, 60, 69).

The nitrate ion is the most highly oxidized form of N found in feedlot runoff. Consumption of NO_3^- in feeds or drinking water can cause any of a number of animal health problems. Nitrate normally represents a small part of the nitrogen contained in feedlot runoff. Values of NO_3^- -N from rain induced feedlot runoff have been found to range from 0 to 17 mg/l (34) and 0 to 6 mg/l (24). Ammonium nitrogen and total-N in feedlot runoff are considerably more concentrated indicating a potentially greater pollution hazard from additional biologically converted nitrate than indicated by initial concentrations of NO_3^- in feedlot runoff.

Ingestion of nitrates may result in a condition known as methemoglobinemia. This condition results when NO_3^- is reduced to NO_2^- within an animal's rumen or intestine by bacterial action and subsequently absorbed into the blood stream of the animal. Nitrite promotes the oxidation of the ferrous iron (Fe^{++}) ion within the hemoglobin molecule to the ferric iron (Fe^{+++}) state to form chocolate-colored methemoglobin. Oxygen is firmly bound to methemoglobin and is not effectively transported from the lungs to oxygen-consuming areas of the body. Severely affected animals may die from asphyxiation (15).

Numerous cases of methemoglobinemia have been reported in infants (15, 92). Generally adults can tolerate relatively higher concentrations of nitrate in drinking water than infants. Studies have indicated that the organisms responsible for NO_3^- reduction in the body are active only at a pH greater than 4.9 and that the pH of gastric juices of affected infants was above 4.0 (16). The gastric juice pH of normal adults is considerably lower than four.

Toxic levels of nitrate-N for various conditions have been compiled by Brown and Smith (10) as follows:

	NO_3^- -N	
Toxic daily dose-humans	0.56 g	Gilbert et al. (32)
Toxic dose-cattle	0.13 g/kg body weight	Whitehead and Moxon (94)
Possible toxic single dose-humans	0.70 g	Sollman (82)
Infant formula concentration-maximum	20 ppm	Walton (92)
U.P.H.S. water standard	10 ppm	Wright (96)

Another health problem related to ingestion of NO_3^- is an adverse relationship upon vitamin A metabolism. Garner, O'Dell, and Rader (29) found that a high level of nitrate in sows rations produced litters with a significantly depleted vitamin A reserve. Work with rats fed a diet containing .21% NO_3^- -N which was also low in iodine produced exerophthalmia, a common vitamin A deficiency symptom (97). As yet the entire relationship between NO_3^- and vitamin A metabolism seems unclear but a negative correlation seems to exist.

The contribution of both N and P to surface waters from feedlot runoff is indirectly a potential pollution hazard. These nutrients may promote eutrophication which refers to the process of enrichment of water with nutrients (85). Excessive growth of aquatic weeds and algae of such density as to be classified as a nuisance occurs at concentrations of 0.3 and 0.01 ppm of water soluble inorganic N and P, respectively (77). Profuse growth stimulated by eutrophication of surface waters frequently produces undesirable odors and tastes, impairs water treatment operations by clogging filters, and generally lowers the esthetic value of surface waters (27). Feedlot runoff contributes significant amounts of both P and N to surface waters. Although the actual amount of P in water required to supply the threshold level of plant available P may be considerably greater than 0.01 ppm, feedlot runoff

characteristically contains high enough concentrations to alter aquatic plant growth in surface waters (87).

Contamination of water with feedlot runoff has pathogenic disease implications. According to Dykstra (22), "The drinking of water infected with intestinal discharges is largely responsible for the almost universal infestation with intestinal parasites." Hull (44) lists 56 diseases which may be transmitted from cattle to man. Of these, 33 may be spread by contact with or ingestion of contaminated water (22). Some of the more common diseases in the latter group are anthrax, brucellosis, cowpox, diphtheria, leptospirosis, Q fever, salmonosis, staphylococcal infections, tetanus, and tuberculosis.

Because of the almost universal presence of coliforms in intestinal discharges and because of the ease with which they can be identified and counted in a water sample, the presence of this organism in a water sample is usually used as an index of fecal pollution in water samples (8). The presence of coliforms indicates the potential presence of fecal-derived pathogens. Geldreich (31) found beef cattle feces to contain 230,000 coliforms/gm. Daily production by a 1000-lb steer would be approximately 6 billion/day. Miner (68) found the MPN (most probable number) of coliforms in feedlot runoff from two experimental lots to range from 22 to 348 million organisms/100 ml.

Quantity and Composition of Feedlot Runoff

Considerable work has been devoted to determining how various types of precipitation, and feedlot design and management variables affect the composition and quantity of feedlot runoff (14, 33, 59, 60, 69, 86). Regression equations of runoff on natural precipitation for three consecutive years on the same feedlot with 6% slope illustrate the variability of volume of runoff

generated due to variation in precipitation events. In 1968, 1969, and 1970 the regression equations were $R = .93P - 1.033$, $R = .446P - .127$, $R = .493P - .152$, respectively, where R = runoff (cm) and P = natural precipitation (cm) (86). The latter two equations are similar to the equation found by Manges, Schmid, and Murphy (59) for a feedlot with 3% slope.

Data from rainfall events indicated that runoff from a feedlot surface may not be expected from less than approximately 1.3 cm of rainfall (86). Runoff resulted in these studies from lesser amounts if rainfall had been received previously within 72 hours. Clark and Stewart (14) showed that rainfall runoff from a feedlot in Texas was decreased when precipitation was received the preceding day. They postulated that under the heavy stocking rates used in the area severe tromping created many deep depressions that can retain significant amounts of rainfall.

Applications of artificial rainfall at controlled intensities and quantities have indicated that higher intensities provide both higher runoff rates and increased total runoff. Doubling rainfall intensity resulted in increasing solids removal by a factor of from three to ten (86). There were no trends to indicate that the solids content of runoff could be attributed to the duration of rainfall. Phosphorus removal was closely associated with solids removal and therefore directly affected by rainfall intensity. Runoff from high intensity rainfall contained a lower soluble salt content than runoff from low intensity rainfall. This trend was most evident during the first part of the rainfall event with the total soluble salt content from both types of rainfall being essentially equal near the end of both types of rainfall events.

Miner et al. (69) found higher concentrations of organic matter and total-N in runoff produced from low intensity rainfall, with moist conditions

preceding the rainfall, and from runoff produced during warm weather. They hypothesized that light rainfall allows more time for organic matter to decompose. The rainwater is held in the feedlot surface for longer periods of time which allows more decomposition and dissolving of organic materials before runoff occurs.

Gilbertson et al. (33) concluded that runoff from feedlots is apparently more dependent upon previous rainfall events and rainfall intensity and duration than on feedlot slope and animal density. No consistent differences in runoff parameters as affected by feedlot slope and cattle density were found for rainfall accumulations whereas lots with 9 sq m/animal yielded 130 to 170% greater runoff quantities than lower density lots with 18 sq m/animal when the runoff was supplied from winter thawing conditions rather than rainfall. The high and low density lots yielded runoff averaging 81 and 54%, respectively, of the precipitation in the form of snow. Runoff from the higher density lots was considerably more concentrated with respect to total and volatile solids, ash content, total-N, NH_4^+ , and total-P. Feedlot slope did not appear to affect the quantity or quality of feedlot runoff from snowmelt.

Very striking differences in the quality of feedlot runoff from snowmelt and rainstorm events were noted by McCalla et al. (60). Ranges in the characteristics and chemical values of cattle feedlot runoff and differences between snowmelt and rainstorm runoff are shown in Table 2. When thaws occurred during some winters, a slurry of undecomposed manure was observed to flow from the feedlot area. The snowmelt runoff that contained large amounts of solids occurred only from lots with cattle that were on high concentrate diets.

Table 2

Ranges in the characteristics and chemical values of runoff from beef cattle feedlots (60)

	Snowmelt runoff			Rainstorm runoff		
	Low	High	Mean	Low	High	Mean
pH	4.1	9.0	6.3	4.8	9.4	6.9
Conductivity (mmhos/cm)	3.0	19.8	7.1	0.9	4.9	3.2
Total solids (%)	0.8	21.8	7.7	0.24	3.3	2.04
Volatile solids (%)	0.6	14.3	3.9	0.12	1.5	0.87
Ash (%)	0.2	9.2	3.8	0.12	2.8	1.17
COD (mg/l)	14,100	77,100	41,000	1,300	8,200	3,100
P (ppm)	5	917	292	4	5,200	361
NH ₄ ⁺ -N (ppm)	6.0	2,028	780	2.0	1,425	143
NO ₃ ⁻ -N (ppm)	0.0	280	17.5	0.0	217	10.0
Total nitrogen (ppm)	190	6,528	2,105	11	8,593	916

The quantity and quality of beef cattle feedlot waste produced varies with the feeding ration. Generally, cattle in feedlots are started on a high roughage ration and quickly shifted to a high concentrate ration. A typical high concentrate ration containing corn, corn silage, and supplement has about 75 to 85% digestible material and 5 to 7% minerals and results in 1.8 to 2.3 kg of feces/animal/day on an oven-dry basis. A typical high roughage diet containing alfalfa hay, corn silage, and supplement has about 50 to 65% digestible material plus 7 to 9% minerals and results in about 4.5 kg of oven-dry feces/animal/day (61).

Assuming that 75% of the feces from a high concentrate ration is digestible, about 1.7 kg/animal/day of material is subject to biological breakdown. About 60% of the feces from a high roughage ration is considered digestible which provides approximately 2.7 kg/animal/day of material subject to biological breakdown. The variation in the organic and mineral composition of manure due to ration may account for some of the variability found in feedlot runoff.

Increased emphasis on land application of cattle feedlot wastes has stimulated research on the essentiality of high levels of Na in feedlot rations. A common practice in feeding ruminants is to add a minimum of 0.5% salt to rations which amounts to about 18 g/animal/day consumption. In some feeding situations salt has been used to limit feed consumption and has led to excess consumption of salt. Klett (51) found a linear decline of Na in solid waste with decreasing levels of supplemental NaCl in the diet which suggests that Na in solid waste materials from feedlots can be regulated by regulation of levels of NaCl intake. Studies on the effect of Na on the performance of finishing steers indicate that excessive levels of salt appear to be excreted (primarily in the urine) and tend to serve no useful purpose in the nutrition of feedlot steers (72). Generally, levels of NaCl can be reduced below those normally recommended in feedlot rations without affecting animal performance (38). Available data indicate considerable variation in NaCl requirements with a major consideration being the energy content of the ration. Additional studies are needed to determine the minimum requirement for salts for animals fed high concentrate diets.

Due to the number of variables determining the quality of feedlot runoff, the composition varies considerably from one runoff event to the next and from location to location. Some chemical parameters of cattle feedlot runoff collected from locations throughout Kansas in two different years illustrate this variability (Table 3).

Feedlot Wastes and Groundwater Quality

Animal waste has been cited as a major contributor of NO_3^- in groundwater. Smith (79) examined 6,000 rural water supplies in Missouri and concluded that animal wastes, improperly constructed shallow wells, and septic

Table 3

Elemental composition and electrical conductivity of beef feedlot runoff lagoon samples taken at 12 locations in Kansas during July, 1970 and 1971. The 1970 data are averages of samples taken at four depths: 5, 50, 100, and 200 cm. The 1971 data are from a single sample taken at 15 cm (91).

Location	Electrical conductivity (mmhos/cm)		ppm								Total inorganic-N ($\text{NH}_4^+ - \text{N} + \text{NO}_3^- - \text{N}$)	
			Na		K		Ca		Mg			
	1970	1971	1970	1971	1970	1971	1970	1971	1970	1971	1970	1971
1	3.1	3.0	142	122	387	583	152	101	74	78	195	145
2	2.7	2.7	139	220	166	325	101	100	61	70	164	119
3	3.3	4.1	221	293	330	604	160	158	85	111	151	167
4	1.0	4.8	73	329	52	617	65	127	34	124	16	161
5	4.2	3.9	268	335	550	729	141	143	97	81	220	61
6	6.3	4.3	339	299	826	708	177	135	78	89	130	218
7	8.6	12.6	653	1320	1100	1920	523	310	153	171	366	543
8	12.8	4.2	1690	403	2030	458	403	136	189	82	207	127
9	7.3	--*	834	--*	752	--*	212	--*	112	--*	221	--*
10	--*	10.6	--*	1460	--*	2210	--*	108	--*	235	--*	136
11	--*	1.4	--*	317	--*	483	--*	101	--*	64	--*	133
12	--*	6.0	--*	500	--*	750	--*	187	--*	170	--*	143

* Lagoon dry at sampling time.

tank drainage were the main contributors of NO_3^- contamination in groundwater. Nitrates found in Kansas groundwater were accredited primarily to nitrogenous materials in sewage and manure (66).

Vertical stratification of NO_3^- in groundwater has been found with higher concentrations predominantly in the shallower wells. In a survey of water quality in Nebraska Knudsen et al. (52) found less than 2 ppm NO_3^- -N in deep wells averaging 18.5 m in depth and greater than 10 ppm NO_3^- -N in wells averaging 9.1 m in depth. Metzler (66) investigated NO_3^- concentrations in public and private water supply wells in north central Kansas. Samples from 36 deep wells having depths from 8.2 to 20.1 m ranged from 0.4 to 15.6 ppm NO_3^- -N with most values being below 5 ppm NO_3^- -N. Samples from 17 shallow wells ranging from 2.7 to 8.8 m in depth ranged from 0.7 to 487 ppm NO_3^- -N with most samples containing greater than 20 ppm NO_3^- -N. Adriano, Pratt, and Bishop (2) found seven domestic wells with an average depth of 71.3 m to contain an average of 6 ppm NO_3^- -N while groundwater samples taken from depths of 14.3 to 17.4 m contained from 45 to 57 ppm NO_3^- -N. The higher concentrations of NO_3^- in shallow wells imply that the origin of the nitrogenous material found in groundwater is near the soil surface.

Although few long term studies on NO_3^- accumulation in groundwater have been reported in the literature, some trends for seasonal variation of NO_3^- in groundwater have been identified. Metzler and Stolenburg (67) sampled four municipal wells for a 2-year period and found that NO_3^- tended to peak in the winter season and then drop off during the growing season. During this period NO_3^- -N ranged from 14 to 35 ppm. Crabtree (18) found an exceptional number of wells with peak concentrations of NO_3^- in November and December.

In considering the buildup of NO_3^- in an aquifer, the turnover of water must be recognized. Duke (21) estimated the mean residence time for water in

the Ogallalah aquifer beneath Colorado's semiarid northern high plains to be 186 years. This estimate was before irrigation wells predominated in the area. A similar estimate by Carlston (11) for a more humid New Jersey drainage basin was 35 days. The range in rate of lateral movement of groundwater is listed as one foot/year to several miles/month by Biggar and Corey (5).

Most of the literature on the contribution of feedlot wastes to groundwater contamination has been relative to feedlots per se and not land application of these wastes, but some insight into the nature of problems associated with land application may be gained by a broader review of groundwater quality as affected by feedlot wastes.

Gillham and Webber (35) placed a nest of 35 piezometers throughout an area surrounding a barnyard for study of groundwater contamination by leachates from the barnyard. A topographic map, bedrock contour map and groundwater depth measurements from the area were used to ascertain groundwater movements. The average depth to groundwater below the barnyard was eight feet. Equal concentrations for 5, 10 and 15 ppm inorganic-N were decidedly elongated in the direction of flow of the groundwater beneath the barnyard. The concentration of inorganic-N was found to be dependent upon the amount of leachate reaching the groundwater and the rate of lateral flow of the groundwater which determined the dilution effect upon the leachate entering the groundwater. Over a 5-month period, calculations which considered the rate of leaching and rate of groundwater flow indicated the movement of 2.0 kg of nitrogen (predominantly NO_3^-) into the groundwater and that 395 cu m of water would be required to dilute this amount of NO_3^- to acceptable health standards. The average concentration of NO_3^- -N in the groundwater for the 5-month study ranged from 0.2 ppm 90 m from the barnyard in the upgradient direction to 66 ppm at a location near the barnyard.

In east central Nebraska, groundwater from a fluctuating high water table was periodically sampled from 1968 to 1970 near a level feedlot on a permeable soil (57). The groundwater level ranged from 0.6 to 2.1 m from the feedlot surface. Except for two samples obtained during the entire study, NO_3^- -N was well below 10 ppm. In 1969 the highest level occurred in conjunction with commencement of irrigation pumping. Prior to irrigation in 1970 a dye injected into the groundwater beneath the feedlot showed that upon initiation of irrigation the water from beneath the feedlot was being sampled at the wells immediately outside the lot. Nitrate levels in the well samples were not changed significantly by initiation of irrigation pumping. Groundwater NO_3^- levels were generally lower downgradient from the feedlot than upgradient, assuming a flow gradient toward the irrigation pump. No explanation for this was found.

McCalla et al. (60) found little NO_3^- buildup in the soil profile beneath a feedlot down to a depth of 2.7 meters. Below 0.6 m all values were less than or equal to 5 ppm NO_3^- -N. At the same depths the buffer zone surrounding the feedlot was higher in NO_3^- -N with some values reaching higher than 10 ppm. The increase in the buffer zone was attributed to ammonia absorption on the surface soil, manure dust from the feedlot, and cattle retention in the area when being weighed or moved. The electrical conductivity of the soil saturation extract of the beef feedlot profile was less than 0.32 mmhos/cm at all depths. Nitrate nitrogen levels as high as 63 ppm were found in the groundwater below the feedlot area but were attributed to leaks in runoff detention structures rather than leaching throughout the feedlot area.

Stewart et al. (84) studied the distribution of NO_3^- and other water pollutants under fields and corrals in the Middle South Platte Valley of

Colorado. Soil samples taken at 30-cm increments to bedrock or the water table under corrals indicate that NO_3^- -N ranged from almost none to 5,600 kg/ha in a 6-m profile. The average NO_3^- level at depths down to 6 m was higher for corrals than for irrigated fields. Generally, corrals contained little NO_3^- in the top 30 to 90 cm, high amounts for the next 2.5 to 3.5 m and then rapidly decreasing amounts at the deeper depths. The average electrical conductivity for all samples obtained at the 0- to 6-m depths for irrigated fields and corrals was 1 and 1.7 mmhos/cm, respectively.

When the redox potential was below 320 to 340 mv (millivolts) in the Colorado study, there was seldom any NO_3^- present, indicating the oxygen level was too low for NO_3^- to accumulate. Nitrate accumulated readily at redox potentials greater than 340 mv. Cores from a feedlot and an irrigated corn field in the same area were chosen to study the possibility of denitrification beneath the feedlots which might explain the rapid decrease of NO_3^- at the lower depths below the feedlots. A higher carbon content and about ten times as many bacteria were found below the 4.6 m depth under the feedlot than under the irrigated corn field. The potential at which NO_3^- failed to accumulate agrees well with values found by Meek, Grass, and MacKenzie (65) which indicated that denitrification may occur at redox potentials less than 300 mv. These factors indicate that a potential probably existed for denitrification to take place at the lower depths.

Water samples taken in the same study indicated a greater movement of NH_4^+ and organic carbon into the groundwater under the corrals than under the irrigated fields. The average NH_4^+ -N concentration below 28 irrigated fields was 0.2 ppm while water samples below 29 feedlots averaged 4.5 ppm NH_4^+ -N. Organic carbon in water samples below irrigated fields averaged 14 ppm compared to 73 ppm for water samples from below feedlots. Although NO_3^- was also

commonly found below both irrigated fields and feedlots in groundwater, less consistent differences were found between these two sources when samples were collected in the area (83).

Adriano et al. (2) considered the NO_3^- and salt content of the unsaturated zone between the zone of root influence and the saturated zone on alluvial lands to be the potential contaminants of groundwater. This zone corresponded to the 3- to 5.5-m depth. At this depth little difference in NH_4^+ and NO_3^- was observed between dairy corrals, and pasture and crop land used for dairy waste disposal. Nitrate-N ranged from 12.9 to 18.6 ppm under the corrals, and from 7 to 10.7 ppm under the pasture and crop land disposal sites at the 3- to 5.5-m depth.

Studies of the upper soil profile under application of feedlot runoff indicate that under high rates of application, NO_3^- may accumulate (76, 91). After the second year of application of cattle feedlot runoff on corn forage at a rate of 46 cm/year, a nitrate buildup of 15 ppm NO_3^- -N was found at a depth of 1 m. Another buildup of 10 ppm NO_3^- -N was found at the 240-cm depth (91). This was a significant change from the situation prior to the first year of application in which no prominent NO_3^- accumulations were found below 30 cm. Satterwhite and Gilbertson (76) applied 30.5 cm of feedlot runoff during one irrigation season and noted average concentrations of 14 and 5 ppm of NO_3^- -N at the 0- to 90-cm depths, respectively. This is compared with less than 1 ppm NO_3^- -N at all depths from 0 to 90 cm before application of feedlot runoff.

Land Disposal of Liquid Feedlot Wastes

Successful long-term use of the soil as a waste disposal medium requires consideration of three major objectives: 1) operation within the pollution

reduction potential of the soil, 2) maintaining the ability of liquids to infiltrate and percolate at acceptable rates in the soil profile, and 3) maintenance of the potential of the soil for crop production. These objectives overlap to some degree and seem to be complimentary in some respects. For example, favorable infiltration and percolation rates generally enhance crop production which in turn may increase the pollution reduction potential of the soil by nutrient uptake. Any one of these objectives may be compromised to a certain extent, depending upon the needs and priorities dictated by a given waste disposal situation, but the first objective will continue to be a primary consideration.

I. The soil's potential for liquid waste renovation.

Soil application of anaerobically-treated swine waste similar to cattle feedlot runoff in quality has been studied as a supplementary waste treatment process (53). The four treatment levels were 3.8 and 7.6 cm at 95% available soil moisture at the same depth. Within the loading range of 35.3 to 77.5 cm of lagoon effluent the four treatment levels performed similarly. Percolation of the grass-covered soil profile reduced the COD, P, and N concentrations 95, 99, and 80%, respectively, during three months of operation. These values were obtained by comparing the content of the effluent as it was applied to the soil surface with the content of soil percolate as it entered tile drains at a depth of 120 cm. The effective depth of the drains (distance the percolate traveled) is not known due to the nature of the flow patterns to the tile drains.

After application of anaerobically-treated swine waste during three consecutive irrigation seasons, the plots continued to accept the anaerobically-treated lagoon water as well or better than during the first

year (54). Three 1.7-cm applications gave better removal of potential pollutants than one 5-cm application. Total-N was the constituent most limiting the amount of liquid that could successfully be applied in a season. At the most intense application rate which was 79 cm in 15 applications throughout the irrigation season, the total-N in the tile drains reached 190 mg/l. The COD was removed much faster than the total-N concentration. Thus, the organic matter in the lagoon effluent did not serve as an adequate energy source for denitrification below the 15-cm depth. Below this depth, soil organic matter was seemingly the primary energy source.

To determine the waste water renovation potential (by ion removal) of six Connecticut soils, 2.54 cm of a synthetic sewage effluent was applied semiweekly for 2 years to undisturbed soil cores (43). The cores were 30 cm in diameter and 100 cm deep. Chemical analysis of the leachate revealed that virtually all the orthophosphate was removed from the effluent by the A horizon of all the soils. All soils evaluated except a sandy Merrimac soil and a calcareous Stockbridge soil removed greater than 85% K, and 75% Ca and Mg, but less than 10% Na. The Stockbridge soil contained abundant dolomitic limestone particles which led to removal of less than 50% Ca and the release of three times the Mg contained in the effluent over a 21-month period. Weathered dolomite was the primary source of Mg. Nitrate and chloride passed readily through the cores throughout the study with a range of 0 to 5% renovation of the synthetic sewage regarding these two ions for all the soils. Crop growth could be expected to improve the renovation potential of these soils in the field. It was calculated that the longevity of the soil systems studied for removing cations would be from 10 to 13 years.

II. Evaluation of the quality of liquid feedlot wastes for irrigation.

Some insight into gaining objectives two and three while using the soil as a waste disposal medium may be achieved by evaluating feedlot runoff from an irrigation water quality perspective. This approach ignores some differences between "natural" irrigation water and liquid feedlot wastes such as carbon content but generally may provide helpful guidelines.

In considering the impact of a given irrigation water upon soil properties, not only the dissolved constituents within the water must be considered but also the chemical and physical properties of the soil and climatological characteristics of the receiving area. Soils that are relatively impermeable and have restricted drainage often accumulate excessive amounts of salts from irrigation water. Failure of excessive amounts of salts to be leached from the root zone may lead to development of saline, nonsaline-alkali, or saline-alkali soils, depending upon which ions predominate in the irrigation water (75). Each of these soil conditions may lead to reduced crop growth.

Definitions of these three soil conditions according to the United States Salinity Laboratory staff (75) are as follows:

Saline Soil--A nonalkali soil containing soluble salts in such quantities that they interfere with the growth of most crop plants. The electrical conductivity of the saturation extract is greater than 4 mmhos per centimeter (at 25°C.), and the exchangeable-sodium-percentage is less than 15. The pH reading of the saturated soil is usually less than 8.5.

Saline-Alkali Soil--A soil containing sufficient exchangeable sodium to interfere with the growth of most crop plants and containing appreciable quantities of soluble salts. The exchangeable-sodium-percentage is greater than 15, and the electrical conductivity of

the saturation extract is greater than 4 mmhos per centimeter (at 25°C.). The pH of the saturated soil is usually less than 8.5.

Alkali Soil--A soil that contains sufficient exchangeable sodium to interfere with the growth of most crop plants, either with or without appreciable quantities of soluble salts.

The adverse effects of saline soils upon plant growth are due mainly to a high osmotic potential within the soil solution which limits the ability of plant roots to imbibe sufficient amounts of water and reduces rates of germination. In a study with red kidney bean (P. vulgaris L.) plants which tend to be very sensitive to soil salinity, for most mixtures of salts a linear relationship between growth and osmotic concentration expressed in atmospheres was found which indicates that the detrimental effects of soil salinity may be due at least in part to reduced availability of soil moisture (30). Ayers (4) noted an interaction between salinity and soil moisture. As soil moisture was increased, a given salinity level reduced to a lesser degree the percent emergence of onion seeds. Meristematic activity and rate of entry of water into corn plants grown in nutrient solutions with high osmotic concentrations was reduced significantly relative to the control nutrient solution at 0.8 atm osmotic concentration (39).

The primary problem associated with nonsaline-alkali soils is the deterioration of soil structure as the exchangeable Na percentage approaches 15. This deterioration results from the dispersion effect of the hydrated Na^+ ion upon soil colloidal particles. A dispersed soil has a lowered capacity for gaseous interchange which may result in oxygen deficiency at the absorbing surfaces of roots, and the reduced ability of plants to take in adequate quantities of water (62). Nonsaline-alkali soils are characterized as being hard, impermeable, and difficult to till. In a study of the various soil

characteristics which might show a wide differential between soil supporting good growth and adjacent alkali spots, infiltration was the most consistent criterion found. The poor infiltration on the alkali spots caused these areas to be deficient in moisture most of the time (26).

As long as excess salts are present, the appearance and properties of saline-alkali soils are generally similar to those of saline soils. The dispersion of soil aggregates caused by Na is not as pronounced as in alkali soils due to the depressing effect of the excess soluble salts. However, if the excess soluble salts are leached downward, the properties of these soils may change markedly and become similar to those of nonsaline-alkali soils (75).

The role of K regarding soil physical properties and more specifically soil dispersion is uncertain. De Sigmond (78) considered the predominant characteristic of an alkali soil to be that the bases Na and K additively constitute more than 12% of the total exchangeable bases on the soil exchange complex. More recent research indicates that the effect of K and Na upon soil physical properties may not be additive (28). The weighted-mean diffusivity for the entry of water into a Pachappa sandy loam soil under unsaturated soil moisture conditions when K saturated was ten times greater than when Na saturated. The weighted-mean diffusivity values for the K saturated soil coincided almost identically with those for the same soil having an exchangeable Na percentage of 25 with the remaining exchangeable cations being calcium.

Reeve et al. (74) compared the effects of K and Na on modulus of rupture and the permeability ratio (air to water) of soils which had been first saturated with Ca and then brought to various levels of exchangeable Na and K by adding the bicarbonate of these two cations. Increasing the exchangeable Na percentage increased markedly the permeability ratio and modulus of rupture

whereas K had very little effect on these parameters. In a study similar to that of Reeve et al. (74), the effect of levels of exchangeable Ca, Mg, K, and Na ranging from 0 to 80% of the total cation exchange capacity on the same two parameters was ascertained for eight soils (9). Generally, over the range of exchangeable cation percentages studied, the permeability ratio increased markedly with increasing exchangeable Na, but increased insignificantly with additions of Mg and K. Modulus of rupture increased over the range of exchangeable cation percentages with the largest increases being from Na, next largest from Mg, with the lowest increase being from K. Combinations of various levels of exchangeable Na and K showed that exchangeable K had little if any additive effect with Na in increasing the permeability ratio but reduced the modulus of rupture for several soils.

The role of K as it affects soil physical properties seems controversial. A review of subject matter relative to saline and alkali soils by Magistad (58) implies that emphasis upon the additive effect of K along with Na in creating alkali soil conditions was first lowered because K rarely composes a significant portion of the cation exchange complex of soils. This assumption may be inaccurate for soils receiving long-term applications of feedlot runoff since this irrigation medium characteristically contains very high concentrations of K when compared with the other cations commonly found on the cation exchange complex of soils as shown in Table 3. Travis et al. (90) attributed part of the reduced infiltration observed in soil columns receiving feedlot runoff to the monovalent cation content (Na, K, NH_4) of the feedlot runoff of which K was a major constituent. The significance of K in alkali soils seems to remain a controversial matter and one which warrants further investigation.

Conventional methods of evaluating the irrigation water quality of feedlot wastes ignore K as a dispersing agent. Accordingly, the sodium absorption

ratio (SAR) is one method of expressing indirectly the quality of irrigation water with respect to its dispersion hazard. The SAR may be expressed as

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

where Na, Ca, and Mg are expressed in milliequivalents/liter (75). A high degree of correlation has been found between the SAR of irrigation water and the exchangeable Na percentage (ESP) which may be expected to develop in a soil upon coming to equilibrium with the irrigation water where ESP may be defined as:

$$ESP = \frac{\text{Exchangeable Na (meq/100 g soil)}}{\text{CEC (meq/100 g soil)}} \times 100.$$

The SAR of irrigation water is used at the U. S. Salinity Laboratory to predict the dispersion hazard likely to develop from various qualities of water. Soil dispersion becomes a problem when the ESP in the soil reaches approximately 15 (75).

Gapon's equation, which is based on the equilibrium between soluble and exchangeable cations in the soil has also been used to predict the ESP likely to develop in a soil from irrigation with a given quality of water (6, 47, 55). The modified version of this equation is expressed as

$$ESP = \frac{100 \text{ Kg} \cdot \text{Na}}{\sqrt{\frac{\text{TSC} - \text{Na}}{2}} + \text{Kg} \cdot \text{Na}}$$

where Kg = Gapon's proportionality factor,

Na = meq soluble Na/l within the irrigation water, and

TSC = meq total soluble cations/l.

Assumptions pertaining to this equation for predicting the dispersion hazard from a given irrigation water are as follows:

1. Free drainage throughout the soil profile
2. The soil cation exchange capacity is occupied by Ca^{++} , Mg^{++} , and Na^+
3. Exchangeable Na is the only dispersing agent.

Gapon's proportionality constant (K_g) varies from horizon to horizon of a given soil and from soil to soil. It is a function of exchangeable ion species and salt concentration (6, 25, 55). Jacobs et al. (47) evaluated K_g for 17 Kansas soils by regression analysis between K_g and soil saturation percentage, both of which were represented by averages from the top 1.5 m of soil. In Kansas, Gapon's equation was used by Jacobs and Whitney (48) to formulate irrigation water quality charts for predicting the dispersion hazard from irrigation water.

Travis et al. (90) studied the effects of cattle feedlot lagoon water applications on undisturbed soil columns by measuring the amount and type of salt accumulation throughout the columns and the soil dispersion as determined by the reduction in water flow through the columns. The lagoon water with characteristics shown in Table 4 was added to undisturbed alluvial soil columns 42 cm in length and 6.7 cm in diameter. Water flow in the soil columns stopped for all soils before two pore volumes of filtrate could be collected. The electrical conductivity of the saturation extracts of the top 15 cm of each column was increased by more than 200% and ranged from 2.80 to 5.05 mmhos/cm. In the top 3 cm of soil Na represented from 36 to 15% of the total leachable cations. The range for $(\text{Na} + \text{K} + \text{NH}_4)$ as a percent of the total exchangeable cations was 76 to 32%. Lagoon water simulant composed of cation concentrations similar to the feedlot lagoon water, but without the organic components, was added to two of the same soil types which received feedlot lagoon water originally to test the hypothesis that the stoppage of

Table 4
Some characteristics of Kansas State University
feedlot lagoon water (90).

Parameter	Concentration	
Cations	(ppm)	(meq/l)
Na	1085.6	47.2
K	686.4	17.6
NH ₄ ⁺ -N	473.2	33.8
Ca	296.0	13.8
Mg	60.0	5.0
Anions		
Cl	1952.5	55.0
SO ₄ ⁼ -S	49.5	3.1
NO ₃ ⁻ -N	7.0	0.5
Total Phosphorus	80.6	16.1
Electrical conductivity	13.4 mmhos/cm	
pH	7.7	
Solids	(ppm)	(percent)
Organic	4152	0.4142
Inorganic	5816	0.5816

water flow through the soil columns was at least in part due to an imbalance in the proportions of Ca, Mg, Na, K, and NH_4 ions. Infiltration of the lagoon water simulant stopped in the finest textured of these two soils indicating that the flow stoppage may in part have been due to an imbalance of the proportions of cations contained in the feedlot lagoon water rather than the organic or some other fraction of the lagoon water not contained in the simulant. Dilution was suggested as a means of improving the quality of feedlot runoff for irrigation.

Some of the changes in infiltration rates from liquid waste application are biological rather than dispersion phenomena. Changes in the biological composition of the soil due to the application of liquid organic wastes have been observed to cause reduced infiltration rates (73, 95). Thomas, Schwartz, and Bendixen (88) found that the primary site of clogging due to sewage spreading on soil was at the 0- to 1-cm depth. Iron, phosphate, polysaccharide, polyuronide, and total organic matter were all found to increase in the zone of clogging. Recovery from plugging was accomplished with removal of organic matter only, but the physical properties of the other compounds may have changed upon dehydration which may have contributed to the unplugging process.

Rath (73) investigated the permeability of an unvegetated surface soil as affected by treatment with anaerobic swine waste lagoon effluent. The effluent was applied so as to maintain the free water surface at the soil surface, a situation similar to that found under sprinkler irrigation. Changes in permeability were assumed to be due to zooglear accumulations in the soil surface. It was found that the permeability of unvegetated soil surface decreased exponentially with time upon application of anaerobic swine waste lagoon effluent. This reduction was considerably greater than for distilled water. High infiltration rates were maintained with short daily

application intervals while greater absolute volumes of effluent percolated over a period of several days with application intervals of up to 12 hours. Continuous application of lagoon effluent resulted in a permeability reduction in the receiving soil of from 0.25 to 1.25 cm/hr by the fourth day after initial rates of greater than 5 cm/hr for a previously saturated soil. The recovery period for permeability following application increased significantly with duration of application.

III. Liquid animal wastes and crop production.

This section of the literature review will be limited to liquid livestock wastes. A more general review of land application of wastes has been prepared by Travis (89) which includes a rather thorough review of recent projects using sewage effluent as an irrigant.

The fertilizer value of livestock and sewage wastes has been recognized for many years as verified by systematic application of these wastes on the land in Europe before the turn of the century (19). In 1934 Weise (93) proposed that the fertilizer value of sewage be used to aid in the agricultural independence of Germany. He noted that agricultural authorities had advocated the application of 30 to 60 cm of sewage per year and that a 50-cm application of sewage would amount to 380 kg N, 100 kg P_2O_5 , and 370 kg K per hectare.

The ability of crops to extract nutrients from liquid manure has been demonstrated by Castle and Drysdale (12). They reported an increase in total yields of grass vegetation, increased clover content, and a decrease in dicotyledonous weeds in a grass legume meadow which received liquid manure, a mixture of primarily cow urine and water. In a following study, 77 kg N/ha and 128 kg K/ha were applied as liquid manure and conventional inorganic fertilizers in November, December, January, February, and March (19). Dry matter

yields were greatest when the liquid manure was applied in February. The conventional inorganic fertilizers produced slightly higher yields of dry matter and crude protein, and showed a greater overall recovery of applied N than the liquid manure but yields from the two sources were statistically different at only one location. The residual value of the liquid manure at the second cutting was negligible. In a third study N and P applied at similar rates as liquid manure and conventional fertilizers produced almost identical yields of dry matter but the liquid manure treatments gave approximately twice the yield of clover (20).

Liquid manure has also been investigated as a grassland fertilizer in Scotland (40, 41, 42). These studies indicated that the N in the liquid manure was used about 60% as efficiently as N from inorganic fertilizers. Optimum use of the high levels of K in the liquid manure required supplemental application of fertilizer N. Soil type, time of application, and weather were found to influence the response from liquid manure applications. Best results were obtained from heavy clay soils and soils high in organic matter. Winter applications of liquid manure on light soils under wet conditions were thought to have resulted in large losses due to leaching.

Recent studies in the United States have shown variable crop response to applications of feedlot runoff. Satterwhite and Gilbertson (76) applied beef feedlot runoff collected in two consecutive years to grass seedlings of various species in a greenhouse study and found the runoff collected the first year to have a negative effect on plant growth while the runoff collected the second year had a positive effect. After 14 days of growth, more than half of the seedlings of some species died from application of the first year runoff whereas seedlings receiving the second year runoff produced 63% more herbage dry matter and had a significantly higher protein content than

seedlings receiving tap water. A high nitrogen concentration in the first year runoff was suggested as a possible cause of the negative growth response to that material.

Field plots with mixed species of grass in east central Nebraska were sprinkler irrigated weekly 6 times from July to September at rates of 0, 1.27, 2.54, 3.81, and 5.08 cm/week of beef feedlot runoff and yielded 69, 164, 3, and 313% greater harvestable grass material, respectively, than corresponding plots receiving stream water (76). Nitrogen analysis of smooth brome grass (Bromus inermis L.), reed canarygrass (Phalaris arundinacea L.), and bluegrass (Poa spp. L.) revealed larger protein content in plant samples taken from plots receiving feedlot runoff than in plant material from corresponding plots receiving stream water. The maximum application rate of 5.08 cm/week for a total of 30.5 cm of feedlot runoff with an electrical conductivity of 4.6 mmhos/cm had a positive effect on growth of grass vegetation.

The effect of land disposal of beef feedlot runoff by furrow irrigation on growth and composition of corn forage was investigated in a 2-year study (91). Rates of 0, 8, 15, 26, and 46 cm/year of runoff with an average electrical conductivity of 3.1 mmhos/cm were applied each year in 5- and 10-cm increments. The higher application rates resulted in increases in the electrical conductivity of the soil saturation extract. A good correlation between accumulative application rate and electrical conductivity of the saturation extract of the surface soil was found as indicated by R^2 values of 0.878 and 0.875 for the two years. Yields increased linearly with application rates the first year but the relationship between accumulative applications and yield the second year was quadratic. During the second year yields increased from application rates of up to 25 cm/year but fell off at higher rates. The yield response to lower rates of feedlot runoff was attributed to

improved soil fertility while the yield decline at higher rates was considered to be likely due to a salt buildup in the soil as the electrical conductivity of the surface soil saturation extract at the higher rates reached 3 mmhos/cm. The relationship between uptake of N, P, K, Ca, Mg, and Na and accumulative application rate was linear the first year and quadratic the second year in a manner similar to the relationship between accumulative application rate and yield. During the last year maximum yield and uptake of most of these elements occurred at the 15 cm/year application rate.

METHODS AND MATERIALS

Field Design

The purpose of this study was to determine the effects of irrigation with cattle feedlot lagoon water on the yield and composition of bromegrass, on movement and accumulation of salts in the soil profile, and on groundwater quality below the application area. The site for this study was located in Pottawatomie County, Kansas 400 m from the Kansas River on an alluvial silt loam soil which varied in texture with depth from a silt loam at the surface to a sand in the form of a sand lense approximately 30 cm thick located at depths ranging from 70 to 120 cm across the study area. The receiving area for the cattle feedlot runoff and the facilities for delivering runoff onto the receiving area were all part of a feedlot pollution control facility installed by a commercial feedlot for retention and disposal of feedlot runoff.

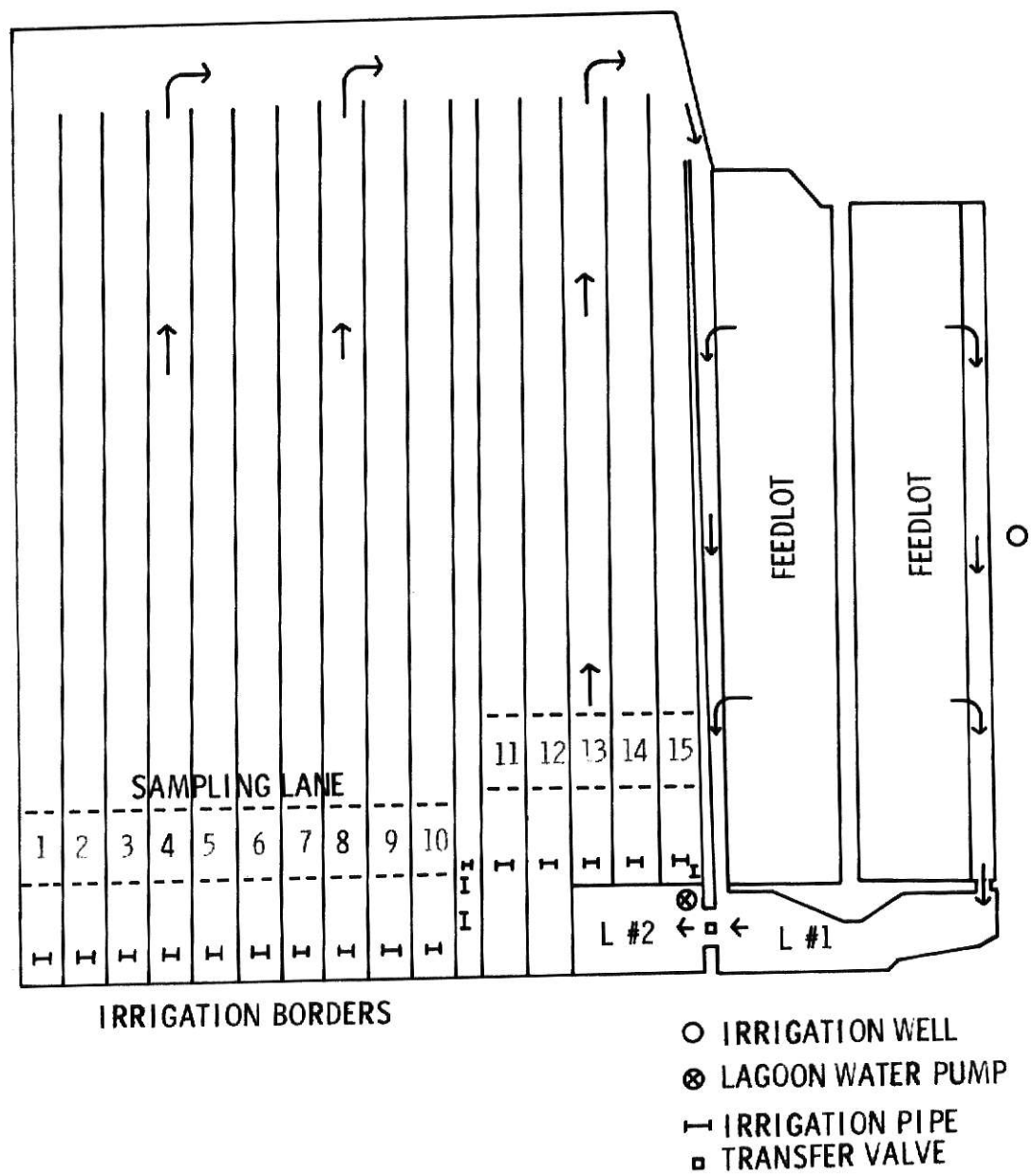
A diagram of the physical layout of the pollution control facilities employed in this study is shown in Figure 1. Runoff from the feedlot area was first collected in lagoon #1 and then allowed to flow into lagoon #2 either as overflow from lagoon #1 or through the transfer valve between the two lagoons. Lagoon #1 emptied into lagoon #2 by gravity flow. Following precipitation runoff events, the runoff retained by the lagoons was used for border irrigation of the adjacent 11-ha field. The various treatments of lagoon water were delivered through 15-cm irrigation pipe to borders which were 18 m in width and were designed with a 2% slope for drainage to the north. A closed system was maintained as any tailwater from lagoon water applications or excessive runoff from precipitation events emptied into the feedlot drainage ditches and returned to the catchment lagoons.

**THIS BOOK
CONTAINS
NUMEROUS PAGES
WITH DIAGRAMS
THAT ARE CROOKED
COMPARED TO THE
REST OF THE
INFORMATION ON
THE PAGE.**

**THIS IS AS
RECEIVED FROM
CUSTOMER.**

FIGURE 1
FIELD AND FEEDLOT LAYOUT

N ↑



The sampling lane (experimental area) was a 30-m strip running perpendicular to the irrigation borders and located 35 m from the delivery points along the irrigation pipe. The location of lagoon #2 in the corner of the field necessitated staggering the irrigation pipe and the sampling area in borders 11 to 15. The sampling area in each border was treated as one plot and will be referred to as a plot or lane. A randomized complete block design composed of five treatments replicated three times was employed. Plot locations are shown in Figure 1. The treatment randomization is shown in Table 6. The field was benched during the leveling process as shown in Figure 2. All of replication three is located on the lower bench.

Bromegrass was planted on the field in the fall of 1971. This crop was not harvested until October of 1972 at which time approximately 200 head of feeder cattle which were on full feed were allowed to graze on the bromegrass. Approximately the same number of cattle were allowed to loaf in the field area intermittantly throughout the winter due to unusually wet weather conditions and resulting unfavorable surface conditions in the feedlot. The sampling lane was fenced off from the rest of the field early in the spring of 1973 and allowed to grow without being pastured or harvested until yield data were collected in May of 1973.

Two sampling wells were placed in each plot for the purpose of monitoring groundwater quality beneath the sampling lane. One of these wells in each plot extended into the upper portion of the water table at a depth of 7.6 m. The other well in each plot extended to bedrock at a depth of 21 m (Figure 3). The deep and shallow sampling wells in each border were spaced 6 m apart and each well was located 6 m from the nearest berm. All the sampling wells were located on the longitudinal center-line of the sampling lane.

FIGURE 2
VERTICAL CROSS-SECTION OF THE ENTIRE SAMPLING LANE

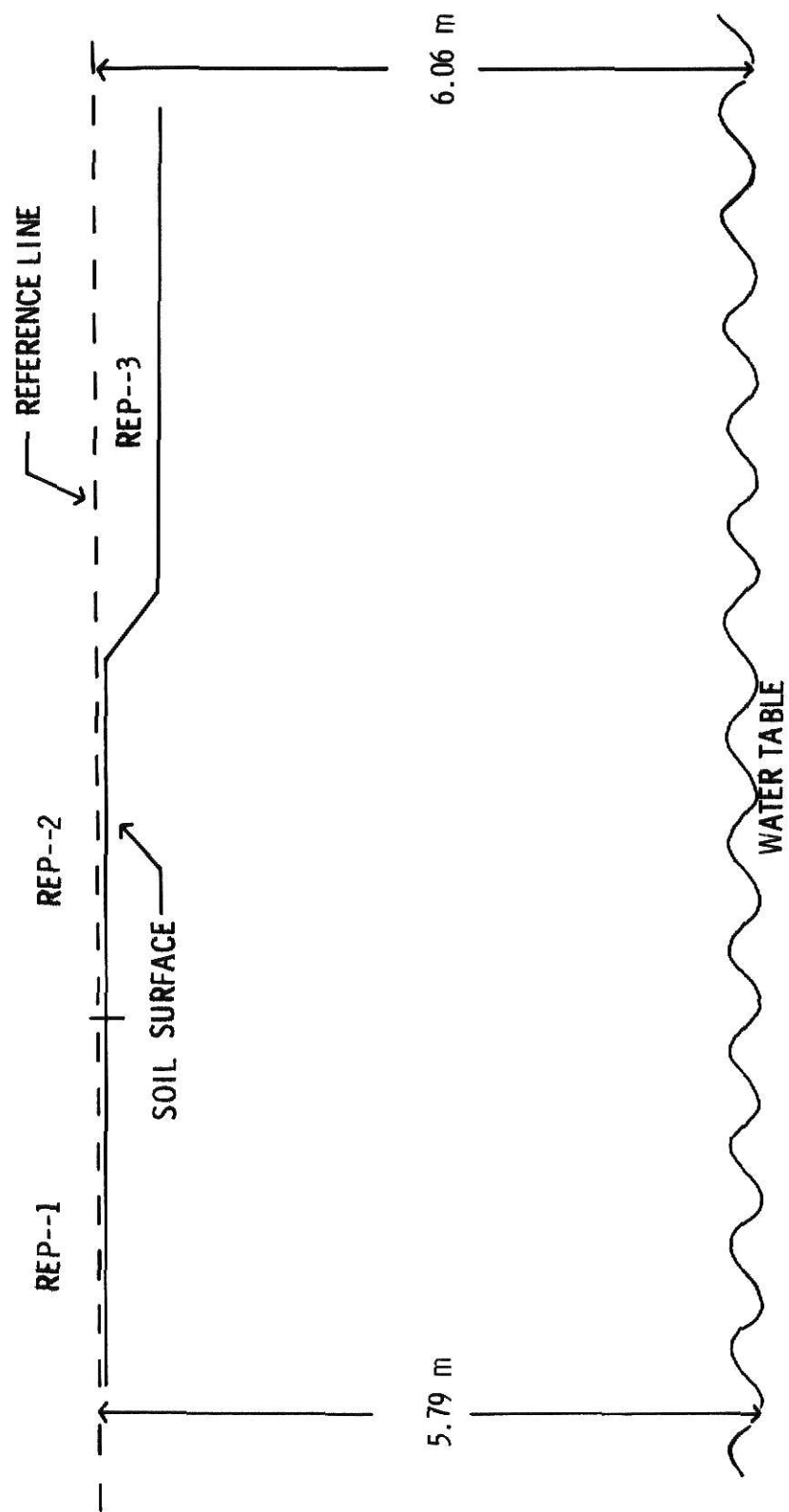
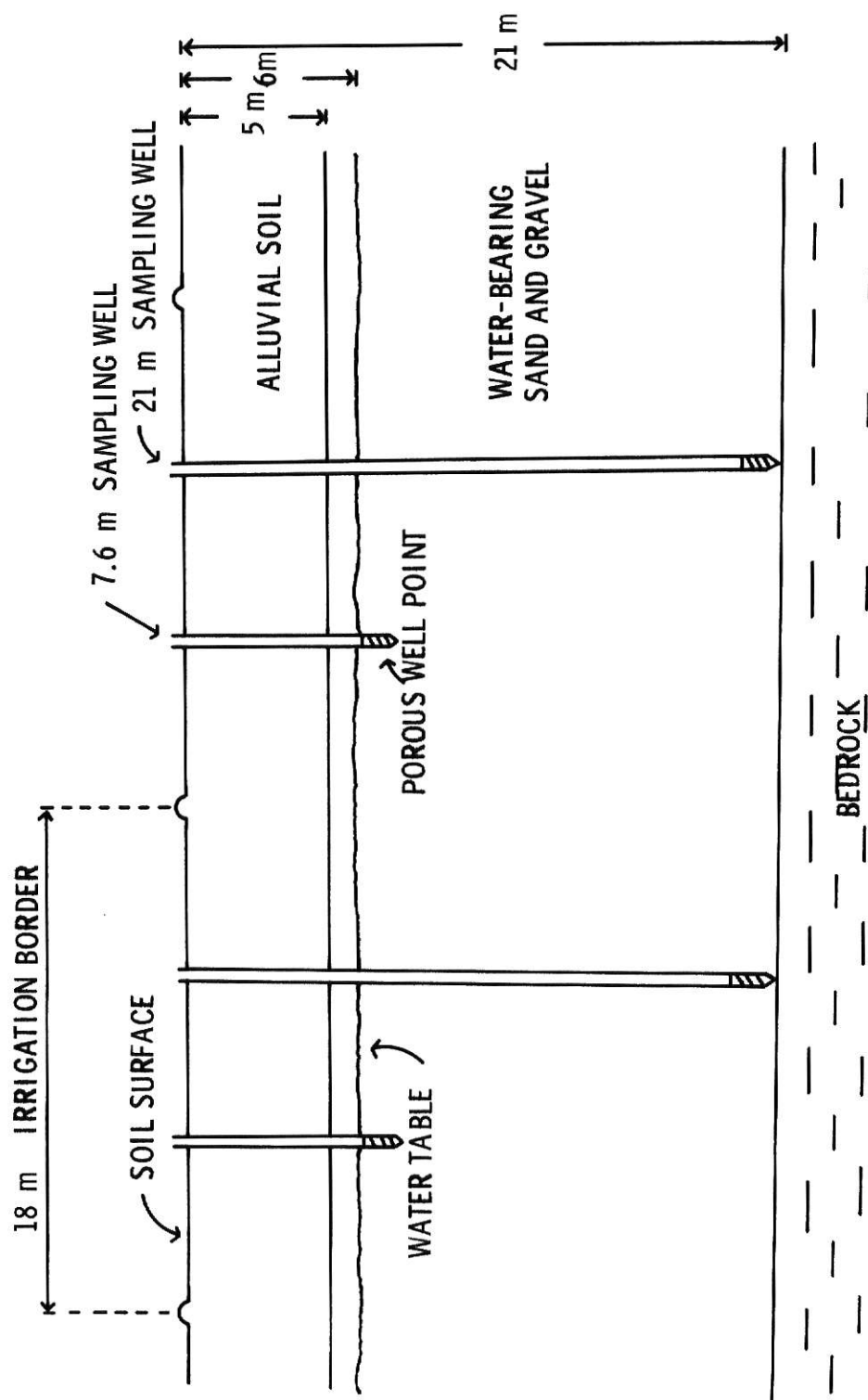


FIGURE 3
VERTICAL CROSS-SECTION OF SAMPLING LANE



The purpose of the shallow wells was for determining the level of contamination in the upper groundwater table while the purpose of the deep wells was to serve as controls for the respective shallow wells in each plot. The deep wells were included in the experimental design under the assumption that an increase in the level of contamination of groundwater at the shallow depth without an accompanying increase at the deeper depth at a point in time would indicate leachate from the soil profile to be a highly probable source of the contamination in the shallow wells. In contrast, if parallel changes in the level of contamination at both depths occurred at a point in time, a regional or nonlocal source would have to be considered as a likely origin of contamination in the groundwater.

The materials for the sampling wells consisted of schedule 40, 5.08 cm PVC pipe and 3.18 x 30 cm Johnson Redhead sand points. After the holes were drilled at the designated depths, the sand points and PVC pipe were placed in the holes and backfilled with sand and gravel to within 60 cm of the soil surface. Soil was then packed around the well-pipe from the top of the grouting and mounded above the soil surface. The grouting and soil pack were for the purpose of preventing the initiation of free-water movement between the well-pipe and the surrounding material.

As noted in Figure 3, the alluvial soil extends down 5 to 6 m from the soil surface. Water-bearing sand and gravel extend from the lower alluvial depositions to bedrock at 21 m below the soil surface. A survey of the depth to the groundwater table in the shallow wells from a reference line level with the soil surface at plot one (Figure 2) was taken soon after the sampling wells were installed to determine the lateral hydraulic head gradient in the groundwater below the sampling lane. The results of this survey are shown in Table 5. The maximum difference in water level between any two of the

shallow wells was 27 cm which was found between plots 1 and 15. The maximum difference in water level between any two of the shallow wells in adjacent plots was 12 cm which was found between plots 7 and 8. It follows that the maximum lateral hydraulic head gradient in the groundwater table between the shallow wells in any two adjacent plots was 0.6 cm/m.

Table 5

Depth (cm) to groundwater beneath the sampling lane from a reference line on the level with plot 1 for the shallow wells in plots 1 to 15.

Plot														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
579	582	582	582	586	582	580	592	589	588	592	593	598	599	606

The hydraulic head difference from the surface of the groundwater beneath the sampling lane at plot 12 to the surface of the Kansas River was measured at a time when the river stage was low relative to the stage at other periods of time during this study as reported by a U. S. weather reporting station located nine kilometers upstream. The hydraulic head difference between the groundwater beneath plot 12 and the Kansas River at the closest point from plot 12 was found to be 80 cm with the gradient being toward the river.

Treatment Application and Measurement

The treatment number, relative rate of application, and material applied for each of the five treatments is presented in Table 6. Two rates of non-diluted lagoon water, two rates of diluted lagoon water, and one rate of irrigation water composed the five treatments. The available lagoon water at the time of irrigation was divided equally between the non-diluted lagoon water treatments and diluted lagoon water treatments. The half of the lagoon water allocated to each of these two treatment types was further allocated

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CONTAINS
NUMEROUS PAGES
WITH ILLEGIBLE
PAGE NUMBERS
THAT ARE CUT OFF,
MISSING OR OF POOR
QUALITY TEXT.**

**THIS IS AS RECEIVED
FROM THE
CUSTOMER.**

Table 6

Allocation of lagoon water to various treatments.

Treatment	Type of treatment	Fraction of lagoon water per	
		Type of treatment	Treatment
1	Straight irrigation well water - - - - - (amount applied equal to volume in treatment 2)	- - - - -	0
	Straight lagoon water - - - - -	1/2	
2	- - - - -	- - - - -	1/5
4	- - - - -	- - - - -	3/10
	Diluted lagoon water - - - - -	1/2	
3	- - - - -	- - - - -	1/5 + irr. water
5	- - - - -	- - - - -	3/10 + irr. water

Treatment randomization:

Plot	Replication - 1					Replication - 2					Replication - 3				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Treatment no.	4	1	3	2	5	4	5	3	1	2	4	1	2	3	5

between the two rates within a treatment type so as to provide one rate that was 1.5 times greater than the other rate on a volume basis. This implies that 0.2 of the available lagoon water was allocated to each of the lower rate treatments and 0.3 of the available lagoon water was allocated to each of the higher rate treatments. The lagoon water allocated to the diluted treatments was diluted to meet water quality standards for irrigation as specified by Jacobs and Whitney (48), thereby creating a greater volume of application for diluted treatments than for comparable non-diluted treatments. One other treatment was composed of irrigation well water at a volume rate equal to that of the lower rate non-diluted lagoon water treatment. The latter treatment was applied to remove water as a growth variable and was eliminated under moist soil conditions at the time of irrigation.

Prior to irrigation, samples of the lagoon water were collected at a depth approximately one-half of the distance from the surface of the lagoon water to the bottom of lagoon #2. A minimum of six samples was collected prior to each irrigation and analyzed for electrical conductivity (mmhos/cm). The remainder of these samples were stored at 5°C until other analyses were performed.

The general procedure for applying the treatments was to apply the non-diluted lagoon water treatments first and then dilute the remaining lagoon water with irrigation well water to the extent that the diluted lagoon water met water quality standards for irrigation. For example, if one started with both lagoons full and if the ratio of irrigation well water to lagoon water needed to be 2:1 to meet irrigation water quality standards, the procedure would be to pump two-thirds of the lagoon water in lagoon #2 onto the field as the non-diluted lagoon water applications. Lagoon #2 would then be filled back up to capacity with well water as a diluting medium. The resulting

diluted mixture would provide material for one-half of the diluted applications. The rest of the material for the diluted applications would be acquired by transferring contents from lagoon #1 to fill lagoon #2 to one-third capacity and then subsequently diluting this material with well water by filling lagoon #2 to full capacity.

To determine the amount of well water needed for dilution of the lagoon water to a given electrical conductivity the following equation was used:

$$(V_L) (EC_L) + (V_W) (EC_W) = (V_L + V_W) (EC_I)$$

where V_L and V_W are the volumes of lagoon and well water and EC_L , EC_W , and EC_I are the electrical conductivities of the lagoon water, well water, and final irrigation water. This equation can be solved for V_W/V_L to give the ratio of well water to lagoon water needed to obtain the desired electrical conductivity of the final irrigation water.

The lagoon water was delivered to the field at a rate of approximately 2.66 kl/min (700 gal/min) by a centrifugal pump. Discharge from the pump was routed through a flow meter located adjacent to the lagoon pump which enabled volumetric measurement of applications of lagoon water.

The metering system was built in an L-shape. One leg of the metering system received lagoon water from the lagoon pump and the other leg received water from an irrigation well, the location of which is shown in Figure 1. After flowing through the metering system the well water and lagoon water both followed the same route of delivery to the field.

Four neutron probe access pipes were placed in each plot for the purpose of measuring the actual amount of irrigant that infiltrated in each plot during an irrigation. A neutron probe access pipe was placed approximately 5 m directly to the north and south of each sampling well. Neutron probe readings were taken immediately before irrigation and 24 hours after the

completion of irrigation at each plot. Soil moisture readings were based on the linear relationship between gravimetric determined soil moisture and neutron probe readings ($R = 0.841$) which was determined for the soil in the application area. The change in soil moisture at each 15-cm increment was added to form a total application of irrigant expressed in surface cm for each access pipe. Averages from the set of access pipes in each plot were used to determine the application of irrigant in each plot.

Several factors determined time of irrigation. Following a substantial accumulation of feedlot runoff in the catchment lagoons, the receiving area was allowed to dry for a few days. Some soil moisture depletion was allowed to occur before irrigating in order to increase the potential amount of runoff that could be successfully applied to the receiving area and to create conditions more conducive to crop growth than would have been created by irrigating immediately after a precipitation event. At temperatures near or below freezing no applications of feedlot lagoon water were feasible due to the greatly reduced infiltration and percolation rates in the soil caused by a lowered viscosity of the applied solution and the frozen condition of the soil. Compliance with feedlot waste regulations required that the lagoons be emptied as soon as possible to provide room for runoff from future precipitation events. The treatments were applied in three separate applications in August, September, and November of 1972. These treatments were the only supplemental irrigations applied to the plot area.

Data Collection and Analysis

Initial soil profile samples were collected from plots 1 to 10 and 11 to 15 in October of 1971 and February of 1972, respectively. These samples were collected at 30-cm increments to a depth of 6 m where mechanically feasible.

In some plots the soil probe would not penetrate a wet sand located at about the 5-m depth. One core was taken from each plot. These samples were frozen until analyzed at which time they were dried at 55°C in a forced air oven and ground and screened through a 14-mesh screen. In April of 1973 another set of soil core samples was collected to a depth of 3 m in a manner similar to that for the first set. The latter set of samples was composited from two cores taken in each plot and were dried at 55°C in a forced air oven immediately after being collected. All the core samples were taken with a truck-mounted hydraulic soil probe in a 1.5 m x 4 cm stainless steel split-core sampler.

The soil profile samples were analyzed for NH_4^+ , NO_3^- , extractable Ca, Mg, Na, and K, P, Cl^- , and pH. A micro-Kjeldahl steam distillation procedure outlined by Bremner and Keeney (7) was used for the NH_4^+ and NO_3^- determinations. An ammonium acetate extraction described by Jackson (45) was used to bring extractable Ca, Mg, Na, and K into a 0.1 N HCl solution. Calcium and Mg were then analyzed using atomic absorption spectrophotometry techniques. Flame photometry was used for the Na and K analyses. The P values were determined as weak acid extractable P using the Bray-1 extracting solution with subsequent colorimetric determination. The color development of the extracted solution was by reduction of the solution with 1-amino-2-naphthol-4-sulfonic acid to allow formation of a phospho-molybdate complex. A 1:1 soil to solution ratio was used for the determination of pH by potentiometric methods.

Soil Cl^- was extracted by adding 50 ml of water to 5 g of soil and shaking the resulting suspension for 5 minutes. The suspension was then centrifuged for 5 minutes and the resulting supernatant was poured off the top and analyzed by use of the following colorimetric procedure. Reagents

used were a standardized 0.0282 N AgNO_3 titrating solution and an indicator solution composed of 5 g of potassium chromate crystals in 100 ml of water. The analytical procedure involved adding 0.5 ml of the potassium chromate solution to the supernatant and titrating with AgNO_3 until a permanent faint red color remained in the supernatant solution.

A composite soil sample from 10 sub-samples taken from the surface 15 cm of each plot was collected in November of 1971 and again in March of 1973. The electrical conductivity of the soil saturation extract and the pH of the saturated soil paste were determined on these samples by methods described by Richards (75). The approximate cation exchange capacity was calculated based on the soil saturation percentage as follows:

- (a) For soils having saturation percentages greater than 50:

$$\text{approximate cation exchange capacity} = \frac{\text{soil saturation \%}}{2.3}$$

- (b) For soils having saturation percentages less than 50:

$$\text{approximate cation exchange capacity} = \frac{\text{soil saturation \%}}{3.3}$$

Exchangeable Na and K were determined as the difference between ammonium acetate extractable values using the procedure described by Jackson (45) and the values for soluble Na and K obtained from flame photometric analysis of saturated soil extracts.

Lagoon water samples that were collected prior to each irrigation were analyzed for total inorganic-N, Ca, Mg, Na, K, P, Cl^- , pH, and electrical conductivity (mmhos/cm). Total inorganic-N was determined by the steam distillation procedure outlined by Bremner and Keeney (7). Chloride was determined by the same procedure used for the determination of water soluble Cl^- in the soil starting with a 50-ml aliquot of lagoon water. The pH was determined potentiometrically and electrical conductivity was determined using a Wheatstone bridge.

Analyses for Ca, Mg, Na, K, and P were performed on digested samples of lagoon water following the wet oxidation procedure described by Jackson (46) as modified by Adriano (1). A 20-ml aliquot of lagoon water was digested in 200 ml tall-form beakers on a hotplate by the addition of 25 ml of a $\text{H}_2\text{O}-\text{HNO}_3-\text{HClO}_4$ mixture in a 1:1:1 ratio (v/v/v) and covered with watchglasses. After evaporation of the HNO_3 , the hotplate was shut off, the beakers allowed to cool for about 10 minutes, and the watchglasses and beaker walls rinsed with deionized water to flush undigested material down into the remaining acid. Digestion was then resumed until the samples reached dryness. The residue was allowed to cool for a short time and 10 ml of 0.1 N HCl was added to bring the residue into solution. The final mixture was then filtered through Whatman 42 filter paper and brought to a 25-ml volume with 0.1 N HCl in preparation for analysis.

Water samples from the sampling wells were collected monthly beginning in June of 1972 for the duration of the study using a pitcher pump. Water samples were collected after 20 and 50 l had been pumped from the shallow and deep wells, respectively. These volumes were large enough to remove all the residual water in the well pipes and assure that the water being sampled was from the groundwater surrounding the sand point at the time of sampling. The excess water pumped before sample collection was transferred out of the sampling lane to prevent alteration of the soil moisture regime around the wells. The water samples were stored at 5°C until analyzed. Prior to analysis, the samples were filtered through Whatman 42 filter paper to remove fine material that was suspended in the well water at the time of pumping.

The filtered water samples were analyzed for NO_3^- -N, NH_4^+ -N, Ca^{++} , Mg^{++} , Na^+ , K^+ , Cl^- , P, and electrical conductivity (mmhos/cm). A 25-ml aliquot was used in the procedure described by Bremner and Keeney (7) for the NO_3^- -N and

NH_4^+ -N analyses. A 10-ml aliquot diluted to 50 ml was analyzed for chloride using the procedure outlined earlier for soil water extractable chloride. The digested lagoon water samples and the well water samples were analyzed for Ca, Mg, Na, and K by the same techniques as described for the analysis of these elements in soil extracts. Phosphorus in the digested lagoon water samples and well water samples was determined by the vanadate-molybdate yellow procedure outlined by Chapman and Pratt (13).

Bromegrass yield data were collected in May of 1973 at the bloom stage of maturity to determine the effects of lagoon water applications the previous summer and fall on dry matter production and N, P, K composition. Three 3 x 1 m subplots were located centrally east and west within the main plots and 1.5, 3.0, and 4.5 m south of the center of each plot. The bromegrass forage was harvested with a sickle bar mounted on a Gravely plot tractor. The Harvested samples were dried at 55°C in a forced air oven. A Wiley mill with stainless steel knives and a stainless steel screen was used to grind the dried plant tissue samples. The ground samples were stored in sealed plastic containers and then analyzed for N, P, and K using a preliminary sulfuric acid digestion procedure outlined by Dr. J. J. Hanway of Iowa State University. In this procedure a 0.5-g sample of plant material, 10 ml of concentrated sulfuric acid, a small piece of copper wire, and a glass bead were added to a 100-ml flask. The flask was then placed on a hotplate and the temperature was slowly raised until all frothing ceased (4-8 hours). The temperature was then raised until the acid boiled. Boiling was continued for 12 hours and then the flasks were allowed to cool and brought to volume with deionized water.

The steam distillation procedure outlined by Bremner and Keeney (7) was used to determine N from a 5-ml aliquot of the digested solution. Only the

NH_4^+ -N in the digest was analyzed. Flame photometry techniques were used for analysis of K in the digested solution. The vanadomolybdophosphoric yellow color method described by Jackson (46) was used to determine P colorimetrically.

RESULTS AND DISCUSSION

Lagoon Water Composition and Application Rates

The composition of well water, straight lagoon water, and diluted lagoon water which was applied in three irrigations in 1972 is shown in Table 7. The values for the diluted lagoon water are calculated values for each element and electrical conductivity based on the concentration of the various constituents in the straight lagoon water and well water used for dilution purposes. The well water values were always lower than the straight lagoon water values except for Ca. The Ca concentration in the straight lagoon water was increased by diluting with well water during each of the three irrigations.

The lagoon water for all three irrigations was accumulated from rainfall runoff. Several small precipitation events created the runoff which supplied lagoon water for irrigations one and three whereas one very high intensity rainfall event filled the lagoons prior to the second irrigation. The electrical conductivity of the lagoon water resulting from the high intensity rainfall and applied in irrigation number two was considerably lower than the electrical conductivity of the lagoon water applied in the other two irrigations (Table 7). These data imply that the high intensity rainfall event produced more dilute runoff with respect to total salt content than did the lower intensity rainfall and support work reported by other investigators (86, 69, 33) which indicates a negative relationship between rainfall intensity and the concentration of dissolved constituents in feedlot lagoon water.

Potassium levels in the lagoon water were consistently higher than any of the other elements. Corn silage generally constitutes from 20% (for finishing) to 85% (for growing) by weight of the ration fed to the cattle at

Table 7

Some chemical characteristics of non-diluted lagoon water, diluted lagoon water (calculated), and well water applied in three irrigations.

	Irrigation	ppm							EC x 10 ³ (mmhos/cm)	pH	Dil.* Ratio
		Inorganic-N (NH ₄ ⁺ -N + NO ₃ ⁻ -N)	P	K	Ca	Mg	Na	Cl			
Straight lagoon water:	1	30.5	42	381	45	42	71	291	2.0	7.0	
	2	23.4	31	244	49	27	44	192	1.4	6.9	
	3	45.0	33	347	72	42	60	241	2.0	7.4	
Diluted lagoon water:	1	10.1	14	131	83	28	39	112	1.2	--	2
	2	15.6	21	165	67	25	37	135	1.1	--	0.5
	3	22.5	16	177	87	32	42	131	1.4	--	1
Well water:	1-3	0.0	0	5	102	21	24	22	0.8	7.6	

* Dil. Ratio--Dilution ratio (well water/lagoon water)

the study site and is characteristically high in K. Rations with high K concentrations probably account for most of the K found in feedlot runoff. Sodium was present in the lagoon water in considerably lower concentrations than K. This observation agrees with the survey reported by Wallingford et al. (91) of beef feedlot lagoon water in Kansas. In Wallingford's survey of 12 locations in two different years, Na concentrations were higher than K at only one location in one year. The Na concentration in feedlot lagoon water is probably also dependent upon the ration with the level of salt supplementation being the main contributor of Na in feedlot rations (51). Salt supplementation at the feedlot study site was maintained just below the level which limited feed consumption.

Inorganic-N, P, Ca, and Mg were all present in substantial quantities in the lagoon water. Chloride concentrations were intermediate between K and the range of concentrations for these elements (N, P, Ca, Mg). The average inorganic-N values ranged from 23.4 to 45.0 ppm. The concentration of all the constituents analyzed changed in a manner approximately proportionate with changes in electrical conductivity of the lagoon water (Table 7). The range of 1.4 to 2.0 mmhos/cm for the electrical conductivity of the lagoon water was lower than most values for lagoon water reported by Wallingford (91).

The total application of lagoon water during the 1972 irrigation season for each plot is listed in Table 8. Also listed is the total application during the 1972 irrigation season of some of the nutrients contained in the lagoon water as calculated from the product of the volumetric application and nutrient concentration in the lagoon water for each irrigation. As indicated by the treatment means, there was little difference in the infiltrated volumetric application of lagoon water on plots with comparable treatments (i. e.,

the total infiltrated volumetric application was similar for the high rate diluted and straight lagoon water treatments and was also similar for the low rate diluted and straight lagoon water treatments). The volumetric application for each plot as listed in Table 8 was the amount of lagoon water which actually infiltrated rather than the total volume (depth) applied to the plot area.

The probable reason for the small differential between the actual volumetric applications in comparable diluted and straight lagoon water treatments was the fact that infiltration rates in the plot area decreased rapidly after initiation of irrigation. Therefore, part of the larger volume of irrigant in the diluted treatments, which was applied at discharge rates similar to the straight lagoon water treatments but for longer periods of time, flowed past the plot area in the irrigation borders and infiltrated at points beyond the plot area. The differential in actual amounts of water infiltrated between comparable diluted and straight lagoon water treatments could be increased by splitting the higher volume treatments into two or more separate applications.

The total application of inorganic-N and P in lagoon water ranged from 12 to 51 and 16 to 67 kg/ha, respectively (Table 8). Potassium applications were substantially higher, ranging from 138 to 574 kg/ha. Considerably more Ca was applied in the diluted lagoon water treatments than the straight lagoon water treatments. The consistently high concentration of Cl^- in the lagoon water was reflected in the high applications of Cl^- which ranged from 118 to 428 kg/ha. Each of the constituents which was analyzed was supplied in lower quantities in the well water treatments than in the lagoon water treatments except for Ca. This can be attributed to the higher concentration of Ca in the well water which was used for diluting relative to the Ca content of the

Table 8

Total volumetric beef feedlot lagoon water and nutrient application
applied in three irrigations from August to November 1972.

Plot	Treatment*	Surface cm	kg/ha						
			Inorganic-N (NH_4^+ + NO_3^-)	P	K	Ca	Mg	Na	Cl
1	SLW (high rate)	9.7	29	37	331	46	42	61	298
2	Well water	7.3	0	0	4	75	15	17	16
3	DLW (low rate)	7.3	11	13	114	54	19	28	93
4	SLW (low rate)	6.5	20	22	195	36	29	35	125
5	DLW (high rate)	17.9	23	31	263	134	47	68	220
6	SLW (high rate)	17.8	57	75	593	93	78	103	428
7	DLW (high rate)	16.6	22	29	246	124	44	63	198
8	DLW (low rate)	13.2	17	23	195	99	35	51	173
9	Well water	5.9	0	0	3	61	12	14	13
10	SLW (low rate)	14.3	47	51	470	77	63	85	350
11	SLW (high rate)	22.2	66	88	799	102	94	148	560
12	Well water	10.8	0	0	6	111	22	25	24
13	SLW (low rate)	7.1	24	29	244	43	31	44	201
14	DLW (low rate)	8.0	8	11	105	65	22	31	89
15	DLW (high rate)	22.6	24	32	306	186	62	89	257
Treatment mean values:									
	Well water	8.0	0	0	4	82	16	19	18
	SLW (low rate)	9.3	30	34	303	52	41	55	225
	DLW (low rate)	9.5	12	16	138	113	25	37	118
	SLW (high rate)	16.6	51	67	574	80	72	104	428
	DLW (high rate)	19.0	23	30	272	148	51	74	225

*SLW - Straight lagoon water
DLW - Diluted lagoon water

straight lagoon water and the application of the well water treatment in only the first two irrigations.

Bromegrass Yields, Composition, and Uptake as Affected by Beef Feedlot Lagoon Water Applications

Bromegrass yield response to the lagoon water applications was quite variable and differences between treatments were not statistically significant at the 0.05 probability level. Variation in stand may have accounted for some of this variability. Prior to initiation of this study, average values for $\text{NO}_3^- \text{-N} + \text{NH}_4^+ \text{-N}$, weak Bray extractable P, and extractable K in the top 30 cm of soil were 80, 187, and 428 ppm, respectively. Large yield responses to additions of N, P, and K in the lagoon water applications would not be expected with these high initial levels in the soil. Yield means ranged from 2,953 to 3,901 kg/ha (Table 9) with the low rate SLW treatment producing the highest yield. Mean yields for both SLW treatments were higher than the mean yields for the DLW treatments and the well water treatment mean was second from the highest. However, no statistically significant (0.05) yield reductions or increases were apparent from applications of lagoon water.

Mean differences between plant N, P, K composition and N, P, K uptake were all nonsignificant at the 0.05 probability level (Table 9). Lack of significant differences between treatment means can probably be attributed to high soil levels of these elements at the initiation of this study and the variability in stand throughout the study area. It may be noteworthy that in all seven categories except percent N the low rate SLW treatment mean values were highest and that in all categories except N uptake and yield the high rate SLW treatment mean values were second highest.

The capacity of the soil to serve as a filter for nutrients contained in feedlot runoff may be enhanced by plant nutrient uptake. Substantial amounts

Table 9

Yield, plant composition, and nutrient uptake of bromegrass as affected by treatment--1973.

Plot	Treatment*	Yield kg/ha	Plant Composition			Nutrient Uptake (kg/ha)		
			%N	%P	%K	N	P	K
1	SLW (high rate)	2482	1.67	.335	3.08	41.5	8.3	76.5
2	Well water	2530	1.63	.335	2.97	41.2	8.5	75.1
3	DLW (low rate)	2702	2.03	.385	3.54	54.9	10.4	97.7
4	SLW (low rate)	3158	1.79	.375	3.45	56.5	11.8	109.0
5	DLW (high rate)	3239	3.03	.419	3.87	98.1	13.6	125.4
6	SLW (high rate)	3469	2.39	.407	3.63	82.9	14.1	125.9
7	DLW (high rate)	3661	2.53	.407	3.50	92.6	14.9	128.1
8	DLW (low rate)	3872	2.14	.391	3.47	82.9	15.1	134.4
9	Well water	4380	2.14	.368	3.27	93.7	16.1	143.2
10	SLW (low rate)	4447	2.26	.406	3.73	100.5	18.1	165.9
11	SLW (high rate)	3852	2.01	.389	3.33	89.4	17.3	148.1
12	Well water	3536	1.72	.337	2.83	60.8	11.9	100.0
13	SLW (low rate)	4097	1.83	.358	3.04	75.0	14.7	124.6
14	DLW (low rate)	3186	1.50	.314	2.51	47.8	10.0	78.0
15	DLW (high rate)	1960	1.45	.289	2.09	28.4	5.7	41.0
Treatment means:								
	Well water	3482	1.83	.347	3.02	65.3	12.2	106.1
	SLW (low rate)	3901	1.96	.380	3.41	77.3	14.9	132.1
	DLW (low rate)	3253	1.89	.363	3.17	61.8	11.8	103.3
	SLW (high rate)	3268	2.02	.377	3.35	71.2	13.2	116.8
	DLW (high rate)	2953	2.33	.372	3.15	73.1	11.4	98.1
LSD .05		NS	NS	NS	NS	NS	NS	NS

*SLW - Straight lagoon water
DLW - Diluted lagoon water

of N, P, and K were taken up in one harvest of bromegrass as shown in Table 9. An average of 69.7, 12.7, and 111.5 kg/ha of N, P, and K, respectively, was removed in the harvested plant material. Since the primary bromegrass growth in this area is in the spring and fall the potential annual plant removal of these elements would be expected to be approximately half again as high as the values for the spring harvest alone. If the bromegrass is pastured rather than harvested by mechanical means, the actual quantity of N, P, and K removed from the application area would probably be lower. Values listed for N, P, and K uptake for mechanically harvested samples would be higher because of less complete removal of the forage by pasturing and the deposition of animal wastes on the pastured area. Pasturing might be expected to create more of a cycling effect in the upper soil profile than a removal effect relative to plant nutrient removal.

The average of 69.7 kg/ha of N taken up in the 1973 spring harvest of bromegrass was greater than the highest total application of inorganic-N (57 kg/ha) applied as lagoon water in the 1972 irrigation season (Table 8). Considerably more P was applied in most of the lagoon water treatments in the 1972 irrigation season than was removed from the soil by plant nutrient uptake in one harvest. An average of 12.7 kg/ha P was contained in the harvested bromegrass as compared with mean applications of P in the lagoon water ranging from 16 to 67 kg/ha as shown in Table 8. The average uptake of K of 111.5 kg/ha was also considerably lower than the amount added in the 1972 lagoon water applications which by treatment ranged from 138 kg/ha for the low rate DLW treatment to 574 kg/ha for the high rate SLW treatment (Table 8). The data for N, P, K application rate and plant uptake in this study indicate that two harvests of bromegrass per year would remove almost twice the N, and

about one-half of the P and K applied in the 16.6 cm application of straight lagoon water.

Effects of Beef Feedlot Lagoon Water Applications on Some Soil Chemical Properties

I. Quality of the lagoon water for irrigation.

The total precipitation received during the time of the study was 152.4 cm which amounted to an average monthly precipitation of 7.6 cm (Table 10). During the period between soil samplings in 1971 and 1973, 133.6 cm of precipitation was received. The 152.4 cm of precipitation for the 20-month study period is proportional to 91.4 cm for a 12-month period which is considerably higher than the average annual precipitation of 81 cm for the area. The above average precipitation was most prevalent in the last half of the study period in which the monthly average was 9.5 cm as compared with 6.0 cm for the first half of the study period. The higher precipitation during the study period should be considered when interpreting movement and accumulation of salts in the soil profile.

The average electrical conductivity of the straight and diluted lagoon water applied during this study was 1.8 and 1.2 mmhos/cm, respectively. Jacobs and Whitney (48) classify irrigation water with these electrical conductivities in the medium salinity hazard range for field crops grown on a medium textured soil. The straight lagoon water is in the upper end of the medium classification while the diluted lagoon water falls in the lower end of this classification. The irrigation water quality classification scheme developed by Jacobs and Whitney (48) assumes application of 60 cm of irrigation water and 25 cm of precipitation per growing season. Less than 60 cm of irrigation water was applied during the 1972 irrigation season, but from

Table 10

Monthly precipitation (cm) for the Fulmer feedlot area.

Month	Precipitation*	Month	Precipitation
October 1971	8.7	August	7.4
November	8.7	September	14.9
December	1.4	October	6.2
January 1972	1.0	November	10.4
February	1.2	December	8.2
March	4.7	January 1973	5.6
April	5.3	February	5.1
May	10.4	March	20.8
June	3.4	April	6.6
July	<u>14.8</u>	May	<u>9.4</u>
	Ave 6.0		Ave 9.5
Total for well sampling period (6/72-5/73)			111.3
Total for period between soil sampling (10/71-3/73)			133.6
Grand total			152.4
Average monthly precipitation			7.6

*Precipitation includes rain, sleet, and snow as reported by a U. S. Weather Bureau reporting station located six miles from the experimental site.

March to November of 1972, 77 cm of precipitation was received at the study area which is considerably more precipitation than assumed by Jacobs and Whitney in their irrigation water quality classification. Assuming unrestricted drainage and recognizing the precipitation characteristics for the study area, the development of a salinity problem severe enough to limit crop growth from application of the lagoon water applied in this study is not predicted by Jacobs and Whitney's classification scheme.

Predicted soil exchangeable Na and K percentages developed under equilibrium conditions and determined by Gapon's equation, the Na absorption ratio (SAR), and the K absorption ratio (PAR) of the lagoon water are shown in Table 11. The SAR-derived values for exchangeable sodium percentage (ESP)

Table 11

Predicted exchangeable Na and K in the Soil from application of straight lagoon water (Aug-Nov 1972)

Irrigation	EC x 10 ³ (mmhos/cm)	meq/l				ESP SAR	ESP		EPP PAR
		Na	K	Ca	Mg		G-max*	G-min*	
1	1.9	3.1	9.8	2.2	3.4	1.4	2.1	1.1	39.2
2	1.4	1.9	6.2	2.5	2.2	0.6	1.6	0.8	31.7
3	2.0	2.6	8.9	3.6	3.5	0.8	1.7	0.9	34.8

* Prediction values for exchangeable Na percentage in the soil using Gapon's equation with Gapon's constant (Kg) equal to 0.02 and 0.01 for G-max and G-min, respectively.

are in the range of ESP values predicted by Gapon's equation for the same lagoon water samples. The highest predicted ESP value was calculated from the lagoon water applied in the first irrigation and was 2.1. This is much lower than 15% exchangeable Na which is considered the critical value for the development of soil dispersion problems. The development of a dispersion hazard from application of lagoon water of the quality available in this

study during the 1972 irrigation season is not predicted from the theoretical values in Table 11. The EPP values predicted to develop in the soil from applications of the lagoon water in 1972 ranged from 31.7 to 39.2 (Table 11). The consequences of EPP values in this range remain controversial.

Changes in some saline-alkali parameters in the top 15 cm of soil from 1971 to 1973 as affected by treatment are listed in Table 12. Generally, the electrical conductivity of the soil saturation extract increased over the study period as indicated by the annual means which were 1.01 and 1.37 for 1971 and 1973, respectively. The most notable exception was in plot 15 where a very substantial reduction in soil electrical conductivity from an initially high value of 4.1 to 1.2 mmhos/cm was observed. Other exceptions were in plots 1 and 14 where electrical conductivity increased slightly and plot 2 where electrical conductivity remained unchanged.

Of the three plots which received well water treatments, an increase in electrical conductivity was observed from 1971 to 1973 in plots 9 and 12. No firm explanation for these observations can be offered. One hypothesis is that the feedlot cattle which were allowed access to the plot area periodically throughout the study may have contributed manure to parts of the sampling lane in quantities large enough to increase the electrical conductivity of the soil solution in these areas. The general increase in electrical conductivity observed in most plots was probably due to lagoon water applications and/or waste accumulations from cattle which were allowed to loaf and graze in the field area.

The high electrical conductivity found in plot 15 in 1971 can be attributed to overflows in previous years of the adjacent feedlot drainage ditch which resulted in deposits of feedlot runoff in this area. The above average precipitation throughout the study period and construction of a dike to

Table 12

Saline-alkali classification parameters from the surface 15 cm of the sampling area of each plot.

Plot	Treatment	EC x 10 ³ (mmhos/cm) (Saturation Extract)		Approx. CEC meq/100 g		Exch. Na%		Exch. K%	pH (Saturated Paste)	
		1971	1973	1971	1973	1971	1973		1971	1973
1	SLW (high rate)	1.3	1.5	11.7	12.7	0.6	1.4	16.0	6.7	6.7
2	Well water	1.3	1.3	11.8	12.4	0.8	0.5	14.1	6.9	6.6
3	DLW (low rate)	0.7	1.5	11.1	11.8	0.4	0.0	16.3	6.9	6.6
4	SLW (low rate)	0.7	1.4	10.8	11.3	0.4	2.2	14.5	6.8	6.6
5	DLW (high rate)	0.8	1.4	11.0	12.4	0.5	1.8	12.7	6.7	6.6
6	SLW (high rate)	0.6	1.4	11.3	11.5	0.5	0.0	14.2	6.9	6.5
7	DLW (high rate)	0.7	1.5	11.0	11.9	0.5	0.0	16.6	6.8	6.5
8	DLW (low rate)	0.4	1.3	10.6	11.2	0.4	0.8	14.0	6.9	6.5
9	Well water	0.6	1.3	10.5	11.0	0.5	0.7	15.2	6.2	6.2
10	SLW (low rate)	0.4	1.4	10.3	11.2	0.6	1.2	15.5	6.4	6.1
11	SLW (high rate)	0.9	1.4	11.8	13.6	0.4	1.7	16.0	6.4	6.2
12	Well water	0.8	1.5	11.7	13.3	0.4	0.9	16.0	6.5	6.2
13	SLW (low rate)	0.8	1.2	11.1	12.8	0.5	0.9	14.5	6.4	6.3
14	DLW (low rate)	1.1	1.2	12.1	12.1	0.4	0.4	13.2	6.4	6.3
15	DLW (high rate)	4.1	1.2	14.5	12.5	1.5	0.2	16.0	6.5	6.4
Annual means:		1971	1.0	11.4		0.6			6.6	
		1973	1.4	12.1		0.8		15.0	6.4	
		ISD.05	NS	0.5		NS			0.2	
Treatment means:		Well water	0.9	1.4	11.3	12.2	0.7	15.1	6.5	6.3
		SLW (low rate)	0.6	1.3	10.7	11.8	1.4	14.8	6.5	6.3
		DLW (low rate)	0.7	1.3	11.3	11.7	0.4	14.5	6.7	6.5
		SLW (high rate)	0.9	1.4	11.6	12.6	1.0	15.4	6.7	6.5
		DLW (high rate)	1.9	1.4	12.2	12.3	0.7	15.1	6.7	6.5
		ISD.05	NS	NS	NS	NS	NS	NS	NS	NS

prevent overflow of feedlot runoff onto plot 15 may have resulted in the sharply reduced electrical conductivity in plot 15 over the study period. Assuming that the recently accumulated soluble salts in plot 15 had not yet come to equilibrium with the soil exchange complex at the initiation of this study, the likelihood of the sharp reduction in electrical conductivity being due to leaching from precipitation and dilute lagoon water applications is enhanced. In addition to 15.4 cm of precipitation, plot 15 received an application of 22.6 cm of diluted lagoon water which averaged 1.2 mmhos/cm in electrical conductivity during the study period. Further long term investigations are needed to establish the equilibrium soluble salt concentration in the soil as affected by treatment with feedlot runoff and precipitation.

Exchangeable Na% values of soil samples from the surface 15 cm for 1971 and 1973 are listed in Table 12. These values were very low in both years and statistically significant differences (0.05) were not found between values for 1971 and 1973 or between treatments within either year. The 1973 exchangeable Na% mean values for the low and high rate SLW treatment areas were approximately twice as high as comparable values for the DLW treatment areas but these differences were not statistically significant at the 0.05 probability level. The 1973 treatment mean values for the exchangeable K% in the surface 15 cm of soil ranged from 14.5 to 15.4% but differences between these means were not statistically significant at the 0.05 probability level.

The pH of the saturated paste of the surface 15 cm of soil was found to be significantly lower (0.05) in 1973 than in 1971. The 1971 and 1973 mean values were 6.6 and 6.4, respectively (Table 12). Differences between treatment means were not statistically significant at the 0.05 probability level in either 1971 or 1973. The decrease in pH with time could possibly have been due to nitrification of the initially high levels of NH_4^+ in the soil or

leaching of exchangeable bases from the surface soil although the latter possibility seems unlikely since the average electrical conductivity of the soil solution was greater in 1973 than in 1971.

II. Accumulation of lagoon water constituents in the soil profile.

Nitrate-N in the soil profile before and after lagoon water applications in 1972 is shown in Figure 4. The reduction in NO_3^- -N throughout the top 300 cm of soil from 1971 to 1973 is quite pronounced, especially in the top 30 cm and at about the 150-cm depth. In 1973 all values for NO_3^- -N were lower than 14 ppm in the top 30 cm whereas in 1971 all NO_3^- -N values were higher than 28 ppm at the same depth. Generally, the noticeable accumulations of NO_3^- -N found in the surface of the soil profile and at the 150-cm depth in 1971 were not present in 1973. Levels of NO_3^- -N at the 225- to 300-cm depth were similar for the two sampling dates. The reduction of NO_3^- -N throughout the top 300 cm of the soil profile is further illustrated in Table 13. The average level of NO_3^- -N throughout the soil profile was 24.9 and 14.1 ppm in 1971 and 1973, respectively.

The levels of NO_3^- -N in the plot areas receiving the various treatments were quite variable in 1971 at the outset of the study. No consistent differences in NO_3^- -N levels between treatments were apparent in 1973 but a peak of about 20 ppm at the 75-cm depth for the well water treatment was evident. This peak may have resulted from carryover from relatively high levels of NO_3^- -N found in this treatment area in 1971. Year by treatment means in Table 13 indicate that the reduction of NO_3^- -N in the soil profile from 1971 to 1973 was similar for all treatments.

A reduction in soil NH_4^+ -N levels from 1971 to 1973 similar to but much more pronounced than the reduction in NO_3^- -N levels is indicated in Figure 5.

Table 13

Treatment and annual means for several soil core constituents (0-300 cm).

Treatment*	Year	ppm								pH
		NH ₄ ⁺ -N	NO ₃ ⁻ -N	Ca	Mg	Na	K	P	Cl	
Annual means:										
	1971	27.3	24.9	4127	221	47	231	37	3	7.6
	1973	4.3	14.1	4732	202	56	231	31	5	7.7
Year x Treatment means:										
1971										
Well water		33.2	29.8	4249	244	55	282	41	7	7.7
SLW (low rate)		25.4	30.9	3608	207	56	153	33	1	7.6
DLW (low rate)		24.0	32.1	4326	256	54	243	38	1	7.5
SLW (high rate)		27.7	19.8	4234	231	28	236	36	5	7.7
DLW (high rate)		22.9	24.0	4353	229	55	231	36	0	7.7
1973										
Well water		6.8	17.8	5198	254	55	269	31	5	7.7
SLW (low rate)		2.6	13.9	4485	174	60	298	23	7	7.8
DLW (low rate)		3.8	18.4	4378	202	52	179	32	2	7.6
SLW (high rate)		5.0	10.0	4596	232	70	262	30	5	7.7
DLW (high rate)		3.7	11.1	4845	221	45	253	30	4	7.8

*SLW - Straight lagoon water

DLW - Diluted lagoon water

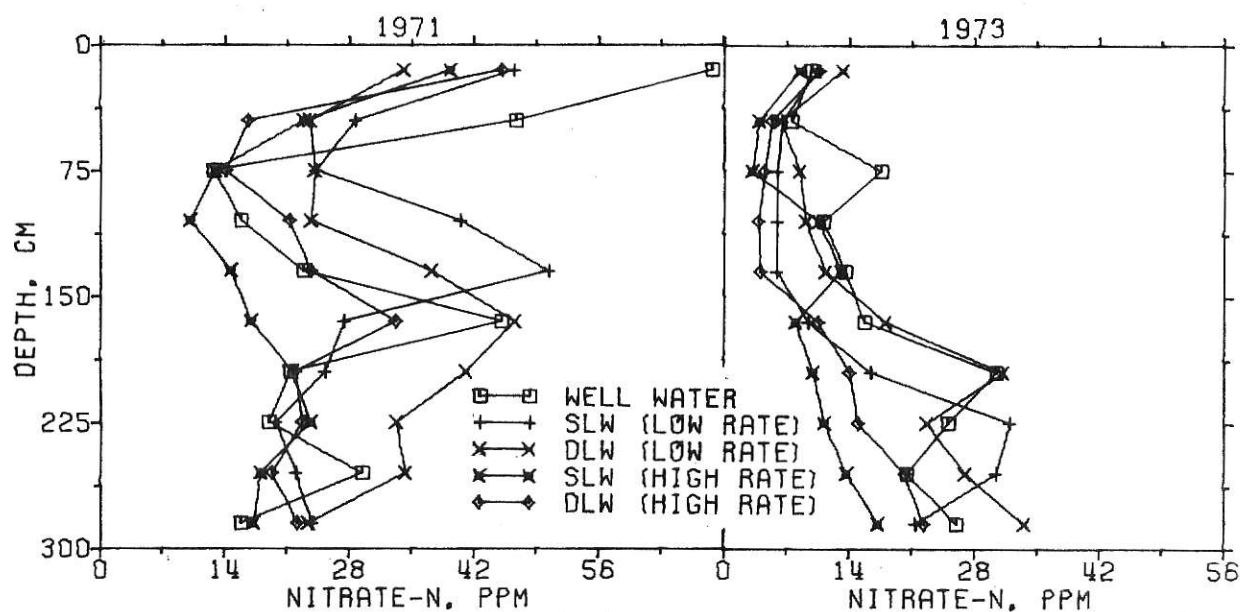


Fig. 4. Soil nitrate-N in core samples before (1971) and after (1973) treatments.

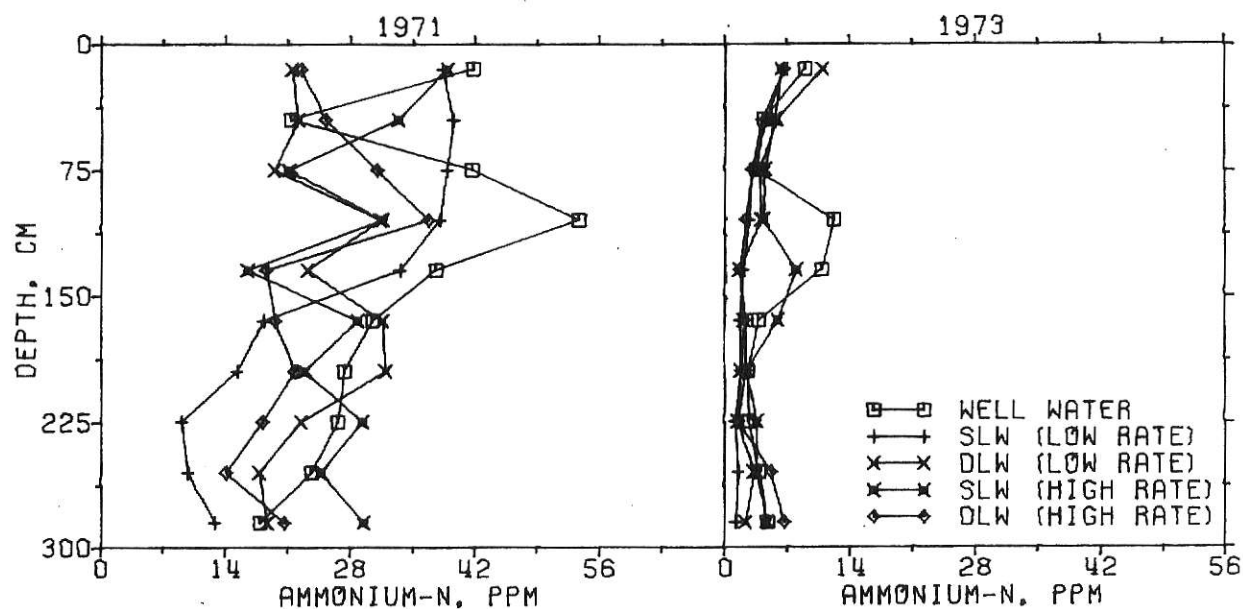


Fig. 5. Soil ammonium-N in core samples before (1971) and after (1973) treatments.

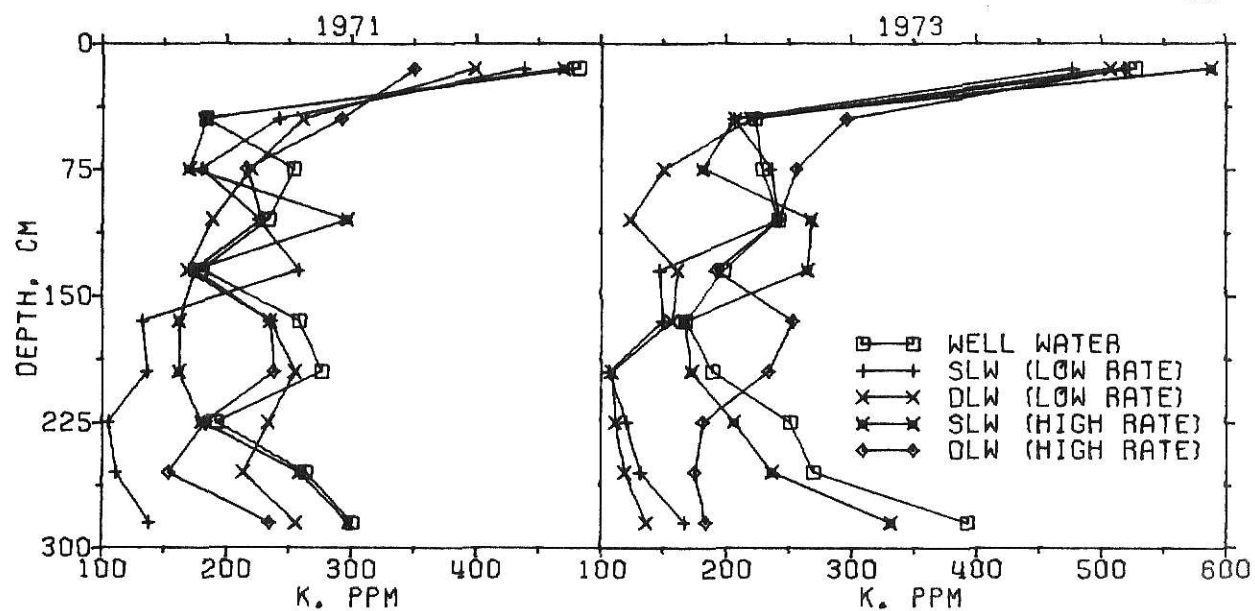


Fig. 6. Extractable soil K in core samples before (1971) and after (1973) treatments.

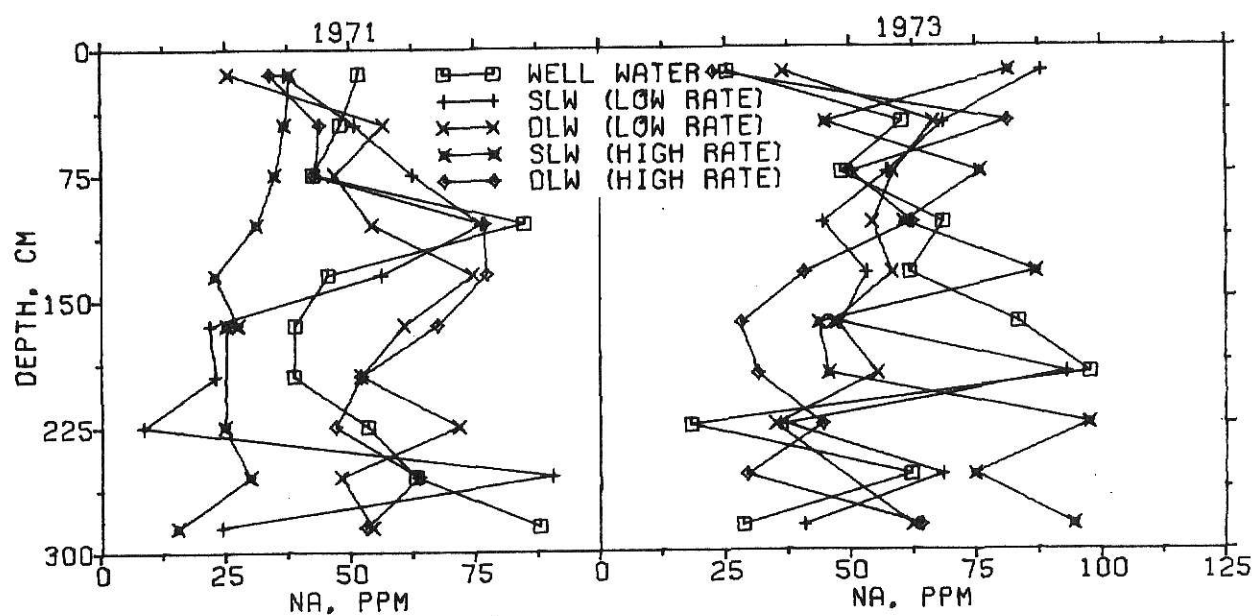


Fig. 7. Extractable soil Na in core samples before (1971) and after (1973) treatments.

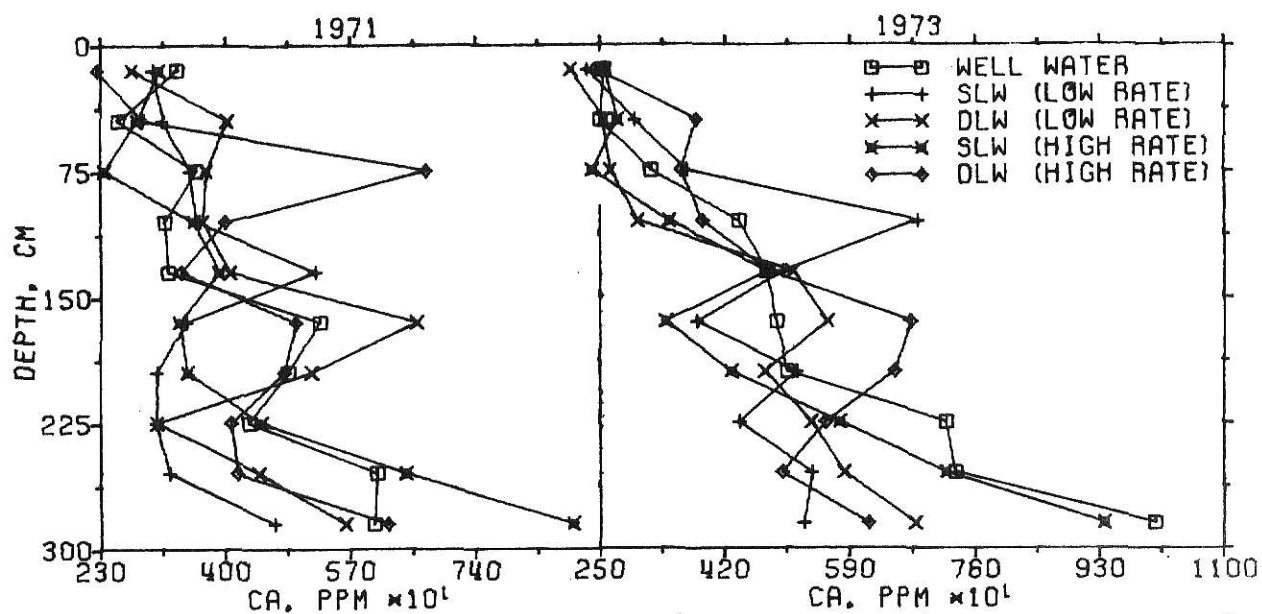


Fig. 8. Extractable soil Ca in core samples before (1971) and after (1973) treatments.

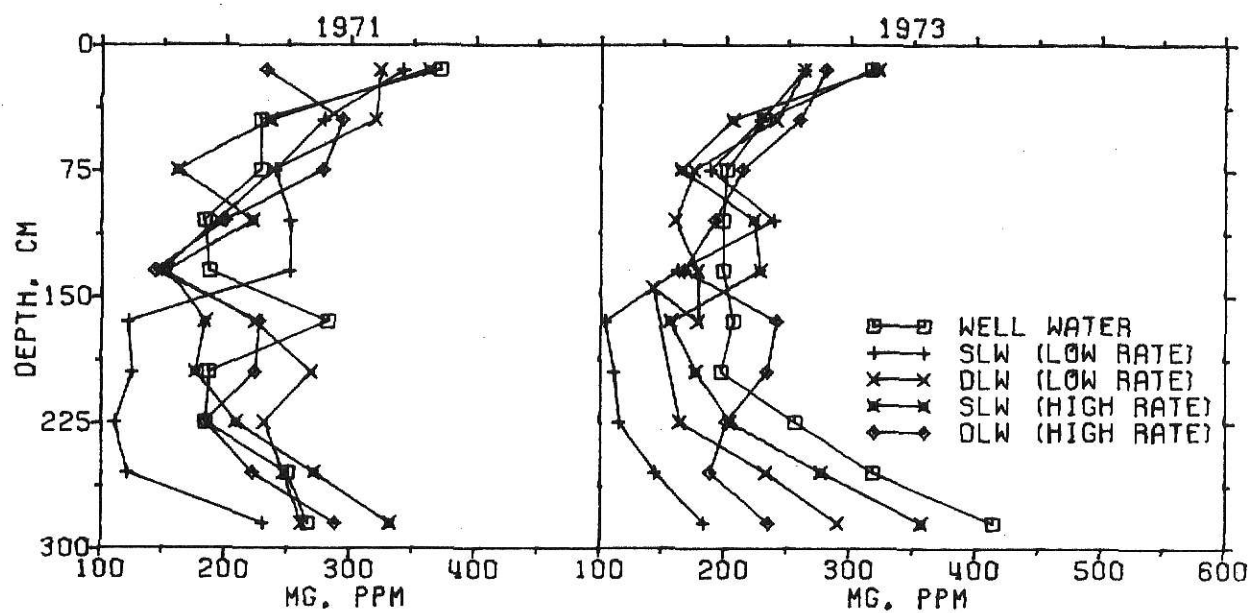


Fig. 9. Extractable soil Mg in core samples before (1971) and after (1973) treatments.

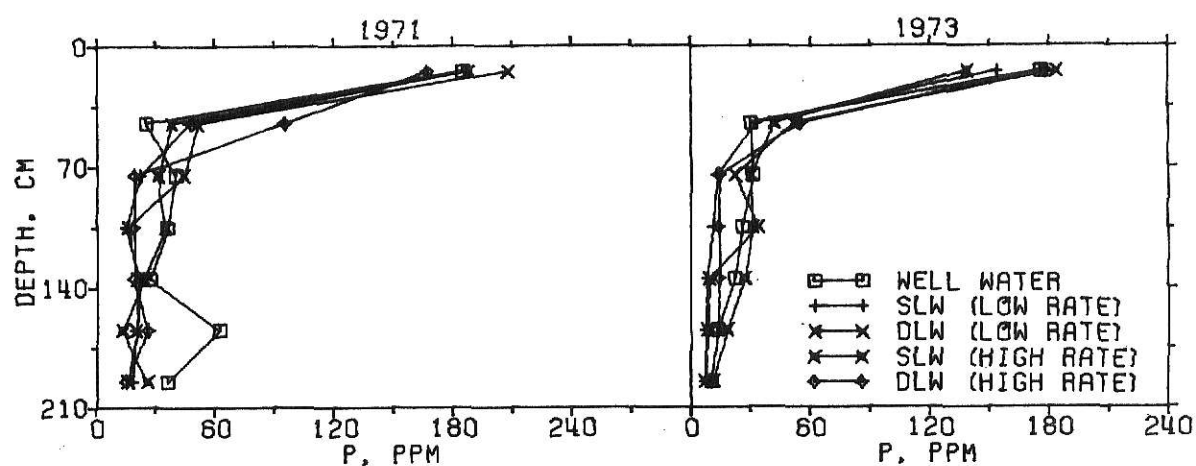


Fig. 10. Weak Bray extractable P in soil core samples before (1971) and after (1973) treatments.

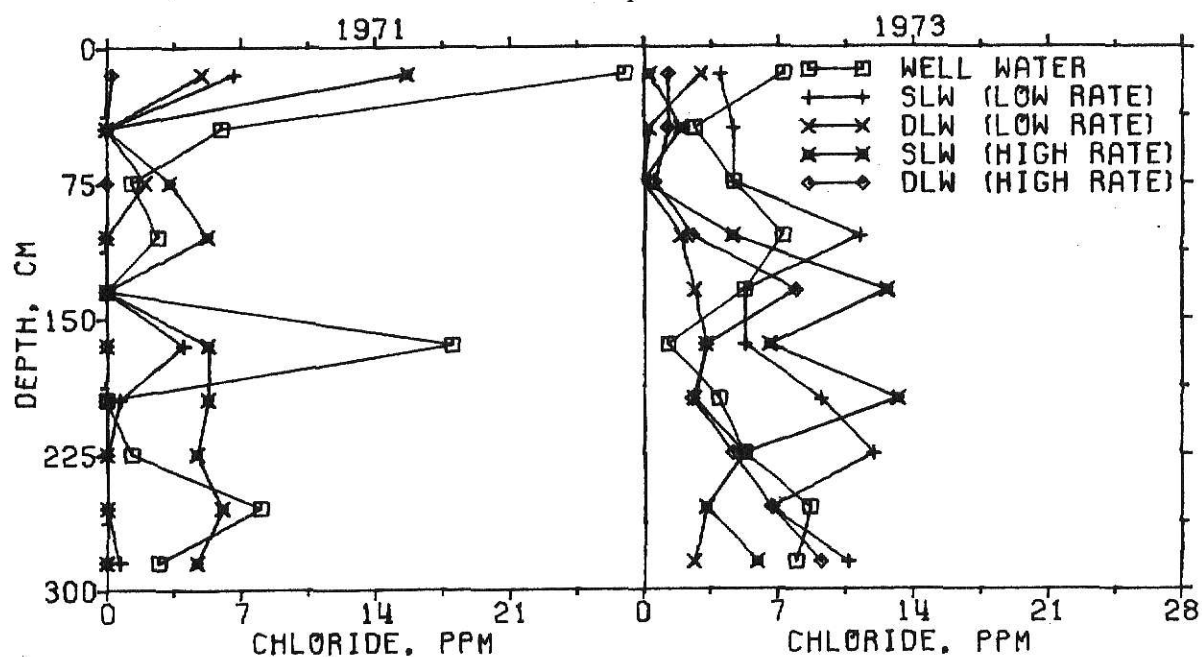


Fig. 11. Water soluble soil chloride in core samples before (1971) and after (1973) treatments.

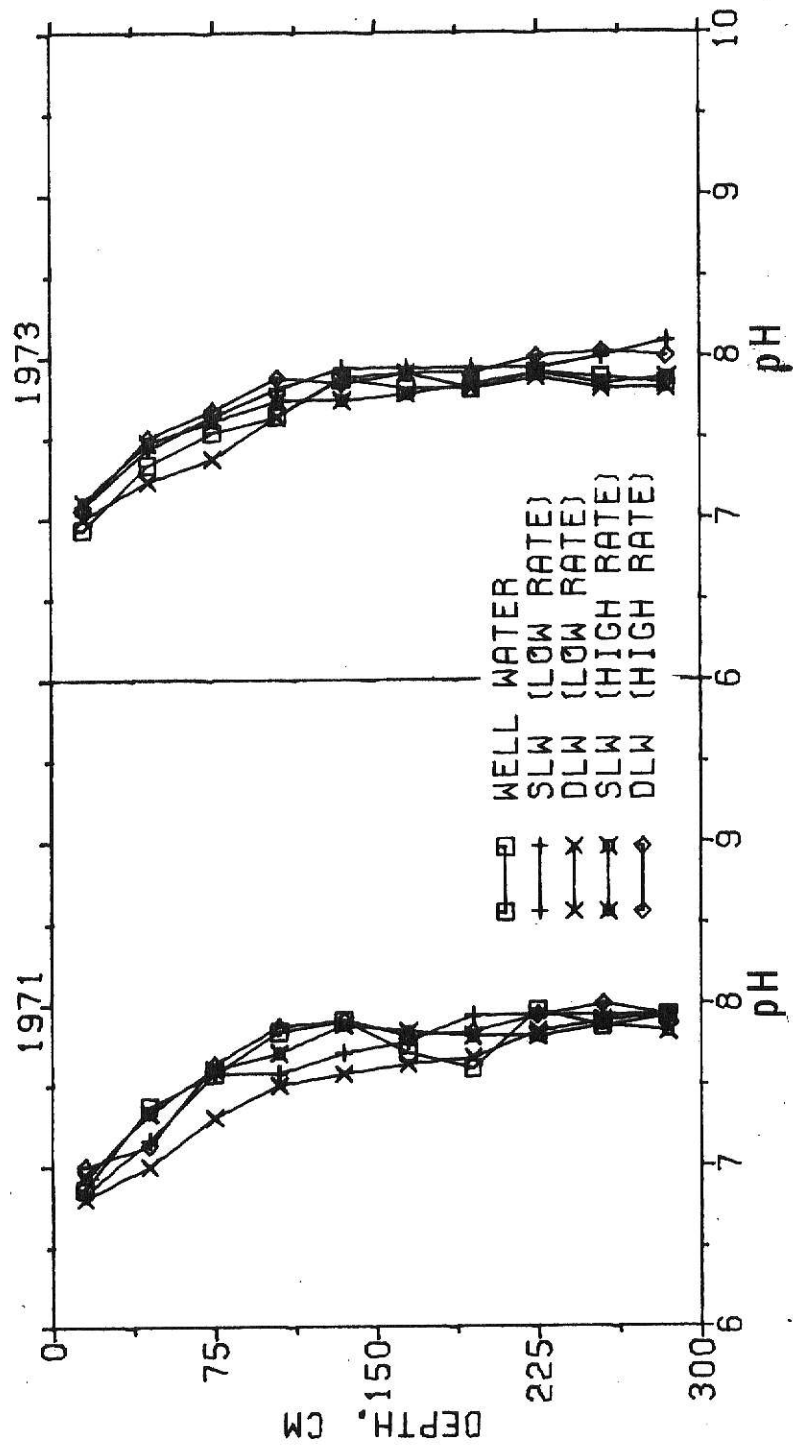


Fig. 12. Soil pH values before (1971) and after (1973) treatments.

The averages for $\text{NH}_4^+\text{-N}$ at the 0- to 300-cm depth in 1971 and 1973 were 27.3 and 4.3 ppm, respectively (Table 13). A peak located at about the 100-cm depth in 1971 in the area which received well water treatments in 1972 was still evident but not as pronounced in 1973. The sharp decreases in the initially high levels of $\text{NH}_4^+\text{-N}$ from 1971 to 1973 were probably due primarily to nitrification.

The accumulations of extractable K in the soil profile from lagoon water applications were primarily located in the 0- to 30-cm zone (Figure 6). At this depth, an increase in extractable K for all treatments was observed from 1971 to 1973. The largest increases over this time period at the 0- to 30-cm depth were observed in the low rate DLW, high rate SLW, and high rate DLW treatments. However, no difference in average extractable K content for all treatments for the 0- to 300-cm depth was found from 1971 to 1973 as the average extractable K content in cores taken in both of these years was 231 ppm (Table 13).

The considerably higher buildup of extractable K in the high rate SLW treatment area than in the other treatment areas at the 0- to 300-cm depth for 1973 as shown in Figure 6 might be expected considering that approximately twice as much K was applied in 1972 to this treatment as was applied at the low rate SLW treatment which received the next highest application of K. In 1973, extractable K in soil of the well water treated area was second only to the high rate of SLW. Such a high concentration was probably an artifact resulting from the initially high level of extractable K in the well water treatment area at the 0- to 30-cm depth at the first sampling date (Figure 6).

Sodium varied quite erratically throughout the 0- to 300-cm depth (Figure 7). The average extractable Na concentrations for the 0- to 300-cm depth in 1971 and 1973 were 47 and 56 ppm, respectively, indicating a slight buildup

of extractable Na from lagoon water applications (Table 13). The variability of extractable Na in the soil profile obscures the location of this buildup. The relatively high extractable Na concentrations at the 0- to 30-cm depth in 1973 in the low and high rate SLW treatment areas relative to the other three treatment areas suggests a tendency for Na to accumulate to a greater degree in the surface soil from straight lagoon water treatments than from diluted lagoon water treatments. This is probably due to lower applications of Na in the diluted lagoon water treatments than in comparable straight lagoon water treatments and also to a greater leaching percentage from the higher volumetric rates of lagoon water applied in the DLW treatment areas.

The distribution of extractable Ca in soil cores for the 0- to 300-cm depth for the 1971 and 1973 sampling dates is shown in Figure 8. No clear differences as affected by time or treatment are evident. The average content for extractable Ca at the 0- to 300-cm depth in soil cores increased slightly from 4,127 ppm in 1971 to 4,732 ppm in 1973 (Table 13).

Average extractable Mg concentrations in soil cores from the 0- to 300-cm depth remained essentially constant from 1971 to 1973 with values of 221 and 202 ppm determined respectively for these two years (Table 13). As shown in Figure 9, the general distribution of extractable Mg in the soil profile at the 0- to 300-cm depth was very similar for 1971 and 1973. The level of extractable Mg in the top increment decreased from 1971 to 1973 in all treatment areas except the high rate DLW treatment area which increased approximately 50 ppm from an initial low value in 1971.

In both 1971 and 1973 weak Bray extractable P in soil cores from the 0- to 300-cm depth was characteristically highest in the top increment with much lower concentrations present at the 30- to 300-cm depth (Figure 10). In the top sampling increment the average weak Bray extractable P concentration

decreased from 1971 to 1973 for all treatments except the high rate DLW treatment which increased slightly over this period. The average content of weak Bray extractable P throughout the 0- to 300-cm depth for all treatments decreased from 37 to 31 ppm from 1971 to 1973. The year by treatment means for weak Bray extractable P in Table 13 indicate that the average P content at the 0- to 300-cm depth for each treatment decreased from 1971 to 1973 also. These decreases coupled with the fact that approximately twice as much P was added in lagoon water as was calculated for P uptake by the bromegrass in one season implies that some of the weak Bray extractable P became fixed in the soil during this study.

The water extractable Cl^- concentration in soil cores from the 0- to 300-cm depth generally increased from 1971 to 1973 (Figure 11). Averages for the various treatments in Table 13 show that water extractable Cl^- decreased in the well water treatment areas and increased or remained constant in the other treatment areas. The initially high values for water extractable Cl^- in the well water and high rate SLW treatment areas in the top soil sampling increment in 1971 may have been due to manure applications in these areas two years prior to initiation of this study. In 1973 detectable water extractable Cl^- concentrations were found throughout the 0- to 300-cm range of depths whereas in 1971 the water soluble Cl^- concentration decreased to 0 intermittently throughout the 0- to 300-cm soil depth. The higher rate of application of water soluble Cl^- in the SLW treatments than in the DLW treatments may be reflected by the relatively high accumulation of water soluble Cl^- (125 to 225 cm) in these treatment areas in 1973 (Figure 11).

Soil core pH values to a depth of 300 cm were similar for 1971 and 1973 (Figure 12). No consistent differences between treatments were observed in

1973 to indicate that the lagoon water treatments affected soil pH to a depth of 300 cm.

Groundwater Quality in the Lagoon Water Application Area

I. Differences between depths.

The statistical significance levels of differences between concentrations of various constituents in water from deep and shallow wells are shown in Table 14. Statistically significant differences (probability level 0.0000) between deep and shallow wells were found for all constituents except $\text{NH}_4^+\text{-N}$. The $\text{NH}_4^+\text{-N}$ values were very low throughout the study at both depths as indicated by the grand means for $\text{NH}_4^+\text{-N}$ in the deep and shallow wells of 0.11 and 0.12 ppm, respectively (Tables 15 and 16).

It should be noted that AOV data for determining significance levels between depths included monthly observation dates of 6/72-5/73 excluding 1/73 when no water samples were collected. The observations from 6/72 and 7/72 were included in this analysis to provide the broadest possible time period for analysis of differences between depths. Separate AOV of shallow and deep well data covered the period 8/72-5/73. Data from the first two observations were deleted from these separate AOV because no lagoon water treatments were applied until August 1972. Unequal subclass analysis of variance procedures based on least squares methods were employed which allowed for missing data in months when the sampling wells failed to produce water. Means from these procedures are adjusted to compensate for the missing data.* The frequency distribution for each constituent at each well is listed in Table 19.

The grand means in Tables 15 and 16 indicate the magnitude of differences between the shallow and deep well samples for the eight constituents analyzed.

* Algorithms for AOV with unequal subclass numbers are those used by A. Heath, Biometrical Services, (USDA-ARS-OA), Beltsville, Maryland.

Table 14

AOV significance probability levels for constituents in deep and shallow well samples.

Source	df	$\text{NH}_4^+ - \text{N}$	$\text{NO}_3^- - \text{N}$	Ca	Mg	K	Na	Cl	$\text{EC} \times 10^3$ (mmhos/cm)
Deep and shallow wells (6/72-5/73)									
Replication	2	0.8986	0.0000	0.1499	0.0000	0.0092	0.0000	0.0000	0.0000
Treatment	4	0.4969	0.0430	0.3599	0.0000	0.0000	0.0755	0.0066	0.0719
Depth	1	0.2545	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Month	10	0.0000	0.6554	0.0000	0.0000	0.0564	0.9987	1.0000	0.0000
Treat. x Depth	4	0.2129	0.0543	0.0228	0.0002	0.0000	0.8496	0.1682	0.0323
Depth x Month	10	0.5624	0.7921	0.1889	0.7544	0.2137	0.9989	0.9978	0.9902
Residual	282								
Shallow wells (8/72-5/73)									
Replication	2	0.6826	0.0000	0.0034	0.0000	0.0000	0.0008	0.0000	0.0000
Treatment	4	0.0728	0.0347	0.4606	0.0086	0.0000	0.5021	0.2992	0.6429
Month	8	0.0000	0.7932	0.0000	0.0000	0.2478	0.5658	0.0722	0.0000
Treat.x Month	32	0.0859	0.9999	0.9868	0.9981	1.0000	0.6752	0.9991	0.8930
Residual	88								
Deep wells (8/72-5/73)									
Replication	2	0.9717	0.0816	0.6603	0.0000	0.0000	0.0000	0.0000	0.0000
Treatment	4	0.9003	0.2506	0.0024	0.0000	0.0000	0.0000	0.0000	0.0000
Month	8	0.0000	0.0073	0.0000	0.0000	0.1320	0.8012	0.9641	0.0000
Treat.x Month	32	0.9963	0.6353	0.3962	0.0000	0.9669	1.0000	1.0000	0.9998
Residual	88								

Table 15

Treatment and monthly means over months 8/72-5/73 for water samples from shallow wells.

Treatment	ppm							EC x 10 ³ (mmhos/cm)
	NH ⁺ ₄ -N	NO ⁻ ₃ -N	Ca	Mg	K	Na	Cl	
Treatment means :								
Well water	0.14	6.6	99.7	21.6	12.2	19.7	18.6	0.73
SLW (low rate)	0.13	7.9	99.5	21.5	13.3	16.1	21.8	0.74
DLW (low rate)	0.13	10.1	101.5	22.2	13.5	16.5	20.7	0.77
SLW (high rate)	0.17	6.7	100.8	23.5	15.5	14.3	22.3	0.76
DLW (high rate)	0.08	5.9	108.6	22.4	15.7	16.1	22.1	0.75
Monthly means :								
Month								
August	0.40	8.4	91.7	18.7	13.9	16.3	21.3	0.65
September	0.40	6.5	113.5	21.7	14.3	22.5	23.4	0.80
October	0.01	8.2	90.8	19.9	14.3	16.3	22.7	0.72
November	0.04	9.0	73.0	27.1	14.2	15.6	18.4	0.58
December	0.03	8.6	110.0	28.6	15.3	15.1	20.7	0.81
February	0.18	7.0	106.7	20.1	14.1	15.5	19.2	0.84
March	0.48	5.8	105.6	21.2	13.6	15.8	19.4	0.74
April	0.04	7.0	116.5	21.8	13.4	16.1	19.7	0.80
May	0.32	6.7	120.1	20.9	13.5	15.9	25.2	0.81
Grand means :								
	0.12	6.8	101.9	22.2	14.3	16.3	20.3	0.75

Table 16

Treatment and monthly means over months 8/72-5/73 for water samples from deep wells.

Treatment	ppm						EC x 10 ³ (mmhos/cm)
	NH ₄ ⁺ -N	NO ₃ ⁻ -N	Ca	Mg	K	Na	
Treatment means :							
Well water	0.13	0.06	83.5	24.1	3.8	78.2	134.9
SIM (low rate)	0.11	0.04	76.7	24.0	3.7	79.0	126.9
DIM (low rate)	0.10	0.02	78.3	22.6	3.6	77.0	108.4
SIM (high rate)	0.11	0.03	88.7	24.5	4.1	68.1	120.3
DIM (high rate)	0.12	0.07	69.9	21.8	3.4	61.4	78.5
Monthly means :							
Month							
August	0.01	0.11	63.9	18.8	3.7	72.9	109.9
September	0.03	0.02	73.5	22.5	3.8	72.1	122.6
October	0.02	0.00	61.3	20.5	3.8	73.1	120.3
November	0.03	0.13	45.8	28.0	3.6	72.2	111.7
December	0.00	0.04	95.2	30.5	3.8	70.4	108.4
February	0.21	0.02	91.8	21.4	3.6	69.6	108.6
March	0.46	0.02	89.5	23.0	3.7	78.3	112.3
April	0.03	0.02	92.2	23.1	3.6	73.5	112.4
May	0.23	0.03	101.6	22.8	3.5	72.6	117.9
Grand means :							
	0.11	0.04	79.4	23.4	3.7	72.7	113.8
							0.87

TABLE 17
AVERAGES FOR EACH ELEMENT AND ELECTRICAL CONDUCTIVITY AT EACH WELL OVER MONTHS
6/72- 5/73 FROM WATER SAMPLES TAKEN FROM DEEP AND SHALLOW WELLS

LANE-WELL	MILLIGRAMS/LITER							ECX10 ³
	NH4-N	NO3-N	CA	MG	K	NA	Cl	
1-S	0.1	0.0	88	20	12	10	9	0.6
1-D	0.0	0.0	76	21	4	22	19	0.6
2-S	0.0	0.0	91	20	11	11	7	0.6
2-D	0.0	0.0	84	22	3	33	45	0.7
3-S	0.1	0.0	85	21	13	13	12	0.6
3-D	0.0	0.0	84	22	3	26	32	0.7
4-S	0.1	0.1	87	21	14	13	15	0.6
4-D	0.0	0.0	80	22	3	27	35	0.7
5-S	0.0	0.8	104	22	17	14	18	0.7
5-D	0.1	0.2	68	21	3	27	33	0.5
6-S	0.1	5.3	107	25	18	14	21	0.8
6-D	0.0	0.0	79	22	3	28	35	0.6
7-S	0.0	8.1	110	23	17	14	17	0.7
7-D	0.0	0.1	73	22	3	28	35	0.6
8-S	0.1	12.1	104	23	14	14	16	0.7
8-D	0.0	0.1	72	22	3	28	36	0.6
9-S	0.0	8.0	103	22	12	13	16	0.7
9-D	0.1	0.1	75	21	3	28	34	0.6
10-S	0.0	10.3	101	21	13	13	17	0.7
10-D	0.1	0.0	68	23	3	32	55	0.7
11-S	0.1	15.2	93	23	14	21	43	0.8
11-D	0.1	0.0	97	28	4	157	309	1.4
12-S	0.0	9.4	102	19	12	24	37	0.8
12-D	0.1	0.0	82	26	4	178	325	1.4
13-S	0.0	14.5	92	20	12	23	39	0.7
13-D	0.1	0.0	78	25	4	177	291	1.4
14-S	0.0	16.9	97	21	12	22	34	0.8
14-D	0.0	0.0	70	22	3	172	252	1.3
15-S	0.0	11.0	100	20	12	19	32	0.7
15-D	0.0	0.0	69	20	3	129	171	1.0

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TABLE 18
STANDARD DEVIATION FOR EACH ELEMENT AND ELECTRICAL CONDUCTIVITY AT EACH WELL OVER MONTHS
6/72- 5/73 FROM WATER SAMPLES TAKEN FROM DEEP AND SHALLOW WELLS

LANE-WELL	MILLIGRAMS/LITER								ECX10 ³
	NH4-N	NO3-N	CA	MG	K	NA	CI		
1-S	0.221	0.067	26.410	2.305	0.641	2.512	8.882	0.125	
1-D	0.139	0.043	29.969	3.141	0.232	1.060	4.548	0.141	
2-S	0.156	0.049	27.754	3.905	1.574	1.656	3.880	0.111	
2-D	0.142	0.056	26.148	3.174	0.139	10.048	24.625	0.102	
3-S	0.130	0.035	27.008	3.068	1.295	0.670	5.127	0.122	
3-D	0.157	0.173	17.476	3.030	0.188	1.220	2.941	0.073	
4-S	0.157	0.252	23.068	3.178	1.065	0.510	5.536	0.130	
4-D	0.103	0.000	31.466	3.027	0.162	1.186	5.025	0.178	
5-S	0.074	1.506	21.651	3.457	1.006	0.547	6.100	0.155	
5-D	0.222	0.496	22.938	3.588	0.193	1.333	4.742	0.134	
6-S	0.185	5.653	25.712	3.542	0.693	0.541	2.975	0.114	
6-D	0.150	0.071	23.846	3.240	0.513	1.420	4.020	0.129	
7-S	0.175	5.666	25.537	3.752	0.776	0.507	4.518	0.144	
7-D	0.152	0.454	18.315	3.040	0.258	0.851	4.381	0.107	
8-S	0.300	7.851	24.022	4.550	1.440	1.123	2.805	0.101	
8-D	0.214	0.292	20.037	3.341	0.141	1.236	3.416	0.116	
9-S	0.132	3.435	18.349	4.828	0.792	0.475	4.103	0.092	
9-D	0.216	0.218	30.247	3.379	0.214	0.754	4.762	0.124	
10-S	0.160	3.598	17.917	3.482	0.640	0.455	4.750	0.072	
10-D	0.262	0.058	22.657	3.930	0.078	1.291	16.212	0.093	
11-S	0.199	6.150	29.106	3.962	4.268	4.437	13.500	0.115	
11-D	0.173	0.026	23.687	4.142	0.260	14.085	17.645	0.158	
12-S	0.197	4.273	29.396	1.857	0.319	0.726	4.785	0.111	
12-D	0.158	0.154	30.404	4.796	0.553	6.959	18.143	0.148	
13-S	0.149	3.074	29.707	1.905	0.225	0.882	3.999	0.156	
13-D	0.198	0.087	26.432	4.395	0.204	12.187	26.849	0.150	
14-S	0.182	7.344	34.914	3.110	0.511	1.167	5.356	0.160	
14-D	0.130	0.179	21.636	4.218	0.285	10.492	19.623	0.109	
15-S	0.143	2.165	27.397	3.362	0.686	1.979	5.658	0.152	
15-D	0.108	0.029	21.781	3.326	0.259	12.387	41.933	0.104	

MISSING DATA=-9.900

MISSING DATA=-9.900

TABLE 19
NUMBER OF SAMPLES FOR EACH ELEMENT AND ELECTRICAL CONDUCTIVITY AT EACH WELL OVER MONTHS
6/72- 5/73 FROM WATER SAMPLES TAKEN FROM DEEP AND SHALLOW WELLS

LANE-WELL	NH4-N	NO3-N	CA	MG	K	NA	Cl	ECX10 ³
1-S	11	11	11	11	11	11	11	11
1-D	11	11	11	11	11	11	11	11
2-S	11	11	11	11	11	11	11	11
2-D	11	11	11	11	11	11	11	11
3-S	11	11	11	11	11	11	11	11
3-D	11	11	11	11	11	11	11	11
4-S	11	11	11	11	11	11	11	11
4-D	11	11	11	11	11	11	11	11
5-S	11	11	11	11	11	11	11	11
5-D	11	11	11	11	11	11	11	11
6-S	11	11	11	11	11	11	11	11
6-D	11	11	11	11	11	11	11	11
7-S	11	11	11	11	11	11	11	11
7-D	11	11	11	11	11	11	11	11
8-S	11	11	11	11	11	11	11	11
8-D	11	11	11	11	11	11	11	11
9-S	8	8	8	8	8	8	8	8
9-D	10	10	10	10	10	10	10	10
10-S	11	11	11	11	11	11	11	11
10-D	11	11	11	11	11	11	11	11
11-S	9	9	9	9	9	9	9	9
11-D	11	11	11	11	11	11	11	11
12-S	7	7	7	7	7	7	7	7
12-D	11	11	11	11	11	11	11	11
13-S	6	6	6	6	6	6	6	6
13-D	11	11	11	11	11	11	11	11
14-S	11	11	11	11	11	11	11	11
14-D	10	10	10	10	10	10	10	10
15-S	11	11	11	11	11	11	11	11
15-D	11	11	11	11	11	11	11	11

The degree to which these differences were maintained throughout the 15 plots is shown in Table 17. The standard deviations for each of the wells by constituent averages in Table 17 are listed in Table 18 to show the variation over time.

Of the seven constituents for which highly significant differences between depths were found, the sign of the difference between averages of the deep and shallow wells in each plot (Table 17) was the same as the sign of the difference between the grand means for the deep wells and the grand means for the shallow wells with respect to NO_3^- -N, Mg, K, Na, and Cl^- (Tables 15 and 16). Average values for Ca were higher in the shallow wells than the deep wells for all plots except plot 11 in which Ca was slightly more concentrated in the deep well. Electrical conductivity was higher in the deep wells than in the shallow wells in replication 3 and lower in the deep wells than shallow wells in replication 2. Electrical conductivity values varied between shallow and deep wells in replication 1.

II. Differences between replications.

Average values for constituents in Table 17 show dramatic differences in shallow well NO_3^- -N levels between replication 1 (plots 1-5) and replications 2 and 3 (plots 6-15). Average NO_3^- -N values in plots 1 to 5 ranged from 0 to 0.8 ppm and ranged from 5.3 to 16.9 ppm in plots 6 to 15. No explanation was found for these differences. One hypothesis is that the groundwater below the eastern two-thirds of the study area was contaminated by leachate from the adjacent feedlot area and/or retention lagoons located to the east of the field area. This hypothesis is weakened by the fact that the lateral head gradient at the surface of the groundwater table favors movement of the groundwater toward the feedlot area and retention structures from the study area

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DOCUMENT(S) IS OF
POOR LEGIBILITY IN
THE ORIGINAL**

**THIS IS THE BEST
COPY AVAILABLE**

(Table 5). With the head gradient toward the feedlot area, groundwater contaminant movement from the feedlot area to the field application area would most likely be due to a diffusion gradient caused by contaminant concentration differentials between the two areas. One filling with feedlot runoff was required to seal lagoon #2 as indicated by partial loss of the first filling (11/71) by seepage. No noticeable losses of lagoon water by seepage occurred with later fillings. Seepage from the first filling may have contaminated groundwater in the surrounding area. Direction of the head gradient does not favor contamination beneath the application area from this source.

Striking differences were also observed between replications 1 and 2 and replication 3 in the Na and Cl^- concentrations in the deep wells. Average concentrations for replications 1, 2, and 3 for Na were 26.6, 29.0, and 162.6 ppm, respectively. Corresponding average concentrations for Cl^- were 31.6, 37.7, and 271.8 ppm, respectively. The reason for these extreme replication differences is unknown but it is hypothesized that the parent material near bedrock changes in composition beneath replication 3 relative to replications 1 and 2.

When the sampling wells were drilled, depth measurements indicated that the depth to bedrock was equal for all the deep wells. Therefore, a variation in the depth of the sampling wells can not be correlated to the observed variations in Na and Cl^- concentrations. A highly significant linear correlation between Na and Cl^- was found for the deep well samples ($r = 0.977$) which indicates that changes in concentrations of these elements were parallel throughout the study. A much lower correlation between Na and Cl^- ($r = 0.417$) was found in the shallow wells.

III. Differences between treatments.

The shallow well statistical significance levels for differences between treatments are listed in Table 14. Treatment differences for NO_3^- -N, Mg, and K were all statistically significant at the 0.05 probability level and treatment differences for NH_4^+ -N were statistically significant at the 0.07 probability level. Comparable probability values are also listed for the deep wells in Table 14. Treatment differences in the deep wells for Ca, Mg, K, Na, Cl and electrical conductivity (mmhos/cm) were all statistically significant at the 0.00 probability level.

Treatment means for the shallow well samples are shown in Table 15. Although the treatment differences are statistically significant for NO_3^- -N, it is difficult to determine whether these differences resulted from the various treatments of lagoon water. The NO_3^- -N treatment means show that the level of NO_3^- -N in the low rate SLW treatment was higher than the level in the high rate SLW treatment. A similar observation of NO_3^- -N levels in the shallow wells being negatively related to the amount of NO_3^- -N applied in lagoon water treatments can be made for the low and high rate DLW treatments. The lowest NO_3^- -N treatment mean (5.9 ppm) was found in the high rate DLW treatments as compared with an average value of 6.9 ppm for the well water treatment. These observations indicate a poor correlation between the amount of N added in lagoon water treatments and the level of NO_3^- -N contamination of groundwater in the shallow wells. Average content of NO_3^- -N in the soil profile at the 0- to 300-cm depth at the initiation of this study was highest in the low rate DLW treatment areas and low rate SLW treatment areas (Table 13). These treatment areas contained the highest levels of NO_3^- -N in the groundwater, indicating a possible relationship between initial soil profile NO_3^- -N levels and NO_3^- -N levels in the shallow wells. It is noteworthy that

values higher than 10 ppm for NO_3^- -N were found at both sampling dates before the first lagoon water treatments were applied.

The treatment means for Mg as listed in Table 15 are more closely correlated with the average rates of Mg application in lagoon water during the 1972 irrigation season (Table 8). Magnesium concentrations in the shallow wells for both high rate applications were higher than the comparable low rate applications and the concentrations in shallow wells in the well water treatment area were relatively low. The largest difference between Mg treatment means was 2.0 ppm. Also shown in Table 15 are the treatment means for the concentration of K in the shallow wells which ranged from 12.2 ppm for the well water treatment to 15.7 ppm for the high rate DLW treatment.

Generally, treatment means for NO_3^- -N, Mg, and K levels in the shallow wells were poorly correlated with the quantity of these nutrients applied in lagoon water treatments. The differences between treatments are also small for these constituents with one exception which is the concentration of NO_3^- -N in the low rate DLW treatment of 10.1 ppm, a value relatively higher than the other treatment means. This value is slightly higher than the public health standard for NO_3^- -N in drinking water of 10 ppm. Continuation of this study will be necessary to identify definite trends in the accumulation of the various constituents that may develop relative to lagoon water treatments.

Treatment differences for NO_3^- -N and NH_4^+ -N concentrations in the deep wells were not significant at the 0.05 probability level. Of the six constituents in the deep wells for which statistically significant differences (0.00) between treatments were found (Ca, Mg, K, Na, Cl^- , and EC), the lowest treatment mean values were in the high rate DLW treatment (Table 16). No other trends in the differences between these means were evident.

The low NO_3^- -N levels in the deep wells compared to the relatively high NO_3^- -N values in the shallow wells (as high as 35.4 ppm) suggest that NO_3^- -N levels at the two depths are independent of each other. The lack of significant differences ($p = 0.25$) in NO_3^- -N levels between treatments in the deep wells compared to significant NO_3^- -N treatment differences ($p = 0.03$) in the shallow wells and a statistically significant treatment by depth interaction (0.0543) for NO_3^- -N levels in the deep and shallow wells also provide evidence for independence of NO_3^- -N levels at the two depths. Contamination is apparently localized in the upper part of the aquifer and the probability is high that the origin of this contamination is the soil profile.

This evidence for lack of mixing of NO_3^- -N between the deep and shallow depths has implications regarding the contents of the other constituents in the groundwater. It seems probable that if there was a lack of mixing of NO_3^- -N between depths there was also a lack of mixing between the deep and shallow depths regarding the other constituents. Assuming a lack of mixing between depths, the origin of the constituents in the groundwater at the lower depths must be the parent material at these depths or some source other than the soil profile.

IV. Differences between months.

Constituent differences between months in the shallow wells were statistically significant at the 0.0000 probability level for NH_4^+ -N, Ca, Mg, and EC while the significance level for Cl^- was 0.07 (Table 14). For the deep well samples, differences between months were statistically significant at the 0.0000 probability level for NH_4^+ -N, Ca, Mg, and EC but differences in Cl^- concentrations by month were not statistically significant at the 0.1 probability level. At the greater depth, differences between months for

NO_3^- -N were statistically significant at the 0.07 probability level. The values for the monthly mean concentrations of the constituents which were analyzed are shown in Figures 13-15 for both the deep and shallow wells.

It is easily apparent from Figure 13 that parallel changes between depths over time occurred for Ca, Mg, and EC. Sharp increases for Ca, Mg, and EC were observed in September and December. These factors were more stable throughout the rest of the observation period. An almost constant level of K was observed in the deep and shallow wells throughout the observation period (Figure 13). The consistently small variation in K over time in all the wells is shown in Table 18. Nitrate in the shallow wells ranged from 0 to 35.4 ppm and reached relative peaks in November and December. However, the conclusions which can be drawn from this observation are limited because of the lack of statistical significance for differences in NO_3^- -N levels in the shallow wells over time. A peak accumulation of NO_3^- -N was also found at this time of year by Metzler and Stolenburg (67) and Crabtree (18). The very low average monthly values for NH_4^+ -N in the deep and shallow wells and for NO_3^- -N in the shallow wells can be distinguished more clearly in Tables 15 and 16.

The deep well monthly means shown in Table 16 for each constituent were regressed on the monthly mean values for the respective constituent in the shallow well samples shown in Table 15. The correlation coefficients from these regressions for NH_4^+ -N, NO_3^- -N, Ca, Mg, K, Na, Cl^- , and EC are 0.579, 0.636, 0.895, 0.987, 0.661, -0.026, 0.735, and 0.939. The very high r values for Ca, Mg, and EC are suggested by the parallel changes of these constituents in the deep and shallow wells as shown in Figure 13. The sharp decrease in Ca and EC observed in November at both the deep and shallow wells was not observed in Mg concentrations.

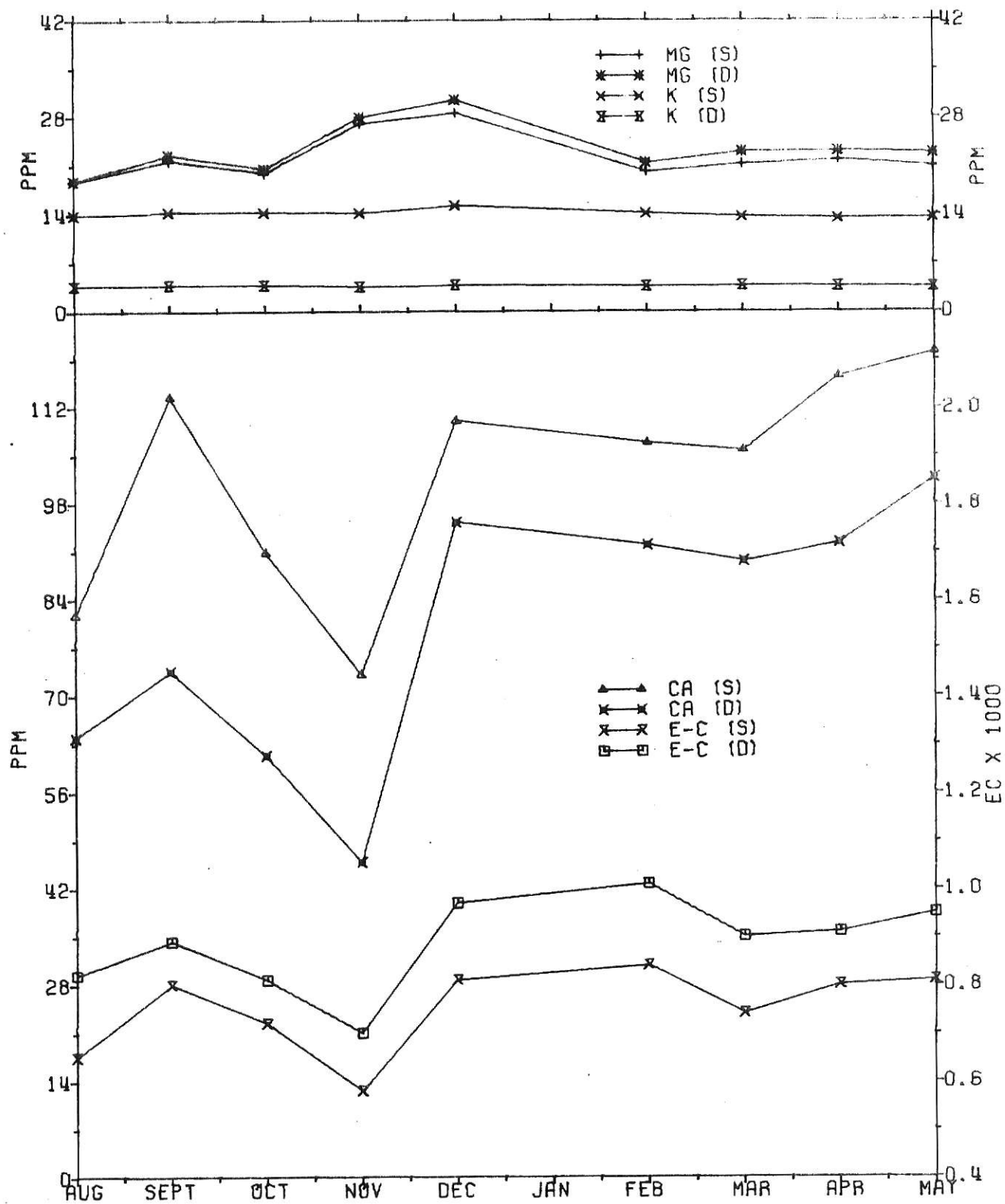


Fig. 13. Monthly means for Mg, K, Ca concentrations and electrical conductivity in samples from deep (D) and shallow (S) wells (8/72-5/73).

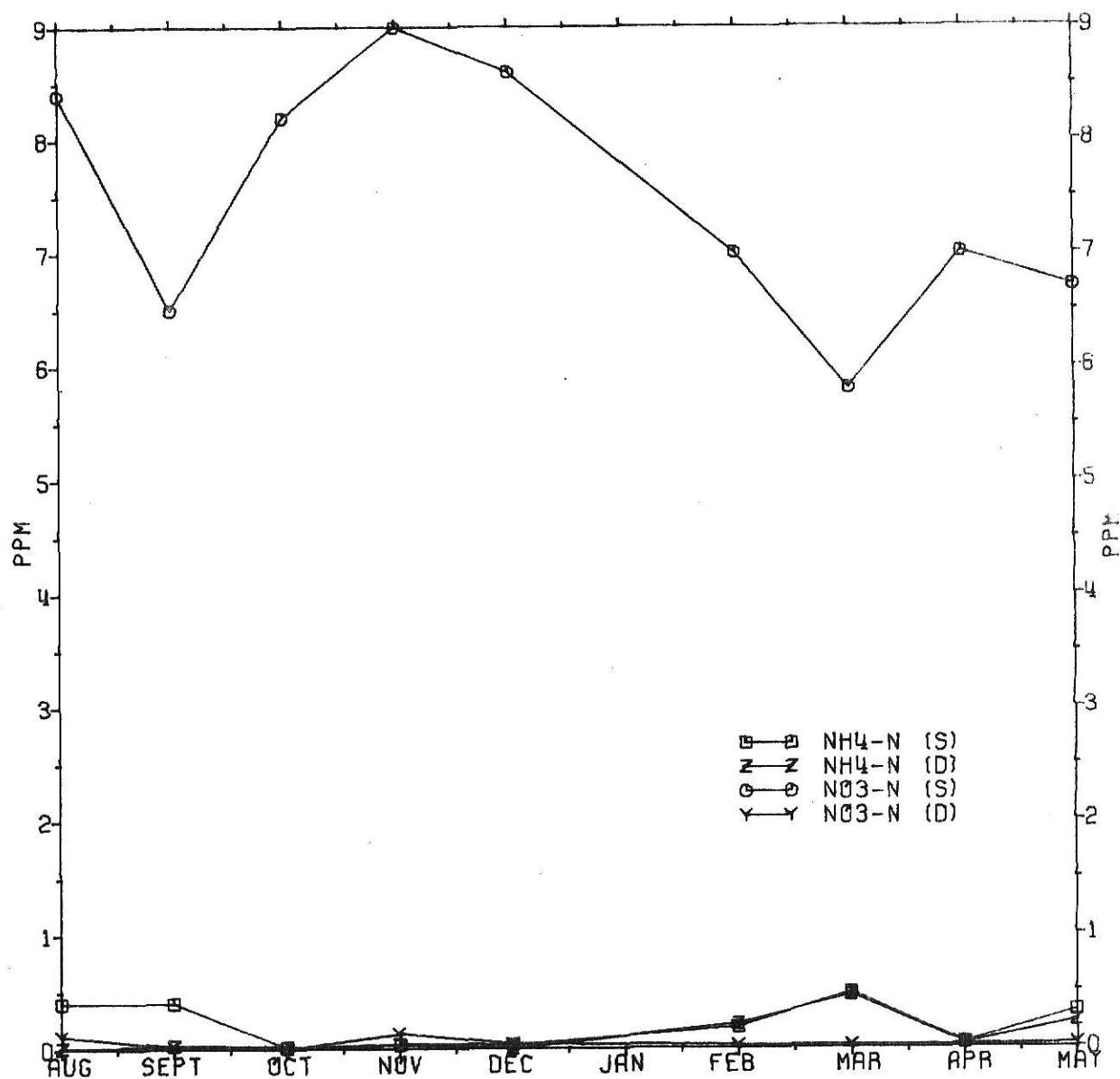


Fig. 14. Monthly means for $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ concentrations in samples from deep (D) and shallow (S) wells (8/72-5/73).

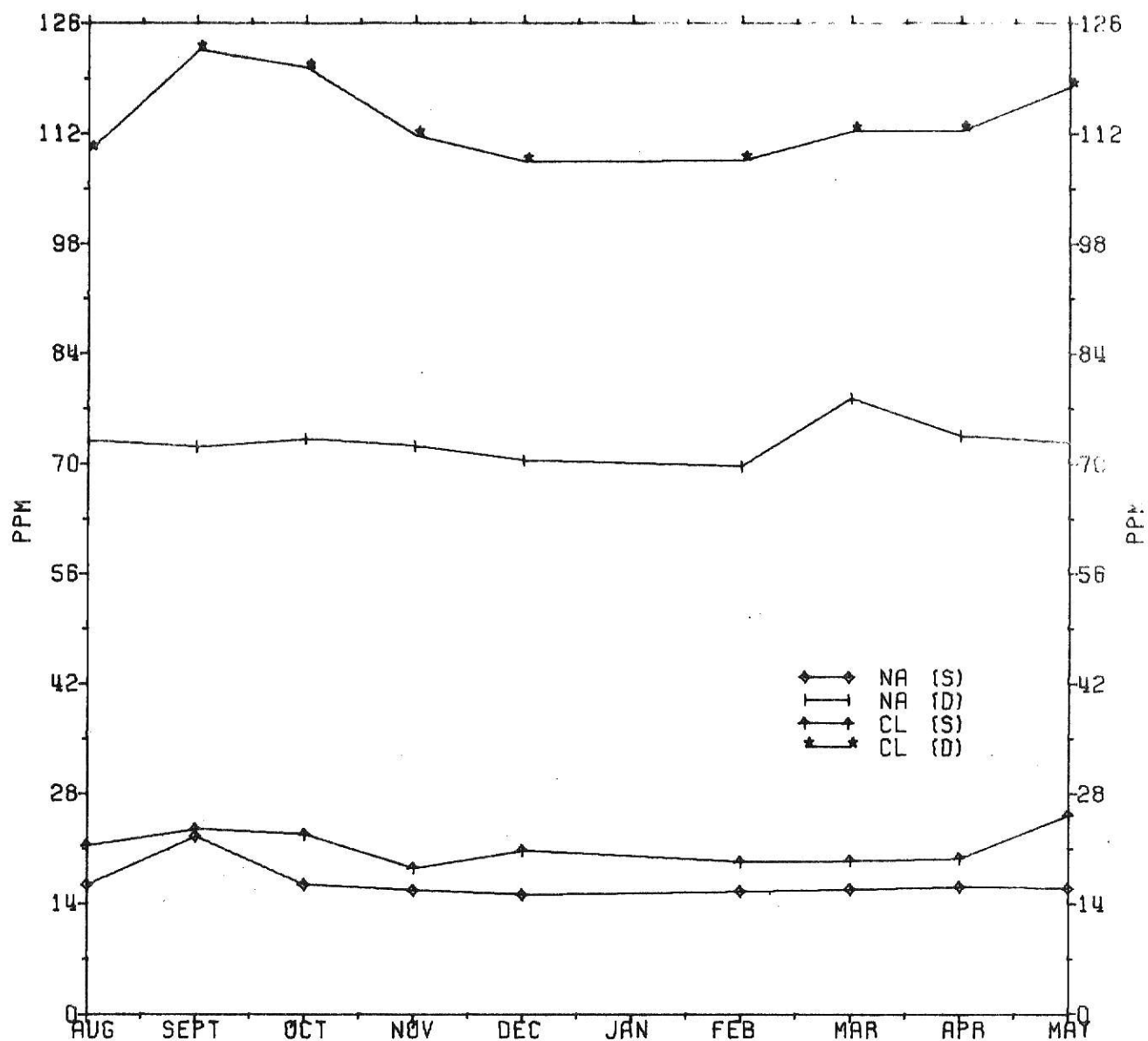


Fig. 15. Monthly means for Na and Cl concentrations in samples from deep (D) and shallow (S) wells (8/72-5/73).

The high values for correlation coefficients indicating parallel changes in deep and shallow wells for a majority of the constituents analyzed raise the question of responsibility for changes in the groundwater composition over time. If one considers the evidence for lack of mixing between deep and shallow aquifers provided from NO_3^- -N analyses in this study and other studies (2, 52, 66), contamination from the overlying soil profile can not be used to explain the contamination at the lower depths. Since a high degree of correlation was found between concentrations of some of the constituents at the deep and shallow depths, a more plausible hypothesis seems to be a dilution effect of some kind which affects the concentration of salts in the groundwater similarly at the deep and shallow depths. This kind of phenomenon could possibly result from variable rates of movement of the groundwater from the original source of contamination over time. No explanation is offered for the independence of Na concentrations in the deep and shallow wells or the lack of synchronization of changes in Mg levels with changes in levels of Ca and EC all of which conflict with this hypothesis.

Since Cl^- and NO_3^- are both anions, they might be expected to leach through the soil profile and into the groundwater at similar rates. The correlation of NO_3^- -N and Cl^- in the shallow wells throughout the study yielded an r value of 0.567. If the source of NO_3^- -N and Cl^- in the groundwater at the shallow depth was the overlying soil, the difference in the levels of these two ions in the soil profile at the initiation of this study as shown in Figures 4 and 11, chemical and biological conversions of N, and unequal uptake of NO_3^- -N and Cl^- by plants may account for some of the differences. Chloride and NO_3^- -N were more closely related at the shallow depths, however, than in the deep wells where the correlation between these two ions yielded an r value of -0.125.

All well water samples were analyzed semi-qualitatively for P by visual comparison with a 1-ppm standard. Color development in the 1-ppm standard was easily detectable visually whereas no color development was observed in any of the well water samples. The lack of P in the well water samples throughout the observation period indicated that P had not leached down through the soil profile and into the water table. This implication is strengthened by the data in Figure 12 which show that relatively large amounts of P accumulated in the upper 30 cm of soil and that the concentrations of P at depths from 30 to 300 cm remained essentially constant. These results substantiate findings by others (43, 53, 54) who reported that the P in soil-applied liquid wastes was removed to the extent of 99% or greater.

SUMMARY AND CONCLUSIONS

Beef feedlot runoff retained during the summer and fall months of 1972 and applied as an irrigant in this study was found to have an electrical conductivity ranging from 1.4 to 2.0 mmhos/cm and which was negatively related to rainfall intensity. This runoff was characteristically high in K and Cl^- with the concentration of these elements being approximately 9X and 6X as concentrated as the average of the other elements analyzed (inorganic-N, P, K, Ca, Mg, Na, Cl^-). No statistically significant differences (0.05) in bromegrass yields, bromegrass N, P, K concentrations, or bromegrass N, P, K uptake were produced by treatments of two rates of straight and diluted lagoon water which averaged 9.3 and 16.6 cm and 9.5 and 19.0 cm, respectively, for the 1972 applications.

Hypothetical and actual values for percent exchangeable Na and electrical conductivity were in close agreement and indicated that a dispersion problem is not likely to result from application of feedlot lagoon water of the quality applied in this study. Neither the average electrical conductivity of the soil solution for 1971 and 1973 of 1.01 and 1.37 mmhos/cm nor the average percent exchangeable Na for 1971 and 1973 of 0.56 and 0.84 differed significantly at the 0.05 probability level. These values are considerably lower than those values for soil salinity and percent exchangeable Na of 4.0 and 15, respectively, which are considered threshold values for reducing crop production. The average observed value and average predicted value for the percent exchangeable K that developed in the soil from application of the lagoon water were 15.0 and 35.2, respectively. The large discrepancy between these two values is probably due to the lack of equilibrium conditions between the lagoon water and soil exchange complex. Further studies are

needed to determine the equilibrium levels for percent exchangeable K, soluble salts, and percent exchangeable Na in this soil under equilibrium conditions with lagoon water applications.

In the high rate SLW treatment area (16.6 cm) in which N, P, and K were applied at the highest rates, bromegrass N, P, K uptake data indicated that two mechanical harvests of bromegrass comparable to the one in this study would remove over twice the N and about one-half of the P and K applied in this lagoon water treatment. It is hypothesized that smaller amounts of nutrients would be removed by grazing due to manure and urine deposition on the field. Grazing, however, would provide cycling of the plant nutrients from the root zone by plant uptake with subsequent consumption by the grazing animal, deposition of the plant nutrients in waste materials on the soil surface, and leaching by precipitation back into the root zone. Both removal and cycling of the plant nutrients in feedlot lagoon water by crops may reduce the groundwater pollution potential of applied feedlot lagoon water.

Substantial reductions of NO_3^- -N and NH_4^+ -N in the soil profile at the 0- to 300-cm depth were observed from 1971 to 1973 for all treatments as indicated by average mean values throughout this depth of 24.9 and 14.1 ppm for NO_3^- -N and 27.3 and 4.3 ppm for NH_4^+ -N for these two sampling dates. The primary accumulation of extractable K in the soil profile was at the 0- to 30-cm depth. At this depth an increase was observed for all lagoon water treatments with the largest increase resulting from the high rate SLW treatment, an increase from 470 to 588 ppm. This is compared with an unexplained increase in extractable K in the well water treatment area from 482 to 527 ppm. The weak Bray extractable P content at the 0- to 300-cm depth decreased from 37 to 31 ppm for all treatments. A reduction in the average weak Bray extractable P from 187 to 166 ppm was observed for all treatments at the 0- to

30-cm depth where the primary concentration of this constituent was found. At the 0- to 300-cm depth a moderate increase in the average water soluble Cl^- content from 3 to 5 ppm was observed. Consistent changes by year or treatment of notable consequence for Ca, Mg, Na, and pH in the total 0- to 300-cm profile were not observed.

The bromegrass N uptake for 1972 based on the uptake from one harvest in 1973 accounted for approximately 120 kg/ha of the decline in N in the 0- to 300-cm profile. An average of 30 kg/ha of inorganic-N was added in the lagoon water treatments. The decrease in soil NO_3^- -N content at the 0- to 300-cm depth of the soil profile from 1971 to 1973 of 10 ppm can be converted to roughly represent a decrease of 460 kg/ha. This estimation indicates that 370 kg/ha of NO_3^- -N in the soil profile at this depth was lost by mechanisms other than plant uptake. By the same reasoning NH_4^+ -N in the soil profile decreased by 1,080 kg/ha, much of which was probably due to nitrification. Preparation of a nitrogen balance is beyond the scope of this paper but these approximations serve to indicate that large quantities of N were removed by mechanisms other than plant uptake and that the potential for losses of large quantities of N by leaching was present.

Analysis of groundwater samples from the 7.6- and 21-m depths often revealed values for NO_3^- -N from the shallow depths greater than 10 ppm (grand mean = 6.8) with the highest observation being 35.4 ppm. Very low levels of NO_3^- -N (grand mean = 0.04 ppm) were found in samples from deep wells. Ammonium-N values were very low for both depths as indicated by grand means of 0.12 and 0.11 ppm for NH_4^+ -N in the shallow and deep wells, respectively. Very highly significant differences (0.0000) between depths were found for all of the constituents which were analyzed quantitatively (NO_3^- -N, Ca, Mg, K, Na, Cl^- , $\text{EC} \times 10^3$) except NH_4^+ -N. No consistent significant differences

between treatments which could be correlated with treatments of lagoon water were identified for any of the constituents analyzed at either depth. The differences between months for Ca, Mg, and $EC \times 10^3$ in both the deep and shallow wells were highly significant (0.0000) with relative peaks for these factors being observed in September and December.

A lack of mixing between depths was implied by the high levels of NO_3^- -N at the shallow depth relative to the very low levels at the deep depth. This assumption is further supported by the fact that significant NO_3^- -N treatment differences (0.03) were found at the shallow sampling depth while the significance level of differences between treatments for NO_3^- -N in the deep wells was 0.25, indicating a lack of influence of NO_3^- -N concentrations in the shallow wells on NO_3^- -N concentrations at the greater depth. These factors may be considered as evidence that the origin of the NO_3^- -N in the groundwater in this study was the soil profile though the relationship between the lagoon water treatments and the NO_3^- -N in the groundwater is not clear.

The evidence for lack of mixing between depths and the closely parallel changes between depths over time for monthly averages of Ca, Mg, and electrical conductivity ($r = 0.895$, 0.987 , and 0.939 , respectively) imply that changes in the concentration of constituents in the groundwater which occur simultaneously at both depths may be due to a dilution effect which affects the dissolved constituents at both depths proportionally. More studies will be needed to provide a positive explanation for these parallel changes.

Semi-qualitative analyses of the well samples from both depths revealed no P in the water samples during this study. The immobility of P in the soil is verified by the relatively high accumulations of this element near the soil surface. The decrease in weak Bray extractable P in the 0- to 30-cm increment (all treatments) coupled with the fact that approximately twice as

much P was added in lagoon water applications as was calculated for P uptake by the bromegrass in one growing season implies that some of the weak Bray extractable P became fixed between the two soil sampling dates.

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APPENDIX

Table 1
Soil NH_4^+-N (ppm) as affected by treatment--replication 1.

Depth (cm)	Plot									
	1		2		3		4		5	
	straight lagoon water (high rate)	1973	well water	1971	diluted lagoon water (low rate)	1971	straight lagoon water (low rate)	1971	diluted lagoon water (high rate)	1973
0-30	56.9	7.3	47.1	18.5	7.9	48.7	6.1	21.1	8.2	
30-60	48.9	9.5	17.0	12.9	5.5	37.2	1.9	31.8	2.4	
60-90	23.6	9.8	89.5	17.8	5.5	61.2	2.1	56.8	2.9	
90-120	28.8	7.6	112.6	40.3	7.1	40.3	2.1	45.0	1.1	
120-150	15.0	20.6	70.4	29.0	3.4	27.1	2.5	16.7	1.5	
150-180	51.6	14.4	55.6	32.8	1.4	25.2	1.8	12.0	2.1	
180-210	20.5	7.3	41.5	49.2	1.8	13.7	0.7	36.0	2.4	
210-240	36.4	5.5	46.8	39.0	1.9	9.8	1.4	32.8	0.7	
240-270	38.2	6.8	41.6	31.8	7.3	7.5	1.1	18.7	1.2	
270-300	55.7	9.0	24.9	18.9	3.2	9.3	0.0	31.1	1.7	
300-330	17.0		32.8	19.5		5.5		8.0		
330-360	22.4		21.2	23.0		5.0		12.6		
360-390	44.0		25.5	9.0		19.6		9.1		
390-420	16.7		26.8	11.9		3.9		13.0		
420-450	16.9		20.2	5.5		7.3		10.2		
450-480	13.3		23.4	6.8		2.6		3.5		
480-510	6.1		11.2	3.9		5.0		3.9		
510-540	7.3		21.2	2.6		3.5		18.0		
540-570	19.9		10.8	--		2.4		--		
570-600	8.6		--	--		8.4		--		

Table 2

Soil $\text{NH}_4^+\text{-N}$ (ppm) as affected by treatment--replication 2.

Depth (cm)	Plot									
	6		7		8		9		10	
	straight lagoon water (high rate)	1973	diluted lagoon water (high rate)	1971	1973	diluted lagoon water (low rate)	1971	1973	well water	straight lagoon water (low rate)
0-30	27.0	7.2	21.8	21.8	5.4	29.3	29.3	20.6	27.9	39.3
30-60	27.1	3.6	26.7	26.7	4.6	22.6	22.6	3.6	15.6	25.6
60-90	9.2	1.7	17.2	17.2	2.4	17.4	17.4	3.7	9.8	15.8
90-120	14.4	2.2	19.2	19.2	1.7	15.6	15.6	3.0	14.4	29.3
120-150	14.1	3.2	20.1	20.1	2.4	18.7	18.7	1.0	32.4	31.8
150-180	28.6	3.3	27.1	27.1	3.5	51.3	51.3	2.9	28.5	18.0
180-210	37.1	2.8	18.3	18.3	2.6	36.0	36.0	2.6	24.9	14.5
210-240	34.6	3.5	12.0	12.0	2.9	12.2	12.2	1.4	20.5	9.1
240-270	14.8	2.2	11.1	11.1	1.7	11.1	11.1	1.1	13.4	6.8
270-300	9.5	1.7	15.1	15.1	2.4	10.7	10.7	1.2	8.4	9.7
300-330	7.3		11.8	11.8		8.4	8.4		8.4	6.6
330-360	16.9		9.1	9.1		9.3	9.3		10.4	9.8
360-390	15.4		9.5	9.5		12.0	12.0		8.0	7.5
390-420	16.3		22.7	22.7		9.8	9.8		8.7	12.3
420-450	15.4		22.6	22.6		8.4	8.4		5.9	5.9
450-480	--		10.5	10.5		--	--		12.4	12.4
480-510	--		6.6	6.6		--	--		--	--
510-540	--		14.2	14.2		--	--		--	--
540-570	--		--	--		--	--		--	--
570-600	--		--	--		--	--		--	--

Table 4

Soil NO_3^- -N (ppm) as affected by treatment--replication 1.

Depth (cm)	Plot									
	1		2		3		4		5	
	straight lagoon water (high rate)		well water		diluted lagoon water (low rate)		straight lagoon water (low rate)		diluted lagoon water (high rate)	
	1971	1973	1971	1973	1971	1973	1971	1973	1971	1973
0-30	46.9	9.0	133.1	7.1	45.5	11.8	57.3	12.7	50.7	9.8
30-60	31.0	6.6	19.7	12.0	32.4	7.5	34.3	5.4	10.3	5.3
60-90	28.7	4.1	9.6	44.7	27.9	7.9	32.0	4.7	11.1	5.8
90-120	6.1	25.5	10.0	27.9	35.1	13.3	32.0	4.0	16.5	4.6
120-150	11.6	35.3	6.5	11.1	46.3	27.5	50.3	5.0	13.4	2.6
150-180	1.7	20.1	75.4	7.6	76.2	36.9	30.6	9.0	25.9	10.8
180-210	4.1	16.5	12.7	21.9	66.1	49.5	30.0	8.3	22.0	14.2
210-240	10.4	10.8	10.9	34.7	59.6	40.5	10.2	16.9	15.8	14.8
240-270	11.6	10.5	42.5	28.8	32.8	56.0	14.4	12.0	11.8	17.3
270-300	11.2	11.1	15.4	35.3	17.4	57.0	11.9	5.1	21.7	27.7
300-330	3.9		14.9		12.6		5.9		7.3	
330-360	2.1		6.4		21.4		11.5		11.9	
360-390	2.8		16.0		13.1		19.8		9.8	
390-420	5.0		5.5		11.1		2.9		15.2	
420-450	6.4		3.6		7.1		8.0		17.6	
450-480	4.1		12.9		8.4		2.2		2.9	
480-510	5.3		0.6		0.4		23.8		0.3	
510-540	1.4		1.8		0.0		6.9		5.0	
540-570	22.1		0.4		--		2.8		--	
570-600	0.4		--		--		6.1		--	

Table 5

Soil $\text{NO}_3^- - \text{N}$ (ppm) as affected by treatment--replication 2.

Depth (cm)	Plot											
	6		7		8		9		10			
	straight lagoon water (high rate)		diluted lagoon water (high rate)		diluted lagoon water (low rate)		well water		straight lagoon water (low rate)			
	1971	1973	1971	1973	1971	1973	1971	1973	1971	1973		
0-30	34.7	7.6	51.5	14.5	27.5	20.5	49.1	13.7	62.5	12.0		
30-60	13.6	1.0	22.6	4.7	5.9	4.0	10.7	7.3	8.0	8.0		
60-90	2.9	1.8	4.3	3.6	11.3	10.4	14.8	5.5	6.8	7.3		
90-120	6.4	3.7	16.5	3.0	18.7	9.3	24.8	3.6	37.3	7.5		
120-150	16.9	1.9	37.8	7.3	40.5	1.7	51.6	28.5	54.5	7.6		
150-180	40.0	2.9	45.1	19.5	30.8	6.2	47.4	33.9	27.2	8.7		
180-210	47.0	12.7	18.1	26.4	24.6	6.0	32.2	32.5	16.5	21.7		
210-240	42.3	21.9	14.8	25.6	7.7	10.1	23.2	28.4	14.8	30.2		
240-270	32.4	24.5	13.1	28.8	9.4	7.5	27.2	25.2	13.7	33.6		
270-300	24.8	26.7	11.8	34.6	11.8	16.8	17.7	20.9	28.4	22.1		
300-330	22.3		13.1		21.9		26.4		20.3			
330-360	40.9		5.5		22.4		18.8		16.7			
360-390	30.4		7.5		13.0		22.4		10.1			
390-420	15.2		12.6		9.4		28.1		19.6			
420-450	8.7		17.7		6.1		--		15.2			
450-480	--		13.7		--		--		13.4			
480-510	--		10.5		--		--		--			
510-540	--		11.9		--		--		--			
540-570	--		--		--		--		--			
570-600	--		--		--		--		--			

Table 6
Soil NO_3^- -N (ppm) as affected by treatment--replication 3.

Depth (cm)	Plot											
	11		12		13		14		15			
	straight lagoon water (high rate)		well water		straight lagoon water (low rate)		diluted lagoon water (low rate)		diluted lagoon water (high rate)			
	1971	1973	1971	1973	1971	1973	1971	1973	1971	1973		
0-30	36.4	9.0	24.0	8.7	17.9	6.8	29.3	7.3	33.0	7.9		
30-60	24.0	4.3	19.9	3.6	43.9	6.2	32.6	7.6	17.2	6.2		
60-90	7.2	3.6	13.6	2.6	34.1	6.1	18.9	7.3	26.9	4.3		
90-120	17.7	3.0	13.0	2.2	52.1	6.6	33.2	5.0	31.0	4.1		
120-150	15.5	2.4	10.7	1.1	46.5	5.1	17.4	5.0	19.9	2.5		
150-180	9.3	1.4	12.4	5.9	24.3	10.7	24.8	11.3	28.6	1.5		
180-210	13.6	0.8	19.2	37.2	29.5	19.4	32.8	17.8	25.7	1.8		
210-240	18.3	1.2	31.4	11.8	34.4	49.0	32.5	38.2	32.4	3.0		
240-270	10.4	6.5	18.9	7.5	38.2	45.5	60.7	17.6	37.6	4.8		
270-300	15.9	14.0	14.5	21.9	31.0	37.3	40.9	36.0	33.2	14.9		
300-330	15.4		10.0		55.1		42.2		40.7			
330-360	15.8		14.8		68.5		23.0		47.2			
360-390	20.6		17.7		67.0		9.4		34.4			
390-420	18.3		18.3		48.6		3.7		13.4			
420-450	23.9		17.7		49.1		4.8		—			
450-480	19.6		14.9		40.0		4.4		5.8			
480-510	—		—		68.6		0.1		1.2			
510-540	—		—		11.5		0.6		8.2			
540-570	—		—		5.5		—		0.1			
570-600	—		—		4.0		—		0.6			

Table 8

Extractable soil calcium (ppm) as affected by treatment--replication 2.

Depth (cm)	Plot									
	6		7		8		9		10	
	straight lagoon water (high rate)	1971	1973	diluted lagoon water (high rate)	1971	1973	diluted lagoon water (low rate)	1971	1973	straight lagoon water (low rate)
0-30	2862	1803	2576	1810	2222	1614		3123	2226	2733
30-60	2826	3828	2828	3412	4495	1884		2735	2688	2350
60-90	2775	3177	4415	4570	4726	2408		4655	3556	3335
90-120	2994	3329	4794	5015	4071	2975		2481	5820	5908
120-150	3608	8514	6356	7581	6357	6574		5139	8669	8116
150-180	6400	5695	9088	8064	7351	8363		9088	10022	5244
180-210	8116	7747	6609	7798	9588	6115		8806	8886	4436
210-240	7834	6581	5399	7473	5057	6153		8832	8339	4614
240-270	6779	5363	6736	6672	5689	5710		9347	6791	4635
270-300	6546	4356	6523	9011	5888	5223		6779	7841	7786
300-330	4962		6049		6866			9375		4686
330-360	4295		3858		5149			4761		4853
360-390	8754		4403		5020			7440		4508
390-420	6049		4403		5649			5359		4330
420-450	3531		4440		1762			--		3393
450-480	--		4290		--			--		3476
480-510	--		4315		--			--		--
510-540	--		8625		--			--		--
540-570	--		--		--			--		--
570-600	--		--		--			--		--

Table 9

Extractable soil calcium (ppm) as affected by treatment--replication 3.

Depth (cm)	Plot											
	11		12		13		14		15			
	straight lagoon water (high rate)		well water		straight lagoon water (low rate)		diluted lagoon water (low rate)		diluted lagoon water (high rate)			
	1971	1973	1971	1973	1971	1973	1971	1973	1971	1973		
0-30	3238	3059	3291	2930	3229	2675	2765	2239	2476	2106		
30-60	2474	1922	1985	2248	4252	3216	4685	3454	3863	3349		
60-90	1740	1531	3408	3600	3022	2537	3837	2537	3563	3201		
90-120	5221	7677	4950	4907	1649	3043	3665	1715	2180	3499		
120-150	5306	3058	1492	2569	1714	1678	2191	2702	1372	2687		
150-180	1338	1870	1364	2248	746	1640	2096	3514	1841	4486		
180-210	1400	2354	1675	4524	739	1846	2178	3043	3369	4486		
210-240	2955	4506	1741	7079	1439	1730	1892	2687	1571	4388		
240-270	5845	8808	3578	7331	1505	4754	2949	3664	1008	2730		
270-300	7109	11173	4070	12028	3424	6172	4683	5683	1754	4907		
300-330	13512		8926		4552		8317		3482			
330-360	8509		7946		9109		7341		3500			
360-390	7754		11538		9567		10498		4218			
390-420	5769		4185		8439		9485		---			
420-450	5526		6879		8017		5156		2863			
450-480	5863		8415		5787		6607		3314			
480-510	--		--		7677		8365		2844			
510-540	--		--		14093		9511		11450			
540-570	--		--		15485		--		14861			
570-600	--		--		18254		--		--			

Table 10

Extractable soil magnesium (ppm) as affected by treatment--replication 1.

Depth (cm)	Plot													
	1		2		3		4		5					
	straight lagoon water (high rate)	1971	1973	well water	1971	1973	diluted lagoon water (low rate)	1971	1973	straight lagoon water (low rate)	1971	1973	diluted lagoon water (high rate)	1971
0-30	364	306		412	334	373	335	341	235	318			115	318
30-60	260	226		258	241	245	217	236	143	175			205	175
60-90	238	250		258	246	235	182	272	144	165			312	165
90-120	253	256		244	247	159	243	183	228	146			149	146
120-150	157	266		282	276	132	213	190	185	143			95	143
150-180	250	226		513	192	221	165	105	106	260			141	260
180-210	116	187		334	132	389	164	104	91	264			286	264
210-240	211	244		193	222	415	216	64	100	168			204	168
240-270	340	327		254	345	401	387	82	79	175			153	175
270-300	459	451		332	469	323	417	60	48	213			229	213
300-330	192			354		773		36					122	
330-360	292			313		468		84					161	
360-390	824			283		316		190					167	
390-420	528			431		128		38					161	
420-450	329			754		71		52					228	
450-480	138			596		54		35					93	
480-510	92			535		92		85					23	
510-540	47			335		64		54					67	
540-570	130			205		--		35					--	
570-600	96			--		--		58					--	

Table 11

Extractable soil magnesium (ppm) as affected by treatment---replication 2.

Depth (cm)	Plot									
	6		7		8		9		10	
	straight lagoon water (high rate)	1973	diluted lagoon water (high rate)	1971	diluted lagoon water (low rate)	1971	well water	1971	straight lagoon water (low rate)	1971
0-30	348	247	302	302	244	303	234	333	298	260
30-60	215	299	239	239	237	253	181	227	209	212
60-90	100	117	145	145	162	146	125	138	133	173
90-120	100	118	130	130	174	122	121	110	229	272
120-150	124	362	222	222	267	191	237	201	330	197
150-180	228	177	424	424	350	353	286	266	186	136
180-210	337	273	291	291	325	324	177	331	184	177
210-240	281	235	297	297	327	186	194	277	194	163
240-270	229	212	436	436	316	237	210	340	200	218
270-300	154	170	505	505	381	269	287	239	493	309
300-330	143		529	529		351		348	479	
330-360	246		335	335		353		150	582	
360-390	481		343	343		498		194	460	
390-420	384		361	361		492		247	590	
420-450	294		352	352		102		--	486	
450-480	--		289	289		--		--	374	
480-510	--		274	274		--		--	--	
510-540	--		565	565		--		--	--	
540-570	--		--	--		--		--	--	
570-600	--		--	--		--		--	--	

Table 12

Extractable soil magnesium (ppm) as affected by treatment-replication 3.

Depth (cm)	Plot														
	11		12		13		14		15						
	straight lagoon water (high rate)	1971	1973	well water	1971	1973	straight lagoon water (low rate)	1971	1973	diluted lagoon water (low rate)	1971	1973	diluted lagoon water (high rate)	1971	1973
0-30	371	358	366	343	388	293	292	217	238	277	238	277	238	277	238
30-60	231	293	297	233	392	332	462	323	365	435	365	323	365	435	365
60-90	148	127	286	221	313	245	333	214	313	375	313	214	313	375	313
90-120	314	292	196	194	345	217	301	116	254	320	254	116	254	320	254
120-150	178	94	74	90	233	75	124	82	91	111	91	82	91	111	91
150-180	73	64	67	77	76	67	97	82	112	116	112	82	112	116	112
180-210	76	69	119	134	86	65	94	83	110	95	110	83	110	95	110
210-240	135	130	82	219	74	80	93	80	108	86	108	80	108	86	108
240-270	244	292	156	273	81	133	108	100	73	78	73	100	73	78	73
270-300	383	450	227	481	137	193	190	164	111	131	111	164	111	131	111
300-330	668		502		271		409			304		409		304	
330-360	512		441		397		368			332		368		332	
360-390	506		588		481		619			491		619		491	
390-420	391		239		404		556			466		556		466	
420-450	406		398		425		319			--		319		--	
450-480	338		540		321		450			374		450		374	
480-510	--		--		618		631			506		631		506	
510-540	--		--		651		658			463		658		463	
540-570	--		--		739		--			748		--		748	
570-600	--		--		858		--			830		--		830	

Table 13

Extractable soil potassium (ppm) as affected by treatment--replication 1.

Depth (cm)	Plot							
	1		2		3		4	
	straight lagoon water (high rate)		well water		diluted lagoon water (low rate)		straight lagoon water (low rate)	5 diluted lagoon water (high rate)
	1971	1973	1971	1973	1971	1973	1971	1973
0-30	547	569	636	536	436	619	387	362
30-60	245	269	235	276	278	242	155	188
60-90	293	309	356	343	293	117	200	160
90-120	396	360	360	326	139	201	180	180
120-150	153	368	279	251	121	150	189	130
150-180	135	209	427	159	220	75	121	184
180-210	67	192	315	100	360	41	108	324
210-240	135	242	193	192	405	67	45	238
240-270	315	293	155	301	360	41	58	189
270-300	450	477	450	469	373	16	40	265
300-330	157		360		675		18	112
330-360	261		315		337		63	139
360-390	657		342		193		135	135
390-420	315		382		94		22	153
420-450	234		585		45		40	216
450-480	121		405		31		13	81
480-510	81		315		85		58	13
510-540	40		306		4		40	427
540-570	153		225		--		18	--
570-600	81		--		--		40	--

Table 16

Extractable soil sodium (ppm) as affected by treatment--replication 1.

Depth (cm)	Plot									
	1		2		3		4		5	
	straight lagoon water (high rate)		well water		diluted lagoon water (low rate)		straight lagoon water (low rate)		diluted lagoon water (high rate)	
	1971	1973	1971	1973	1971	1973	1971	1973	1971	1973
0-30	46.0	36.2	63.8	22.7	23.5	26.6	17.1	48.8	27.7	4.4
30-60	29.8	58.9	29.8	68.0	59.5	57.7	29.8	17.8	38.3	13.3
60-90	38.3	81.6	25.5	36.3	38.3	57.7	63.8	0.0	55.3	17.8
90-120	44.0	54.4	74.3	9.1	88.0	35.5	68.8	39.9	60.5	79.9
120-150	19.3	140.5	71.5	22.7	66.0	62.1	66.0	22.2	88.0	48.8
150-180	57.8	45.3	83.9	58.9	52.3	26.6	33.0	31.1	145.8	35.5
180-210	30.2	58.9	96.2	4.5	123.8	48.8	29.0	97.6	99.0	35.5
210-240	49.5	149.6	125.1	0.0	79.8	53.3	24.8	17.8	71.5	88.8
240-270	55.0	54.4	154.0	9.1	99.0	31.1	261.3	57.7	27.5	53.3
270-300	22.0	158.6	206.0	31.7	30.3	137.6	52.3	0.0	66.0	39.9
300-330	19.3		55.0		71.5		0.0		19.3	
330-360	24.8		165.0		101.8		8.3		82.5	
360-390	49.5		57.8		35.8		13.9		90.8	
390-420	8.3		156.8		107.3		16.5		118.3	
420-450	16.5		93.5		60.5		24.8		63.3	
450-480	16.5		154.0		5.5		13.9		0.0	
480-510	8.3		88.0		2.8		13.9		0.0	
510-540	0.0		154.0		11.0		30.3		55.0	
540-570	74.3		41.3		--		8.3		--	
570-600	77.0		--		--		13.9		--	

Table 17
Extractable soil sodium (ppm) as affected by treatment--replication 2.

Depth (cm)	Plot									
	6		7		8		9		10	
	straight lagoon water (high rate)	1971	1973	diluted lagoon water (high rate)	1971	1973	diluted lagoon water (low rate)	1971	1973	straight lagoon water (low rate)
0-30	23.4	71.0	46.8	44.1	23.5	44.1	53.2	29.2	44.7	39.2
30-60	29.8	57.7	51.1	39.2	51.0	34.3	68.0	58.9	55.3	83.4
60-90	23.5	106.5	25.6	49.1	59.6	24.5	51.0	58.9	55.3	44.1
90-120	22.0	48.8	57.8	49.1	55.0	93.2	147.5	49.0	45.0	54.0
120-150	19.3	71.0	46.8	44.1	115.0	34.3	65.0	98.1	47.5	107.9
150-180	24.8	71.0	44.0	34.3	112.5	93.2	32.5	68.7	32.5	78.5
180-210	30.3	48.8	52.3	58.9	22.5	63.8	20.0	34.3	2.5	112.8
210-240	24.8	39.9	68.8	29.4	30.0	88.3	20.0	4.9	0.0	24.5
240-270	19.3	115.4	66.0	24.5	22.5	39.2	22.5	0.0	10.0	103.0
270-300	16.5	26.6	85.3	127.5	55.0	29.4	42.5	9.8	20.0	34.3
300-330	11.0		82.5		55.0		7.5		17.5	
330-360	30.3		55.0		50.0		84.3		30.0	
360-390	55.0		66.0		30.0		82.5		25.0	
390-420	38.5		173.3		35.0		12.5		17.5	
420-450	44.0		41.3		10.0		--		2.5	
450-480	--		52.3		--		--		0.0	
480-510	--		27.5		--		--		--	
510-540	--		88.0		--		--		--	
540-570	--		--		--		--		--	
570-600	--		--		--		--		--	

Table 18
Extractable soil sodium (ppm) as affected by treatment---replication 3.

Depth (cm)	Plot							
	11		12		13		14	
	straight lagoon water (high rate)		well water		straight lagoon water (low rate)		diluted lagoon water (low rate)	diluted lagoon water (high rate)
	1971	1973	1971	1973	1971	1973	1971	1973
0-30	44.7	137.4	38.3	34.4	49.0	176.6	29.9	39.2
30-60	51.0	24.5	46.8	54.0	68.0	103.0	59.5	107.9
60-90	42.5	39.2	51.1	49.0	68.1	127.5	42.5	93.2
90-120	27.5	78.5	32.5	147.2	115.0	39.2	20.0	34.3
120-150	30.0	49.1	0.0	63.9	55.0	29.4	42.5	78.5
150-180	0.0	14.7	0.0	122.6	0.0	34.3	17.5	19.6
180-210	15.0	29.4	0.0	255.1	37.5	68.7	10.0	29.4
210-240	0.0	103.0	12.5	49.0	0.0	68.7	105.0	24.5
240-270	15.0	54.0	12.5	176.6	0.0	44.1	22.5	34.3
270-300	7.5	98.1	15.0	44.1	0.0	88.3	77.5	19.6
300-330	2.5		62.5		0.0		65.0	
330-360	0.0		0.0		0.0		85.0	
360-390	47.5		0.0		0.0		35.0	
390-420	0.0		5.0		0.0		12.5	
420-450	0.0		40.0		0.0		60.0	
450-480	25.0		65.0		0.0		60.0	
480-510	--		--		0.0		55.0	
510-540	--		--		105.0		70.0	
540-570	--		--		7.5		--	
570-600	--		--		20.0		--	

Table 19

Weak Bray extractable soil phosphorus (ppm) as affected by treatment--replication 1.

Depth (cm)	Plot									
	1		2		3		4		5	
	straight lagoon water (high rate)		well water		diluted lagoon water (low rate)		straight lagoon water (low rate)		diluted lagoon water (high rate)	
	1971	1973	1971	1973	1971	1973	1971	1973	1971	1973
0-30	213	213	244	220	262	280	193	123	169	220
30-60	49	54	42	51	83	66	13	10	47	22
60-90	69	69	78	68	63	45	28	10	12	9
90-120	74	75	93	63	26	78	14	14	30	11
120-150	49	59	64	51	31	8	19	10	20	12
150-180	20	33	173	21	34	6	35	8	13	16
180-210	26	19	33	13	20	7	10	6	23	15

Table 20

Weak Bray extractable soil phosphorus (ppm) as affected by treatment---replication 2.

Depth (cm)	Plot									
	6		7		8		9		10	
	straight lagoon water (high rate)	1971 1973	diluted lagoon water (high rate)	1971 1973	diluted lagoon water (low rate)	1971 1973	well water	1971 1973	straight lagoon water (low rate)	1971 1973
0-30	193	175	174	150	208	220	178	145	189	160
30-60	43	44	66	21	14	39	10	10	43	23
60-90	10	11	12	7	29	13	5	9	7	9
90-120	14	11	14	9	9	8	7	6	9	9
120-150	11	15	15	10	10	11	3	7	6	8
150-180	16	14	50	10	18	15	7	11	6	7
180-210	39	9	10	8	18	12	11	8	8	7

Weak Bray extractable soil phosphorus (ppm) as affected by treatment--replication 3.

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Table 22

Water-soluble soil chloride (ppm) as affected by treatment--replication 1.

Depth (cm)	Plot									
	1		2		3		4		5	
	straight lagoon water (high rate)		well water		diluted lagoon water (low rate)		straight lagoon water (low rate)		diluted lagoon water (high rate)	
	1971	1973	1971	1973	1971	1973	1971	1973	1971	1973
0-30	43	0	68	0	9	1	7	6	2	0
30-60	0	2	10	0	0	1	0	0	0	0
60-90	10	0	4	2	6	0	0	0	0	0
90-120	16	12	0	20	0	0	0	0	0	8
120-150	0	20	0	12	0	4	0	0	0	12
150-180	16	0	48	4	0	0	0	0	0	4
180-210	16	12	0	12	0	6	2	6	0	0
210-240	14	8	0	16	0	0	0	2	0	2
240-270	18	8	20	26	0	0	0	2	0	0
270-300	14	8	8	24	0	2	0	8	0	6
300-330	32		28		2		0		0	
330-360	14		30		0		2		0	
360-390	0		30		0		0		0	
390-420	0		4		0		0		0	
420-450	2		0		0		0		0	
450-480	0		12		4		0		0	
480-510	0		0		4		0		0	
510-540	0		0		0		0		0	
540-570	0		0		-		0		-	
570-600	0		-		-		0		-	

Table 23

Water-soluble soil chloride (ppm) as affected by treatment---replication 2.

Depth (cm)	Plot									
	6		7		8		9		10	
	straight lagoon water (high rate)		diluted lagoon water (high rate)		diluted lagoon water (low rate)		well water		straight lagoon water (low rate)	
	1971	1973	1971	1973	1971	1973	1971	1973	1971	1973
0-30	0	0	0	2	7	2	2	22	13	6
30-60	0	4	0	0	0	0	4	6	0	14
60-90	0	0	0	0	0	0	0	12	0	6
90-120	0	2	0	0	0	6	4	2	0	32
120-150	0	2	0	0	0	0	0	4	0	14
150-180	0	4	0	0	0	2	2	0	6	10
180-210	0	0	0	0	0	2	0	0	0	8
210-240	0	0	0	0	0	8	0	0	0	16
240-270	0	2	0	4	0	8	0	0	0	16
270-300	0	6	0	6	0	4	0	0	0	22
300-330	0		0		0		6		0	
330-360	0		0		0		0		0	
360-390	0		0		0		0		0	
390-420	0		0		0		0		0	
420-450	0		0		0		0		0	
450-480	-		0		-		-		0	
480-510	-		0		-		-		-	
510-540	-		0		-		-		-	
540-570	-		-		-		-		-	
570-600	-		-		-		-		-	

Table 24

Water-soluble soil chloride (ppm) as affected by treatment--replication 3.

Depth (cm)	Plot									
	11		12		13		14		15	
	straight lagoon water (high rate)	1971	1973	well water	1971	1973	straight lagoon water (low rate)	1971	1973	diluted lagoon water (high rate)
0-30	4	2	0	11	0	0	0	0	6	0
30-60	0	0	2	4	0	0	0	0	0	0
60-90	0	0	0	0	0	8	0	0	0	0
90-120	0	0	0	4	0	2	0	0	0	0
120-150	0	16	0	0	0	2	0	0	4	0
150-180	0	16	0	4	6	6	0	0	8	12
180-210	0	28	2	0	0	14	0	0	0	6
210-240	0	8	0	4	2	18	0	0	0	8
240-270	0	0	0	4	6	2	0	0	8	12
270-300	0	0	0	4	2	2	0	0	2	16
300-330	0	4	0	0	6	2	0	0	2	16
330-360	0	0	0	0	6	0	0	0	0	0
360-390	0	0	0	4	4	0	0	0	0	0
390-420	0	0	0	4	8	0	0	0	0	0
420-450	0	0	0	4	2	0	0	0	0	0
450-480	0	0	0	0	0	0	0	0	0	0
480-510	0	0	0	2	0	0	0	0	0	0
510-540	-	-	-	-	0	0	0	0	0	0
540-570	-	-	-	-	0	0	0	0	0	0
570-600	-	-	-	-	0	0	0	0	0	0

Table 25

Soil pH as affected by treatment---replication 1.

Depth (cm)	Plot									
	1		2		3		4		5	
	straight lagoon water (high rate)		well water		diluted lagoon water (low rate)		straight lagoon water (low rate)		diluted lagoon water (high rate)	
	1971	1973	1971	1973	1971	1973	1971	1973	1971	1973
0-30	7.1	7.2	7.2	7.3	7.0	7.1	7.1	7.3	7.1	7.2
30-60	7.4	7.5	7.3	7.3	7.0	7.3	7.5	7.9	7.6	7.9
60-90	7.1	7.3	7.5	6.9	7.0	7.2	7.8	8.1	8.0	8.0
90-120	7.2	7.2	7.7	7.0	7.6	7.5	7.8	8.0	8.1	8.1
120-150	7.8	7.1	7.8	7.6	7.8	7.8	7.8	8.0	8.1	8.2
150-180	7.7	7.3	7.3	7.6	7.7	7.9	7.9	8.0	7.9	7.9
180-210	7.8	7.5	7.5	7.6	7.7	7.8	8.0	8.2	7.8	7.8
210-240	7.7	7.7	7.9	7.7	7.7	7.9	8.0	8.1	7.9	8.0
240-270	7.8	7.7	7.7	7.6	7.8	7.6	7.9	8.2	8.0	8.1
270-300	7.9	7.7	7.8	7.6	8.0	7.7	8.0	8.6	7.9	8.0
300-330	7.9		7.5		7.9		8.4		8.0	
330-360	7.9		7.8		8.0		8.1		8.0	
360-390	7.8		7.8		8.2		8.0		8.0	
390-420	8.0		7.8		8.1		8.3		8.0	
420-450	8.0		7.7		8.3		8.2		7.9	
450-480	8.1		7.5		7.7		7.7		8.2	
480-510	8.4		7.7		8.2		8.1		8.4	
510-540	8.4		7.7		8.2		8.0		7.9	
540-570	7.9		7.8		--		8.4		--	
570-600	8.0		--		--		8.2		--	

Table 26

Soil pH as affected by treatment--replication 2.

Depth (cm)	Plot									
	6		7		8		9		10	
	straight lagoon water (high rate)	1973	diluted lagoon water (high rate)	1971	diluted lagoon water (low rate)	1971	well water	1971	straight lagoon water (low rate)	1971
0-30	7.0	7.1	7.1	7.1	6.8	6.8	6.6	6.6	6.7	6.9
30-60	7.5	7.7	7.5	7.5	7.8	7.8	7.5	7.5	7.5	7.5
60-90	8.0	8.0	8.1	8.1	8.0	8.0	7.9	7.9	7.9	7.9
90-120	8.1	8.2	8.0	8.0	8.1	8.1	7.8	7.8	7.9	8.0
120-150	7.9	8.1	7.8	7.8	7.9	7.9	8.0	8.0	7.8	8.0
150-180	7.8	7.9	7.7	7.7	7.9	7.9	7.8	7.8	8.0	8.0
180-210	7.7	7.9	7.9	7.9	8.1	8.1	7.8	7.8	8.0	8.0
210-240	7.8	7.9	8.0	8.0	8.1	8.1	8.0	8.0	8.1	7.9
240-270	7.9	7.9	8.1	8.1	8.1	8.1	8.0	8.0	8.1	8.0
270-300	7.9	8.0	8.1	8.1	8.0	8.0	8.1	8.0	8.1	8.0
300-330	7.9		8.2	8.2	8.0	8.0	8.0	8.0	8.1	8.0
330-360	7.8		8.2	8.2	8.0	8.0	8.0	8.0	8.1	8.0
360-390	7.9		8.1	8.1	8.0	8.0	8.0	8.0	8.1	8.0
390-420	8.0		8.1	8.1	8.1	8.1	7.9	7.9	8.0	8.0
420-450	8.0		8.0	8.0	8.3	8.3	—	—	8.1	8.0
450-480	—		8.1	8.1	—	—	—	—	8.1	8.1
480-510	—		8.1	8.1	—	—	—	—	—	—
510-540	—		8.0	8.0	—	—	—	—	—	—
540-570	—		—	—	—	—	—	—	—	—
570-600	—		—	—	—	—	—	—	—	—

Table 27

Soil pH as affected by treatment--replication 3.

Depth (cm)	Plot							
	11		12		13		14	
	straight lagoon water (high rate)		well water		straight lagoon water (low rate)		diluted lagoon water (low rate)	diluted lagoon water (high rate)
	1971	1973	1971	1973	1971	1973	1971	1973
0-30	6.7	7.0	6.8	6.8	6.7	7.0	6.8	6.9
30-60	7.1	7.2	7.3	7.1	6.5	6.9	6.7	6.8
60-90	7.7	7.5	7.3	7.7	7.0	7.0	6.8	6.9
90-120	7.8	7.8	8.0	7.8	7.0	7.4	7.0	7.3
120-150	7.9	8.0	7.9	8.1	7.1	7.8	7.5	7.8
150-180	8.0	8.1	8.0	8.0	7.2	7.8	7.9	7.9
180-210	7.9	8.1	7.5	7.9	7.3	7.7	7.8	7.9
210-240	7.9	8.1	8.0	8.0	7.7	7.7	7.8	8.0
240-270	7.9	7.9	7.9	8.0	7.8	7.8	7.9	8.1
270-300	7.9	7.9	7.9	7.9	7.7	7.7	7.8	7.9
300-330	7.8		7.6		7.7		7.8	
330-360	7.8		7.8		7.7		7.7	
360-390	7.8		7.8		7.6		7.9	
390-420	7.9		7.9		7.7		7.8	
420-450	7.9		7.8		7.7		7.9	
450-480	7.9		7.8		7.7		7.9	
480-510	--		--		7.8		8.0	
510-540	--		--		7.7		7.9	
540-570	--		--		7.8		7.8	
570-600	--		--		7.7		7.7	

TABLE 28
SUMMARY OF WATER DATA FROM DEEP AND SHALLOW SAMPLING WELLS
FOR MONTHS 6/72- 5/73

LANE-WELL	AMMONIUM NITROGEN										MILLIGRAMS / LITER				
	MO- 6	MO- 7	MO- 8	MO- 9	MO-10	MO-11	MO-12	MO- 2	MO- 3	MO- 4	MO- 5				
1-S	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.5	0.1	0.5				0.5
1-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.3				0.3
2-S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.0	0.2				0.2
2-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.2				0.2
3-S	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.3	0.0	0.3				0.3
3-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.4				0.4
4-S	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.2	0.3	0.0	0.4				0.4
4-D	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.1				0.1
5-S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0				0.0
5-D	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.4	0.6	0.0	0.4				0.4
6-S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.4				0.4
6-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.1	0.0				0.0
7-S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.0	0.1				0.1
7-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.1				0.1
8-S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.2	0.0				0.0
8-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0				0.0
9-S	0.0	0.0	0.0	0.0	0.0	0.0	0.1	-9.9	-9.9	-9.9	0.3				0.3
9-D	-9.9	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.6	0.0	0.1				0.1
10-S	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.4	0.0	0.3				0.3
10-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.8	0.0	0.2				0.2
11-S	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	-9.9	-9.9	0.5				0.5
11-D	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.3	0.0	0.4				0.4
12-S	0.0	0.0	0.0	0.0	0.0	-9.9	-9.9	-9.9	-9.9	0.1	0.5				0.5
12-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.2	0.2				0.2
13-S	0.0	0.0	0.0	0.0	0.0	-9.9	-9.9	-9.9	-9.9	-9.9	0.3				0.3
13-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.0	0.2				0.2
14-S	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.6	0.0	0.1				0.1
14-D	-9.9	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.0	0.2				0.2
15-S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0				0.0
15-D	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.3	0.0	0.0				0.0

MISSING DATA=-9.9

TABLE 29
SUMMARY OF WATER DATA FROM DEEP AND SHALLOW SAMPLING WELLS
FOR MONTHS 6/72- 5/73

NITRATE NITROGEN

LANE-WELL	MO- 6	MO- 7	MO- 8	MO- 9	MO-10	MO-11	MO-12	MO- 2	MO- 3	MO- 4	MO- 5
1-S	0.1	0.0	0.2	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0
1-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
2-S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
2-D	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
3-S	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
3-D	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4-S	0.0	0.8	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0
4-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5-S	2.8	4.1	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0
5-D	1.5	0.4	0.0	0.2	0.0	0.8	0.0	0.0	0.0	0.0	0.0
6-S	12.6	11.0	15.4	9.1	4.5	1.4	1.0	3.2	0.6	0.0	0.0
6-D	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
7-S	17.6	14.0	9.4	9.0	9.3	11.0	11.7	3.4	1.1	0.3	2.0
7-D	1.5	0.0	0.4	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
8-S	8.9	5.7	16.0	10.9	17.6	22.4	26.1	13.1	5.0	0.1	7.6
8-D	0.9	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0
9-S	5.9	9.3	8.5	8.7	8.5	10.8	11.6	-9.9	-9.9	-9.9	0.6
9-D	-9.9	0.4	0.4	0.0	0.0	0.2	0.4	0.0	0.1	0.0	0.0
10-S	13.8	17.8	11.9	9.2	10.7	11.2	9.3	9.9	7.5	7.8	3.8
10-D	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1
11-S	12.5	0.0	14.2	18.6	17.2	18.4	17.9	19.1	-9.9	-9.9	18.8
11-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12-S	8.4	12.0	7.8	3.1	6.9	-9.9	-9.9	-9.9	-9.9	16.6	10.7
12-D	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13-S	15.7	13.1	13.4	9.8	18.7	-9.9	-9.9	-9.9	-9.9	-9.9	16.2
13-D	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14-S	13.2	19.1	16.1	11.3	15.6	15.7	11.1	8.7	16.1	35.4	23.4
14-D	-9.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15-S	10.4	11.3	12.3	7.9	11.3	11.9	9.6	10.0	9.5	10.6	16.3
15-D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

MISSING DATA=-9.9

TABLE 30
SUMMARY OF WATER DATA FROM DEEP AND SHALLOW SAMPLING WELLS
FOR MONTHS 6/72- 5/73

LANE-WELL	CALCIUM										MILLIGRAMS / LITER				
	MO- 6	MO- 7	MO- 8	MO- 9	MO-10	MO-11	MO-12	MO- 2	MO- 3	MO- 4	MO- 5				
1-S	52	105	42	106	111	53	93	109	86	100	111				
1-D	24	85	57	45	35	80	98	96	106	103	102				
2-S	66	117	28	111	112	66	92	105	82	106	114				
2-D	62	103	99	96	30	42	95	97	100	99	98				
3-S	52	74	70	112	42	57	104	101	91	121	110				
3-D	55	67	92	97	65	64	96	93	99	101	100				
4-S	44	60	126	82	81	78	93	104	82	102	110				
4-D	68	119	83	65	29	20	95	93	103	100	102				
5-S	112	110	83	118	52	89	125	115	105	117	119				
5-D	60	76	22	49	51	57	84	91	79	81	102				
6-S	76	123	93	121	109	45	118	117	129	121	122				
6-D	40	91	93	69	81	31	79	89	100	99	101				
7-S	36	110	121	120	104	125	114	106	127	120	124				
7-D	77	49	39	67	68	64	95	87	76	83	90				
8-S	44	115	104	113	85	98	132	114	119	94	122				
8-D	60	65	64	78	31	55	99	94	78	85	90				
9-S	98	116	65	115	117	89	115	-9	-9	-9	109				
9-D	-9	46	16	97	94	37	95	86	77	99	99				
10-S	109	87	115	94	92	61	111	92	117	117	119				
10-D	31	72	61	76	59	28	70	90	83	79	102				
11-S	78	55	87	131	66	67	120	101	-9	-9	130				
11-D	87	87	123	64	66	71	129	98	107	108	125				
12-S	99	92	115	117	41	-9	-9	-9	-9	125	123				
12-D	60	62	64	42	104	33	109	112	100	110	110				
13-S	60	80	59	115	120	-9	-9	-9	-9	-9	121				
13-D	49	93	37	81	82	34	111	93	93	81	106				
14-S	99	35	50	119	105	56	111	103	119	142	131				
14-D	-9	79	65	102	42	30	81	77	63	73	91				
15-S	91	72	60	122	118	55	108	92	124	126	130				
15-D	91	82	38	39	76	32	87	76	71	73	89				

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MISSING DATA=-9

TABLE 31
SUMMARY OF WATER DATA FROM DEEP AND SHALLOW SAMPLING WELLS
FOR MONTHS 6/72- 5/73

LANE-WELL	MAGNESIUM											MILLIGRAMS / LITER			
	MO- 6	MO- 7	MO- 8	MO- 9	MO- 10	MO- 11	MO- 12	MO- 2	MO- 3						
1-S	18	18	18	18	18	24	23	20	22						
1-D	19	19	18	21	17	26	27	20	21						
2-S	10	19	22	19	17	24	24	18	19						
2-D	22	20	21	22	18	28	28	21	21						
3-S	18	20	20	20	17	25	27	19	19						
3-D	21	20	19	22	18	26	28	20	22						
4-S	20	20	18	24	18	25	27	19	19						
4-D	21	20	18	22	18	26	28	21	23						
5-S	22	23	20	23	20	29	29	20	22						
5-D	19	20	16	21	18	27	29	20	22						
6-S	22	22	23	29	24	31	32	25	24						
6-D	21	20	18	22	18	26	29	20	22						
7-S	24	21	18	24	20	29	30	21	22						
7-D	21	20	18	21	18	26	28	20	22						
8-S	21	20	19	21	20	30	33	21	21						
8-D	20	20	17	21	18	27	28	20	21						
9-S	21	19	17	20	19	28	30	-9	-9						
9-D	-9	19	18	21	18	26	29	20	21						
10-S	21	19	18	21	19	27	29	19	21						
10-D	23	21	19	22	19	28	32	20	22						
11-S	22	21	17	22	20	27	30	21	-9						
11-D	27	26	21	27	27	33	38	27	28						
12-S	19	19	15	19	19	-9	-9	-9	-9						
12-D	22	18	20	26	26	31	35	25	26						
13-S	20	18	16	21	21	-9	-9	-9	-9						
13-D	23	21	18	22	24	30	34	23	25						
14-S	20	19	16	19	21	25	26	18	20						
14-D	-9	17	17	22	21	27	30	17	21						
15-S	18	17	15	19	19	24	27	17	19						
15-D	21	18	16	19	20	24	28	17	20						

MISSING DATA=-9

TABLE 32
SUMMARY OF WATER DATA FROM DEEP AND SHALLOW SAMPLING WELLS
FOR MONTHS 6/72- 5/73

POTASSIUM

LANE-WELL	MO- 6	MO- 7	MO- 8	MO- 9	MO-10	MO-11	MO-12	MO- 2	MO- 3	MO- 4	MO- 5
1-S	11	11	12	12	12	12	13	13	13	12	12
1-D	4	4	4	4	4	4	4	4	4	4	4
2-S	7	12	12	12	12	12	12	11	11	12	11
2-D	3	3	3	3	4	3	3	3	3	3	3
3-S	14	14	14	14	14	14	16	12	12	12	12
3-D	3	3	3	3	3	3	3	3	3	3	3
4-S	15	15	14	15	15	15	15	13	13	12	12
4-D	3	3	3	3	3	3	3	3	3	3	3
5-S	17	17	17	17	17	17	18	17	16	15	15
5-D	3	3	3	3	3	3	3	3	3	3	3
6-S	18	17	18	18	18	18	19	19	18	17	17
6-D	4	3	3	3	3	3	3	3	3	3	3
7-S	16	16	17	17	17	17	18	17	16	16	16
7-D	3	3	3	3	3	2	3	3	3	3	3
8-S	14	13	13	14	14	15	16	14	14	10	14
8-D	3	3	3	3	3	3	3	3	3	3	3
9-S	12	11	12	12	12	13	13	-9	-9	-9	11
9-D	-9	3	3	3	3	3	3	2	3	3	3
10-S	12	12	12	13	13	13	14	13	12	12	12
10-D	3	2	3	3	3	3	3	3	3	3	3
11-S	14	2	14	15	15	15	16	15	-9	-9	14
11-D	4	4	4	4	4	4	4	4	4	4	4
12-S	11	12	11	12	12	-9	-9	-9	-9	12	12
12-D	4	4	4	4	4	4	4	4	4	4	2
13-S	12	12	12	12	12	-9	-9	-9	-9	-9	12
13-D	4	4	4	4	4	4	4	4	4	4	4
14-S	12	12	12	12	12	11	13	12	12	13	12
14-D	-9	3	3	4	4	3	4	3	3	3	3
15-S	11	12	11	12	12	11	13	12	12	12	12
15-D	3	3	3	3	3	3	3	3	3	3	3

MISSING DATA=-9

TABLE 33
SUMMARY OF WATER DATA FROM DEEP AND SHALLOW SAMPLING WELLS
FOR MONTHS 6/72- 5/73

LANE-WELL	SODIUM															MILLIGRAMS / LITER																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
	MO- 6	MO- 7	MO- 8	MO- 9	MO-10	MO-11	MO-12	MO- 2	MO- 3	MO- 4	MO- 5	MO- 6	MO- 7	MO- 8	MO- 9	MO-10	MO-11	MO-12	MO-13	MO-14	MO-15	MO-16	MO-17	MO-18	MO-19	MO-20	MO-21	MO-22	MO-23	MO-24	MO-25	MO-26	MO-27	MO-28	MO-29	MO-30	MO-31	MO-32	MO-33	MO-34	MO-35	MO-36	MO-37	MO-38	MO-39	MO-40	MO-41	MO-42	MO-43	MO-44	MO-45	MO-46	MO-47	MO-48	MO-49	MO-50	MO-51	MO-52	MO-53	MO-54	MO-55	MO-56	MO-57	MO-58	MO-59	MO-60	MO-61	MO-62	MO-63	MO-64	MO-65	MO-66	MO-67	MO-68	MO-69	MO-70	MO-71	MO-72	MO-73	MO-74	MO-75	MO-76	MO-77	MO-78	MO-79	MO-80	MO-81	MO-82	MO-83	MO-84	MO-85	MO-86	MO-87	MO-88	MO-89	MO-90	MO-91	MO-92	MO-93	MO-94	MO-95	MO-96	MO-97	MO-98	MO-99	MO-100																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
1-S	12	12	13	11	11	11	10	8	8	5	7	10	10	11	11	11	11	10	8	8	5	7	10	10	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11

MISSING DATA=-9

TABLE 34
SUMMARY OF WATER DATA FROM DEEP AND SHALLOW SAMPLING WELLS
FOR MONTHS 6/72- 5/73

LANE-WELL	CHLORIDE												MILLIGRAMS / LITER										
	MO- 6	MO- 7	MO- 8	MO- 9	MO-10	MO-11	MO-12	MO- 2	MO- 3	MO- 4	MO- 5	MO- 6	MO- 7	MO- 8	MO- 9	MO-10	MO-11	MO-12	MO- 2	MO- 3	MO- 4	MO- 5	MO- 6
1-S	20	13	29	11	7	0	3	0	6	6	3												
1-D	23	18	19	30	20	19	19	16	15	25	15												
2-S	10	16	10	6	11	4	7	6	5	4	3												
2-D	75	67	42	32	101	34	32	29	25	31	30												
3-S	24	17	14	11	15	11	11	3	10	13	13												
3-D	33	40	33	34	31	31	29	30	33	34	31												
4-S	23	25	15	21	16	10	13	10	11	9	16												
4-D	36	42	33	34	36	29	27	38	37	33	44												
5-S	27	19	15	22	17	16	23	19	19	3	21												
5-D	38	43	26	31	31	30	31	34	38	35	36												
6-S	22	22	18	19	22	18	22	25	22	20	28												
6-D	40	39	34	37	39	31	35	30	31	36	42												
7-S	25	23	10	16	15	17	17	16	12	17	22												
7-D	43	42	29	39	38	32	34	32	34	35	38												
8-S	19	13	16	19	18	17	18	20	11	14	17												
8-D	34	39	32	41	32	34	35	41	38	36	40												
9-S	17	21	10	19	19	11	16	-9	-9	-9	20												
9-D	-9	41	28	33	31	32	40	28	34	37	39												
10-S	24	29	16	18	17	15	16	15	13	14	19												
10-D	93	78	59	55	43	49	52	46	50	37	50												
11-S	47	76	37	38	32	48	38	32	-9	-9	45												
11-D	323	331	315	311	323	299	294	289	293	291	339												
12-S	36	37	34	38	37	-9	-9	-9	-9	34	48												
12-D	276	316	320	346	335	328	329	326	337	330	332												
13-S	40	38	32	39	41	-9	-9	-9	-9	-9	44												
13-D	285	253	255	266	272	312	314	302	309	312	331												
14-S	36	39	34	39	36	26	26	31	35	42	40												
14-D	-9	215	245	278	279	262	240	236	262	252	259												
15-S	26	34	29	35	37	21	31	32	38	38	39												
15-D	209	160	179	272	193	153	115	152	148	162	142												

MISSING DATA=-9

TABLE 35
SUMMARY OF WATER DATA FROM DEEP AND SHALLOW SAMPLING WELLS
FOR MONTHS 6/72- 5/73

LANE-WELL	ELECTRICAL CONDUCTIVITY (MILLIMHOS/CM)											MILLIGRAMS / LITER	
	MO- 6	MO- 7	MO- 8	MO- 9	MO-10	MO-11	MO-12	MO- 2	MO- 3	MO- 4	MO- 5		
1-S	0.4	0.7	0.4	0.7	0.7	0.4	0.7	0.7	0.5	0.6	0.6		
1-D	0.3	0.7	0.5	0.7	0.4	0.5	0.7	0.7	0.7	0.7	0.7		
2-S	0.5	0.7	0.4	0.7	0.7	0.4	0.6	0.7	0.5	0.6	0.6		
2-D	0.6	0.8	0.7	0.7	0.5	0.4	0.7	0.7	0.7	0.7	0.7		
3-S	0.7	0.7	0.7	0.7	0.4	0.4	0.7	0.7	0.6	0.7	0.7		
3-D	0.5	0.7	0.7	0.7	0.6	0.5	0.7	0.7	0.7	0.7	0.7		
4-S	0.4	0.5	0.7	0.5	0.5	0.4	0.7	0.7	0.6	0.6	0.6		
4-D	1.0	0.7	0.7	0.6	0.4	0.4	0.7	0.8	0.7	0.7	0.7		
5-S	1.1	0.7	0.6	0.8	0.5	0.5	0.7	0.8	0.6	0.8	0.8		
5-D	0.6	0.6	0.4	0.5	0.4	0.4	0.7	0.7	0.6	0.6	0.7		
6-S	0.7	0.8	0.6	0.8	0.3	0.5	0.8	0.8	0.8	0.8	0.8		
6-D	0.5	0.7	0.4	0.6	0.7	0.4	0.6	0.7	0.7	0.7	0.7		
7-S	0.7	1.1	0.5	0.8	0.7	0.6	0.8	0.8	0.7	0.8	0.8		
7-D	0.7	0.7	0.7	0.6	0.7	0.4	0.7	0.8	0.6	0.6	0.6		
8-S	0.5	0.8	0.7	0.8	0.7	0.8	0.9	0.8	0.8	0.7	0.8		
8-D	0.5	0.5	0.5	0.6	0.4	0.4	0.8	0.8	0.6	0.6	0.6		
9-S	0.8	0.7	0.6	0.8	0.8	0.6	0.8	0.8	0.8	0.7	0.7		
9-D	-9.9	0.5	0.4	0.7	0.7	0.4	0.7	-9.9	-9.9	-9.9	0.6		
10-S	0.8	0.6	0.8	0.8	0.8	0.6	0.8	0.8	0.8	0.8	0.7		
10-D	0.6	0.6	0.8	0.7	0.6	0.4	0.7	0.8	0.8	0.8	0.7		
11-S	0.7	0.6	0.6	0.9	0.9	0.7	0.9	0.9	-9.9	-9.9	0.9		
11-D	1.6	1.5	1.5	1.2	1.2	1.1	1.5	1.5	1.3	1.3	1.5		
12-S	0.9	0.7	0.8	0.8	0.6	-9.9	-9.9	-9.9	-9.9	0.9	0.8		
12-D	1.2	1.3	1.3	1.5	1.6	1.2	1.6	1.6	1.4	1.5	1.4		
13-S	0.6	0.8	0.5	0.8	0.9	-9.9	-9.9	-9.9	-9.9	-9.9	0.8		
13-D	1.4	1.4	1.1	1.3	1.3	1.2	1.6	1.6	1.4	1.3	1.5		
14-S	0.8	0.6	0.5	0.8	0.9	0.5	0.8	0.8	0.8	1.0	0.9		
14-D	-9.9	1.2	1.2	1.5	1.2	1.1	1.3	1.4	1.2	1.2	1.3		
15-S	0.8	0.6	0.5	0.8	0.5	0.5	0.8	0.8	0.8	0.9	0.9		
15-D	1.2	1.0	0.9	1.0	0.9	0.8	1.0	1.1	1.0	1.0	1.0		

MISSING DATA=-9.9

EFFECTS OF BEEF FEEDLOT LAGOON WATER ON GROUNDWATER
QUALITY; SOIL CHEMICAL PROPERTIES, AND PLANT COMPOSITION

by

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Beef feedlot runoff which was retained in catchment lagoons was applied as an irrigant for bromegrass to determine the effects of this practice on bromegrass yields, bromegrass N, P, K concentrations and uptake, selected soil chemical properties, and groundwater quality beneath the application area. This study was located on an alluvial silt loam soil in a relatively humid area of Kansas (annual precipitation = 81 cm). The feedlot lagoon water was applied as two rates of straight and diluted lagoon water which ranged from 1.4 to 2.0 mmhos/cm and 1.1 to 1.4 mmhos/cm in electrical conductivity, respectively. One treatment of well water was applied as a control.

Average applications of 9.3 and 19.0 cm of diluted lagoon water, 9.5 and 16.6 cm of straight lagoon water, and 8.0 cm of well water in one irrigation season produced no consistent differences in yields, N, P, K composition, or N, P, K uptake of bromegrass. No significant differences (0.05) between these treatments were observed relative to the electrical conductivity, exchangeable Na percentage, exchangeable K percentage, or pH of the saturated soil paste of the surface 15 cm of soil, but a significant (0.05) reduction from 1971 to 1973 was observed in the pH of the saturated soil paste of from 6.6 to 6.4. From this study it was estimated that one season's growth of bromegrass removed over twice the N and about one-half of the P and K applied in the largest straight lagoon water treatment, the treatment which supplied these nutrients at the largest amounts.

Analyses of soil cores collected before and after lagoon water treatments from the 0- to 300-cm depth in 1971 and 1973 indicated that no consistent differences developed between treatments relative to NO_3^- -N or NH_4^+ -N content but revealed very pronounced decreases from 1971 to 1973 for both of these forms of N. For the total 0- to 300-cm profile a reduction of approximately 85 and 45% in NH_4^+ -N and NO_3^- -N levels, respectively, was observed

from 1971 to 1973. These reductions were much greater than can be accounted for by bromegrass N uptake for one growing season. This fact suggests that mechanisms other than nutrient uptake, such as leaching or denitrification, must have accounted for a large portion of the missing N.

The lagoon water applications produced an accumulation of extractable K in the soil profile at the 0- to 30-cm depth for all treatments. The largest accumulation was observed in the SLW treatment, an increase of from 470 to 588 ppm. Although approximately twice as much P was added in the lagoon water treatments as was removed by the bromegrass in one growing season, the average weak Bray extractable P for the 0- to 300-cm depth and for the 0- to 30-cm depth decreased for all treatments implying that P became fixed in the soil over this time period. After the first season of lagoon water applications, a moderate increase in the average water soluble Cl^- content of from 3 to 5 ppm was observed for the 0- to 300-cm depth but no notable changes in extractable Ca, Mg, Na, or pH in the soil profile were observed at this depth.

Analyses of groundwater samples from beneath the application area at depths of 7.6 and 21 m revealed highly significant differences between these depths relative to concentrations of NO_3^- -N, Ca, Mg, K, Na, Cl^- , and electrical conductivity values. Concentrations greater than 10 ppm for NO_3^- -N in the shallow wells were common while the mean for all NO_3^- -N values from the deep wells was 0.04 ppm. Mean values of 0.12 and 0.11 ppm were found for NH_4^+ -N in the shallow and deep wells, respectively. No consistent significant differences between treatments which could be correlated with treatments of lagoon water were identified for any of the constituents analyzed (NO_3^- -N, NH_4^+ -N, Ca, Mg, K, Na, Cl^- , P, electrical conductivity). Highly significant differences between months were observed for Ca and Mg concentrations and for electrical conductivity at both depths. Changes over time at the shallow

and deep depths were closely parallel for each of these constituents as indicated by r values of 0.895, 0.987, and 0.939, respectively, for the correlation between monthly averages at the two depths. No P was detected in the water samples at either depth.