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Wastewater Irrigation at Tallahassee, Florida

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WASTEWATER IRRIGATION AT TALLAHASSEE, FLORIDA

by

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in groundwater; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

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ABSTRACT

Effluent from a secondary treatment plant was applied to crops on Lakeland fine sand at Tallahassee, Florida. Summer crops included coastal bermudagrass, sorghum x sudangrass, pearl millet, corn and kenaf at irrigation rates up to 200 millimeters (mm)/week [8 inches (in.)/week]. Winter crops included rye and ryegrass at irrigation rates up to 100 mm/week (4 in./week). Yields and nutrient uptake increased with application rate, while recovery efficiency decreased. Nitrogen recovery above 50% required rates in the range of 25-50 mm/week (1-2 in./week).

Test wells in the 200 mm/week plots did show NO_3-N levels above 10 milligrams/liter (mg/l). Results of this work and a companion study by the U.S. Geological Survey showed mixing and dilution in the groundwater. The soil was very effective in removing fecal coliform bacteria and BOD from the percolating effluent.

Field studies showed that nitrification was essentially complete in the upper 120 centimeters (cm) [4 feet (ft)] of soil. Phosphorus removal within this same depth exceeded 99%, and complete removal was obtained before reaching the water table some 12-15 meters (m) (35-45 ft) below ground surface. Soil pH remained in the vicinity of 6.5.

A model of cation transport showed that surface exchange was linearly coupled with flow velocity. Good description of transport in a packed-bed reactor was obtained for the NH_4^+/K^+ system.

A model of phosphorus transport showed that at low velocities surface exchange was diffusion limited, while at higher velocities surface kinetics was controlling. The model described transport in a packed-bed reactor quite well.

A model of phosphorus kinetics was developed using Langmuir-Hinshelwood kinetics for the heterogeneous process. It also included a homogeneous reaction. Effects of pH and soil/solution ratio in a batch reactor were accounted for. The relevant species of phosphate ion was identified as $H_2PO_4^-$.

This report was submitted in fulfillment of Grant No. S800829 by the University of Florida, Agricultural Engineering Department, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period April 1, 1971, to December 1, 1978.

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ACKNOWLEDGMENTS

Many persons contributed to the progress of this study. Mr. Thomas P. Smith, Director of Underground Utilities, City of Tallahassee, began the effluent irrigation system at Tallahassee in 1966 and encouraged expanded research on its performance, beginning in 1971. He provided much support for this work and stimulated a lot of discussion on the subject in Florida. All of the field and laboratory measurements were conducted jointly with Mr. William G. Leseman, Director, Tallahassee Water Quality Laboratory. We learned the art and science of waste treatment together. Mr. Alfred Nguy served as laboratory assistant for the project and worked closely with Mr. Leseman and his staff.

Ms. Rolan Chu and Mr. Brian McMahon conducted the experiments and wrote computer programs for the studies on rate processes. The three of us, along with Mr. Leseman and Mr. Nguy, held many intensive discussions about chemical kinetics and transport processes.

Mr. Jack Woodard, Florida Department of Natural Resources, Tallahassee, provided assistance with installation of test wells for the field study.

Dr. Glenn W. Burton, Plant Geneticist, Coastal Plains Experiment Station, Tifton, Georgia, provided seeds for Tiflate pearl millet and encouraged the forage studies.

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Mr. Richard E. Thomas served as initial project officer and provided stimulating discussions on land treatment of wastes. Mr. Lowell E. Leach served in this capacity in the latter period and provided helpful suggestions during the completion phase of the project.

SECTION 1

INTRODUCTION

Land application systems for treatment of wastes have been in operation for a long time at a large number of locations. Several different techniques (irrigation, recharge and overland flow) have been employed with a large variety of wastes (agricultural, municipal and industrial). A review of many of the land application systems (both U.S. and foreign) has been given by Stevens (1972). Detailed reviews of facilities have been given also by Sullivan et al. (1973), Hartman (1975) and Carroll et al. (1975). Two municipal systems which have received particular attention include Melbourne, Australia (Seabrook, 1975 and Johnson et al., 1974) and Pennsylvania State University (Kardos et al., 1974 and Richenderfer et al., 1975). In recent years, a number of books have appeared on land treatment processes and systems (Sopper and Kardos, 1973; Vesilind, 1975; Sanks and Asano, 1976; Shuval, 1976; D'Itri, 1977; Elliot and Stevenson, 1977; and Loehr, 1977). Survey of the literature has been given by Tofflemire (1977) and by Carlisle and Stewart (1977).

Several other publications have appeared which aid in evaluation and design of land treatment systems. The U.S. Environmental Protection Agency has published a design manual (USEPA, 1977) which outlines factors to consider and procedures for design and evaluation. Economic considerations have been discussed by Young and Carlson (1974), Pound et al. (1975) and Young (1976).

The city of Tallahassee was probably the first city in Florida to utilize wastewater irrigation. During the 1940's, two treatment plants were constructed and subsequently discharged to a natural drainage stream and then flowed to Lake Munson. Much of the surface drainage also flowed through this stream and lake. In 1961, a 227 m^3/day (0.060 mgd) high rate trickling filter was constructed at the municipal airport. Field tests at that site showed that the soil could sustain an irrigation rate of 100 mm/day (4 in./day) satisfactorily. In 1966, a 9300 m^3/day (2.5 mgd) high rate trickling filter was put into operation near the airport site, and included an irrigation system with design capacity of 3700 m^3/day (1 mgd). The irrigation field of 6.5 ha (16 acres) was divided into four equal plots. Experience showed that these plots could handle 250 mm/day (10 in./day) over a four day rotation without noticeable hydraulic problems. Plots received maintenance mowing without removal of vegetation. The effects on groundwater quality were unclear.

An extensive study of geological and groundwater characteristics was conducted in the vicinity of the irrigation site and surrounding area during the period March 1972-June 1974 by the U.S. Geological Survey (Slack, 1975).

Logs were made on 23 test wells, along with hydrologic and chemical measurements.

This study was initiated in 1971 to evaluate the effects of wastewater irrigation of a sandy soil on 1) growth and yields of forage crops, 2) changes in soil and groundwater characteristics and 3) coupling among transport processes in the soil. Both summer and winter crops were grown which were suitable for production in the southeastern United States and for which extensive literature was available. Extensive literature was also available on the soil type (Lakeland fine sand) prevalent at the treatment plant.

For convenience, a table of conversion factors from metric to English units has been included (Table 1).

TABLE 1. CONVERSIONS FROM METRIC TO ENGLISH UNITS

Metric Unit	x	Factor	=	English Unit
meters (m)		3.28		feet (ft)
millimeters (mm)		0.0394		inch (in)
hectare (ha)		2.47		acre (a)
kilogram (kg)		2.205		pound (lb)
kilogram/hectare (kg/ha)		0.892		pound/acre (lb/a)
metric ton/hectare (mton/ha)		0.446		ton/acre (ton/a)
hectoliter/hectare (hl/ha)		0.87		bushels/acre (bu/a)
meter^3/minute (m^3/min)		263		gallons/minute (gpm)
meter^3/day (m^3/day)		$263 \cdot 10^{-6}$		million gallons/day (mgd)

SECTION 2

CONCLUSIONS

This study demonstrated the feasibility of growing both summer and winter forage crops under effluent irrigation.

Yields and nutrient contents compared favorably with values from the literature.

Yields and nutrient uptake increased with application rate, while efficiency of nutrient recovery showed a decrease. Nitrogen recovery above 50% required application rates of 25 to 50 mm/week (1 to 2 in./week).

Soil pH remained around 6.5, in the optimum range for crop production.

Lakeland fine sand was very effective in removing phosphate, BOD and fecal coliform bacteria from the effluent.

Shallow groundwater was influenced by effluent irrigation, but mixing with groundwater caused dilution.

Field measurements showed that nitrification essentially reached completion in the upper 120 cm (4 ft) of soil.

The model of phosphorus transport showed coupling between surface exchange and convection. Surface exchange was diffusion limited at the lower flow rates. Field and laboratory results correlated very closely.

A model of phosphate kinetics based on Langmuir-Hinshelwood kinetics described batch data very well. Effects of soil/solution ratio and pH were accounted for in this study. The model included both heterogeneous catalysis and a homogeneous reaction.

The model of cation transport described data for NH_4^+/K^+ system very well. Surface exchange was shown to be diffusion limited.

SECTION 3

RECOMMENDATIONS

The feasibility of a grazing operation coupled with effluent irrigation should be investigated. This work showed that forage production was reasonable for green chop.

Performance on poorly drained soil should be studied, with particular reference to nitrogen behavior. In this work appreciable nitrogen did reach the groundwater.

The relationship between cation exchange capacity and nitrogen uptake should be established.

Role of various factors on retention and movement of pathogens in soils receiving wastewater should be established.

Determine breakdown and movement of carbon compounds in soil receiving wastewater.

A more accurate measure of long-term phosphorus fixing capacity of soils is needed.

A simplified model of cation transport in a mixed cation system should be developed.

SECTION 4

SITE DESCRIPTION

LOCATION

The study was a cooperative effort between the city of Tallahassee, Florida and the Agricultural Engineering Department, University of Florida, Gainesville. All field studies were conducted in Tallahassee at the Thomas P. Smith Wastewater Renovation Plant (formerly Southwest Sewage Treatment Plant), located southwest of the city (Fig. 1) at the intersection of Spring Hill Road and Capitol Circle (Fig. 2).

TREATMENT PLANT

In 1966, the high-rate trickling filter was put on line with a flow of 950 m^3/day (0.25 mgd). By 1969 the flow had reached 3800 m^3/day (1 mgd). By October 1974 the Southwest Plant passed design capacity and reached 13000 m^3/day (3.5 mgd), at which time the new 28,000 m^3/day (7.5 mgd) conventional activated sludge plant was opened. The name of the plant was then officially changed to Thomas P. Smith Wastewater Renovation Plant. To accommodate the steadily increasing flow, four large sprinklers were installed in a 7.3 ha (18 acre) forest area to handle the flow above that needed for the agronomic study. This unit went into operation in March 1972.

IRRIGATION SYSTEM

System layout was according to Figure 3. A centrifugal pump with 2.7 m^3/min (720 gpm) capacity provided effluent from the polishing pond. Irrigation lines were portable aluminum with a 20-cm (8-in.) main, 10-cm (4-in.) laterals and 5-cm (2-in.) sublaterals. Risers were 2.5-cm (1-in.) galvanized pipe 3 m (10 ft) in height. The impact sprinklers were Rainbird 70 with a delivery rate of 0.21 m^3/min (55 gpm) at 850 kg/cm^2 (60 psi), which provided an application rate of 1.25 cm/hr (0.5 in./hr). Plots were 30 m x 30 m (100 ft x 100 ft) with 40 m (120 ft) between plots to reduce spray drift. Valves were located on sublaterals to allow diverting of flow among the various plots.

CHARACTERISTICS

The treatment plant was located adjacent to the Apalachicola National Forest. Hendry and Sproul (1966) identified this area as part of the Lake Munson Hills, at the western edge of the Woodville Karst Plain. Surface elevation ranged 16-23 m (50-70 ft) above mean sea level, water table elevation

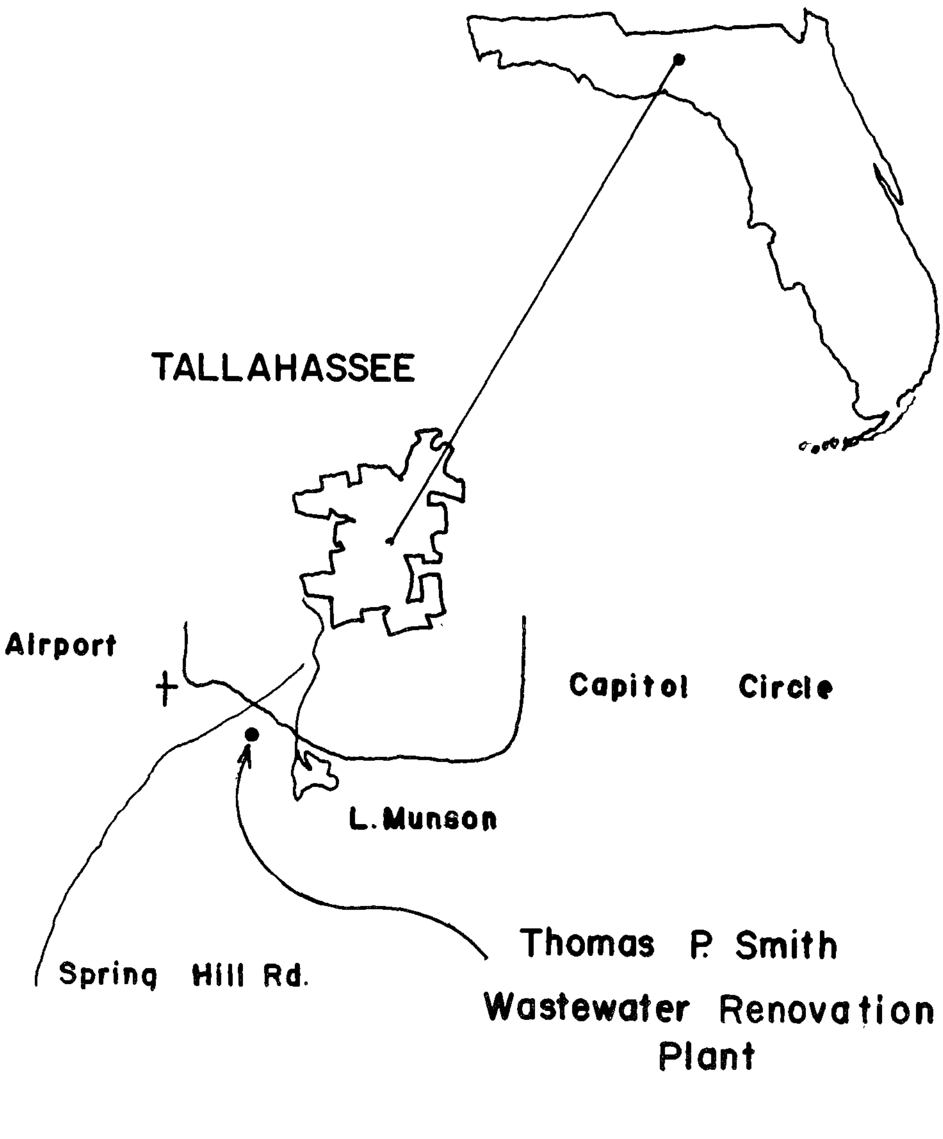

Figure 1. General location of study site.

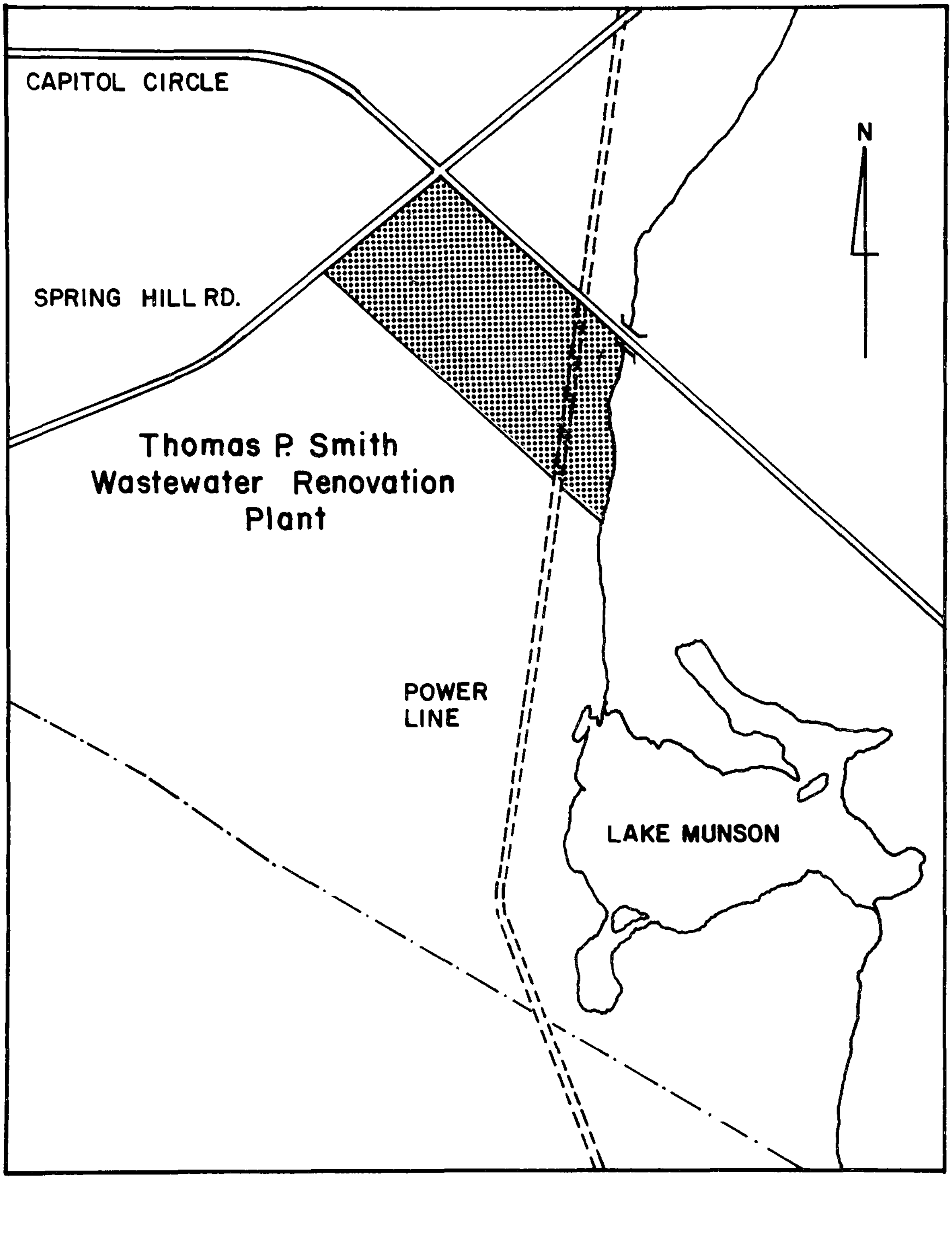

Figure 2. Detailed location of study site.

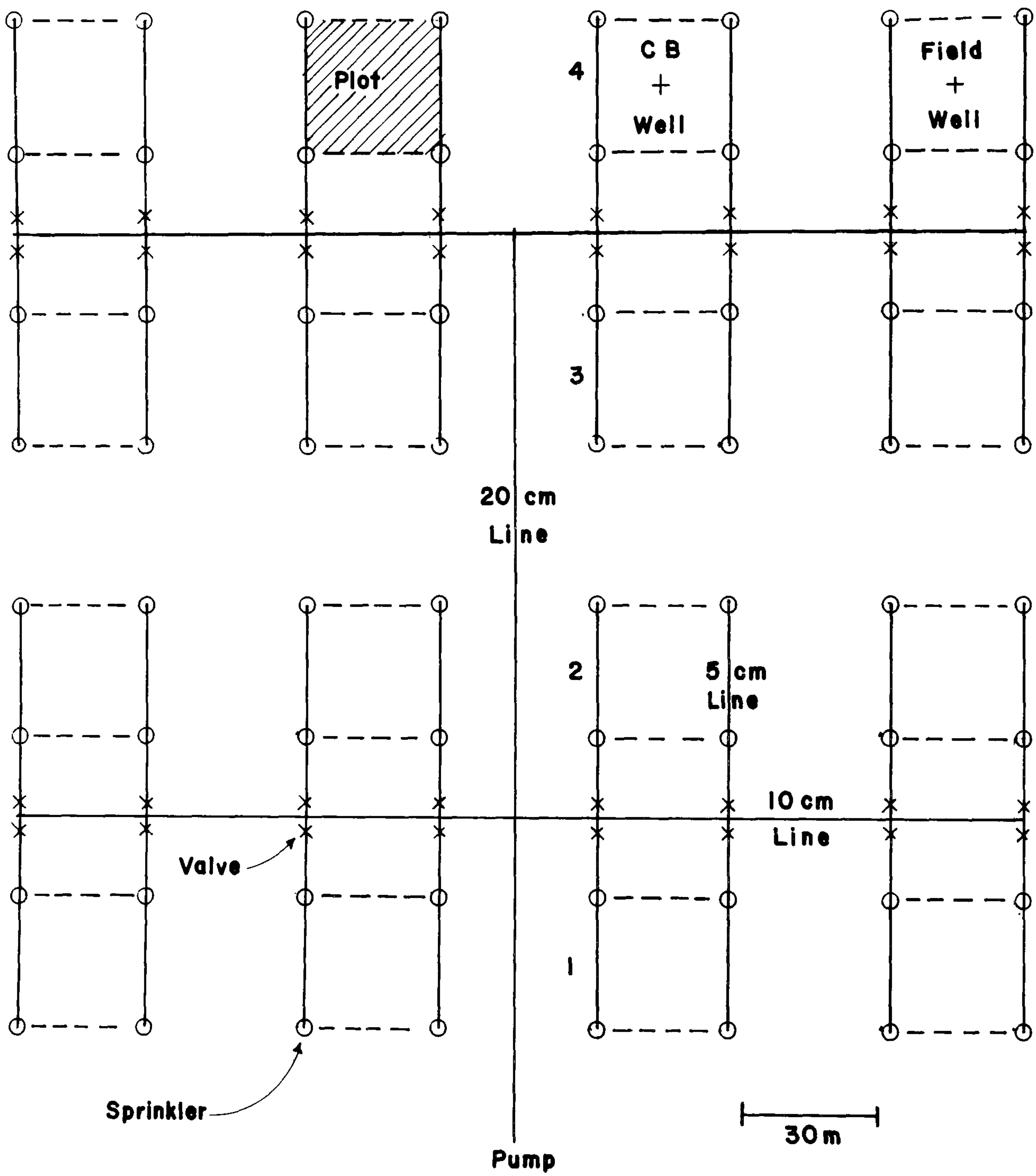

Figure 3. Layout of irrigation system and field plots,

ranged from 7-10 m (22-30 ft). The top of the Floridan aquifer was 0-4 m (Slack, 1975). A well, drilled at the site by the Florida Department of Natural Resources Bureau of Geology for calibration of equipment, provided a stratigraphic profile of the geology (Table 2). Core samples from the background well (Table 3) showed sand underlain by clay at 11.5-17 m with limestone below 17 m. The water table depth was 13.5 m (45 ft) below ground surface. The water table depth at the field well was 13 m (42 ft) below ground surface. Soil samples collected prior to construction of the trickling filter showed a pattern of 6-8 m (20-25 ft) of yellow quartz sand, a clay lens up to 3 m (10 ft) in thickness, white quartz sand 3-4 m (10-12 ft) thick, then limerock. Vegetation in the area was mostly turkey oak and slash pine. The soil was Lakeland fine sand, a Quartzipsamment in the Entisol order. A soil profile taken near the treatment plant showed the soil contained approximately 95% sand, 2% silt and 3% clay (Table 4). The pH of a 1:1 soil/water mixture was approximately 5.5, and cation exchange capacity was very low. Water holding capacity of the soil was about 8 cm/m (1 in./ft).

TABLE 2. LITHOLOGIC LOG OF CALIBRATION WELL AT THE TREATMENT PLANT

Depth m	Description
0-3	SAND, quartz, dark yellowish orange, fine to coarse, subangular-subrounded, loose, trace - 1% heavy minerals.
3-4	SAND, as above, but very pale orange in color.
4-9	SAND, quartz, grayish orange to dark yellowish orange, fine to coarse, mostly medium to coarse, loose, has burrowed or disrupted liminae appearance.
9-10	SAND, quartz, very pale orange, fine to medium, some coarse, loose, trace - 1% heavy minerals.
10-14	CLAY, mottled gray, light brown and dark yellowish orange, very sandy and silty at top - decreasing downward, soft but tough, waxy, abrupt contact with below.
14-15	CAVITY
15-17	CALCILUTITE, very pale orange, partially recrystallized, very finely sandy, soft but tough, microfossiliferous (Sorites, Miliolids).
17-18	CAVITY
18-18.5	CALCILUTITE, grayish orange, partially recrystallized, hard, sandy.
18.5-19	CAVITY
19-20	CALCILUTITE, yellowish gray, very clayey textured and soft, sandy.
20-23	DOLOMITIZED CALCARENITE, pale orange, very hard, partially recrystallized, very microfossiliferous but indistinct.
23-26.5	CALCARENITE, pale yellowish orange, partially recrystallized, hard to soft, very microfossiliferous with good porosity and permeability in soft zones.
26.5-28	CAVITY - filled with rotten, broken limestone material.

(continued)

TABLE 2. (continued)

Depth m	Description
28-39	CALCILUTITIC CALCARENITE, very pale orange, partially recrystallized, very microfossiliferous, soft, good porosity and permeability.
39-40	CALCILUTITE, very pale orange, partially recrystallized, hard, very "tight" - silty textured.
40-46.5	CALCARENITE, very pale orange, partially recrystallized, very microfossiliferous (first appearance of Leps) moderately hard, very porous and permeable, appears to have calcareous algae "globs" - especially from 140-148 feet, macrofossiliferous molds.
46.5-51.5	CALCILUTITE, pale yellowish brown, partially recrystallized, very evenly fine grained, microfossiliferous (no Leps), friable, partially dolomitized. One inch base of interval appears to be organic.
51.5-59.5	DOLOMITE, moderate yellowish brown, recrystallized, hard, some moldic porosity, (with some zones silty textured and soft).
59.5-60	CAVITY
60-62	DOLOMITIC CALCARENITE, pale yellowish brown, very moldic, very microfossiliferous but fossils indistinct, hard, brittle, recrystallized, grades into below.
62-64.5	CALCILUTIC CALCARENITE, grayish orange, partially recrystallized, microcoquina of small microfossils, porous and permeable, friable.
64.5-70	AS ABOVE, with few macrofossils fragments and molds and few zones of complete recrystallization - lower three feet pale yellowish brown in color.
70-71.5	CALCILUTITIC CALCARENITE, very pale orange, partially recrystallized, microfossiliferous, soft to medium hard, with harder gray zones (conglomeratic appearance).
71.5-73	AS ABOVE, but more recrystallized and harder - lower six inches appears dolomitized (small silt size rhombs) and laminated, and is pale brown (? organics) in color.

(continued)

TABLE 2. (continued)

Depth m	Description
73-73.5	DOLOMITE, pale brown, crystalline, very hard, microfossiliferous, but very indistinct, grades into below.
73.5-74	SAME AS 73-73.5.
74-74.5	SAME AS 73-73.5.
74.5-75	CAVITY.
75-76	DOLOMITE, light brown, crystalline (sucrosic), with zones of non-crystalline, partially recrystallized Calcarenite, hard.
76-84	DOLOMITE, as 73-73.5, with some zones very micromoldic, grades into below.
84-89	CALCARENITE, very pale orange, soft to moderately hard, partially recrystallized, microfossiliferous, but indistinct, intergranular and micromoldic porosity.
89-	CALCARENITE, Pale yellowish brown, partially recrystallized, very microfossiliferous but indistinct (many Leps), hard, intergranular and micromoldic porosity but poorly permeable.

Source: Florida Department of Natural Resources, Bureau of Geology.

TABLE 3. LITHOLOGIC LOG OF BACKGROUND WELL

Depth m	Description
0-0.3	Topsoil
0.3-1.5	Sand, dark yellow, medium grain size
1.5-3	Sand, light yellow, medium grain size
3-6	Sand, yellow, medium grain size
6-7.5	Sand, light yellow, trace of clay
7.5-9.5	Sand, very light yellow, medium grain
9.5-10	Sand, dark purple clay
10-10.5	Sand, gray, medium grain
10.5-11.5	Sand, white clay layers
11.5-13.5	Clay, gray, dense
13.5-15	Clay, dark yellow
15-16	Clay, deep yellow, greenish gray streaks
16-17	Clay, lime rock fragments
17-18	Limestone, soft white
18-21	Limestone, dolomite, yellowish brown
21-24	Limestone, dolomite, tan

Source: Florida Department of Natural Resources, Bureau of Geology.

TABLE 4. CHARACTERISTICS OF LAKELAND SAND NEAR THE IRRIGATION SITE

				Particle Size Distribution							
				Sand						Silt	Clay
Depth cm	Horizon	pH H_2O	CEC meq/100 gm	VC	C	M	F	VF	Total		
0-8	A1	5.5	3.59	0.7	21.2	48.7	21.9	1.7	94.2	2.6	3.2
8-58	C1	5.7	1.39	1.0	21.6	48.7	22.5	1.5	95.3	1.9	2.8
58-104	C2	5.4	1.37	1.2	21.6	47.2	23.8	1.7	95.5	1.0	3.5
104-155	C3	5.5	1.11	1.5	20.3	43.5	28.9	2.3	96.5	1.5	2.0
155-185	C4	5.3	0.83	1.4	21.1	44.1	26.7	2.0	95.3	1.1	3.6
185-203	C5	5.0	0.54	1.5	22.4	46.0	26.2	1.8	97.9	0.7	1.4

CEC = cation exchange capacity
VC = very coarse, 2-1 mm
C = coarse, 1-0.5 mm
M = medium, 0.5-0.25 mm
F = fine, 0.25-0.10 mm
VF = very fine, 0.10-0.05 mm
Silt = 0.05-0.002 mm
Clay = < 0.002 mm

Source: University of Florida Soil Characterization Laboratory.

SECTION 5

SYSTEM CHARACTERISTICS

INTRODUCTION

Data was collected on wastewater, groundwater and soil to characterize response of the system to wastewater irrigation. Behavior of these three was clearly interrelated. Groundwater samples were collected for the highest irrigation rates due to failure of the wells at the lower rates. Climatic data was included to show variability in temperature and rainfall. There were several nights during the winter season when irrigation would have caused ice formation. However, this was only a minor problem.

WASTEWATER

In September 1974 the activated sludge unit went on line. Values for BOD and solids content (Table 5) for the period 4/71-9/74 were for the trickling filter and for 10/74-3/76 were for the activated sludge plant. Final BOD was

TABLE 5. BOD AND SOLIDS CONTENT OF THE WASTEWATER*

Period	BOD Raw mg/l	BOD Final mg/l	Total Solids Raw mg/l	Total Solids Final mg/l	Suspended Solids Raw mg/l	Suspended Solids Final mg/l
4/71-9/71	169	60	507	375	138	28
10/71-3/72	189	70	520	385	128	29
4/72-9/72	180	70	506	386	131	34
10/72-3/73	230	75	515	402	144	26
4/73-9/73	125	49	439	303	172	39
10/73-3/74	168	61	580	370	206	42
4/74-9/74	187	51	538	338	253	39
10/74-3/75	206	25	478	373	208	52
4/75-9/75	156	25	511	377	188	42
10/75-3/76	160	13	510	375	195	26
Avg.	177	50	610	368	176	36

* From a 24-hour proportional composite sample collected each week.

measured in samples from the outfall of the polishing pond. Suspended solids averaged 36 mg/l, which represented 4 mtons/ha/yr (2 tons/acre/yr) at 200 mm/week. Even this high rate did not cause noticeable clogging of the soil. Chemical characteristics were measured on 24 hr proportional composite samples collected at the pump intake (Table 6). Average values obtained here agree with those reported elsewhere (Kardos _et al_., 1974 and Metcalf and Eddy, Inc., 1972).

GROUNDWATER

Background quality of groundwater in the vicinity of the treatment plant was measured in a well near the power line (Figure 2). Concentrations of various chemical elements were very low (Table 7) and remained essentially constant during the study period. Chloride was approximately 2 mg/l, compared to 50 mg/l in the wastewater, and provided a good indicator for changes in groundwater quality due to irrigation.

The field well (Figure 3) showed the influence of irrigation (Table 8). Application rates for that plot were 200 mm/week (8 in./week) during the summer season and 100 mm/week (4 in./week) during the winter season. Chloride averaged 49 mg/l, compared to 51 mg/l in the effluent. A mass balance for chloride showed the effluent comprised about 96% of the groundwater at this well. Total nitrogen averaged 18.6 mg/l, or 59% as much as in the effluent. It should be noted that nitrification ($NH_4 \rightarrow NO_3$) was essentially complete. Potassium concentration dropped from 6.2 mg/l in the effluent to 0.7 mg/l in the well. The decrease in nitrogen and potassium was attributable, in part, to crop uptake by the various crops grown on this plot. Total phosphorus decreased from 10.5 mg/l in the effluent to 0.021 mg/l in the groundwater; soil fixation of phosphorus was complete.

There appeared to be greater dilution of the percolating water with groundwater in the well in the coastal bermuda (CB) plot (Table 9). Chloride in the well was 38 mg/l, or 75% of the value for effluent. Based upon this dilution factor, the concentration of total nitrogen in the percolating water was 11.3/0.75 = 15 mg/l. Since the effluent averaged 31.3 mg/l, this represented a change of about 16 mg/l, or roughly 50%. Since nitrogen recovery by coastal bermudagrass at 200 mm/week (8 in./week) was less than 50%, some nitrogen appeared to be removed by other mechanisms. From this study it was not possible to discriminate among accumulation by roots, assimilation by organisms, or reduction by organisms. Average data for effluent and the three wells were assembled for comparison (Table 10). For all parameters the field and CB well values were intermediate to effluent and background levels. Dilution was indicated by a comparison of the data with data from the USGS study (Slack, 1975). Well 21, in the USGS study, was very near the CB well and was cased to 75.3 m (247 ft). During 1974, chloride averaged 16 mg/l and total nitrogen 3.3 mg/l.

Counts of fecal coliform, by the membrane method, never showed positive counts, although the effluent was shown to contain as high as 10^5 fecal coliform/100 ml. BOD measurements showed values below 5 mg/l. These results indicated that the soil was very effective in removing bacteria and suspended

TABLE 6. CHEMICAL CHARACTERISTICS OF THE SECONDARY EFFLUENT

Period	Characteristic												
	pH	G umho	Cl	NO_3 N	NH_4 N	Kjeldahl N	Total N	Ortho P mg/l	Total P	K	Ca	Mg	Na
4/71-9/71	7.6	460	-	3.2	18.2	21.4	24.6	6.5	-	-	-	-	-
10/71-3/72	7.2	520	61	4.4	19.3	-	-	7.1	-	-	-	-	-
4/72-9/72	7.2	530	60	2.8	19.5	33.0	35.8	-	12.6	6.1	32	9.6	39
10/72-3/73	7.3	530	74	2.6	20.1	36.7	39.3	8.5	13.3	-	-	-	-
4/73-9/73	7.2	410	51	2.6	13.7	23.9	26.5	7.1	9.4	7.5	64	17.6	55
10/73-3/74	7.4	480	47	2.0	18.2	28.4	30.4	9.0	11.2	5.5	32	9.3	36
4/74-9/74	7.3	480	40	2.8	17.2	33.2	36.0	9.0	11.0	3.7	29	8.7	33
10/74-3/75	7.6	440	42	7.9	11.3	31.8	40.8	7.7	8.8	4.0	29	10.0	26
4/75-9/75	7.6	400	43	4.7	11.5	25.7	30.5	7.7	9.1	5.8	28	9.4	33
10/75-3/76	7.7	420	44	8.7	7.4	17.0	25.7	8.2	9.5	8.8	36	10.3	41
4/76-9/76	7.8	440	44	12.9	2.0	10.1	23.0	8.4	9.4	8.4	34	9.6	42
Avg.	7.5	465	51	5.0	14.4	26.1	31.3	7.9	10.5	6.2	35	10.6	38

TABLE 7. CHEMICAL CHARACTERISTICS OF THE BACKGROUND WELL*

Period	pH	G umho	Cl	NO_3 N	NH_4 N	Kjeldahl N	Total N	Ortho P	Total P	K	Ca	Mg	Na
								mg/l					
3/73-9/73	7.8	58	2	<1	<1	1.0	<2	-	0.030	0.3	10.5	0.5	1.4
10/73-3/74	8.1	48	2	<1	<1	1.0	<2	0.014	0.025	0.2	6.2	0.5	0.7
4/74-9/74	8.3	46	2	<1	<1	1.2	<2	0.014	0.037	0.1	7.6	0.6	0.8
10/74-3/75	8.4	47	2	<1	<1	1.0	<2	0.011	0.022	0.1	8.4	1.0	1.1
4/75-9/75	8.3	51	1	<1	0.1	0.9	<2	0.004	0.011	0.4	8.6	1.5	3.8
10/75-3/76	8.5	57	1	<1	0.1	1.0	<2	0.007	0.015	0.2	8.5	1.2	4.7
4/76-9/76	8.4	61	1	<1	0.1	0.8	<2	0.009	0.025	0.3	10.5	0.6	1.0
Avg.	8.3	53	2	<1	<1	1.0	<2	0.010	0.024	0.2	8.6	0.8	1.9

* From weekly samples.

TABLE 8. CHEMICAL CHARACTERISTICS OF THE FIELD WELL*

Period	pH	G umho	Cl	NO_3 N	NH_4 N	Kjeldahl N	Total N	Ortho P	Total P	K	Ca	Mg	Na
								mg/l					
4/73-9/73	7.5	320	51	16.4	<1	1.7	18.1	0.016	0.027	0.8	34	3.2	31
10/73-3/74	7.5	330	52	17.6	<1	1.6	19.1	0.014	0.025	0.6	29	2.8	22
4/74-9/74	7.7	350	49	20.6	<1	1.5	22.1	0.014	0.032	0.8	35	3.6	25
10/74-3/75	7.9	340	48	19.3	<1	1.4	20.6	0.007	0.016	0.8	37	5.2	24
4/75-9/75	7.7	320	48	16.8	<1	0.9	17.7	0.007	0.014	0.7	32	4.9	30
10/75-3/76	7.9	310	48	14.2	<1	1.2	15.3	0.006	0.014	0.4	36	4.5	26
4/76-9/76	7.8	350	45	16.0	<1	1.0	17.0	0.007	0.018	1.1	40	4.6	29
Avg.	7.7	331	49	17.3	<1	1.3	18.6	0.010	0.021	0.7	35	4.1	27

* From weekly samples.

TABLE 9. CHEMICAL CHARACTERISTICS OF THE COASTAL BERMUDA WELL*

Period	pH	G umho	Cl	NO_3 N	NH_4 N	Kjeldahl N	Total N	Ortho P	Total P	K	Ca	Mg	Na
								mg/l					
10/74-3/75	8.1	310	36	9.8	1.6	1.8	11.6	0.016	0.030	0.7	40	6.8	17
4/75-9/75	8.1	320	43	11.9	0.3	1.1	13.0	0.011	0.025	1.0	33	5.2	24
10/75-3/76	8.1	300	38	9.2	0.5	1.4	10.6	0.009	0.017	0.5	36	5.4	21
4/76-9/76	8.2	340	37	8.7	0.4	1.2	9.9	0.008	0.020	0.7	43	6.5	24
Avg.	8.1	320	38	9.9	0.7	1.4	11.3	0.011	0.023	0.7	38	6.0	22

* From weekly samples.

TABLE 10. AVERAGE CHEMICAL CHARACTERISTICS OF EFFLUENT AND VARIOUS WELLS

Sample	pH	G umho	Cl	NO_3 N	NH_4 N	Kjeldahl N	Total N	Ortho P	Total P	K	Ca	Mg	Na
								mg/l					
Effluent	7.5	465	51	5.0	14.4	26.1	31.3	7.9	10.5	6.2	35	10.6	38
Background Well	8.3	53	2	< 1	< 1	1.0	< 2.0	0.010	0.024	0.2	9	0.8	2
Field Well	7.7	331	49	17.3	< 1	1.3	18.6	0.010	0.021	0.7	35	4.1	27
CB Well	8.1	320	38	9.9	0.7	1.4	11.3	0.011	0.023	0.7	38	6.0	22

organics. Wells were always pumped a minimum of 2 min. before sample collection to obtain a representative sample.

SOIL

Soil samples were collected from several plots at various depths and at different times to characterize some of the soil properties in relation to chemical processes and crop production. Since irrigation practices on the plots were changed over the years from the beginning of plant operation in 1966, it was not possible to select plots which had received uniform treatment. Results are reported for the plots on which coastal bermudagrass was sprigged in 1973. The basic features of the system will be apparent from the results.

Analyses were performed at the University of Florida Soil Testing Laboratory. After air drying, samples were passed through a coarse sieve to remove roots and other debris. Soil pH was measured in a slurry of 50 g soil/100 ml distilled water using a minimum equilibration period of 30 minutes. Analyses of pH, phosphorus and extractable bases (K, Ca, Mg, Na) were performed using 5 g soil in 25 ml extractant of 0.7 N ammonium acetate in 0.54N acetic acid buffered at pH 4.8. A shaking time of 30 minutes was used.

In 1971 and 1972 soil samples were collected at depth increments of 0-15 cm and 15-30 cm with an auger. The need for more detail became apparent. In 1973 samples were collected at depths of 15, 30, 60, 90 and 120 cm. Soil was removed with hole diggers to within 4 cm of the selected depth. A sample 8 cm in length was then collected with a 5-cm diameter tube.

High-rate irrigation experiments were conducted to measure distributions of phosphate, ammonia and nitrate in the soil solution. Attempts to collect soil solution samples at irrigation rates up to 200 mm/week failed due to the hydraulic characteristics of the sandy soil. Samples were collected under continuous irrigation.

pH

Results are given in Tables 11-13 and Figure 4. These values were in the same range as the value 6.4 reported by Fiskell and Zelazny (1971) for Lakeland soil. Values of pH changed little or none with depth. Hortenstine (1973) observed this same effect with effluent irrigation on Immokalee sand at Walt Disney World in Florida.

Extractable Bases

By leaching soil with a neutral salt, such as ammonium acetate, it is possible to determine the extractable (or exchangeable) basic cations (primarily K, Ca, Mg, Na) held by the soil (cf. Jacobs *et al.*, 1971).

Results for this study are shown in Tables 11-14 and Figures 5-11. A noticeable change in the balances of cations occurred between the sampling dates of 3/71, 10/71 and 3/72 (Tables 11-13); viz an increase in calcium

TABLE 11. CHARACTERISTIC OF SOIL EXTRACTS - MARCH 1971.

Plot	Depth cm	pH	P mg/kg	K	Ca	Mg	Na
				- - - - - - -	meq/100 gm	- - - - - - -	
1	0-15	6.5	15.5	0.038	1.15	0.56	0.69
	15-30	6.5	7.6	0.031	0.55	0.43	0.61
2	0-15	6.5	15.7	0.066	0.95	0.55	0.60
	15-30	6.6	8.7	0.036	0.53	0.47	0.59
3	0-15	6.6	18.0	0.064	1.06	0.56	0.60
	15-30	6.7	10.6	0.046	0.65	0.45	0.62
4	0-15	6.7	28.7	0.069	1.16	0.61	0.60
	15-30	6.7	19.0	0.046	0.75	0.51	0.62
Avg.	0-15	6.6	19.5	0.059	1.08	0.57	0.63
	15-30	6.6	11.5	0.041	0.62	0.47	0.61

TABLE 12. CHARACTERISTICS OF SOIL EXTRACTS - OCTOBER 1971.

Plot	Depth cm	pH	P mg/kg	K	Ca	Mg	Na
				- - - - - - -	meq/100 gm	- - - - - - -	
1	0-15	6.5	17.1	0.038	2.12	0.41	0.41
	15-30	6.5	15.3	0.020	1.35	0.36	0.37
2	0-15	6.8	19.2	0.054	1.58	0.44	0.39
	15-30	6.8	11.7	0.041	0.85	0.26	0.37
3	0-15	6.5	16.7	0.028	1.52	0.30	0.39
	15-30	6.7	14.1	0.020	0.90	0.24	0.39
4	0-15	6.6	16.8	0.049	1.48	0.42	0.39
	15-30	6.6	11.3	0.026	0.92	0.26	0.39
Avg.	0-15	6.6	17.4	0.041	1.68	0.39	0.40
	15-30	6.6	13.1	0.026	1.01	0.28	0.38

TABLE 13. CHARACTERISTICS OF SOIL EXTRACTS - MARCH 1972.

Plot	Depth cm	pH	P mg/kg	K	Ca	Mg	Na
				- - - - - - - meq/100 gm - - - - - - -			
1	0-15	6.9	17.1	0.013	1.70	0.38	0.39
	15-30	6.9	18.1	0.015	1.62	0.39	0.35
2	0-15	6.9	16.4	0.038	1.55	0.31	0.37
	15-30	6.9	16.3	0.031	1.50	0.36	0.35
3	0-15	6.9	15.3	0.010	1.38	0.36	0.35
	15-30	7.0	17.8	0.010	1.45	0.34	0.37
4	0-15	6.9	22.8	0.015	1.80	0.39	0.39
	15-30	6.9	19.8	0.008	1.30	0.34	0.39
Avg.	0-15	6.9	17.9	0.020	1.60	0.36	0.37
	15-30	6.9	18.0	0.015	1.47	0.35	0.36

TABLE 14. EXTRACTABLE BASES

Plot	Depth cm	4/71	10/71	4/72	Avg.
		- - - - - - - - - meq/100 gm soil - - - - - - - - -			
1	0-15	2.44	2.99	2.48	2.63
	15-30	1.62	2.10	2.37	2.03
2	0-15	2.17	2.46	2.27	2.30
	15-30	1.62	1.52	2.24	1.79
3	0-15	2.29	2.25	2.09	2.21
	15-30	1.76	1.55	2.17	1.83
4	0-15	2.44	2.33	2.60	2.46
	15-30	1.92	1.60	2.04	1.85
Avg.	0-15	2.33	2.51	2.36	2.40
	15-30	1.73	1.69	2.21	1.88

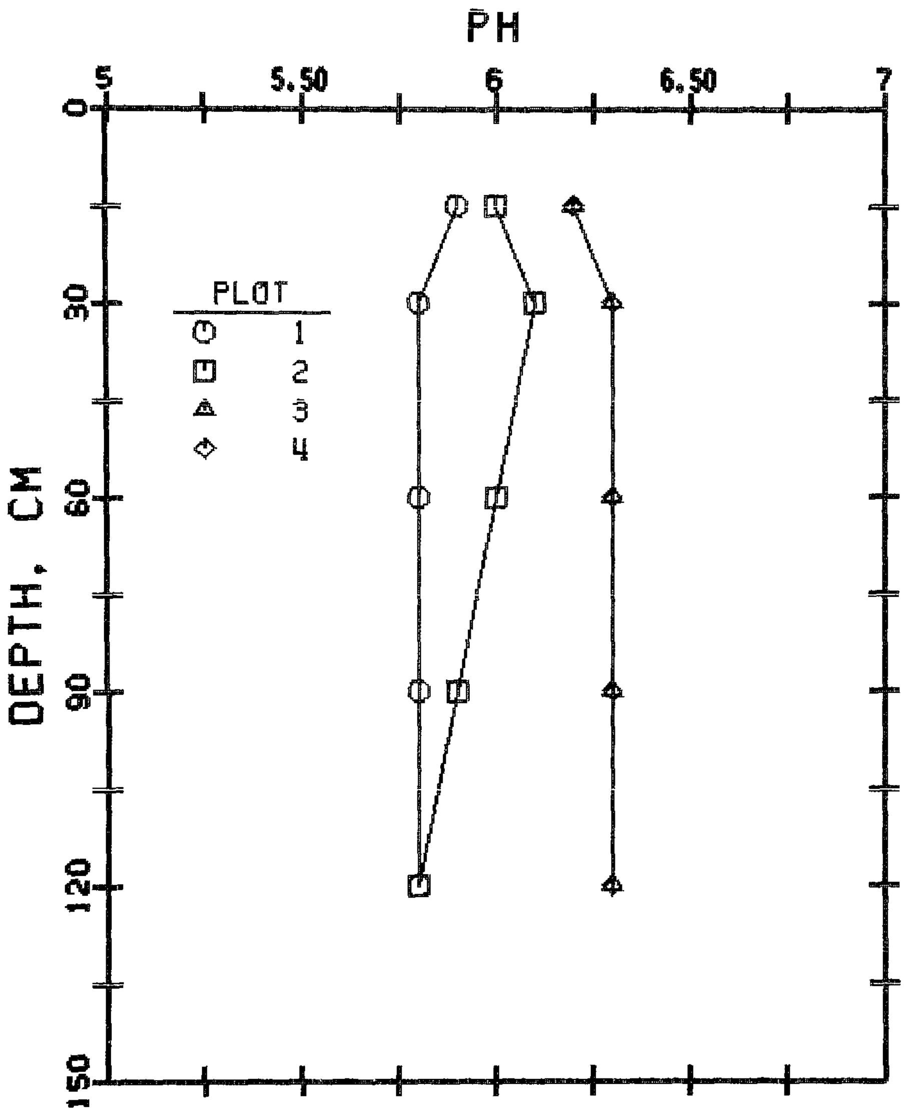

Figure 4. Distribution of pH in field plots.

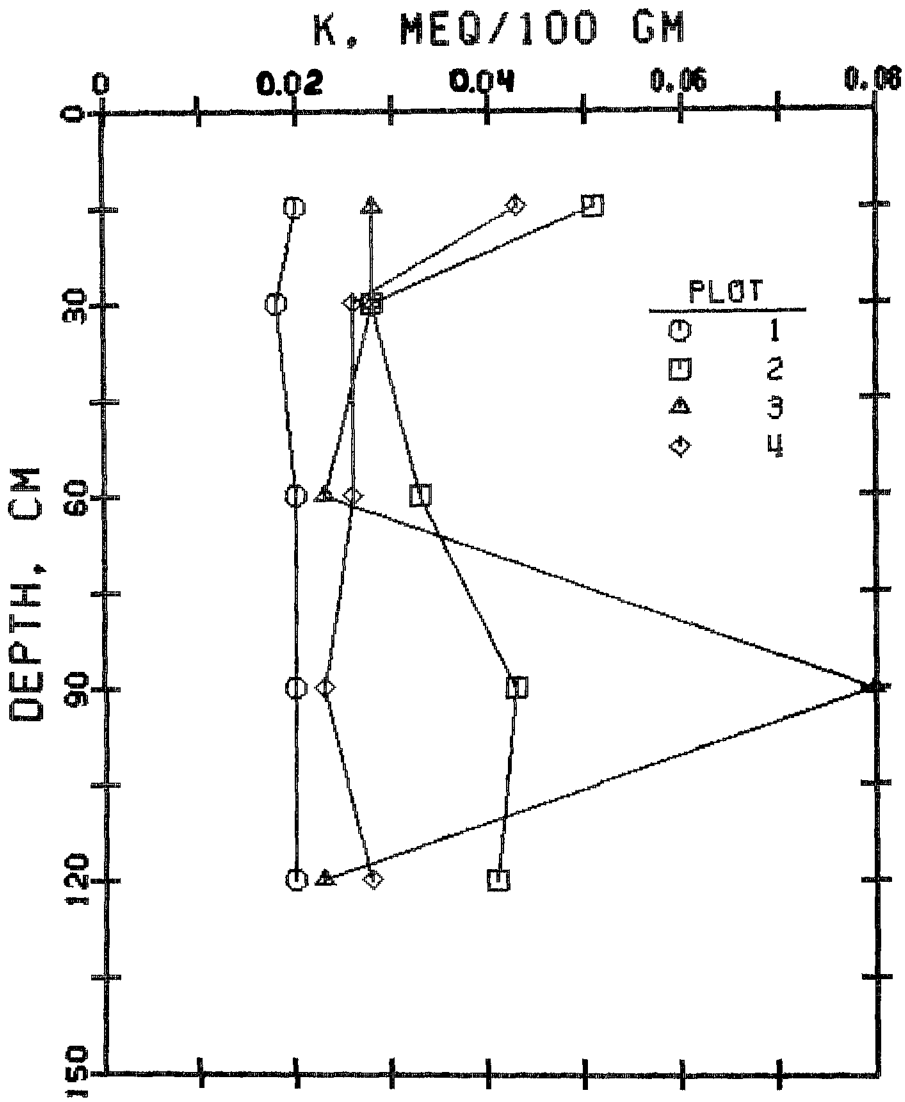

Figure 5. Distribution of K in field plots.

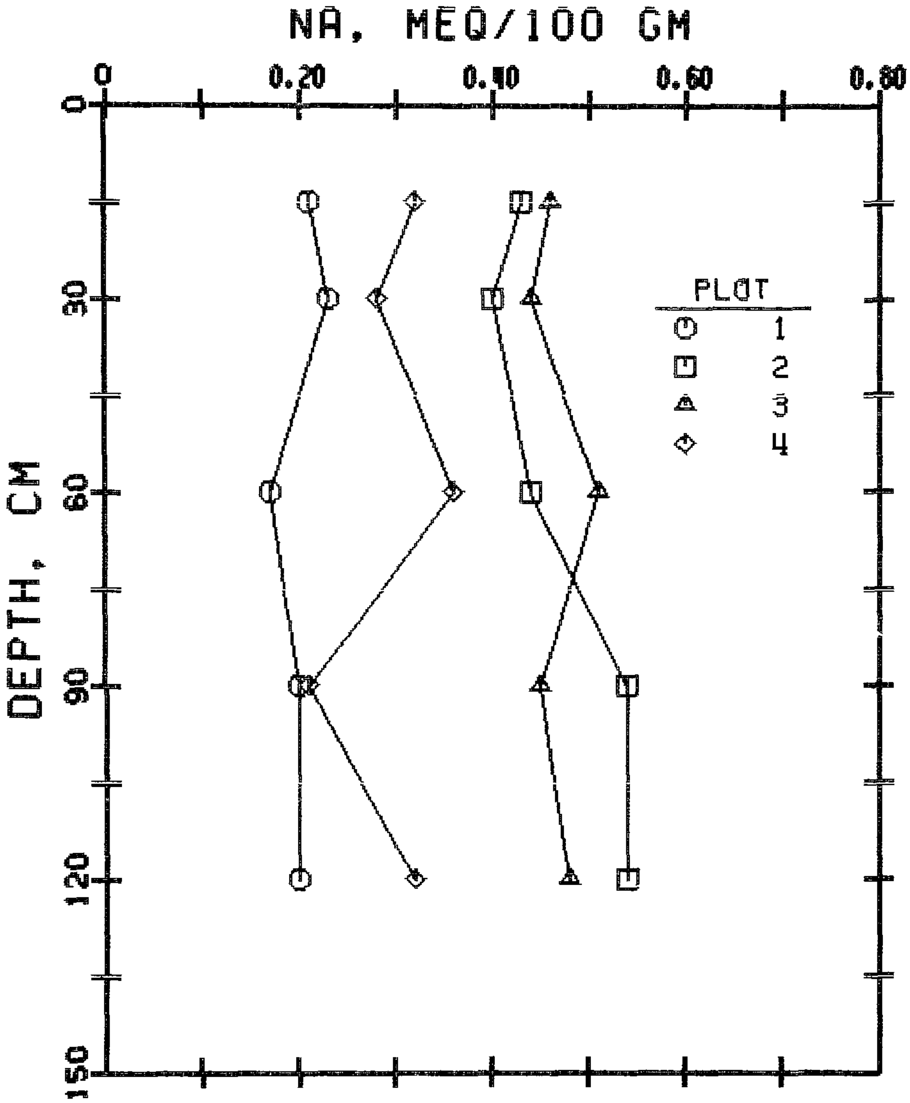

Figure 6. Distribution of Na in field plots.

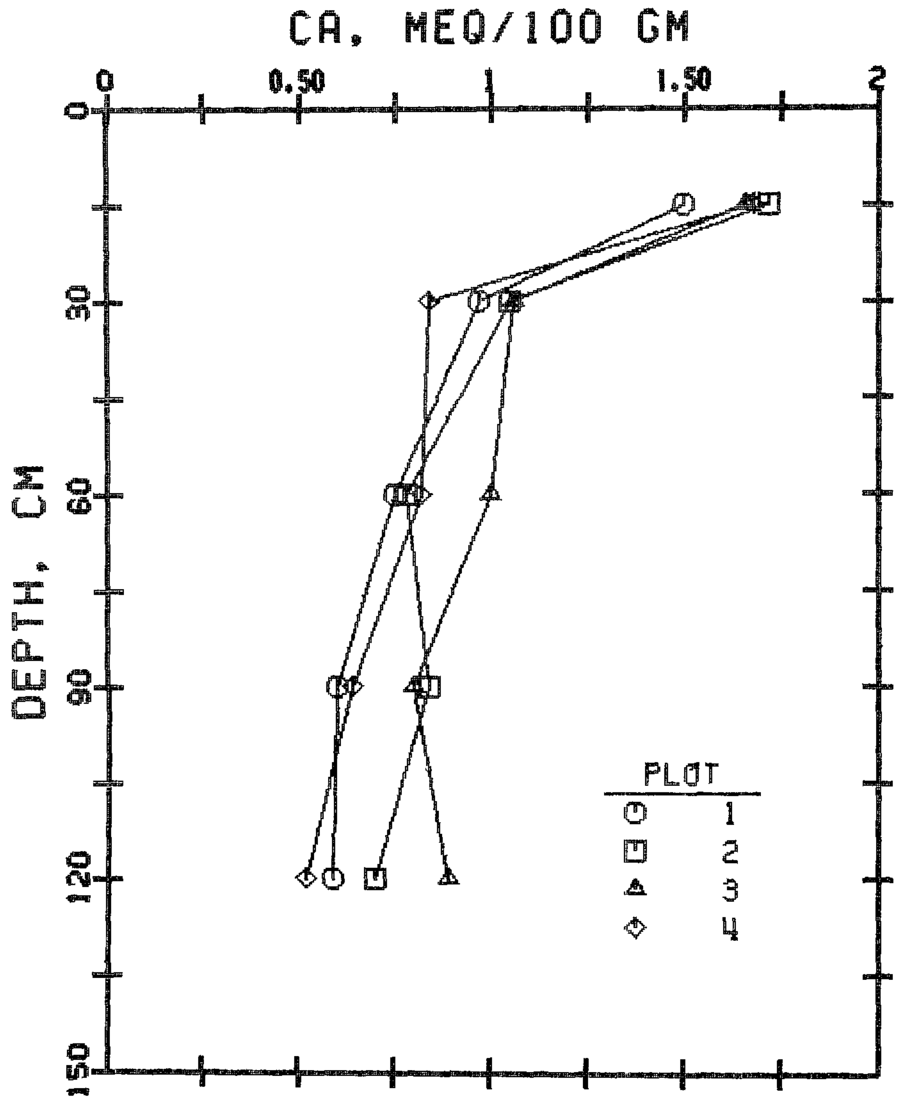

Figure 7. Distribution of Ca in field plots.

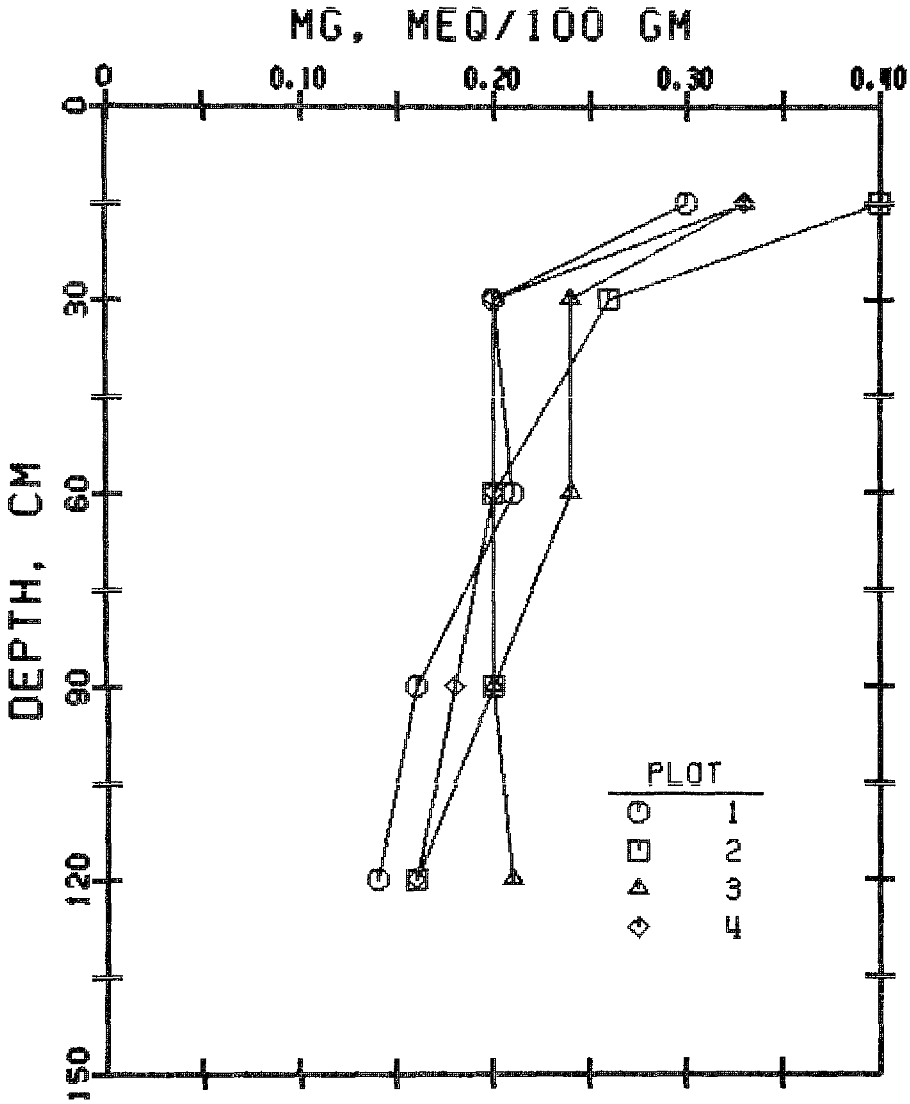

Figure 8. Distribution of Mg in field plots.

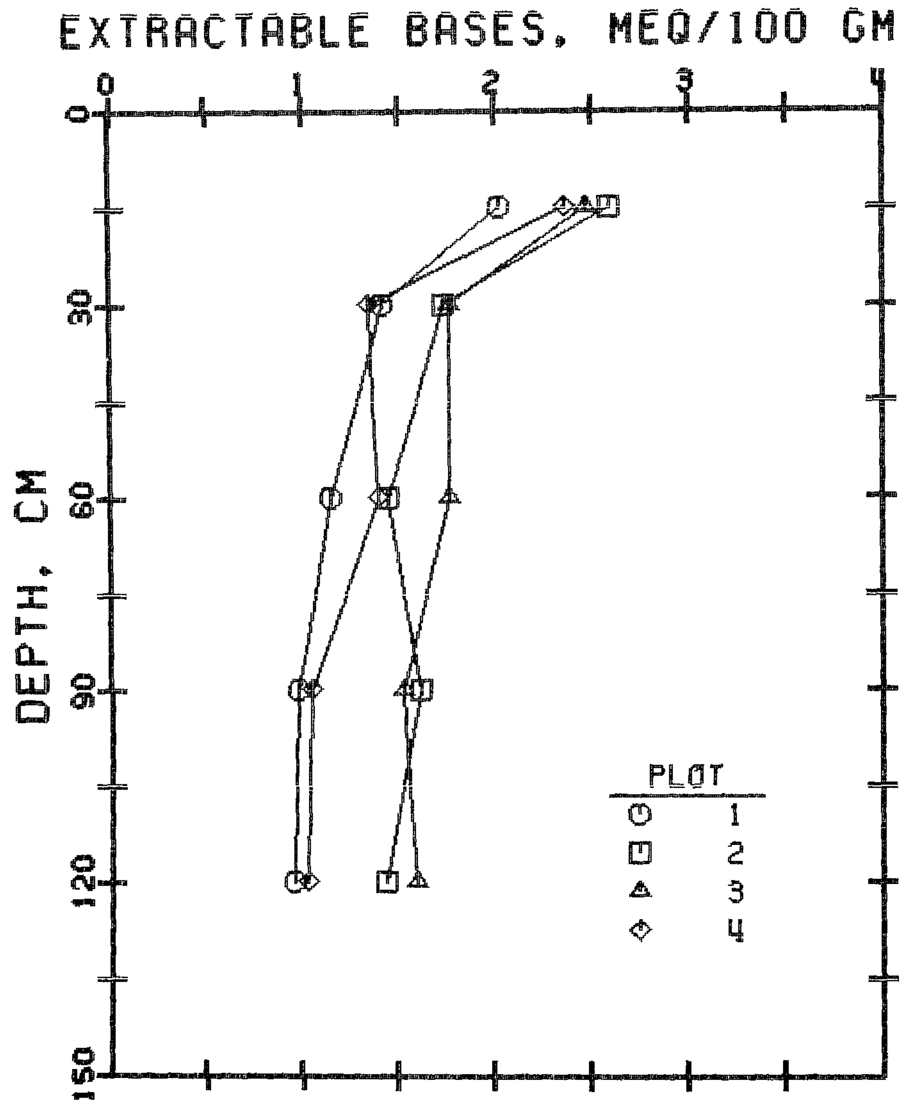

Figure 9. Distribution of total extractable bases in field plots.

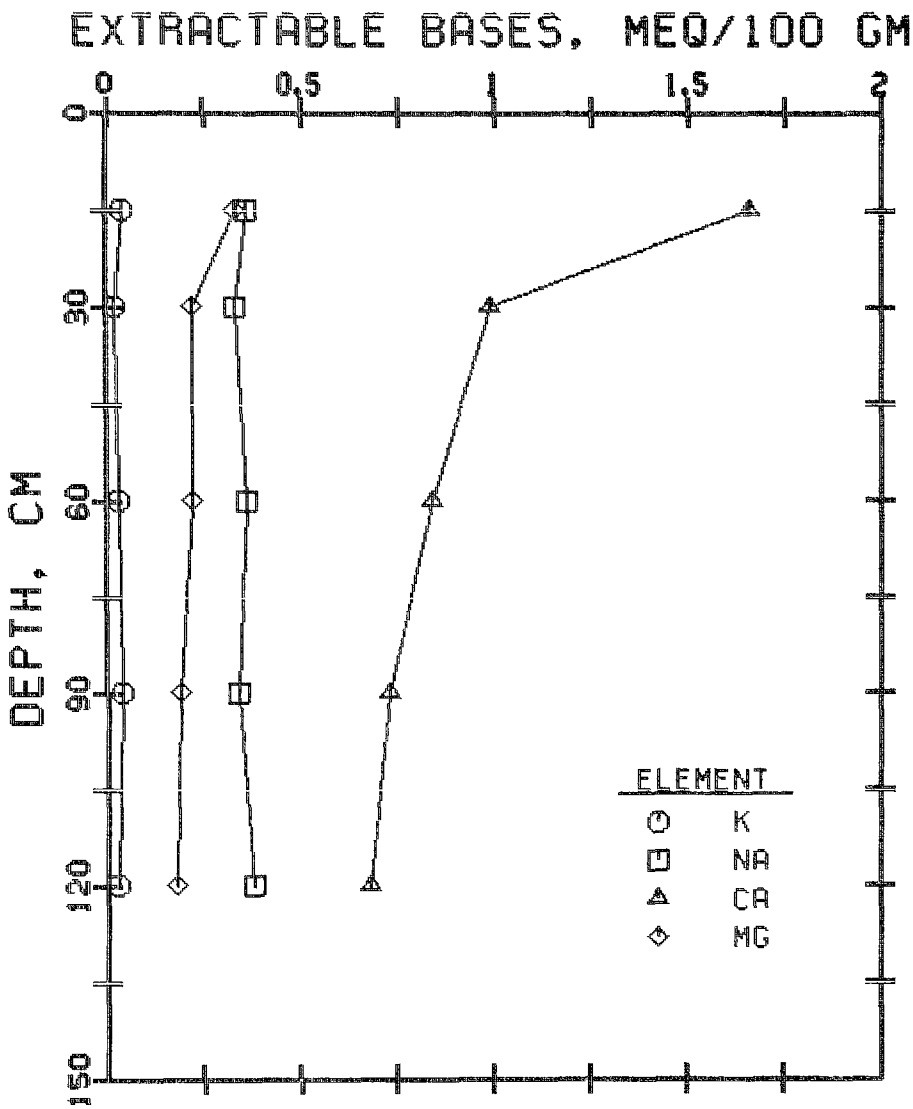

Figure 10. Distribution of extractable bases in field plots.

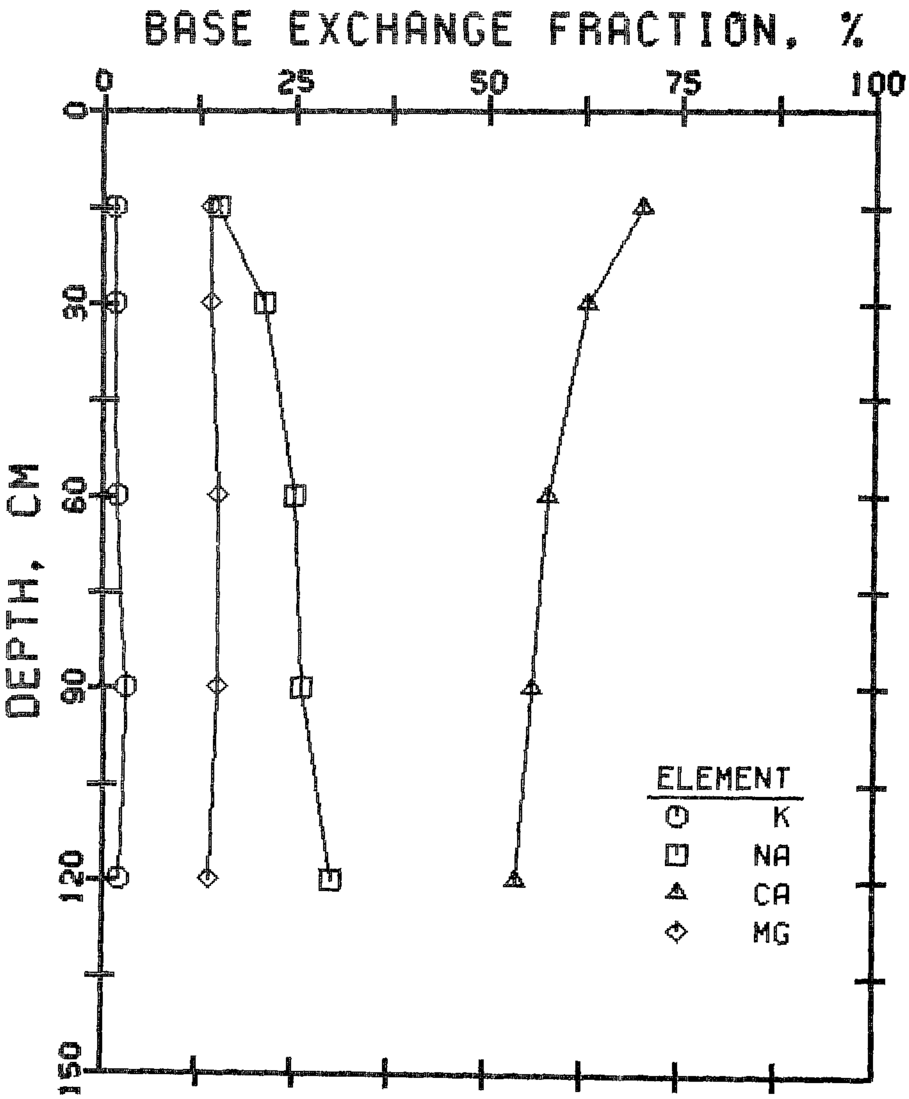

Figure 11. Distribution of base exchange fraction in field plots.

with a corresponding decrease in the others. The quantity of extractable bases remained essentially constant with time (Table 14), but showed a decrease from 2.40 at 0-15 cm to 1.88 at 15-30 cm.

In 1973, soil samples were collected from five depths. Potassium and sodium showed little change with depth (Figures 5 and 6), while calcium and magnesium showed strong decreases with depth (Figures 7 and 8). These values are in the same range reported by Fiskell and Zelazny (1971) for Lakeland soil. The sum of extractable bases decreased with depth (Figure 9). The same trend was reported by Fiskell and Zelazny (1971) for Lakeland and by Hortenstine (1973) for Immokalee soil. Greater weathering and higher organic matter near the soil surface cause this distribution. Values for the four plots were averaged for each depth to obtain average base cation concentrations. Values were then averaged for each cation from the four plots and divided by the average base concentration to determine base exchange fraction. Results are shown in Figure 10 for the four cations. More than one-half the base exchange was occupied by calcium. Most soils are dominated by calcium (Jacobs et al., 1971; Buckman and Brady, 1969; Fiskell and Zelazny, 1971; and Hortenstine, 1973). Potassium occupied less than 5% of base exchange, due to the fact that the fraction of potassium in the effluent was very low (less than 5%).

The calcium fraction decreased with depth, from 70% at 15 cm to 54% at 120 cm (Figure 11). Sodium showed a corresponding increase from 15% at 15 cm to 30% at 120 cm. It can be shown that for a mixed cation system (monovalent and divalent cations) that as total cation exchange capacity decreases the balance of adsorbed cations will shift toward monovalents and away from divalents. This agrees with the increase of sodium with depth and the complimentary decrease of calcium, induced by the decrease of base exchange with depth.

The distribution of basic cations between adsorbed and solution phases are shown in Table 15 for the 15 cm depth. Overman and West (1972) showed

TABLE 15. DISTRIBUTION OF BASIC CATIONS BETWEEN ADSORBED AND SOLUTION PHASES.

Cation	K	Ca	Mg	Na
Adsorbed, meq/100 gm	0.036	1.66	0.33	0.36
Solution, meq/l	0.16	1.60	0.79	1.70
Adsorbed / Solution	38	176	71	36

that Lakeland fine sand drained to a water content of approximately 10% under gravity drainage. Assuming a bulk density of 1.70 g/cm3, the distribution ratio for potassium was calculated to be:

$$\frac{\text{K Adsorbed}}{\text{K Solution}} = \frac{0.036\ \text{meq}}{100\ \text{mg}}\ \frac{(1.70)\text{g}}{\text{cm}^3}\ \frac{\text{cm}^3}{(0.10)\text{cm}^3}\ \frac{10^3\text{cm}^3}{1}\ \frac{1}{(0.16)\text{meq}} = 38$$

Solution values were assumed to be the same as in the effluent. Even though the exchange capacity of the soil was low, the reserve of adsorbed cations was appreciable.

Phosphorus

Values for ammonium acetate - extractable phosphorus (Tables 11-13 and Figure 12) showed a strong decrease with depth in all cases. This decrease in weakly bound phosphorus with depth resulted from the logarithmic decay in solution P concentration with depth due to phosphorus fixation by the soil (Overman et al., 1976). A plot was irrigated with effluent continuously for three days in July, 1970, and soil solution samples were collected at the end of that period. Measurements of orthophosphate showed a decrease from approximately 10 mg/l P in the effluent to 0.1 mg/l P at 120 cm (Figure 13), for a removal of 99%. Hortenstine (1973) observed this same decay on Immokalee sand receiving effluent. Phosphorus fixation in these Florida acid soils was associated with oxides of iron and aluminum. Hortenstine (1973) demonstrated that addition of lime to the soil enhanced fixation. Hook et al. (1973) reported rapid fixation of phosphorus by a clay loam soil in the Pennsylvania State University studies. More than 90% of the phosphorus in the effluent was removed in the upper 15 cm of soil.

Nitrogen

The soil solution samples collected for phosphate analysis from the three-day continuous irrigation were also analyzed for NH_4-N and NO_3-N. Ammonia concentration showed a rapid decrease with depth (Figure 14), and appeared to follow first order kinetics. Nitrate concentration showed a corresponding increase with depth. These measurements indicated a high level of activity by nitrifying organisms in the soil, since nitrification was essentially complete in the upper 90 cm.

CLIMATE

Temperature and rainfall data were taken from National Oceanic and Atmospheric Administration records at the Tallahassee Municipal Airport located approximately 3 km (2 mi.) from the treatment plant (Tables 15-20). The transition from cool to warm season occurred during March-April, while the reverse transition occurred during October. Accordingly, summer crops were planted around April 1 and winter crops were planted in October. While the average minimum temperature was above freezing for all months, the number of days with freezing temperatures ranged from 21 in the 1971-1972 winter season to 50 in the 1975-1976 winter season. Daytime temperatures were always above freezing. June-September represented the period of high stress for crop growth due to high daytime temperatures. Rainfall was extremely variable during the period 1971-1976, with an average value of 179 cm (71 in.) and a range of 148-223 cm (58-88 in.). The least monthly rainfall was 1.40 cm (0.55 in.) in April 1972, while the greatest monthly value was 44.52 cm

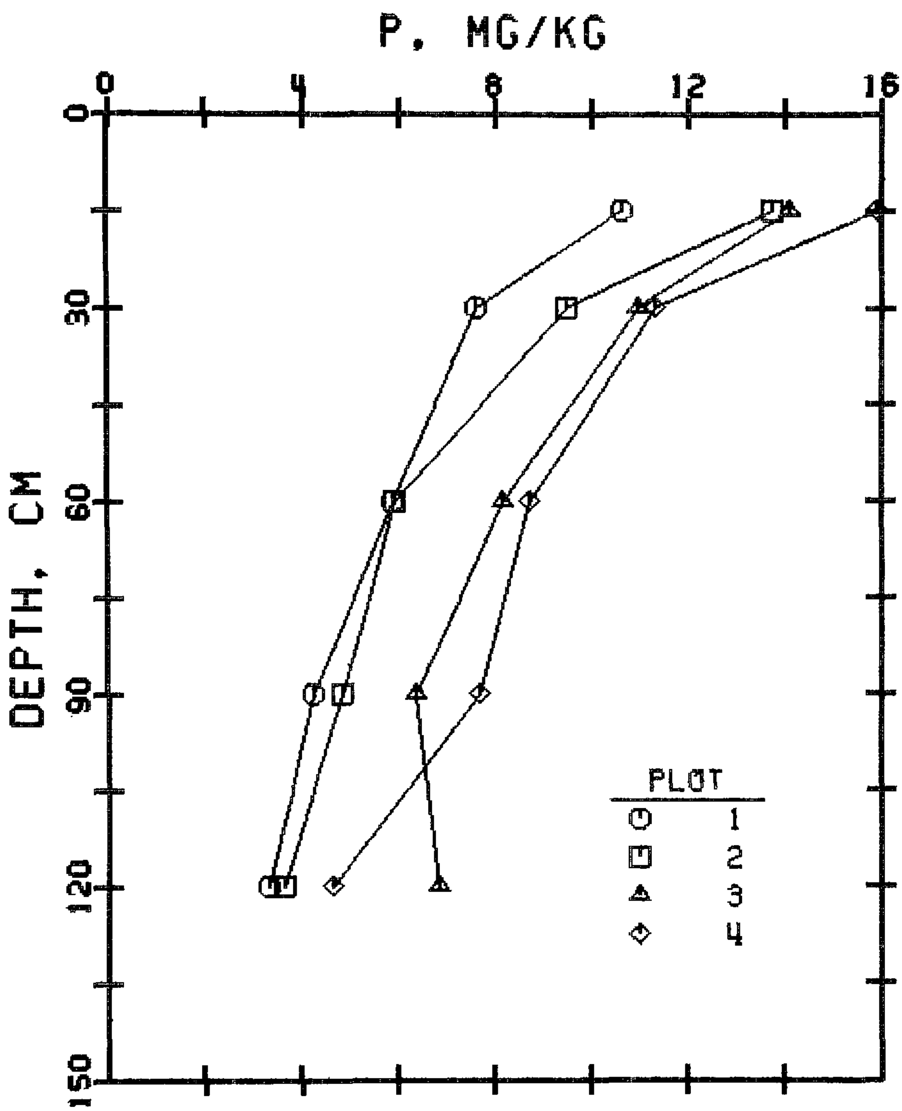

Figure 12. Distribution of extractable P in field plots.

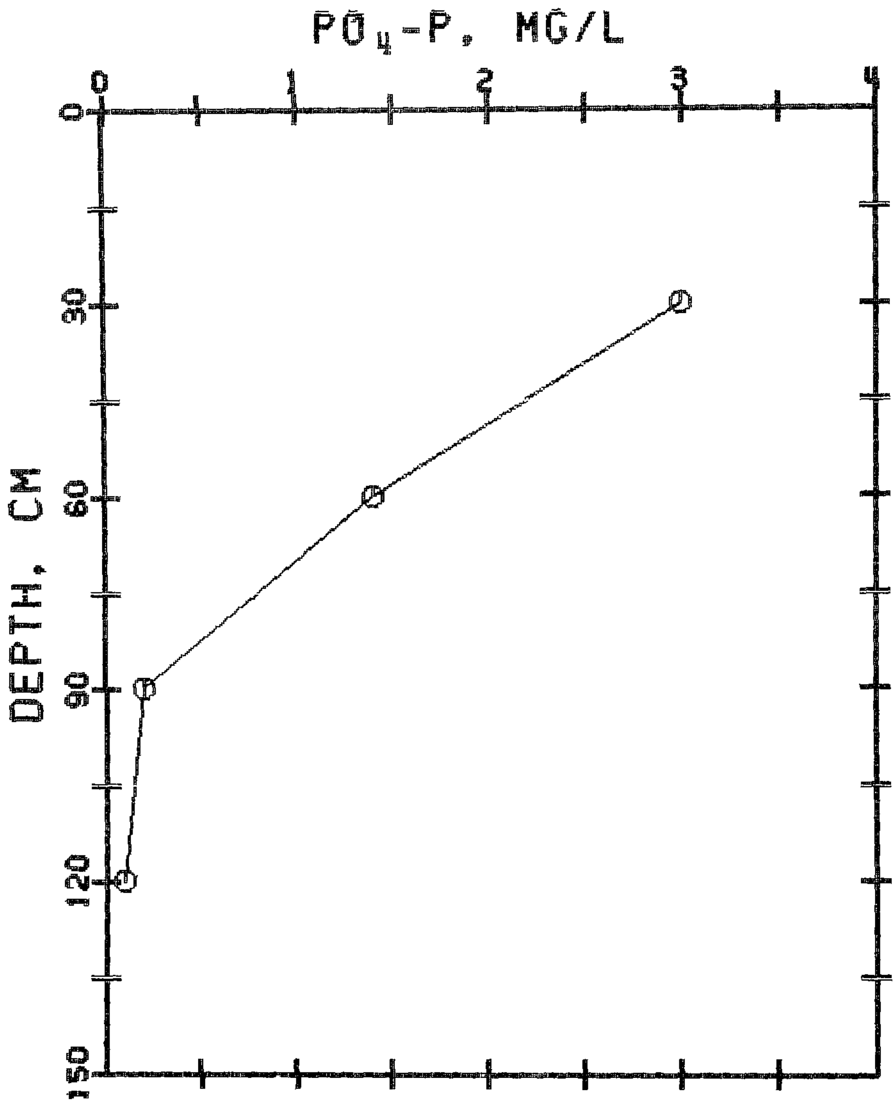

Figure 13. Distribution of solution P under steady irrigation.

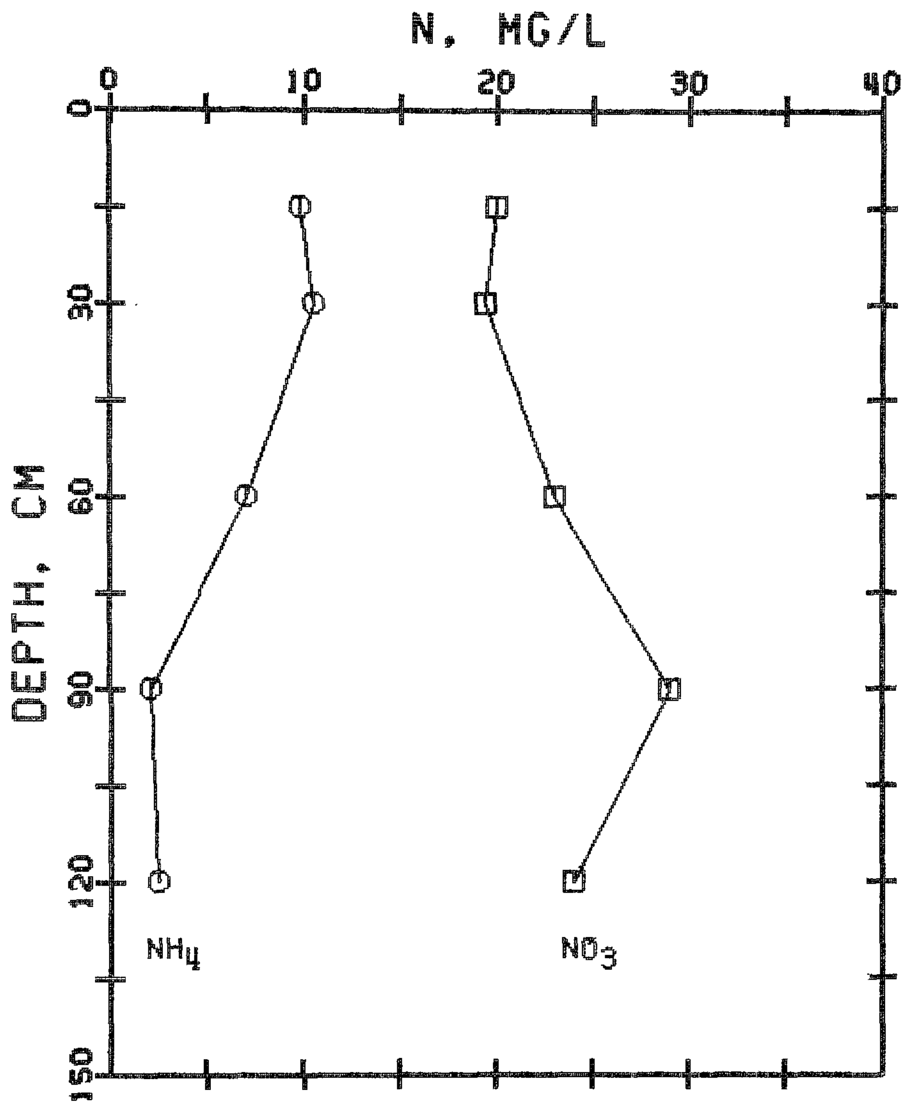

Figure 14. Distribution of NH4-N and NO_3-N under steady irrigation

(17.5 in.) in July 1975. The greatest amount in a single day was 14.73 cm (5.8 in.) in June 1975. Runoff was not a problem due to the high permeability of the sandy soil. Frequent afternoon showers during June-August did present some difficulty with harvests. In spite of rainfall and sizable irrigation levels, summer crops did show moisture stress at times due to the low water-holding capacity of the soil.

TABLE 16. CLIMATOLOGICAL DATA FOR TALLAHASSEE - 1971*

Year	Month	Temperature, °C Max	Avg Max	Avg	Avg Min	Min	Rain, cm Total	Greatest Day
1971	Jan	27	18	11	3	-12	7.72	3.38
	Feb	27	19	12	4	-10	13.92	5.72
	Mar	28	21	13	4	-5	12.23	3.33
	Apr	31	26	17	8	-2	4.70	1.85
	May	33	29	21	13	1	10.36	3.78
	June	37	33	26	19	14	18.90	5.26
	July	35	32	26	21	19	27.43	8.53
	Aug	34	32	27	21	19	27.31	4.39
	Sept	34	32	26	20	12	3.99	1.73
	Oct	34	29	22	15	5	8.79	5.84
	Nov	30	23	14	6	-3	2.24	1.19
	Dec	29	23	17	11	-1	10.44	4.65

Number of days with freezing - 39

* Source: National Atmospheric and Oceanic Administration.

TABLE 17. CLIMATOLOGICAL DATA FOR TALLAHASSEE - 1972*

Year	Month	Temperature, °C Max	Avg Max	Avg	Avg Min	Min	Rain, cm Total	Greatest Day
1972	Jan	28	21	15	9	-4	16.56	3.73
	Feb	27	18	12	6	-6	17.91	4.57
	Mar	29	24	16	7	-1	14.73	6.63
	Apr	33	28	20	12	3	1.40	0.66
	May	32	29	23	17	8	23.06	10.01
	June	37	32	26	19	9	28.27	14.73
	July	36	33	27	21	16	10.49	3.35
	Aug	38	34	28	22	19	13.28	4.04
	Sept	36	33	26	19	16	0.28	0.15
	Oct	32	28	21	14	6	4.45	2.95
	Nov	30	21	15	9	-4	25.04	10.59
	Dec	27	21	14	7	-3	12.32	7.75

Number of days with freezing - 23

* Source: National Atmospheric and Oceanic Administration.

TABLE 18. CLIMATOLOGICAL DATA FOR TALLAHASSEE - 1973*

Year	Month	Temperature, °C Max	Avg Max	Avg	Avg Min	Min	Rain, cm Total	Greatest Day
1973	Jan	27	18	11	4	-8	12.60	3.07
	Feb	24	18	11	3	-8	18.19	7.65
	Mar	29	24	18	12	0	34.47	8.74
	Apr	30	25	18	11	1	33.35	11.86
	May	35	29	22	16	4	21.29	7.62
	June	35	32	27	21	19	18.01	4.22
	July	35	34	28	23	20	11.20	2.21
	Aug	35	33	27	22	17	27.38	4.37
	Sept	34	32	27	22	18	13.46	4.29
	Oct	32	29	21	13	-1	5.97	3.12
	Nov	29	25	18	11	-1	8.15	4.95
	Dec	26	19	11	3	-8	18.95	4.62

Number of days with freezing - 32

* Source: National Atmospheric and Oceanic Administration.

TABLE 19. CLIMATOLOGICAL DATA FOR TALLAHASSEE - 1974*

Year	Month	Temperature, °C Max	Avg Max	Avg	Avg Min	Min	Rain, cm Total	Greatest Day
1974	Jan	27	24	19	14	6	8.53	3.15
	Feb	26	20	12	4	-8	7.29	4.24
	Mar	31	26	18	11	2	7.62	3.35
	Apr	29	26	18	11	1	10.13	5.46
	May	34	31	24	17	8	21.82	8.79
	June	34	32	26	19	14	9.75	3.23
	July	35	33	27	21	16	19.30	4.39
	Aug	34	32	27	22	21	23.83	7.75
	Sept	34	31	26	21	12	26.49	9.07
	Oct	30	27	18	10	5	2.36	2.36
	Nov	29	22	14	6	-4	4.17	2.03
	Dec	27	18	11	4	-7	9.65	3.76

Number of days with freezing - 31

* Source: National Atmospheric and Oceanic Administration.

TABLE 20. CLIMATOLOGICAL DATA FOR TALLAHASSEE - 1975*

Year	Month	Temperature, °C Max	Avg Max	Avg	Avg Min	Min	Rain, cm Total	Greatest Day
1975	Jan	27	19	13	6	-4	29.67	8.28
	Feb	27	21	14	7	-6	7.24	2.72
	Mar	28	22	16	9	-1	15.70	8.51
	Apr	33	26	19	11	0	18.21	7.52
	May	36	31	24	18	14	26.26	4.70
	June	34	32	27	21	17	12.12	5.46
	July	34	31	26	22	17	44.52	11.61
	Aug	36	33	27	22	21	17.27	4.83
	Sept	34	30	25	19	10	12.40	5.49
	Oct	31	27	21	15	4	11.20	8.15
	Nov	29	23	16	8	-3	3.81	2.51
	Dec	26	18	11	3	-6	19.89	8.92

Number of days with freezing - 38

* Source: National Atmospheric and Oceanic Administration.

TABLE 21. CLIMATOLOGICAL DATA FOR TALLAHASSEE - 1976*

Year	Month	Temperature, °C Max	Avg Max	Avg	Avg Min	Min	Rain, cm Total	Greatest Day
1976	Jan	24	17	8	1	-9	14.05	6.71
	Feb	28	23	14	5	-7	3.07	2.01
	Mar	29	24	17	10	0	13.46	5.38
	Apr	33	28	19	11	3	4.19	1.70
	May	31	29	22	16	8	29.62	7.67
	June	36	31	26	20	16	27.99	6.65
	July	38	34	28	22	20	10.64	3.10
	Aug	36	33	28	22	19	18.67	5.72
	Sept	34	31	25	19	13	7.09	3.45
	Oct	31	24	17	11	2	29.95	9.27
	Nov	25	19	12	5	-6	26.52	12.53
	Dec	25	17	10	3	-7	10.39	2.34

Number of days with freezing - 48

*Source: National Atmospheric and Oceanic Administration.

SECTION 6

CROP YIELDS AND GROWTH RESPONSE

INTRODUCTION

These studies focused on agronomic field crops; viz, forage and grain crops. Crops grown are listed in Table 22. Corn was grown for both silage and grain. All of these (except kenaf) are grown extensively in the United States, so that considerable experience is already available on their production and utilization. Also, data on growth and nutrient uptake is available from the literature, providing comparison between response to fertilization and response to effluent irrigation.

Limited studies were conducted on several species of trees to determine the response to effluent irrigation on well-drained soil.

TABLE 22. CROPS GROWN UNDER EFFLUENT IRRIGATION AT TALLAHASSEE, FLORIDA

Common Name	Scientific Name
	Summer Crops
Coastal bermudagrass	*Cynodon dactylon* (L.) Pers.
Pearl millet	*Pennisetum typhsides* (Burm.) Staph and E. C. Hubbard
Sorghum x sudangrass	*Sorghum vulgare* Pers. x *Sorghum sudanese* Stapf
Corn	*Zea Mays* L.
Kenaf	*Hybiscus cannabinus* L.
	Winter Crops
Rye	*Secale cereale*
Ryegrass	*Lolium multiflorum*

Effluent irrigation should be viewed in two ways: 1) wastewater renovation and 2) crop production. Viewed by the first, the nutrients of concern are nitrogen and phosphorus; by the second, major (N, P, K), minor (Ca, Mg, etc.) and micro (Fe, Zn, Cu, etc.) elements are all important. For example, removal of nitrogen from the wastewater by the crop depends upon crop vigor, which depends upon other elements (such as K). For this reason, wastewater and plant samples were analyzed for a variety of elements other than N and P.

Application levels of an element were estimated from average effluent concentration for the crop season, irrigation rate and irrigation period. The formula used was

$$A = 0.01\ CIT$$

where A = nutrient applied, kg/ha
C = concentration in effluent, mg/l
I = irrigation rate, mm/week
T = irrigation period, weeks

To aid in conversion between English and metric units, a table of conversion factors (Table 1) has been included in this report. For example, 1 kg/ha = 0.892 lb/acre; a value in lb/acre is 0.892 times the value in kg/ha.

Crop uptake of an element was estimated by

$$H = 0.1\ YDN$$

where H = nutrient harvested, kg/ha
Y = green yield, metric tons/ha
D = dry matter, %
N = nutrient composition, %

Crop recovery of an element was calculated from the definition of simple recovery as

$$R = \frac{H}{A} \times 100$$

where R is recovery efficiency in %. It should be noted that some investigators correct H for background uptake where no nutrient is applied, reflecting base fertility of the soil. For Lakeland fine sand base fertility is low, so that simple recovery is adequate. The significance of recovery efficiency should be properly understood -- it indicates that capacity of the crop to capture the particular element under the prevailing environmental conditions, and reflects crop/soil/environmental interactions. It does not provide a mass balance for the element, since no indication of storage (roots, soil, organisms), leaching to groundwater, or gaseous losses are provided.

Net values for dry matter content and nutrient content were calculated as weighted averages by the formula

$$V_{avg} = \sum_{n=1}^{N} V_n W_n / W$$

where V_{avg} = weighted average value, %

V_n = value for nth harvest, %

W_n = dry weight for nth harvest, mton/ha

W = total dry weight for all harvests, mton/ha

CROP YIELDS AND NUTRIENT RECOVERY

Results are presented in this section on crop production under wastewater irrigation on Lakeland fine sand. Measurements were made of green weight, dry matter composition and nutrient composition for the various field crops. Estimates were then made of dry yields, nutrient uptake and recovery efficiencies. The approach was to use several crops under various irrigation rates to identify suitable crops and to bracket the loading rates. It is important in fertility studies to have enough treatment levels (minimum of three) to be able to estimate the response curve, either yield vs rate or nutrient vs rate. Such curves approximate a curve of diminishing returns, exhibiting an asymptotic approach to a maximum. Data presented here follows that general trend.

Availability of equipment and personnel for the project favored treatment levels over replication. All harvesting operations utilized an available commercial forage harvester (rather than a plot harvester) with a work force of no more than two persons. In most cases, four irrigation rates were used. Irrigation sprinklers were located on 30 m x 30 m (100 ft x 100 ft) spacing. Irrigation intensity was 13 mm/hr (0.50 in./hr).

Throughout the experiments no commercial fertilizer, herbicides or pesticides were used. Limited cultivation of crops was practiced for weed control. In some cases, weed infestation did present a problem.

In this section summaries of yield, nutrient uptake and nutrient recovery are presented for the crops listed in Table 22. These response curves were estimated for each crop from the basic data compiled in Appendix A. In Appendix A data are presented by years due to commonality of effluent characteristics and cultural practices. In this report mton is used to denote metric tons, to minimize confusion. Cultural practices and analytical procedures are included in Appendix A, also.

Coastal Bermudagrass

Estimates of yields and nutrient uptake for coastal bermudagrass are shown in Figures 15-23. All of the curves exhibit the asymptotic response which is typical of fertility studies. Dry matter content averaged about 28% in the green forage. Values for dry matter yield (Figure 15) agreed closely with fertility studies by Burton et al. (1963). Estimates of N uptake (Figure 16) also increased with application as reported by Burton et al. (1963), showing close agreement at lower rates and slightly below their values at higher application rates. It should be noted that application rates were for the growing season (approximately 6 months) rather than for the year. Recovery efficiency followed a curve of diminshing returns, dropping from 85%

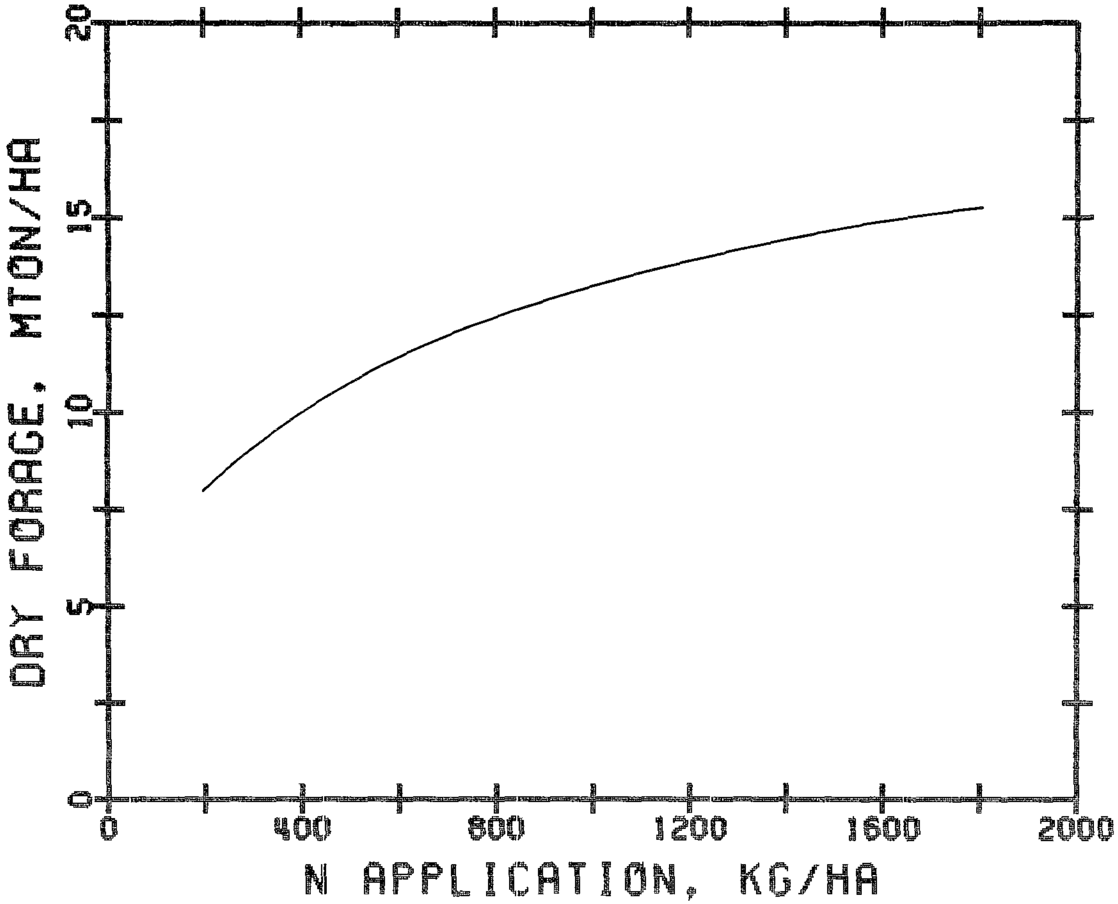

Figure 15. Estimated yield response of coastal bermudagrass.

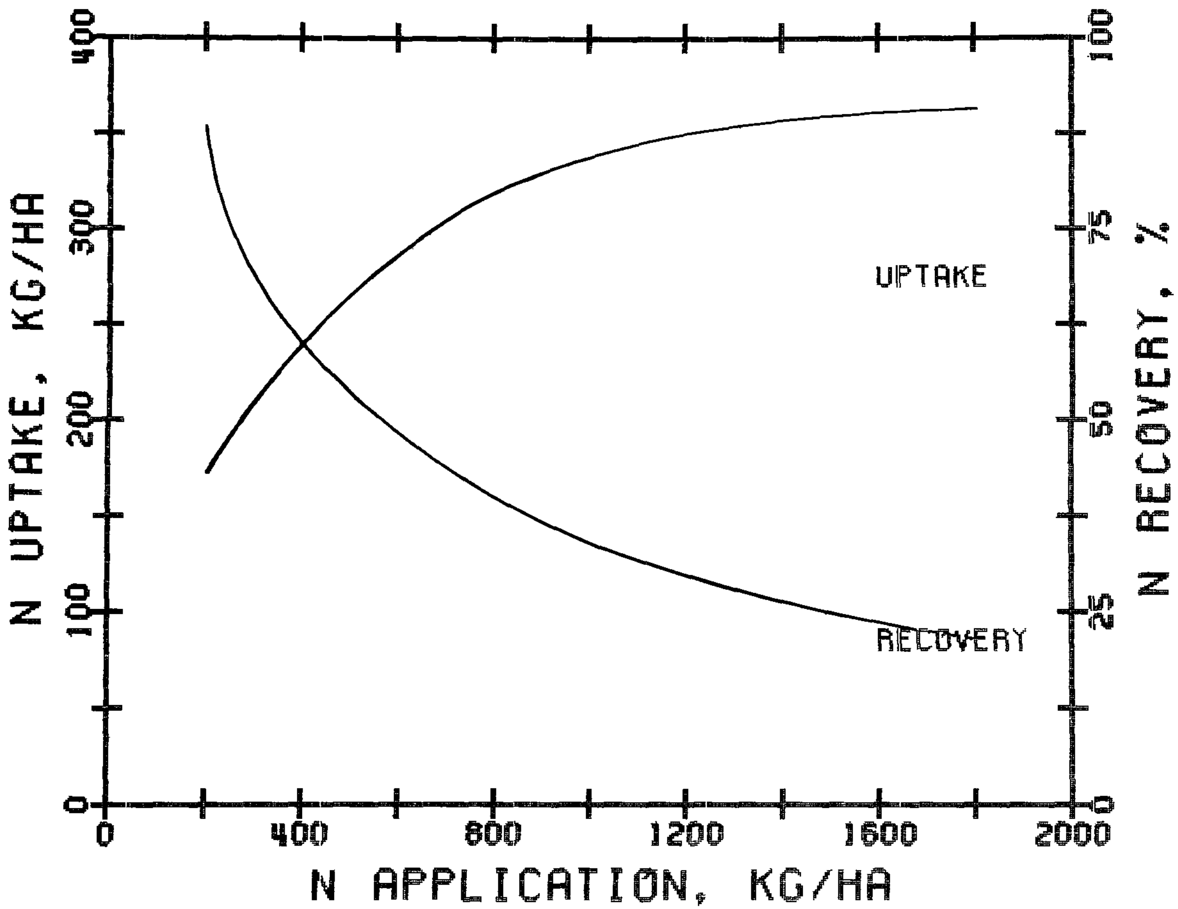

Figure 16. Estimated nitrogen recovery by coastal bermudagrass.

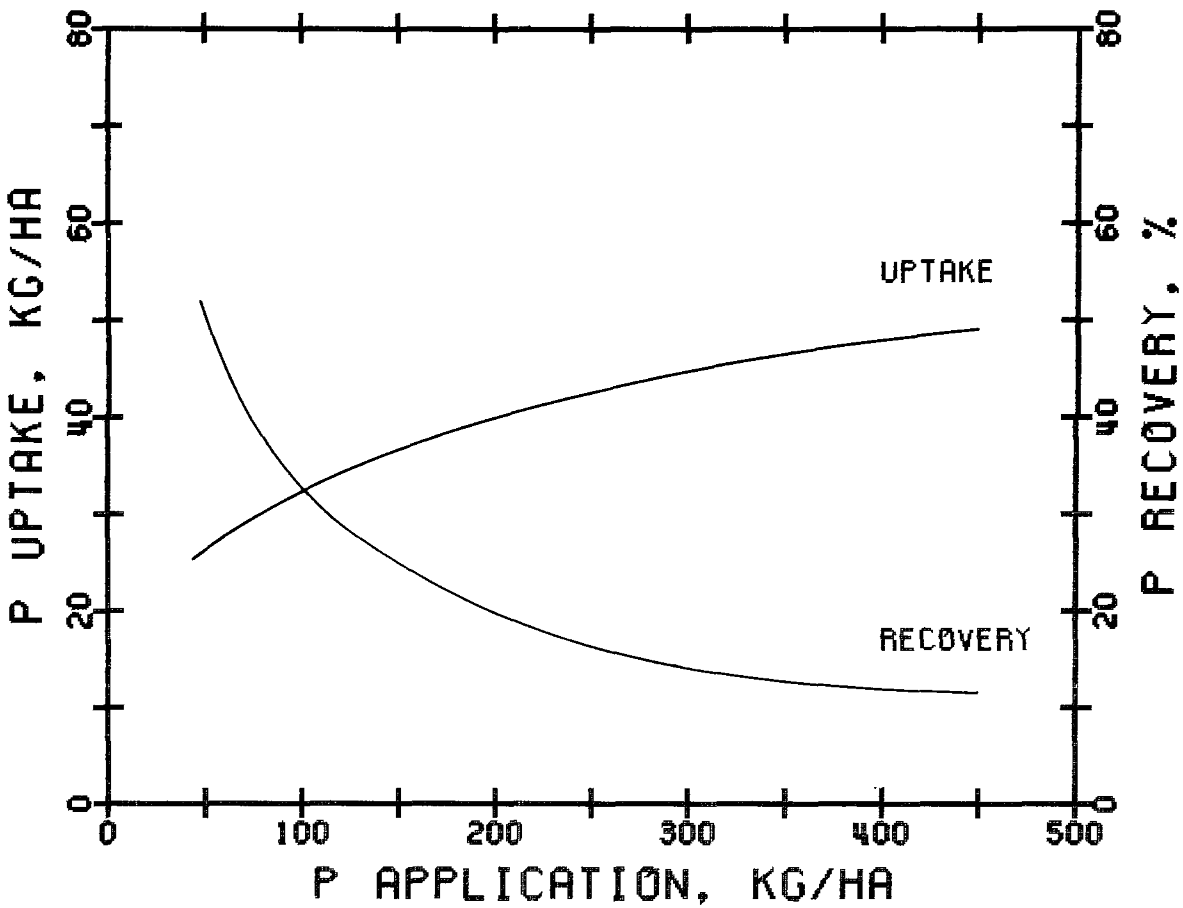

Figure 17. Estimated phosphorus recovery by coastal bermudagrass.

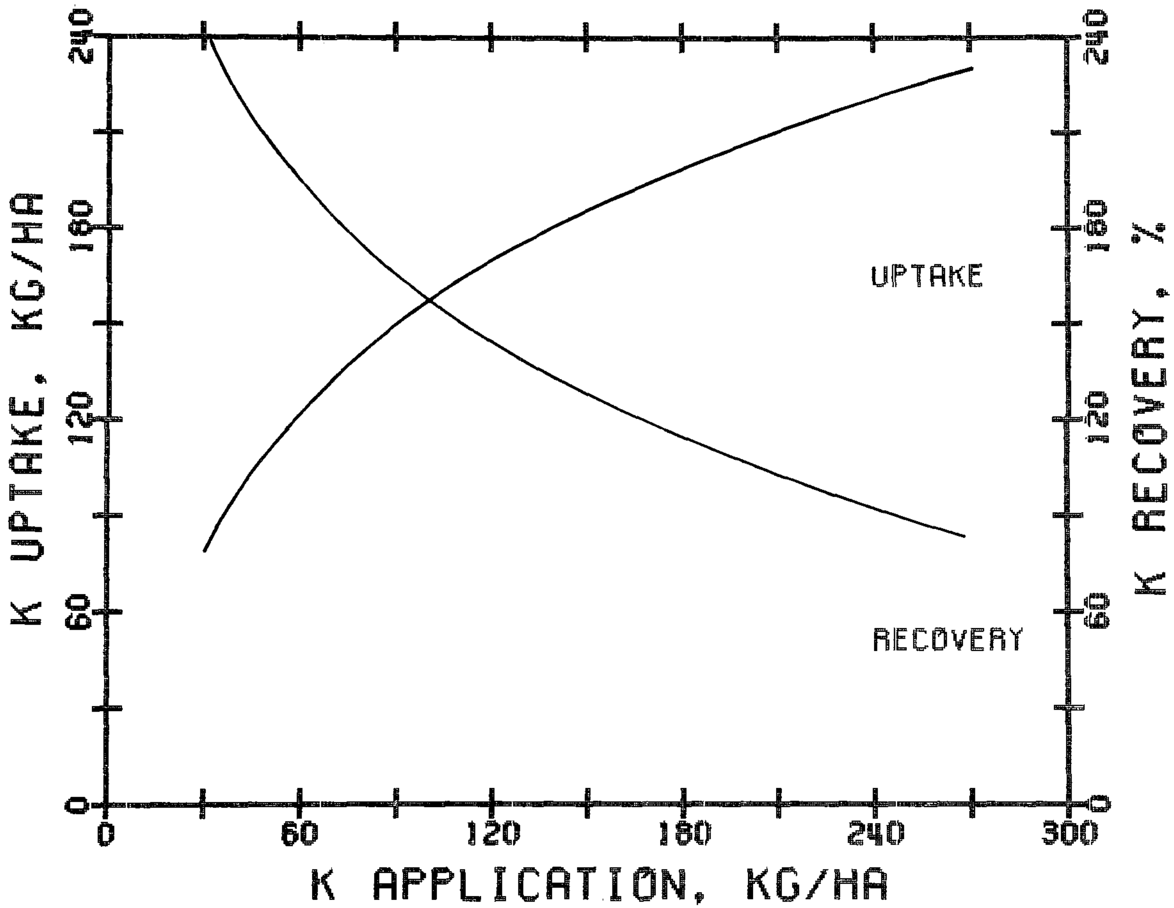

Figure 18. Estimated potassium recovery by coastal bermudagrass.

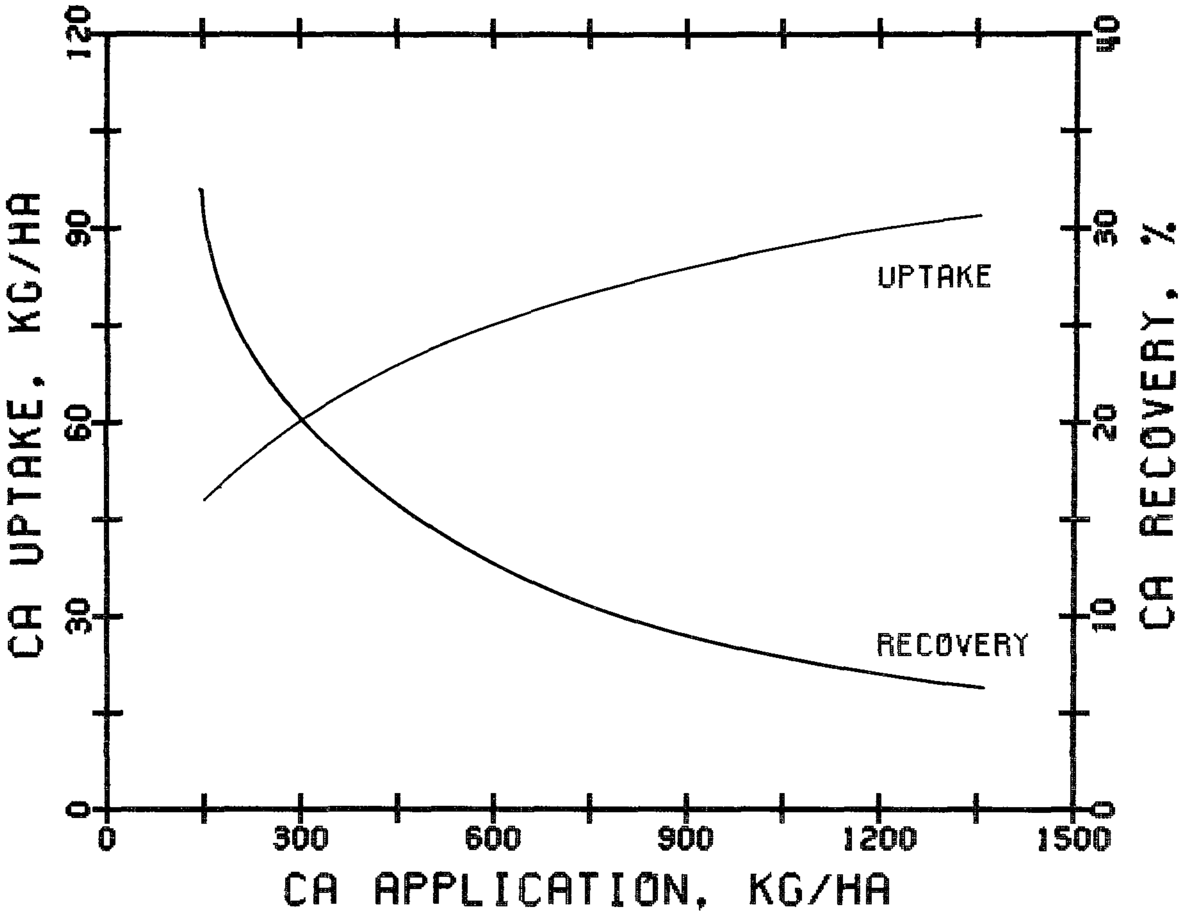

Figure 19. Estimated calcium recovery by coastal bermudagrass.

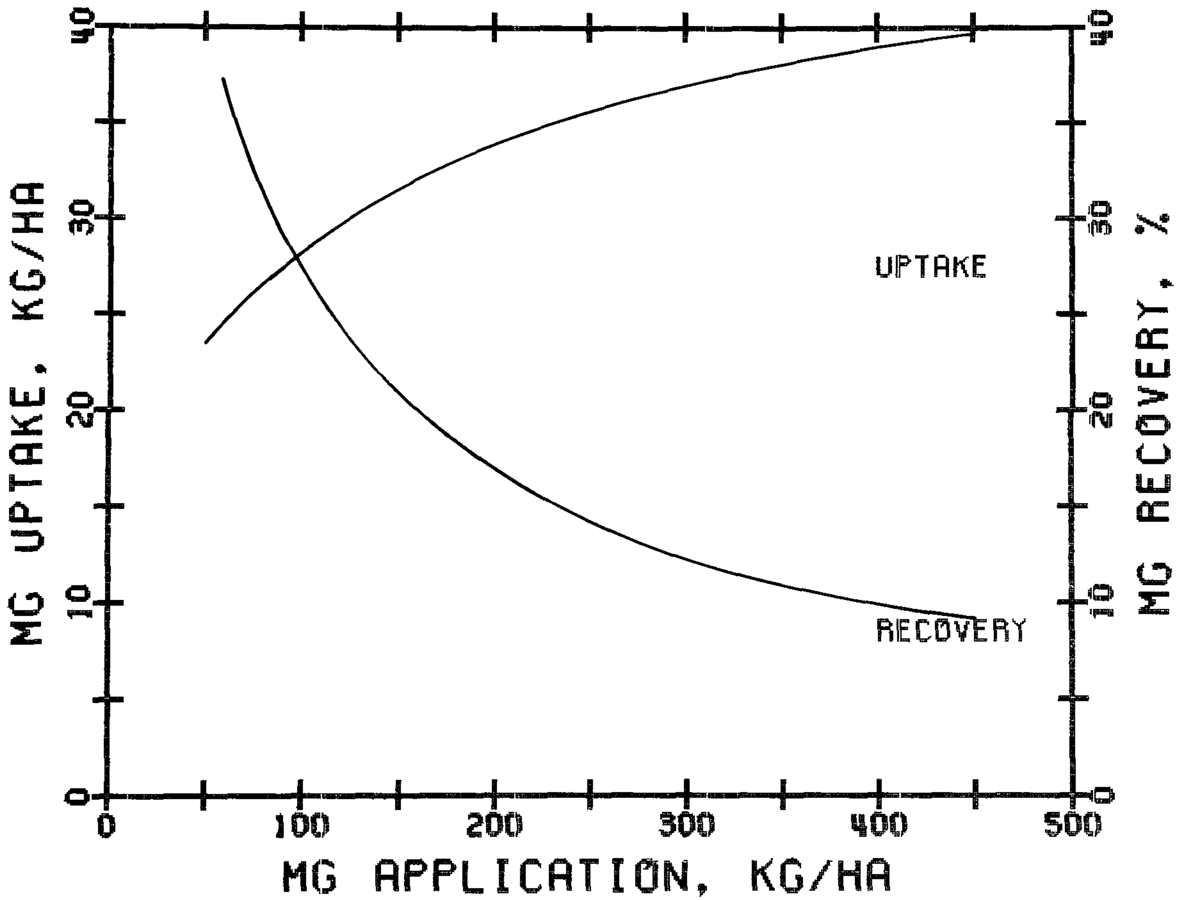

Figure 20. Estimated magnesium recovery by coastal bermudagrass.

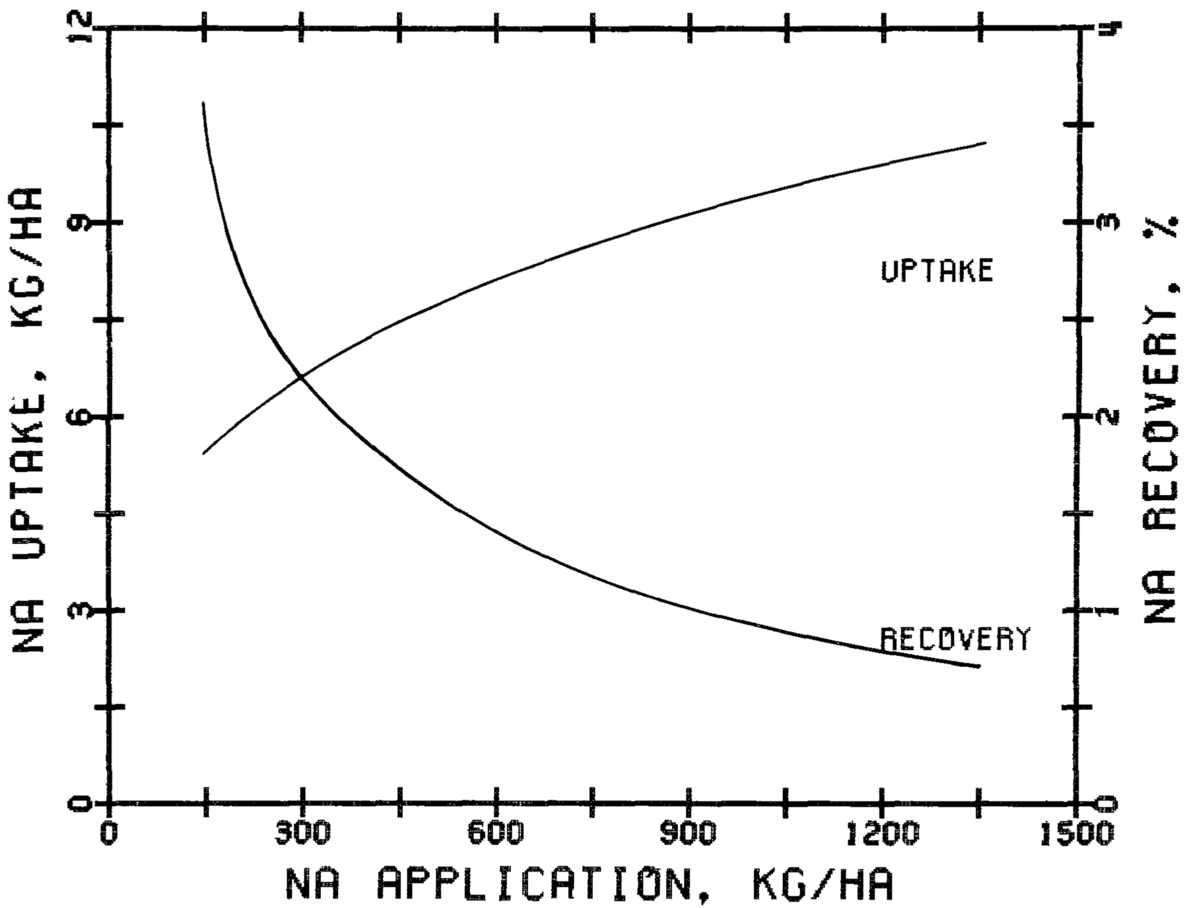

Figure 21. Estimated sodium recovery by coastal bermudagrass.

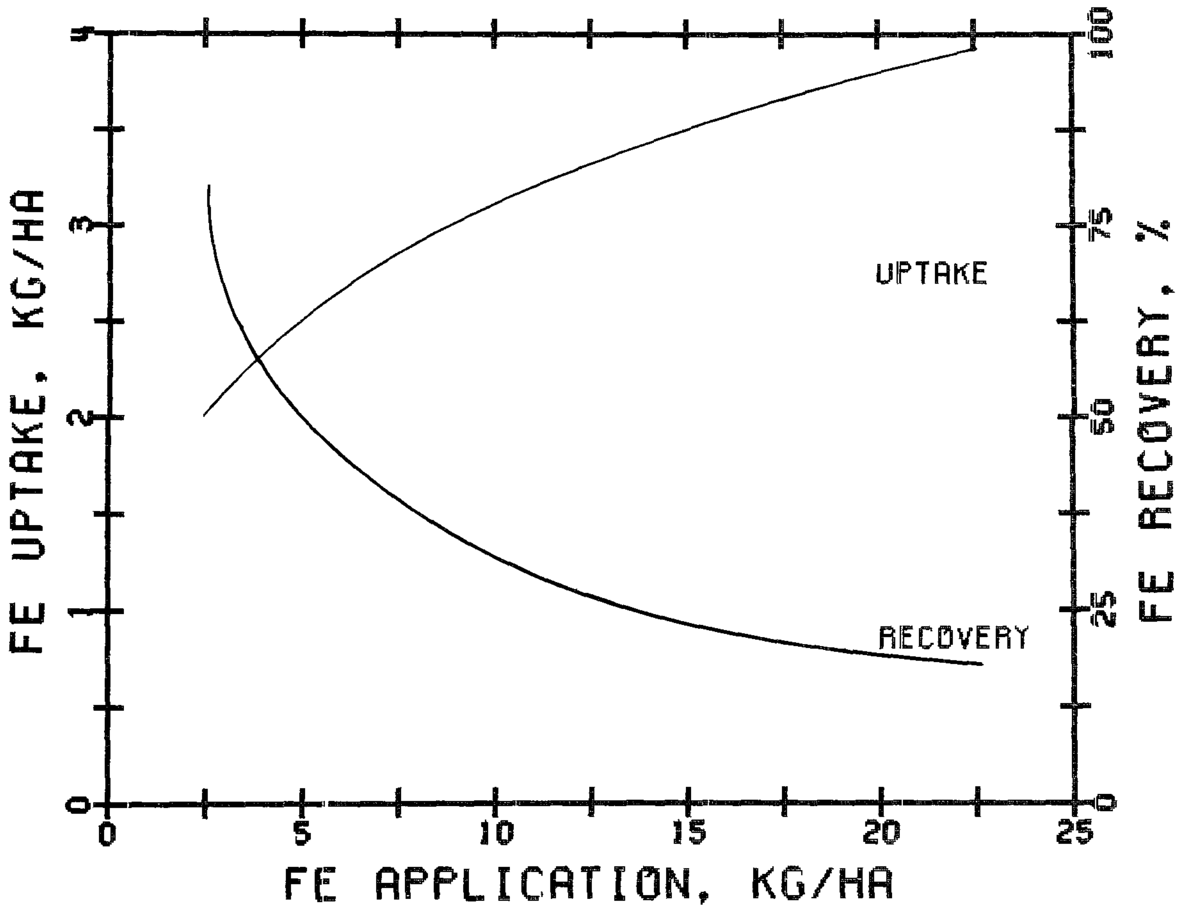

Figure 22. Estimated iron recovery by coastal bermudagrass.

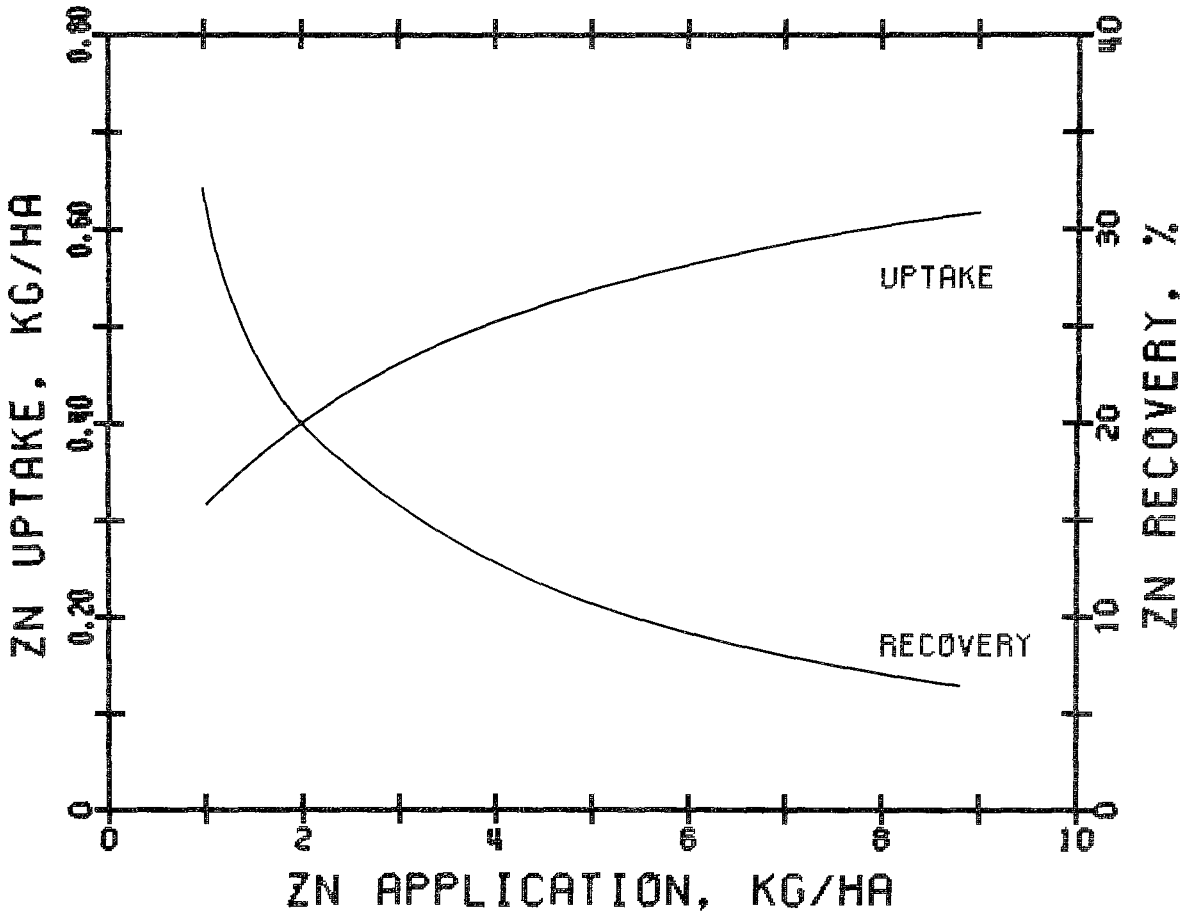

Figure 23. Estimated zinc recovery by coastal bermudagrass.

at 200 kg/ha to 60% at 400 kg/ha. The response curve of P (Figure 17) also showed asymptotic response. These values agreed closely with those of Adams et al. (1967). Although P recovery by the crop was low, losses of P were minimal since this soil had a high capacity to retain P (Overman, et al., (1976). Results indicated that coastal bermudagrass showed strong response to K (Figure 18). For application rates below 200 kg/ha, K uptake exceeded application, suggesting possible need for supplemental K. Results from fertility studies (Adams et al., 1967 and Woodhouse, 1968) agreed with these estimates, and also showed uptake in excess of application.

Uptake of other elements by coastal bermudagrass is shown in Figures 19-23. These may aid in estimating the mineral and trace element composition of the forage for animal feed.

Under conditions of adequate moisture and nutrients, coastal bermudagrass should be harvested 5 or 6 times during the warm season. From Figure 15, for an N application of 400 kg/ha (360 lb/acre) the estimated yield of dry forage was 10 mtons/ha (4.5 tons/acre). For hay production (65% dry matter) this represented 15 mtons/ha (7.0 tons/acre), while greenchop (28% dry matter) was 36 mtons/ha (16 tons/acre).

Sorghum x Sudangrass

A strong response to nutrient application occurred for sorghum x sudangrass (Figures 24-32). The yield curve (Figure 24) agreed fairly closely with fertility studies in Gainesville, Florida, with this variety (Agronomy Mimeo Report, 1971), where 228 kg/ha applied N produced 9.3 mton/ha of dry forage. Nitrogen content (approximately 1.75%) agreed with the range of values from experiments in Alabama (Hoveland et al., 1967), and were somewhat below the 2.5% from Reulke and Prine (1974) in Florida using more frequent harvest than in the present study.

Uptake of K by sorghum x sudangrass (Figure 27) exceeded application below 120 kg/ha. This indicated potential K deficiency with effluent irrigation and possible need for supplemental K. Other elements were supplied in adequate quantities since recoveries were below 100% (Figures 28-32).

With adequate moisture and nutrients, sorghum x sudangrass should be harvested about 3 times during the season. Estimated yields of dry forage from Figure 24 were 10 mtons/ha (4.5 tons/acre) at 400 kg/ha (360 lb/acre) applied N. Corresponding yields of green chop (19% dry matter) were 53 mtons/ha (23 tons/acre).

Pearl Millet

Pearl Millet showed a strong response to applications of nutrients (Figures 33-41). Estimated yields (Figure 33) agreed well with those from Florida (Agronomy Mimeo Report, 1971) and from Georgia (Hart and Burton, 1965.) Nitrogen uptake rose rapidly with increases in applied N (Figure 34), while recovery dropped sharply from approximately 50% at 200 kg/ha of N. These values of uptake by pearl millet were somewhat below those of Hart and Burton (1965), primarily due to a harvest frequency of roughly 8 weeks in the

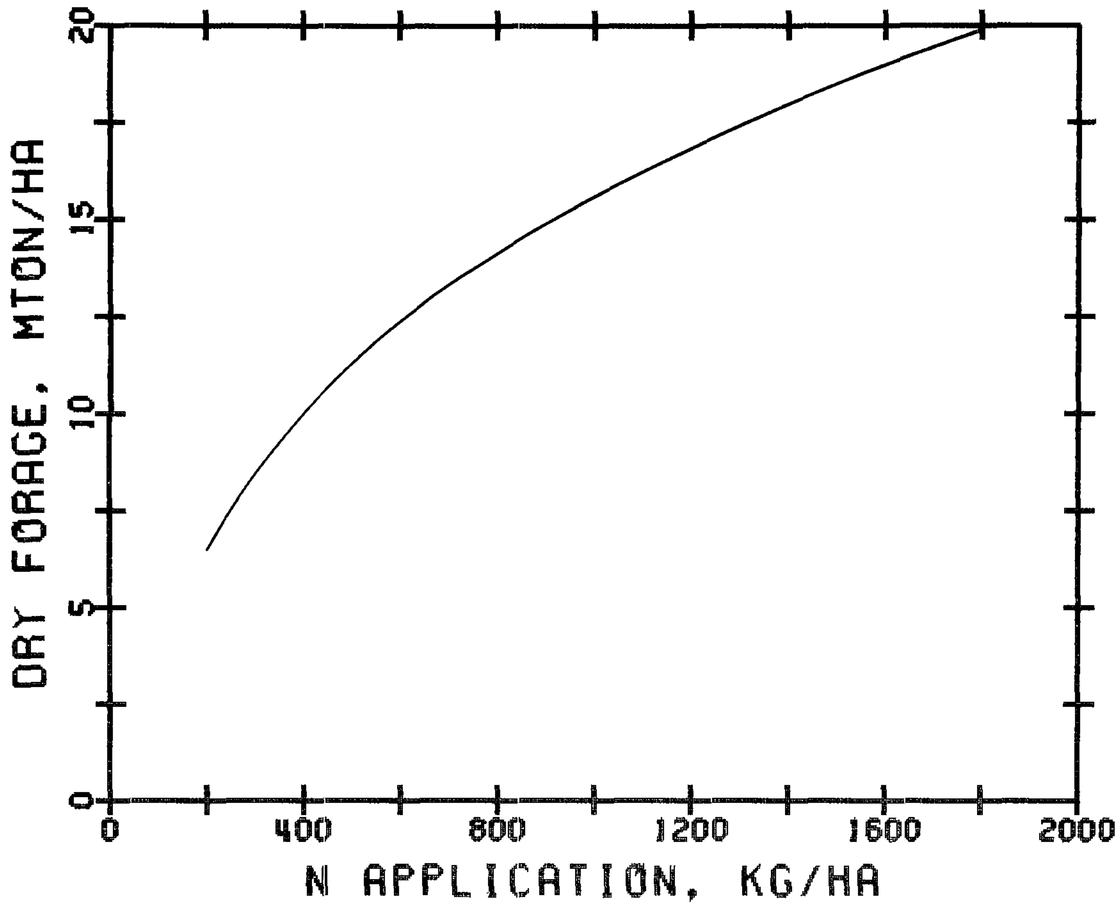

Figure 24. Estimated yield response of sorghum x sudangrass.

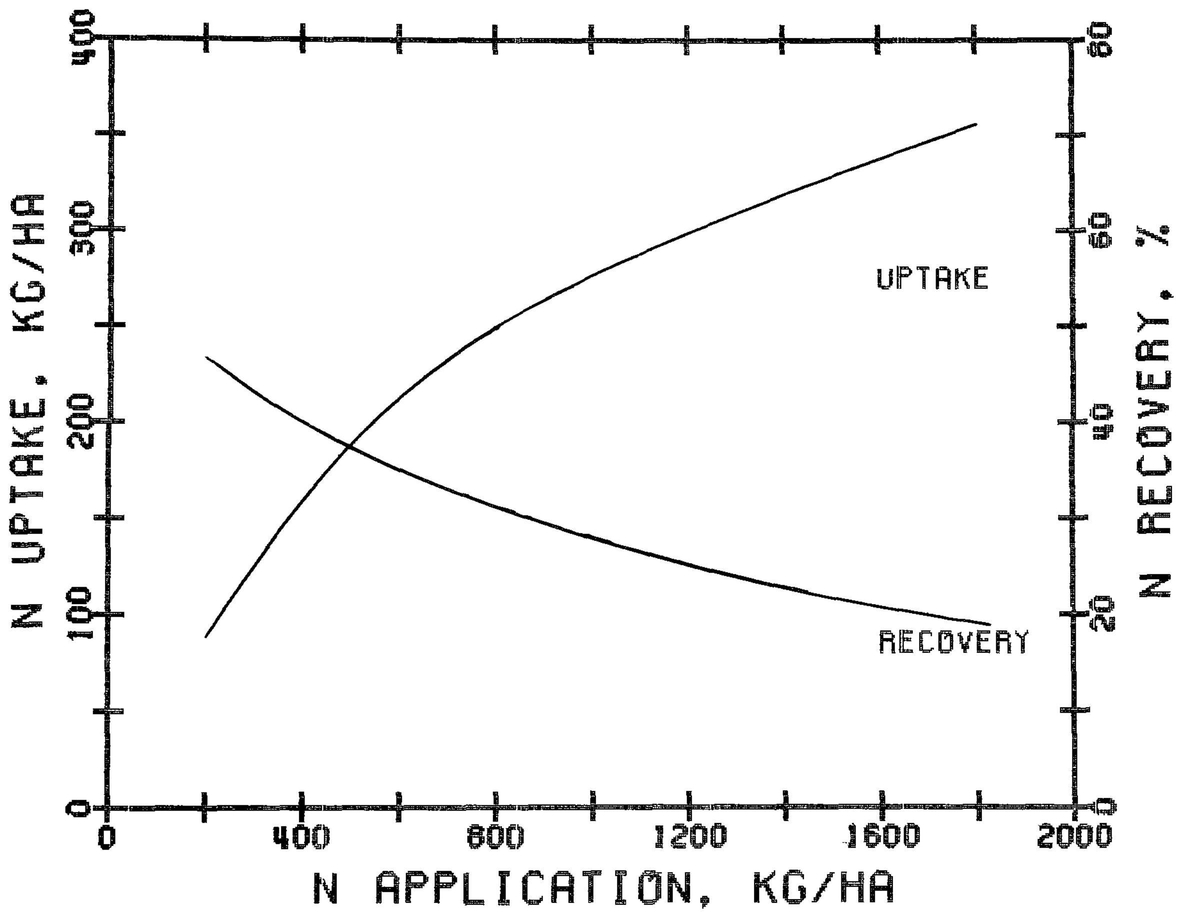

Figure 25. Estimated nitrogen recovery by sorghum x sudangrass.

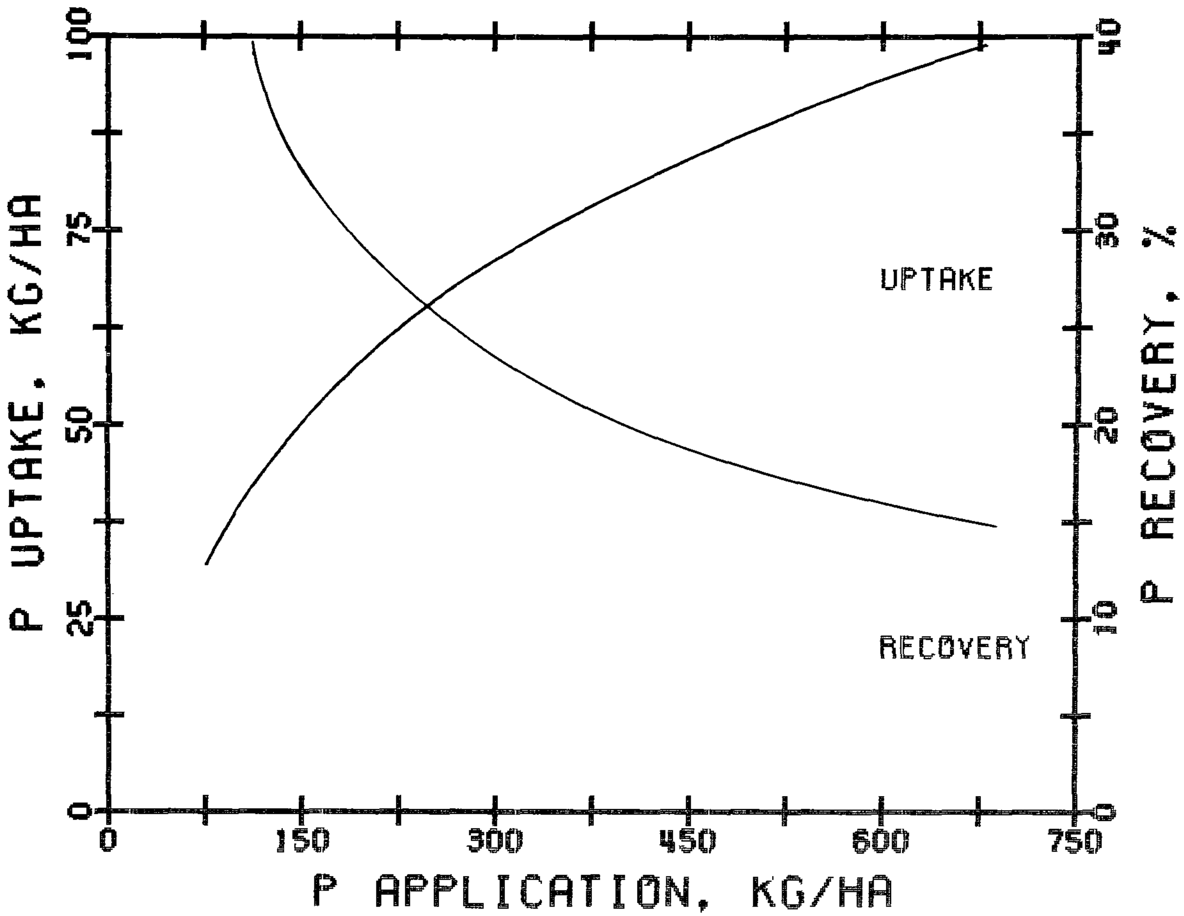

Figure 26. Estimated phosphorus recovery by sorghum x sudangrass.

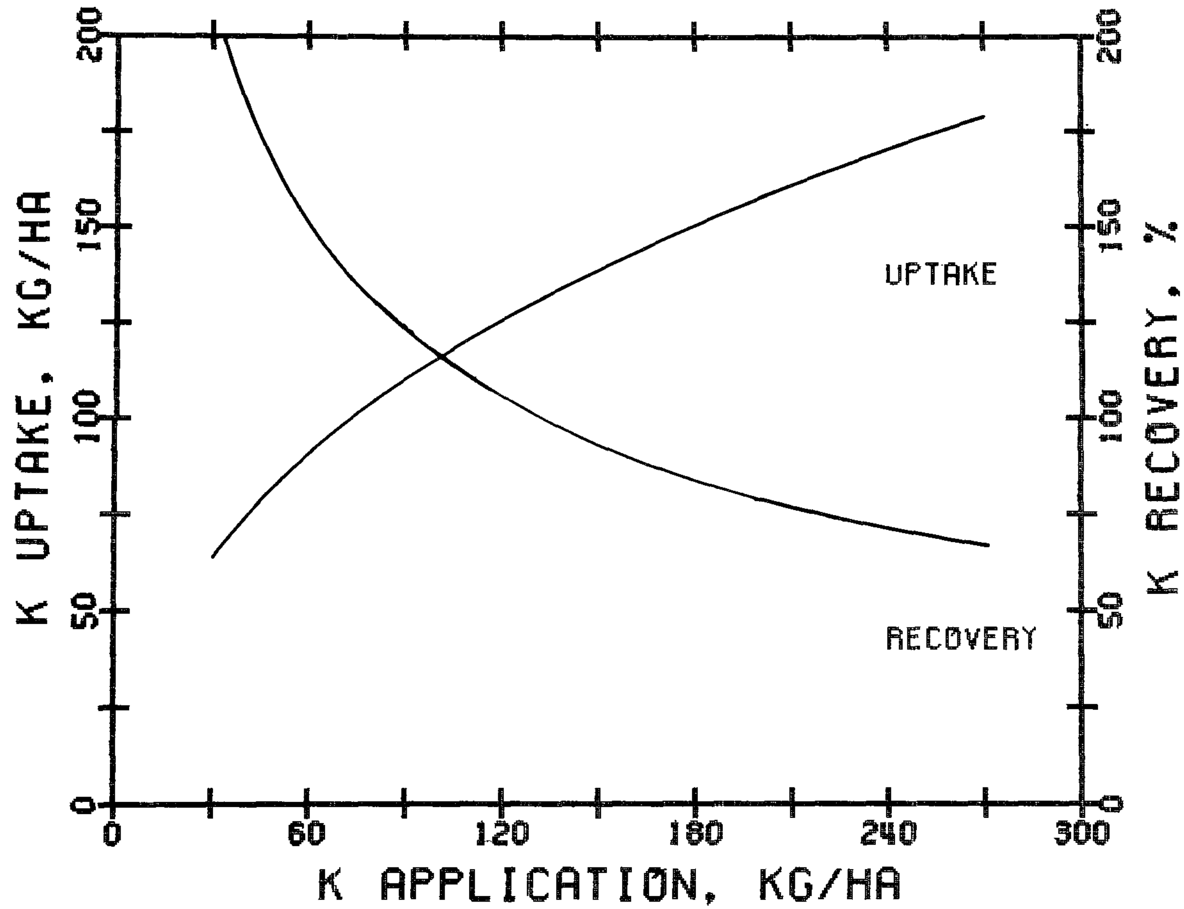

Figure 27. Estimated potassium recovery by sorghum x sudangrass.

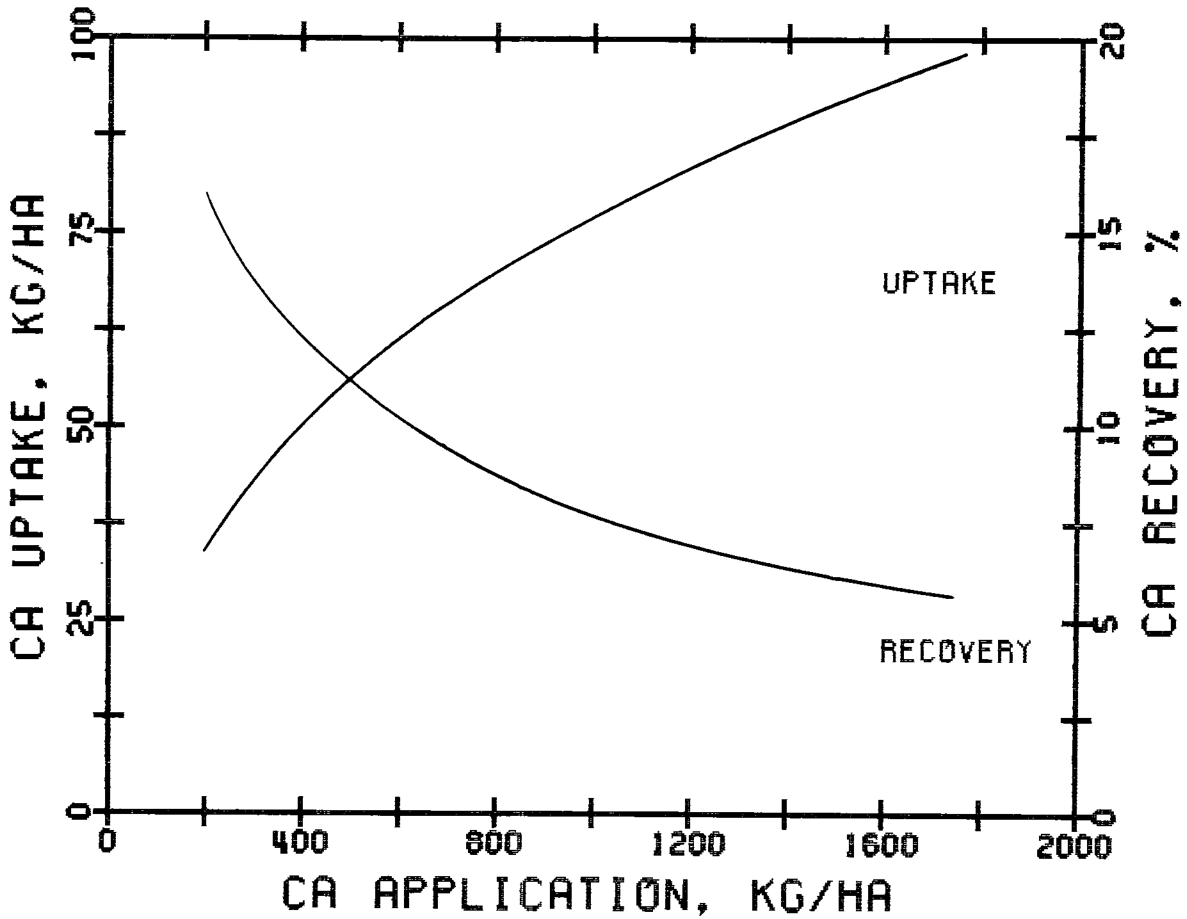

Figure 28. Estimated calcium recovery by sorghum x sudangrass.

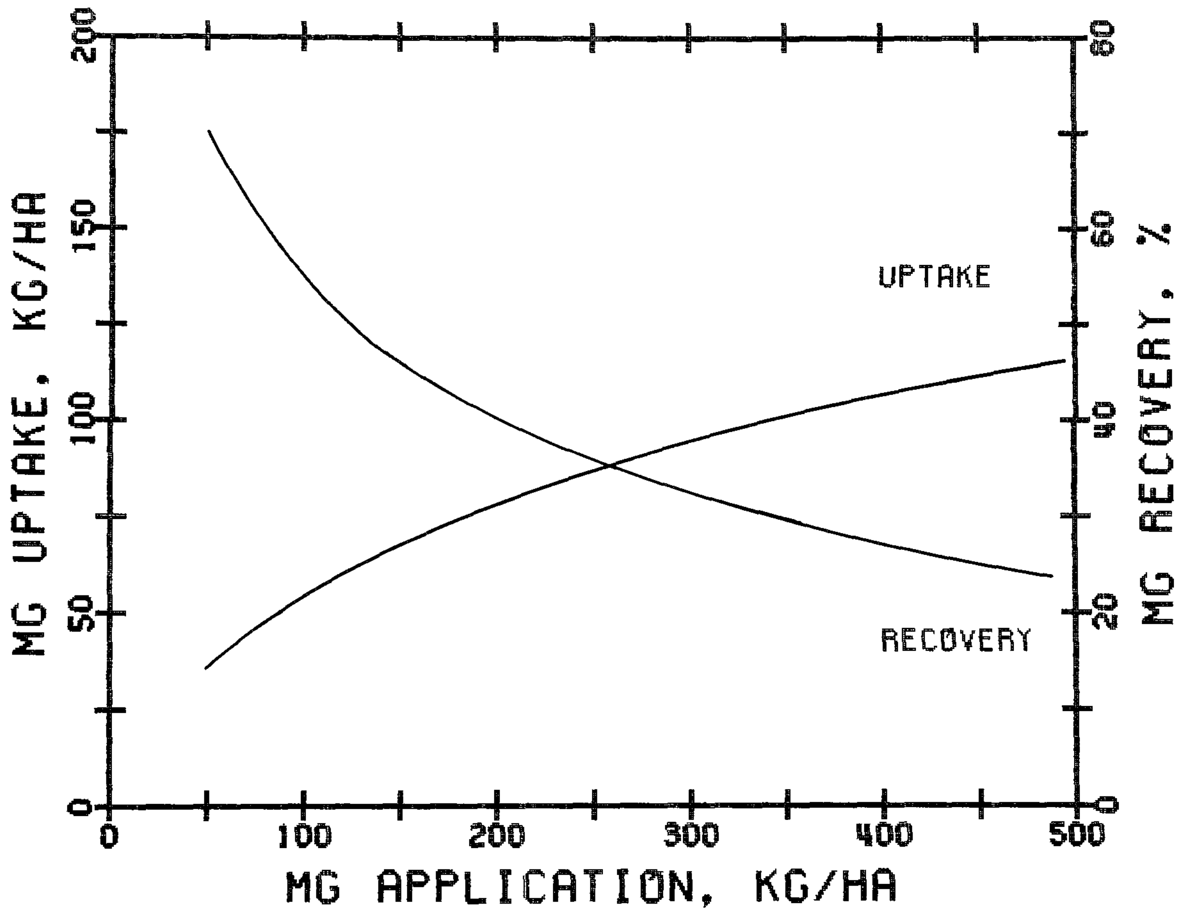

Figure 29. Estimated magnesium recovery by sorghum x sudangrass.

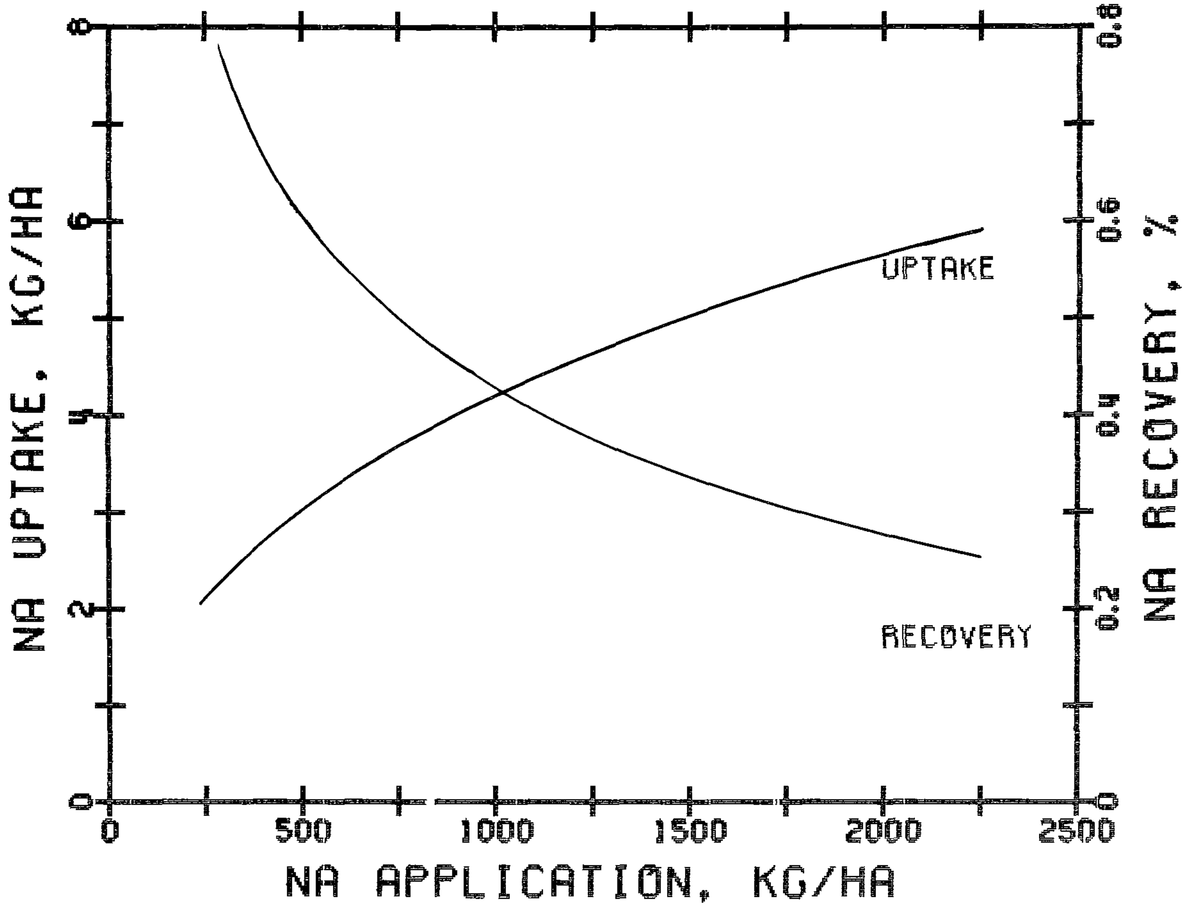

Figure 30. Estimated sodium recovery by sorghum x sudangrass.

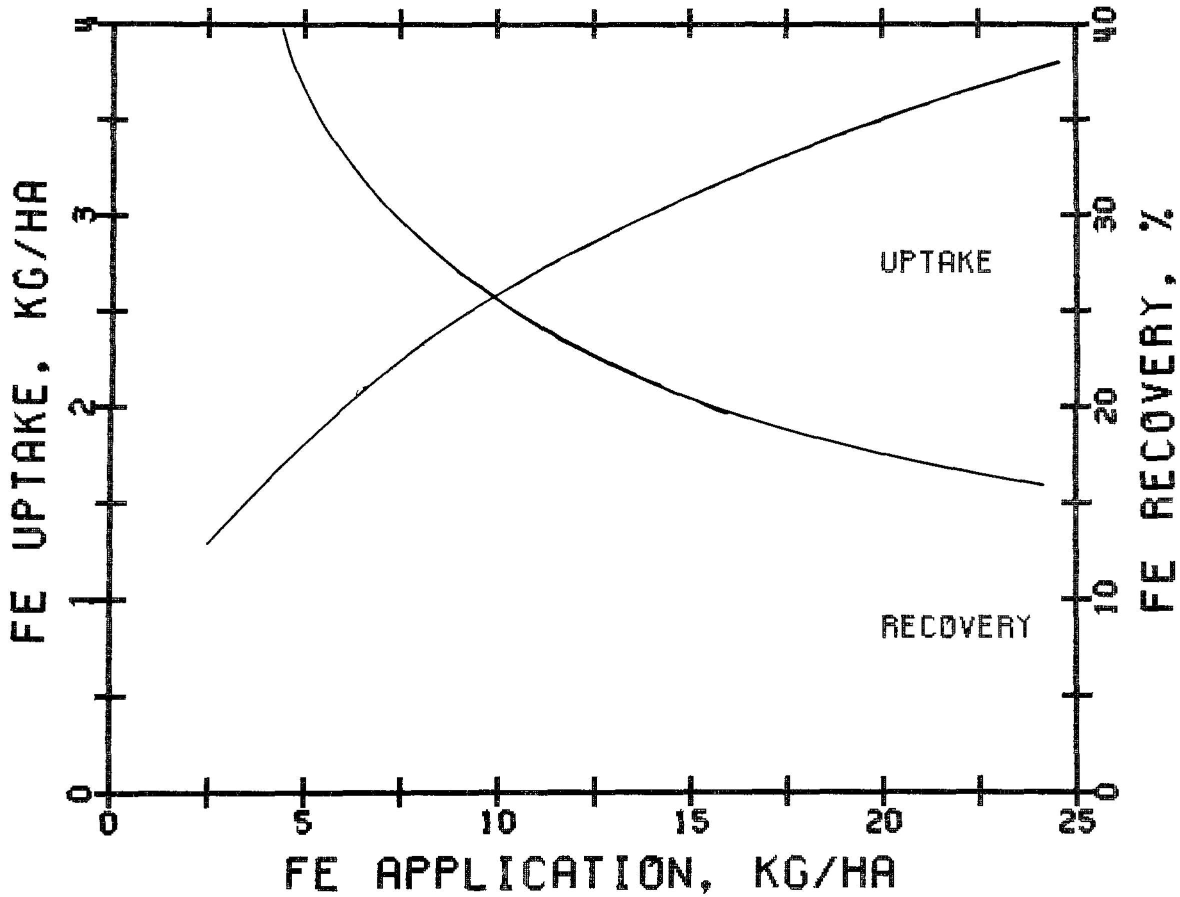

Figure 31. Estimated iron recovery by sorghum x sudangrass.

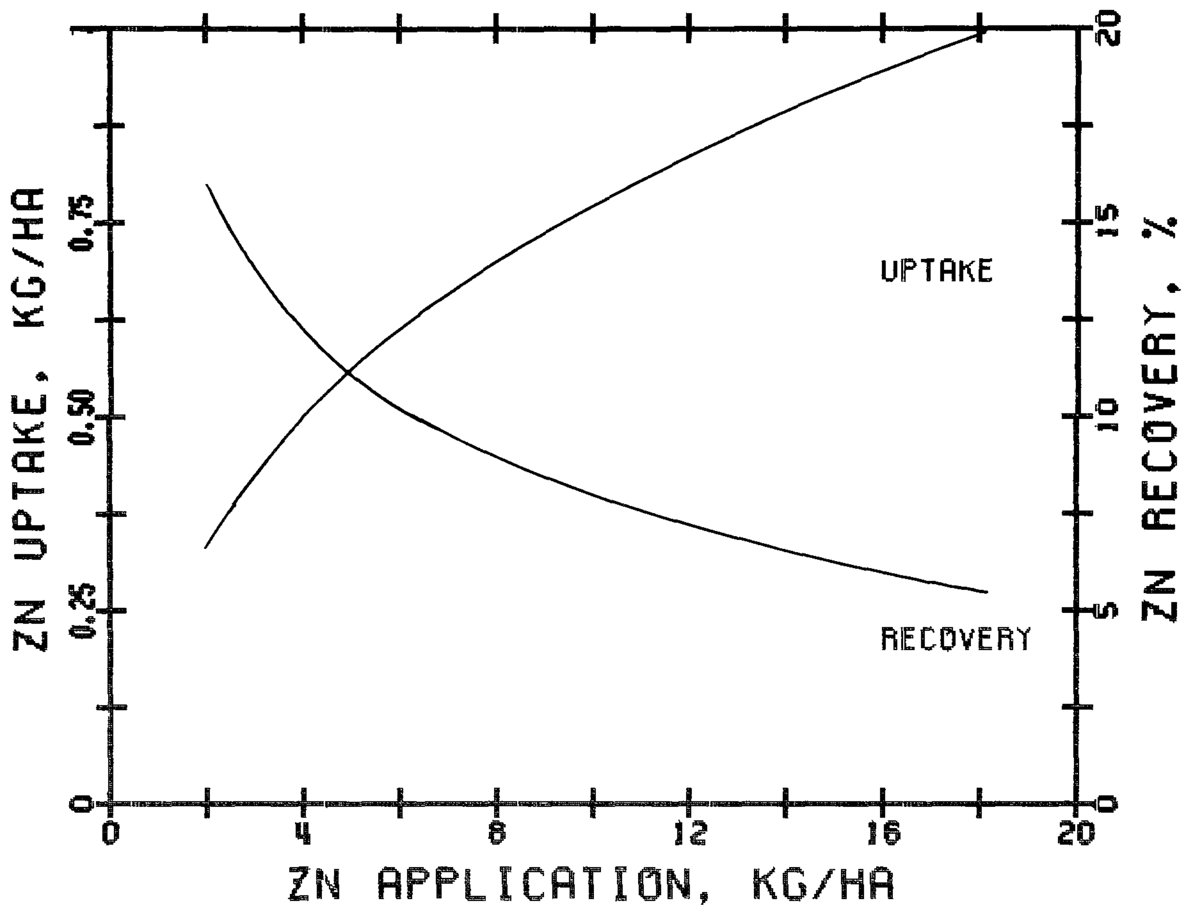

Figure 32. Estimated zinc recovery by sorghum x sudangrass.

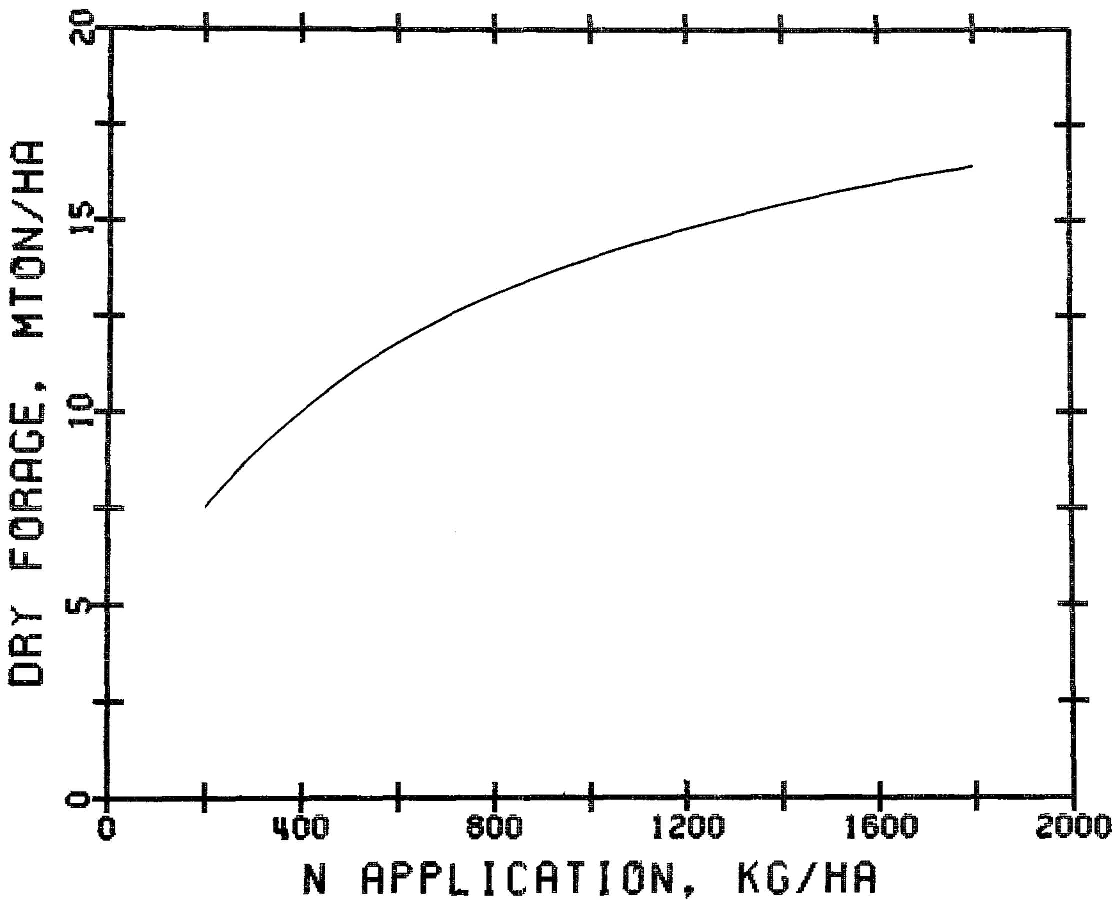

Figure 33. Estimated yield response of pearl millet.

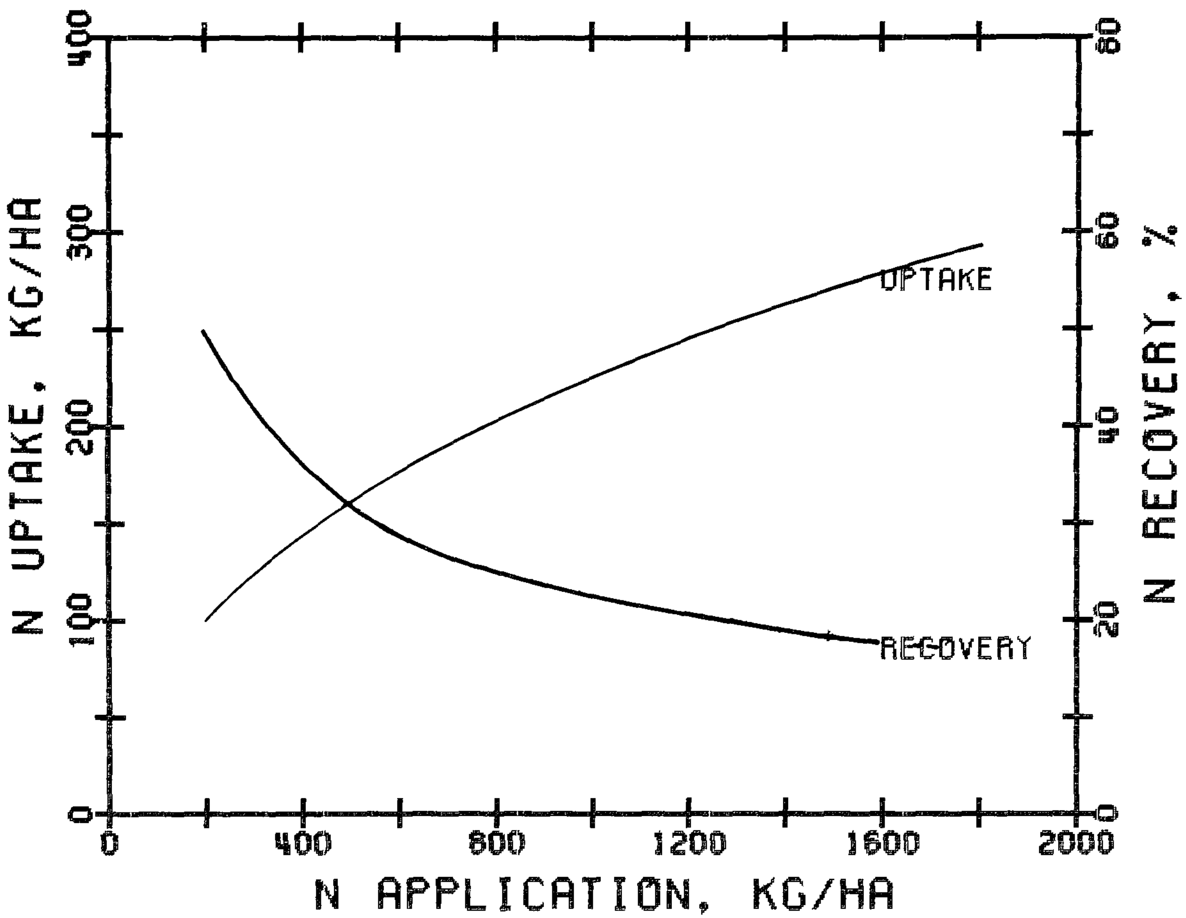

Figure 34. Estimated nitrogen recovery by pearl millet.

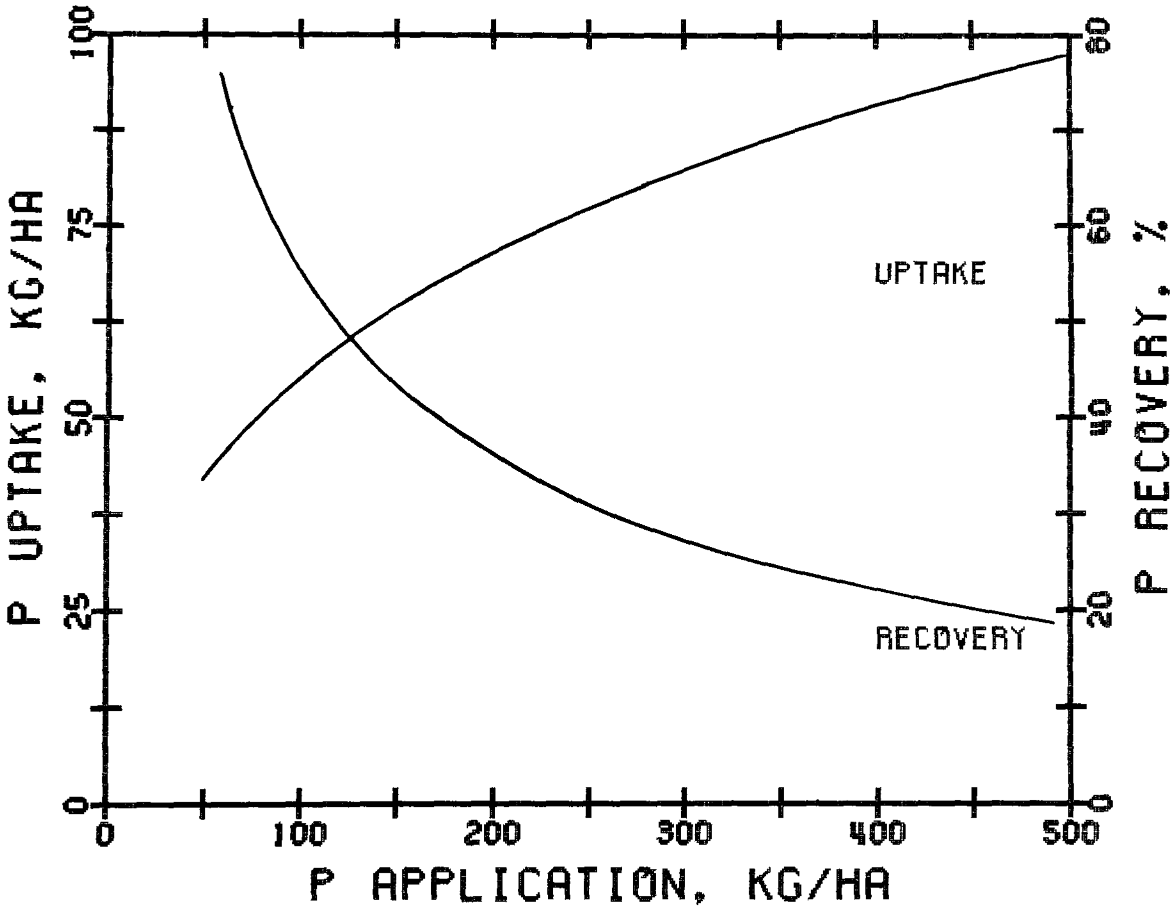

Figure 35. Estimated phosphorus recovery by pearl millet.

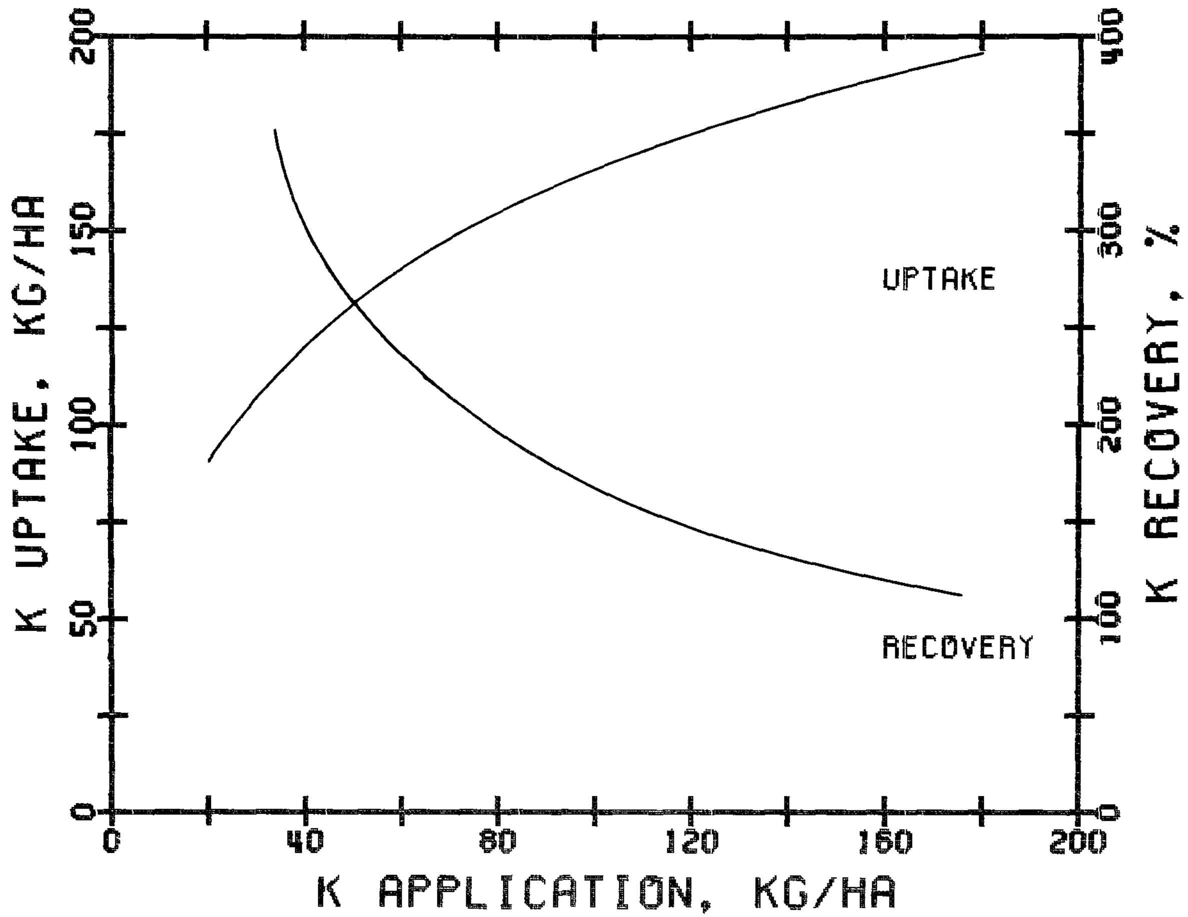

Figure 36. Estimated potassium recovery by pearl millet.

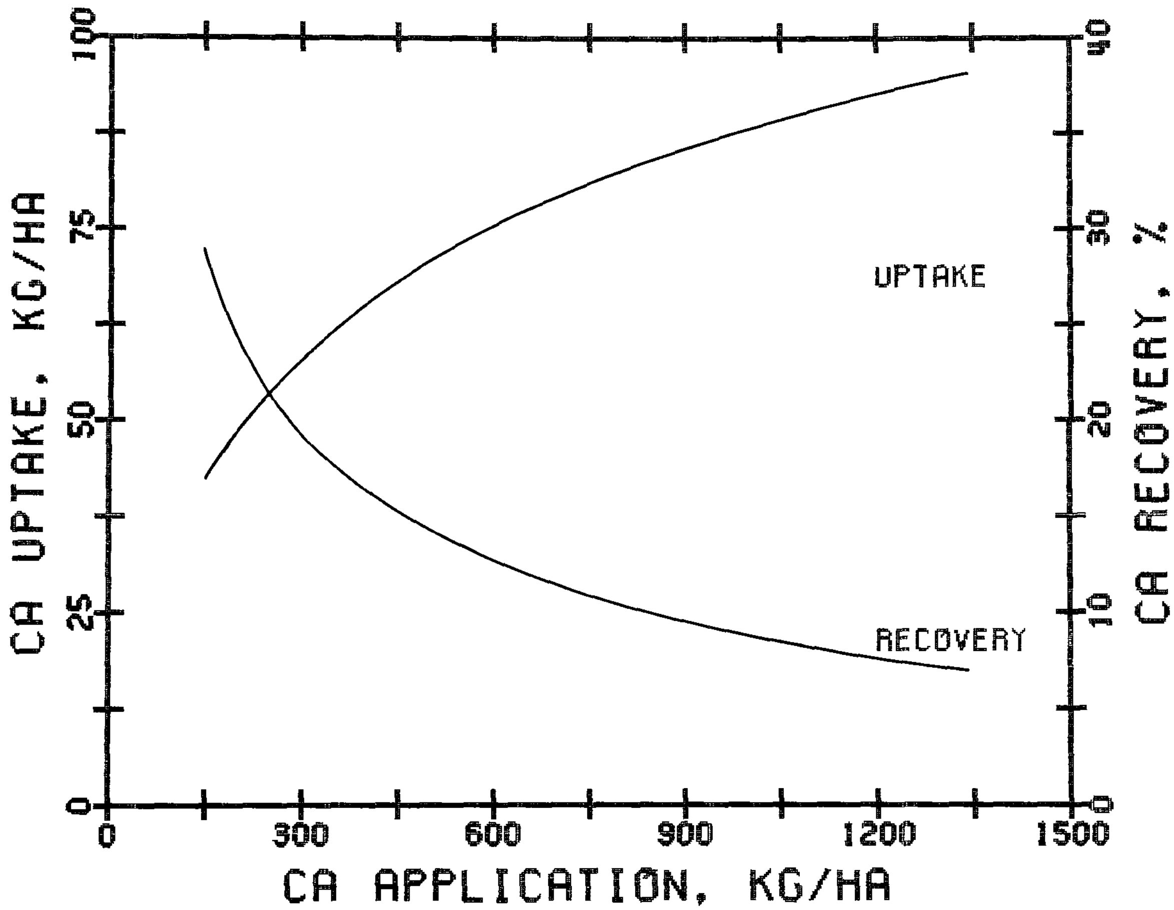

Figure 37. Estimated calcium recovery by pearl millet.

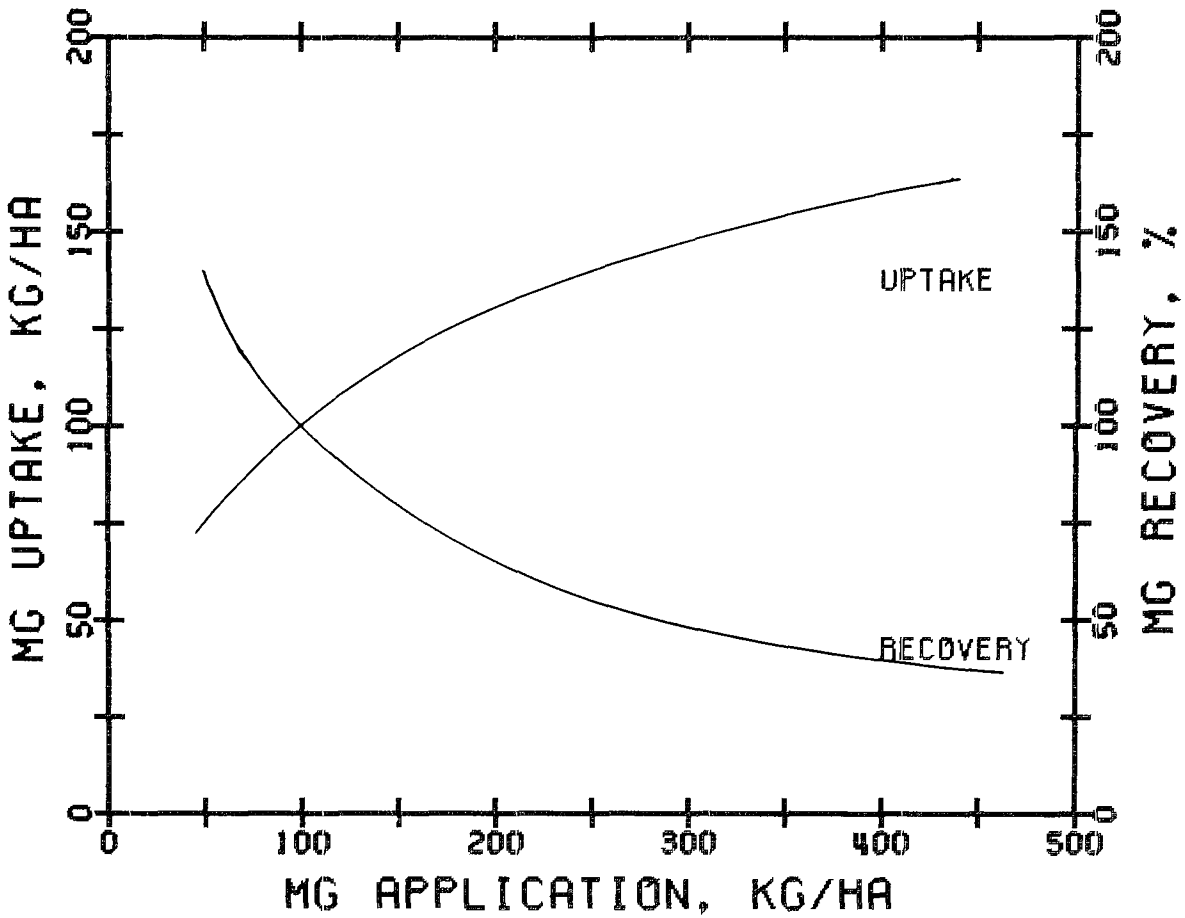

Figure 38. Estimated magnesium recovery by pearl millet.

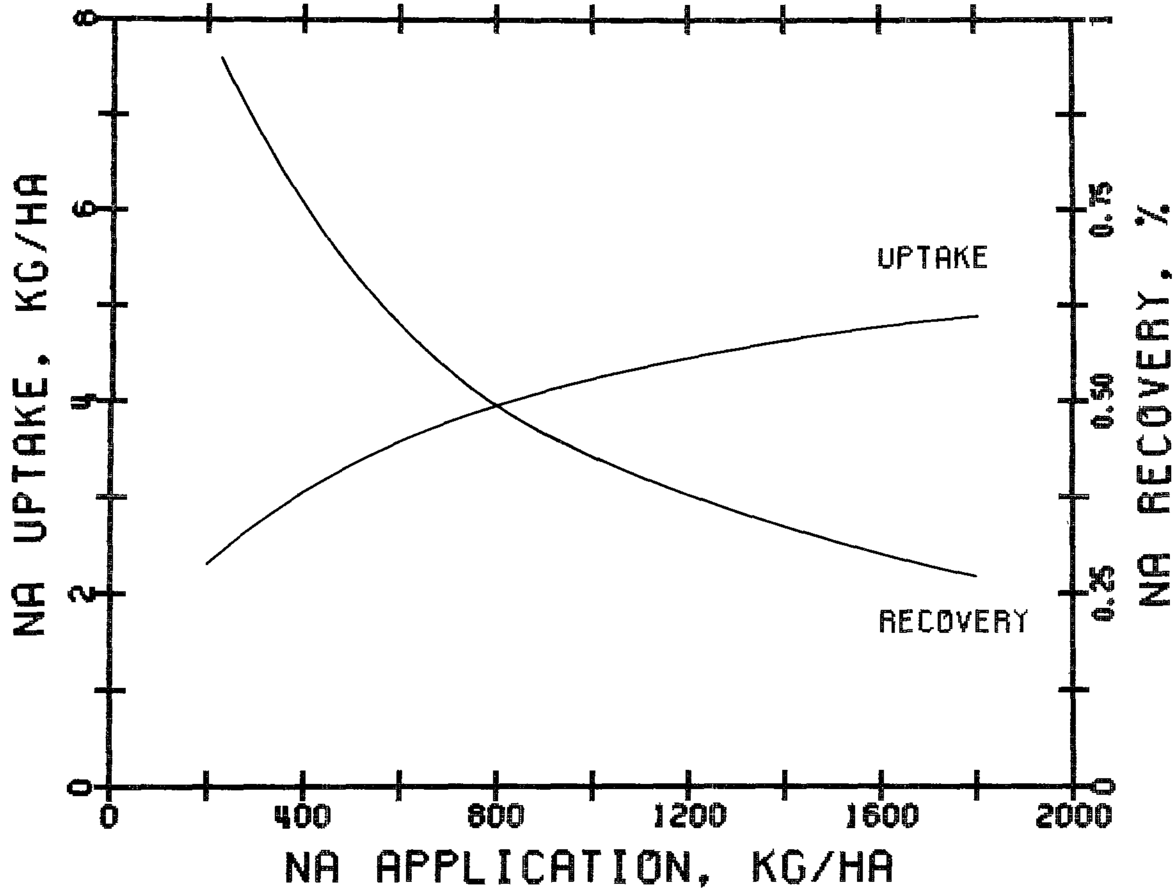

Figure 39. Estimated sodium recovery by pearl millet.

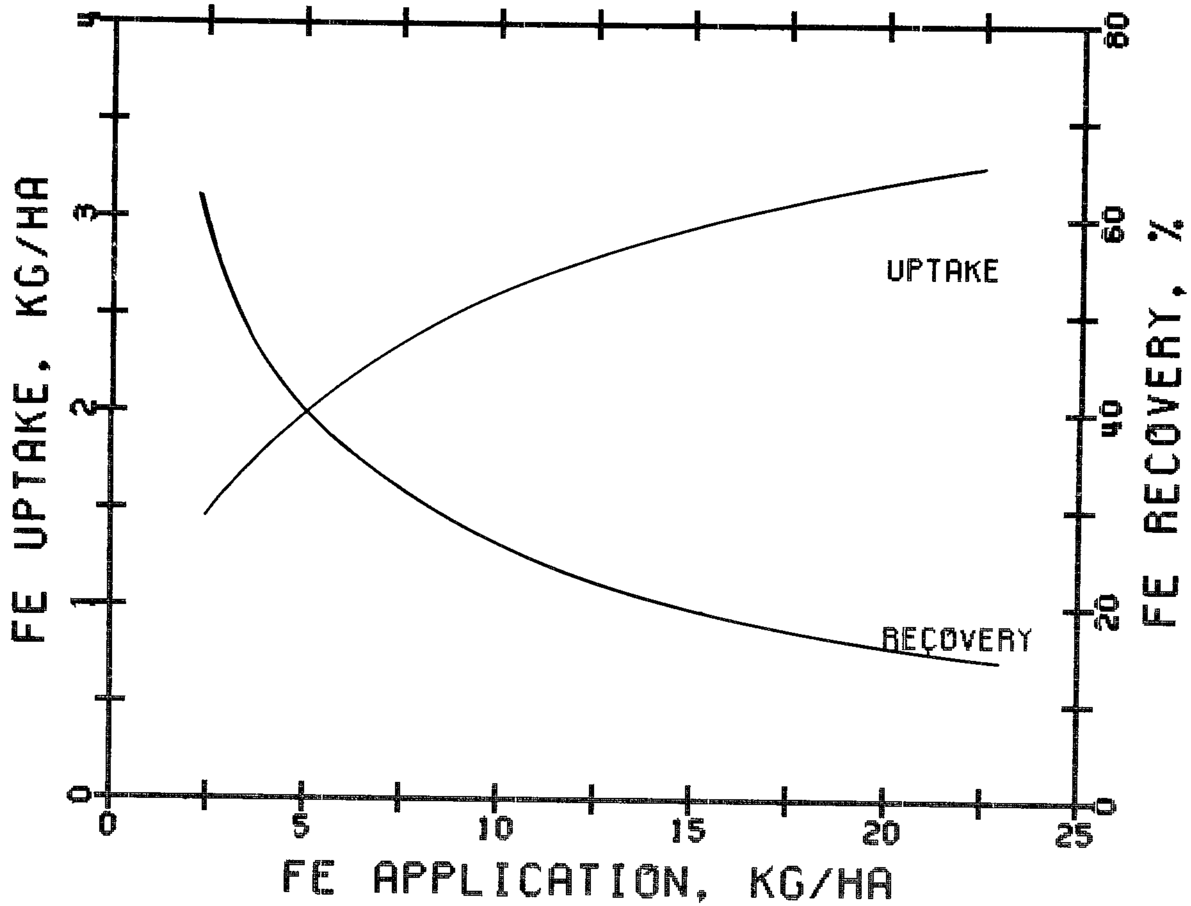

Figure 40. Estimated iron recovery by pearl millet.

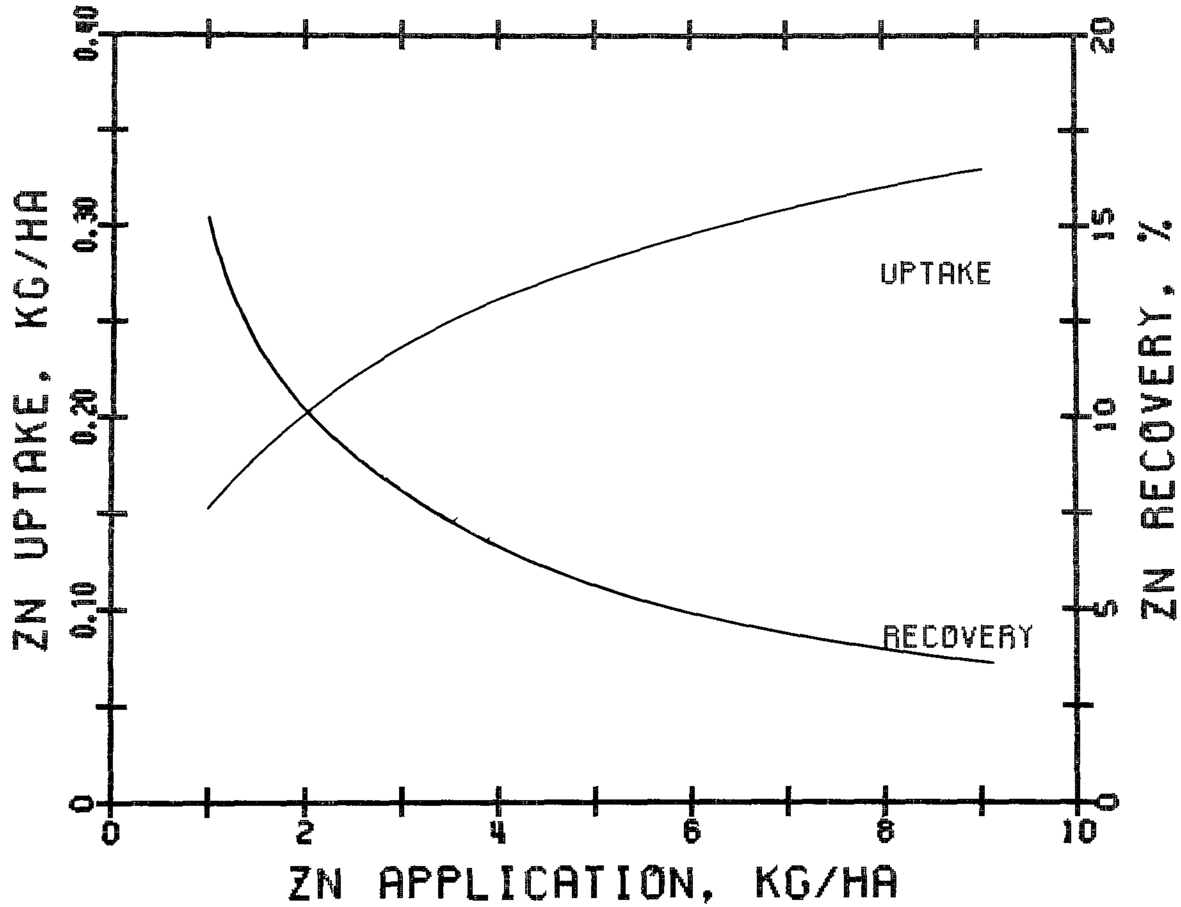

Figure 41. Estimated zinc recovery by pearl millet.

Georgia experiments. The nitrogen content of forages generally decreases with age, so that harvesting more frequently may increase total N uptake.

Particular attention should be called to K uptake (Figure 36). It was estimated that pearl millet had a large capacity to recover K, and at low application rates exhibited some deficiency. Supplemental K could be beneficial in this range. Effluent appears to supply other elements in sufficient quantities (Figures 37-41) since recoveries were below 100%.

With adequate moisture and nutrients pearl millet should be harvested 3 or 4 times during the growing season. At 400 kg/ha (360 lb/acre) applied N, forage yield of 10 mton/ha (4.5 tons/acre) was estimated (Figure 23). The corresponding yield of greenchop (17% dry matter) was 59 mtons/ha (26 tons/acre).

Corn Silage

Dry yields and N uptake (Figures 42 and 43) from this study agreed with results from Alexander et al. (1963), but were somewhat below those of Robertson et al. (1965) and Gonske and Keeney (1969). Uptake of N by corn is more efficient in bands than in broadcast application, as in effluent irrigation. Crop uptake estimates of P, K, Ca and Mg (Figures 44-46) agreed closely with those of Alexander et al.(1963). Estimates of Fe and Zn concentrations (Figures 49 and 50) of 0.020% and 0.0050%, respectively, were in the range of other results (Linsner, 1970). All the elements were adequate (Figures 42-50), except K.

Since corn silage has a short growing season (10-14 weeks), it could be followed with another summer crop (such as soybeans).

Estimated forage yield at 200 kg/ha (180 lb/acre) applied N were 5 mtons/ha (2.2 tons/acre), from Figure 42. The corresponding yield of greenchop (20% dry matter) was 25 mtons/ha (11 tons/acre).

Corn Grain

Estimated yields of corn grain are given in Figure 51. These values agreed closely with those of Stanley and Rhoads (1971) in Florida and Jung et al. (1972) in Wisconsin. Nitrogen uptake estimates (Figure 52) from this study were below those of Jung et al. (1972), for two reasons. First, the Wisconsin soil had a slightly higher base fertility than the Florida soil. Second, corn intercepts more of the nitrogen banded application than for broadcast, as in effluent irrigation. This same effect was noted above for corn silage.

Estimates of other elements are given in Figures 53-59. Other nutrients appeared to be present in adequate quantities. However, at 25 mm/week corn ears did not fill out completely in the 1973 season, indicating possible K deficiency under extended production of corn at low application rates. Supplemental K might be necessary under these conditions.

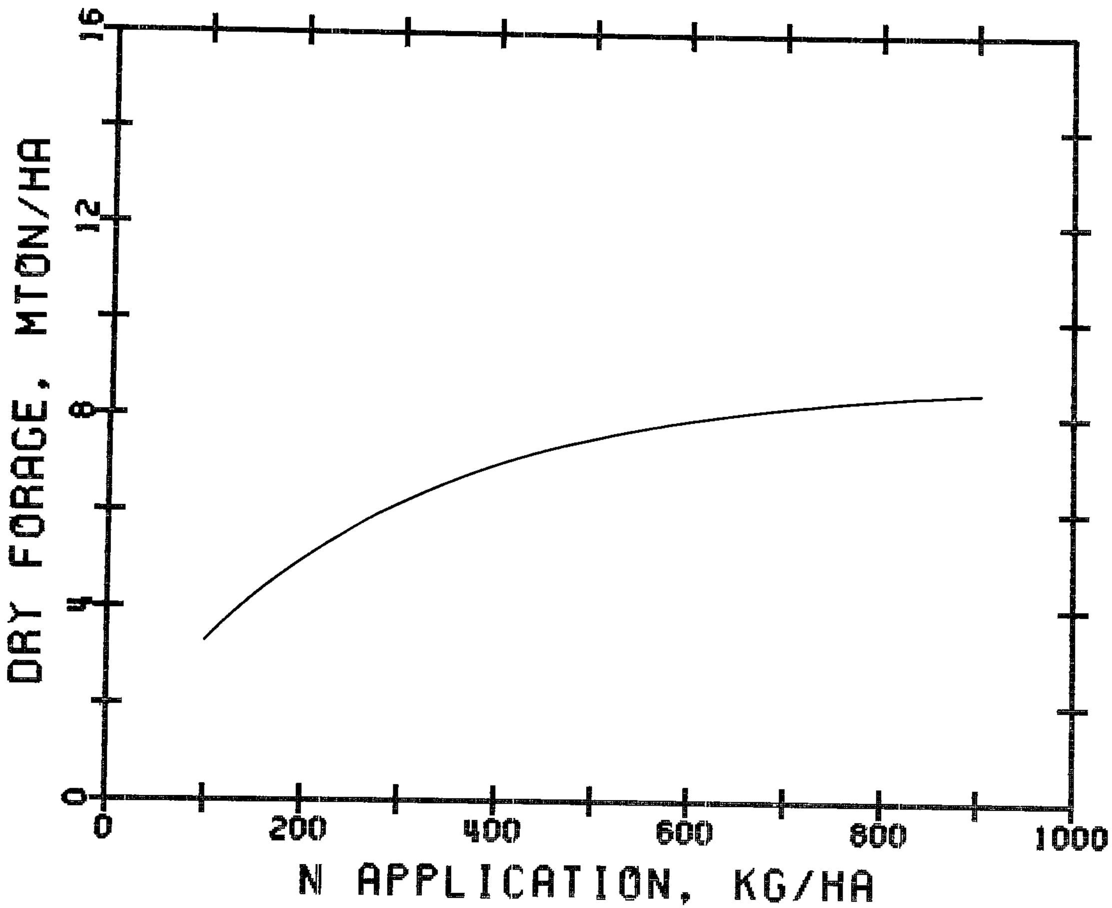

Figure 42. Estimated yield response of corn silage.

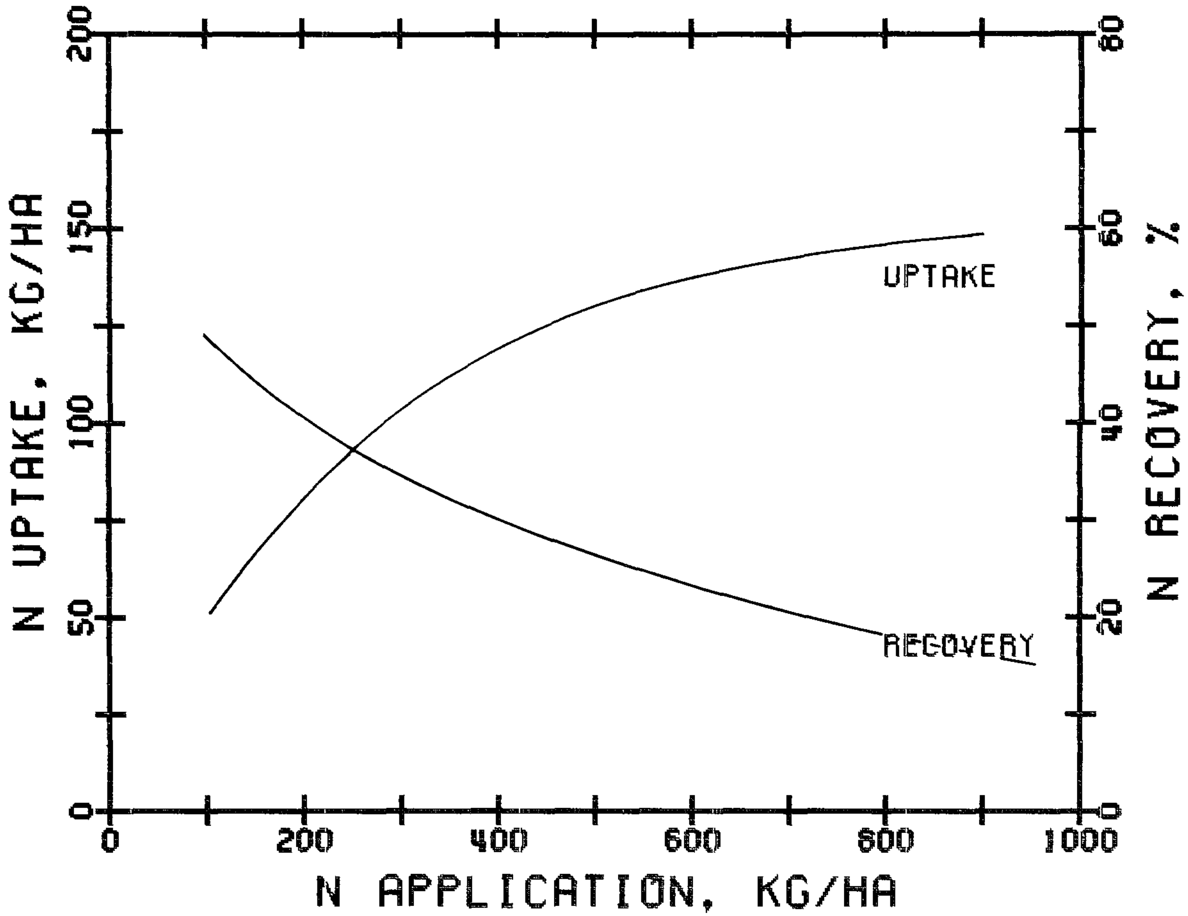

Figure 43. Estimated nitrogen recovery by corn silage.

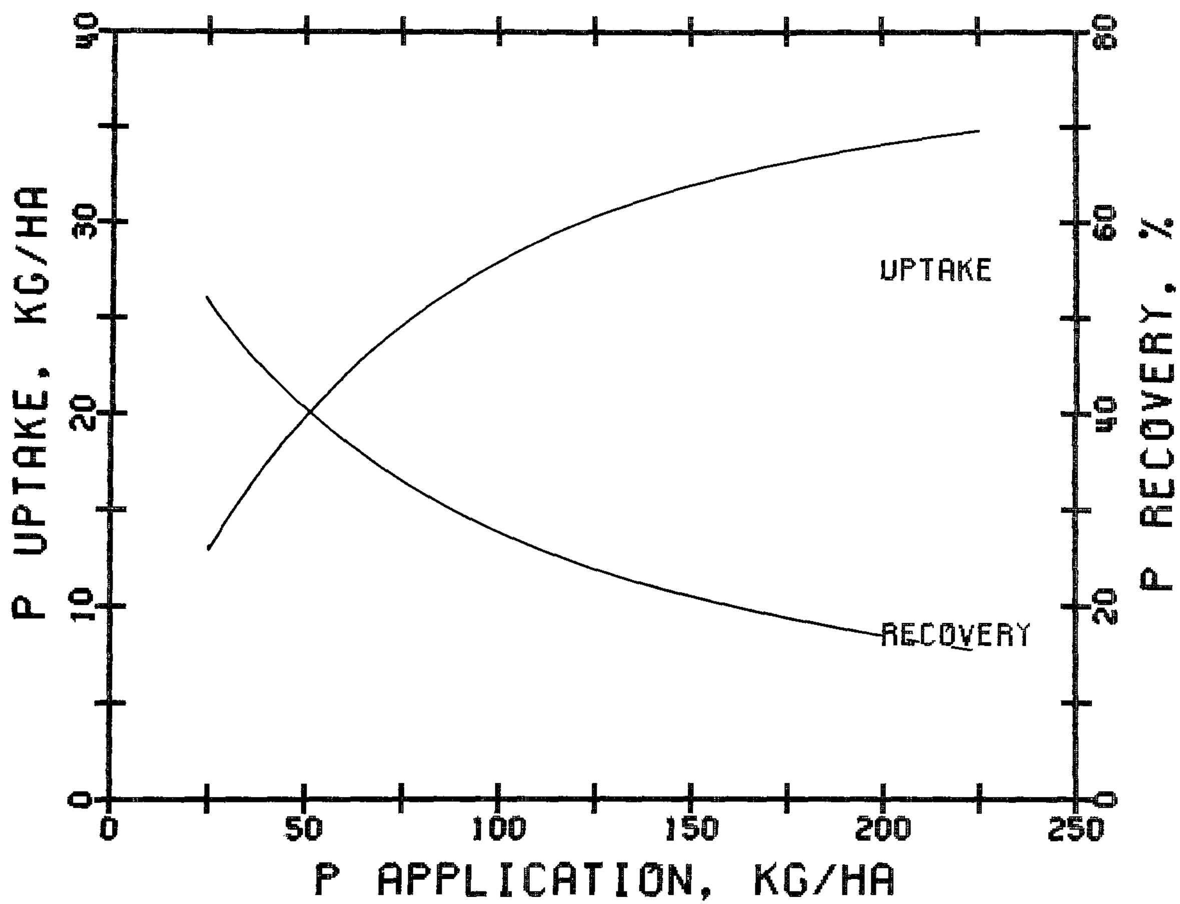

Figure 44. Estimated phosphorus recovery by corn silage.

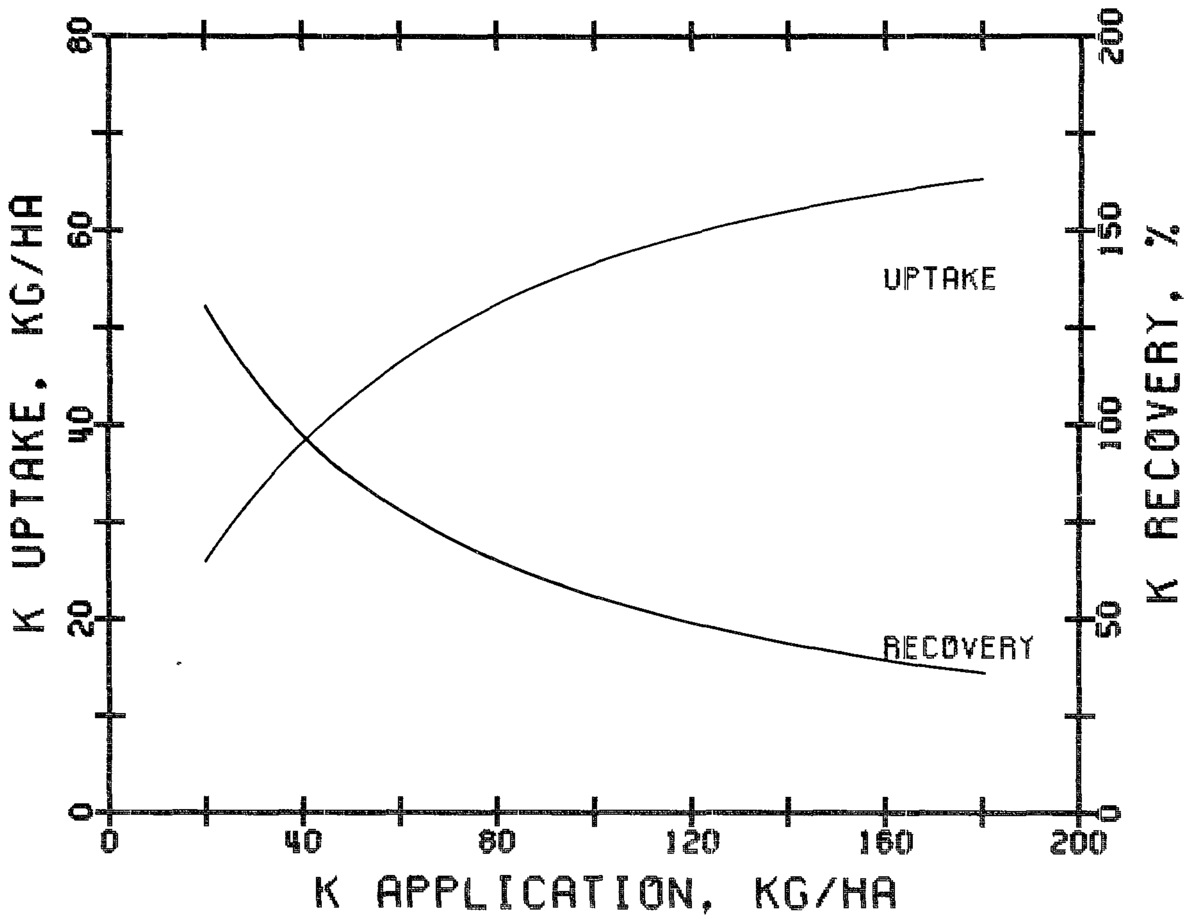

Figure 45. Estimated photassium recovery by corn silage.

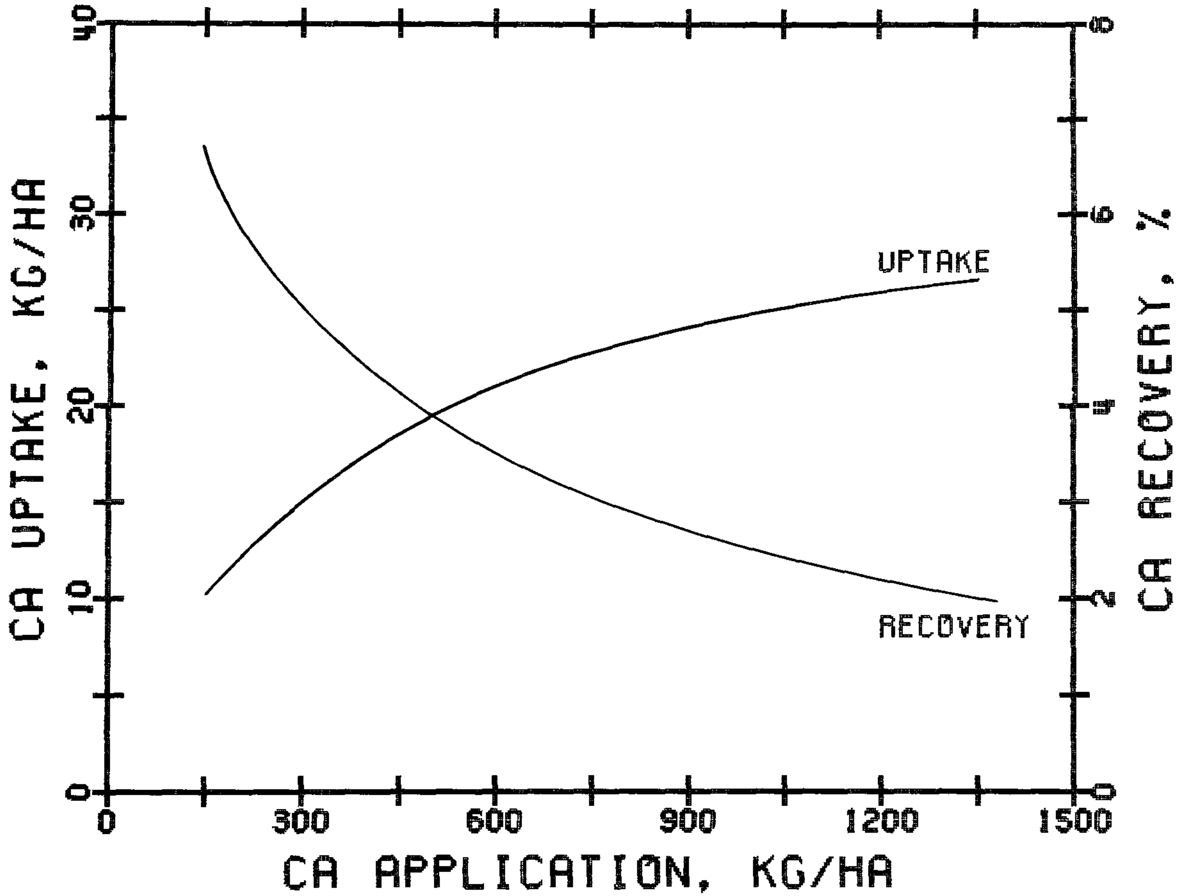

Figure 46. Estimated calcium recovery by corn silage.

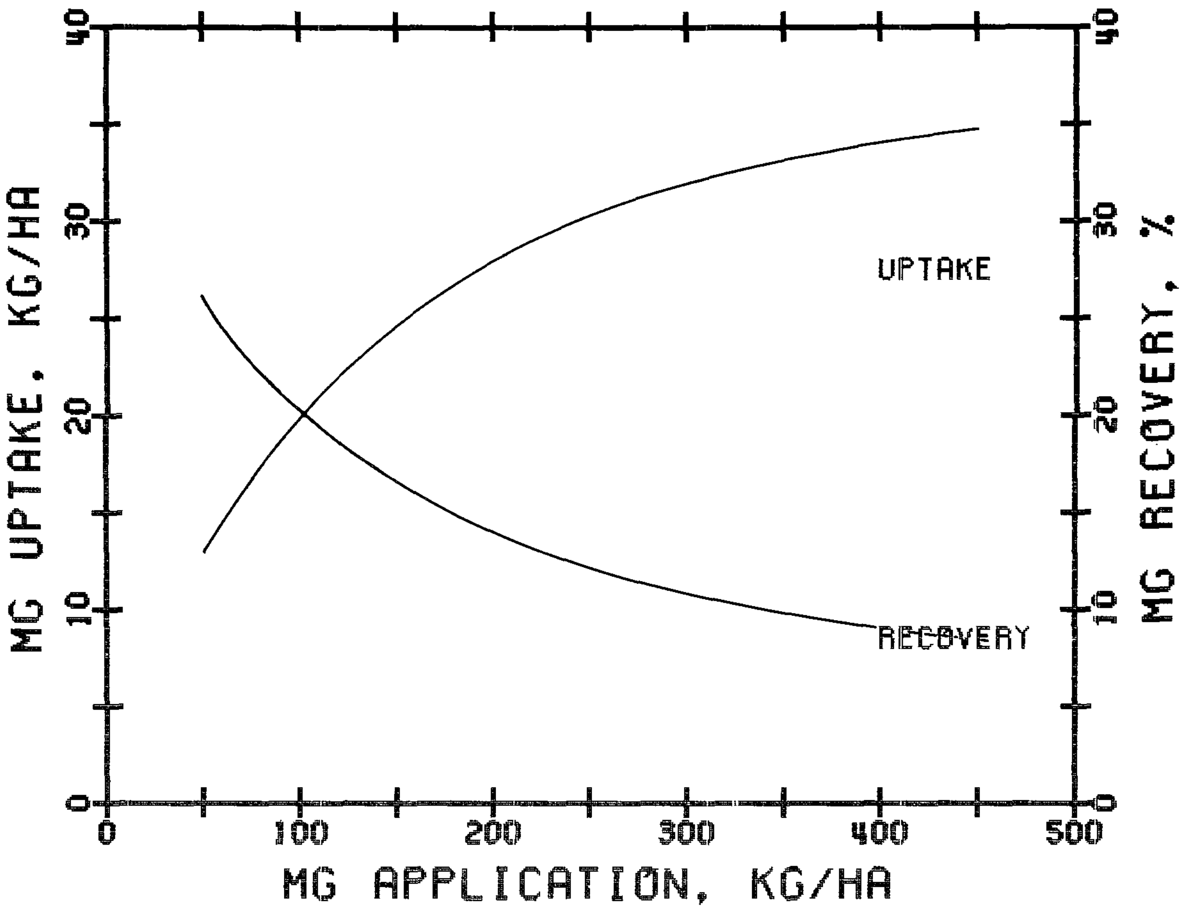

Figure 47. Estimated magnesium recovery by corn silage.

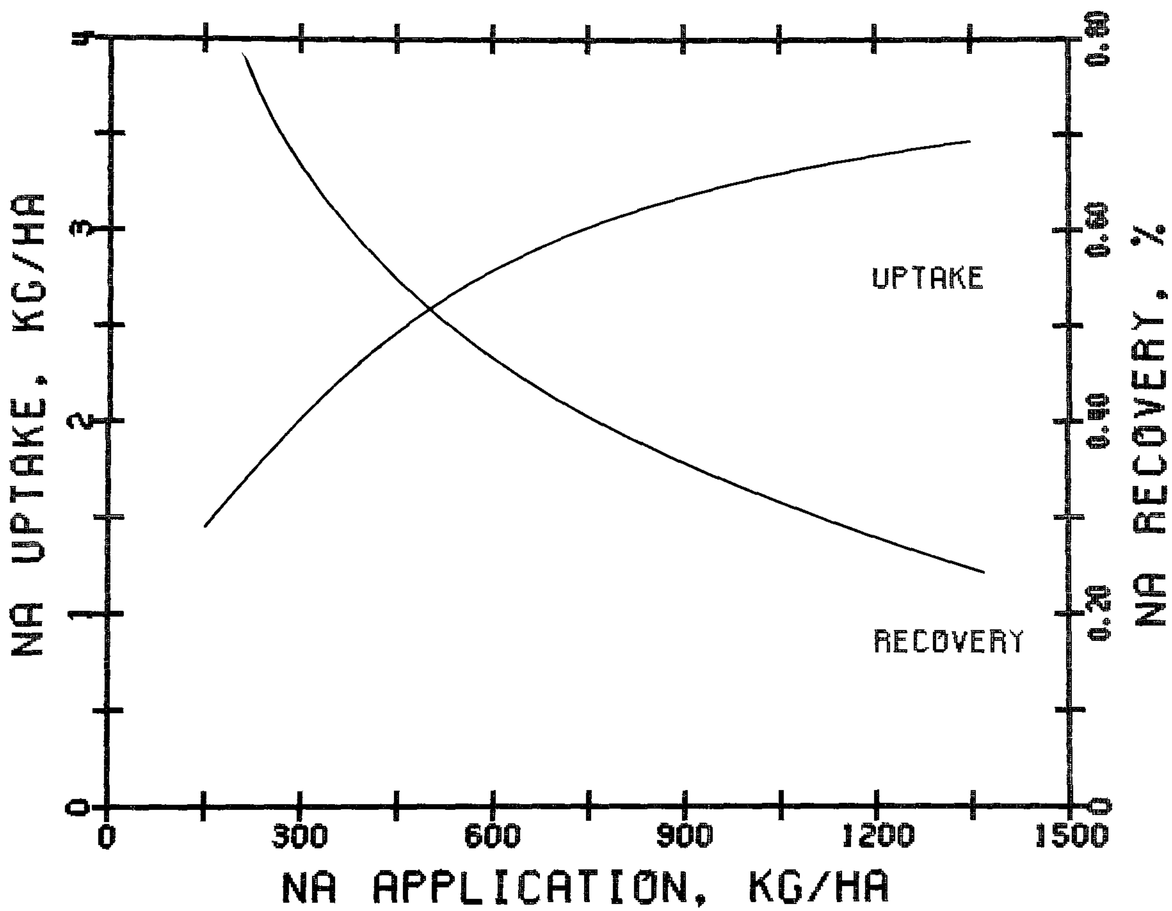

Figure 48. Estimated sodium recovery by corn silage.

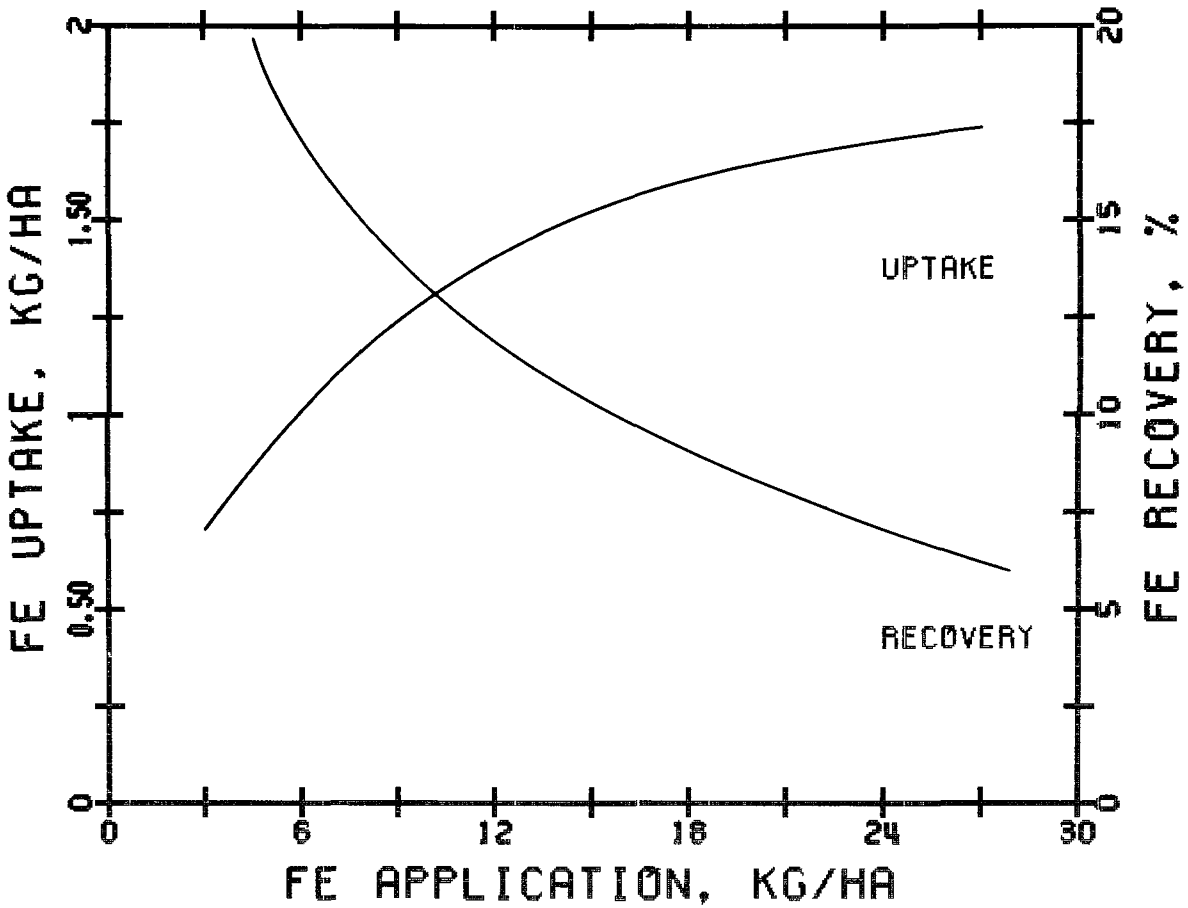

Figure 49. Estimated iron recovery by corn silage.

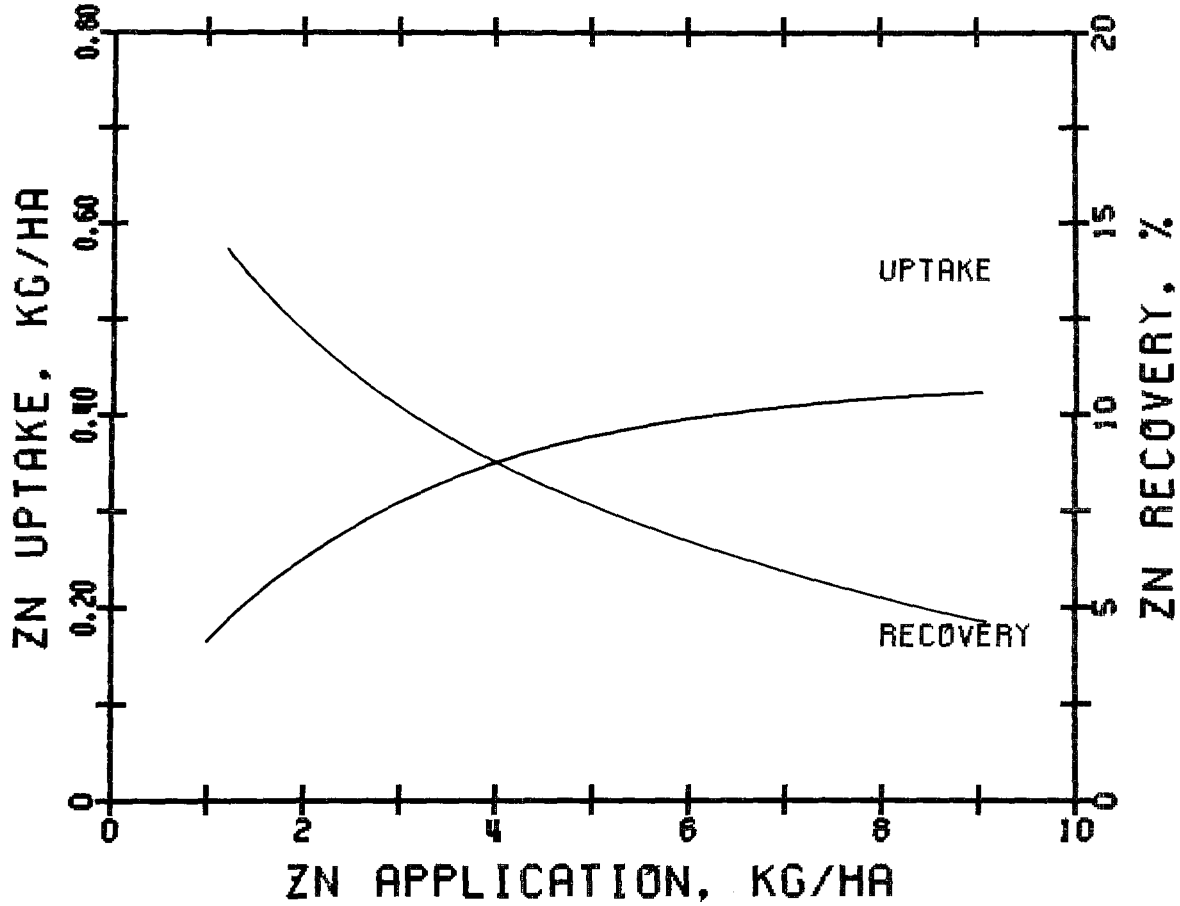

Figure 50. Estimated zinc recovery by corn silage.

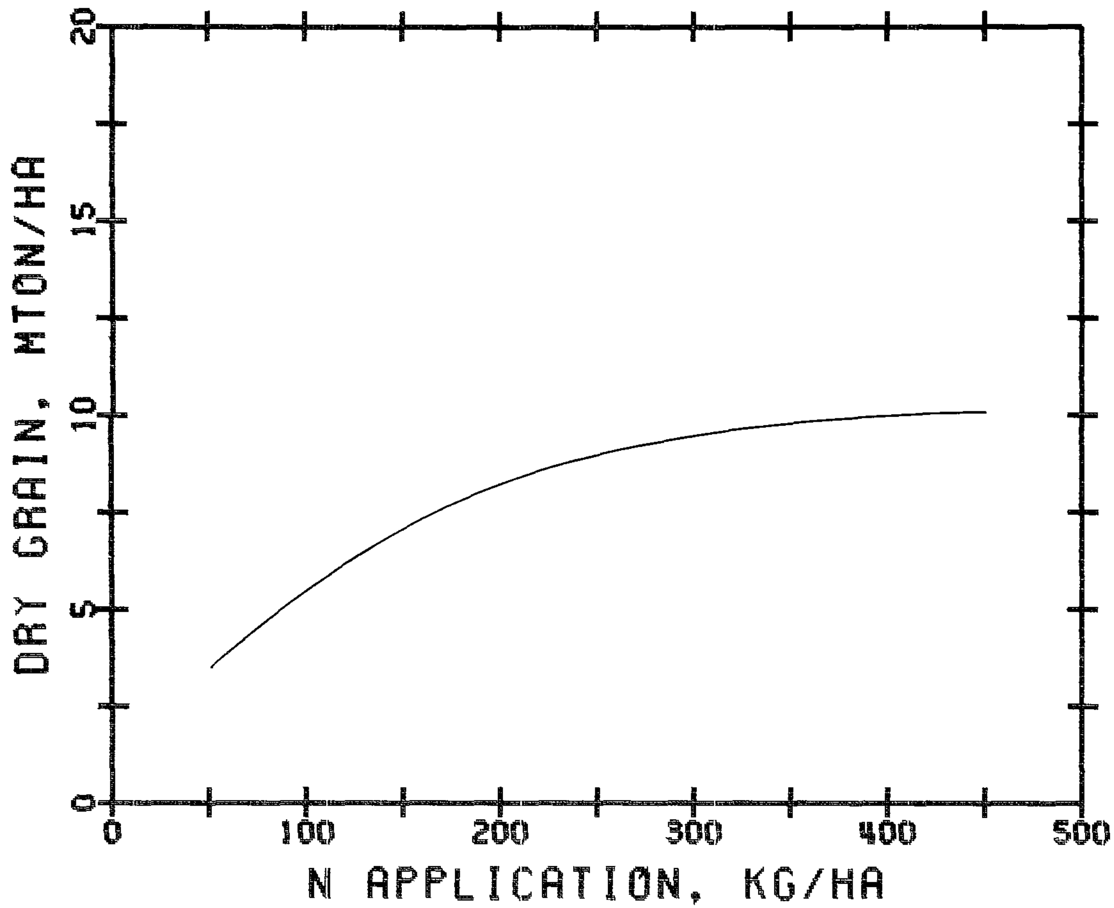

Figure 51. Estimated yield response by corn grain.

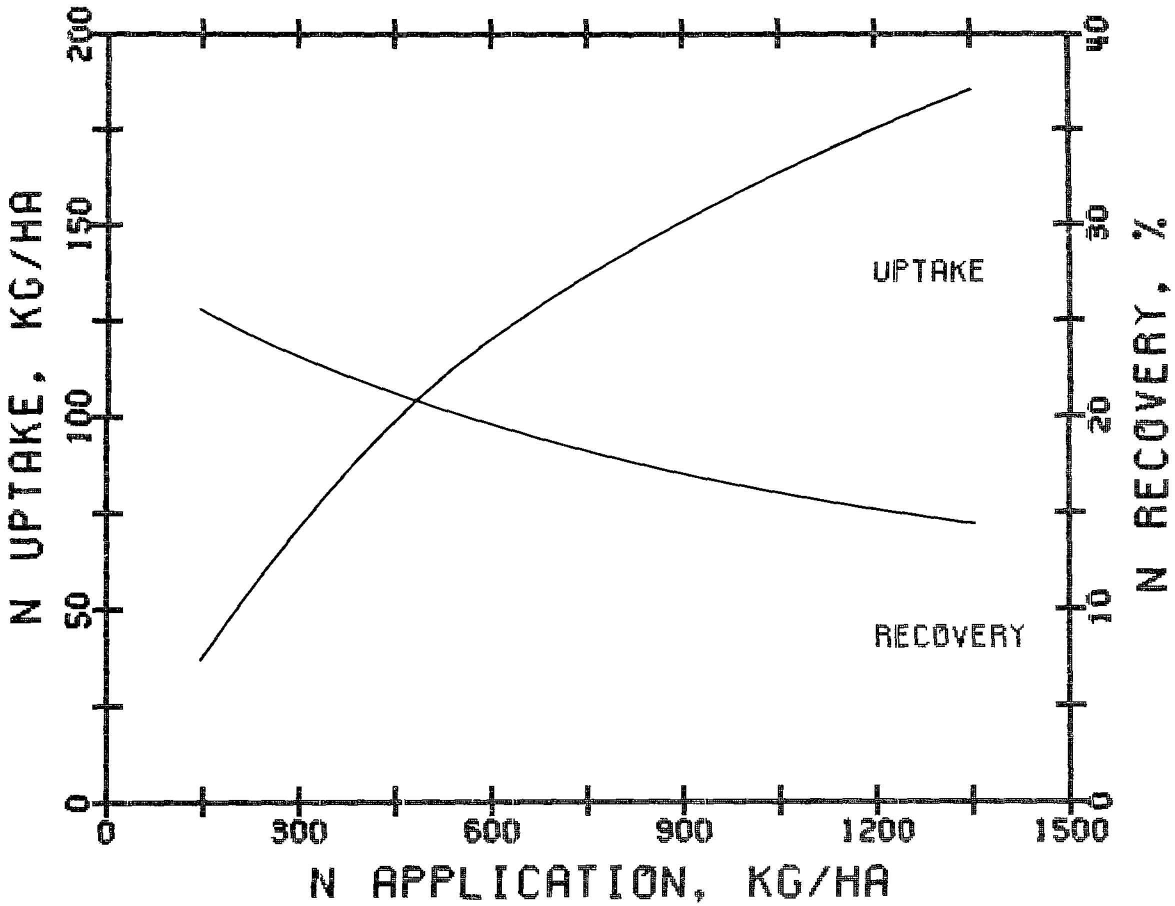

Figure 52. Estimated nitrogen recovery by corn grain.

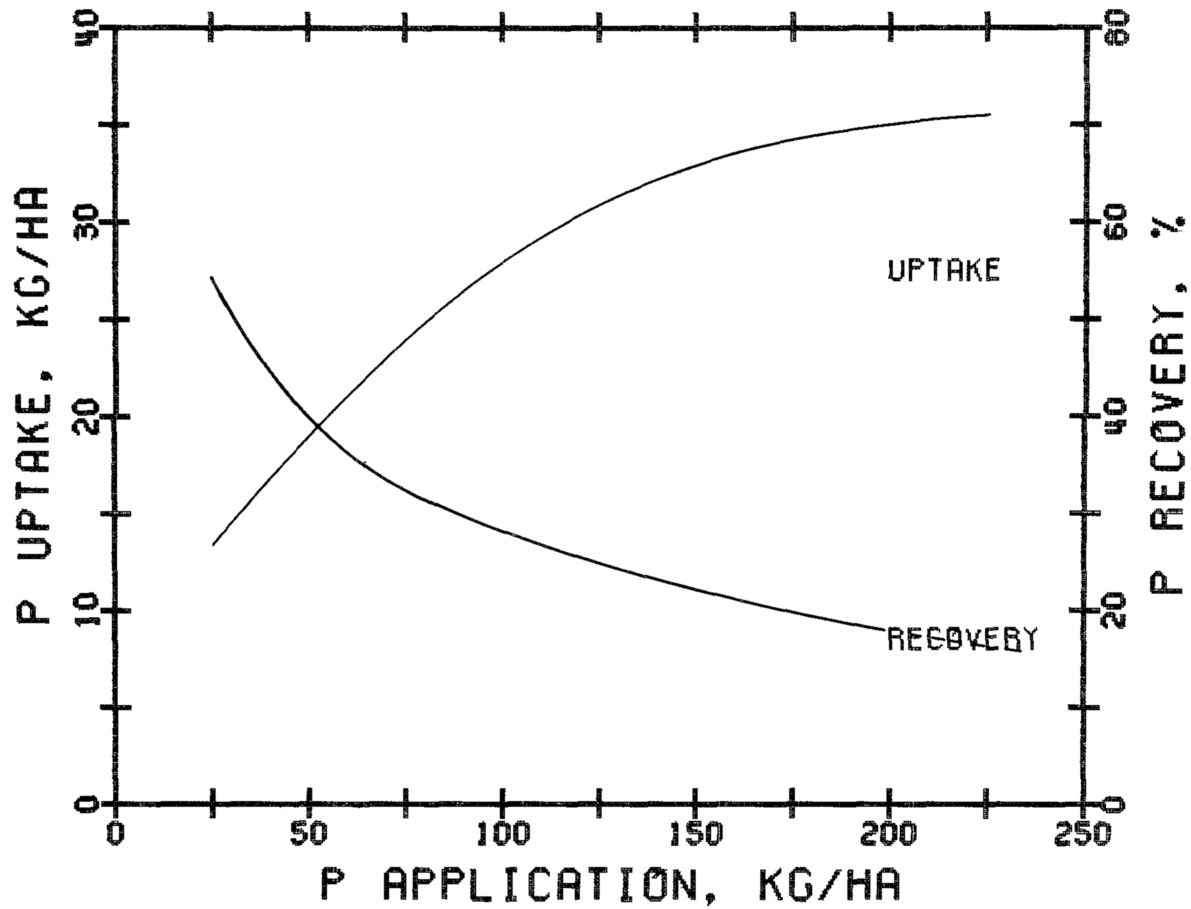

Figure 53. Estimated phosphorus recovery by corn grain.

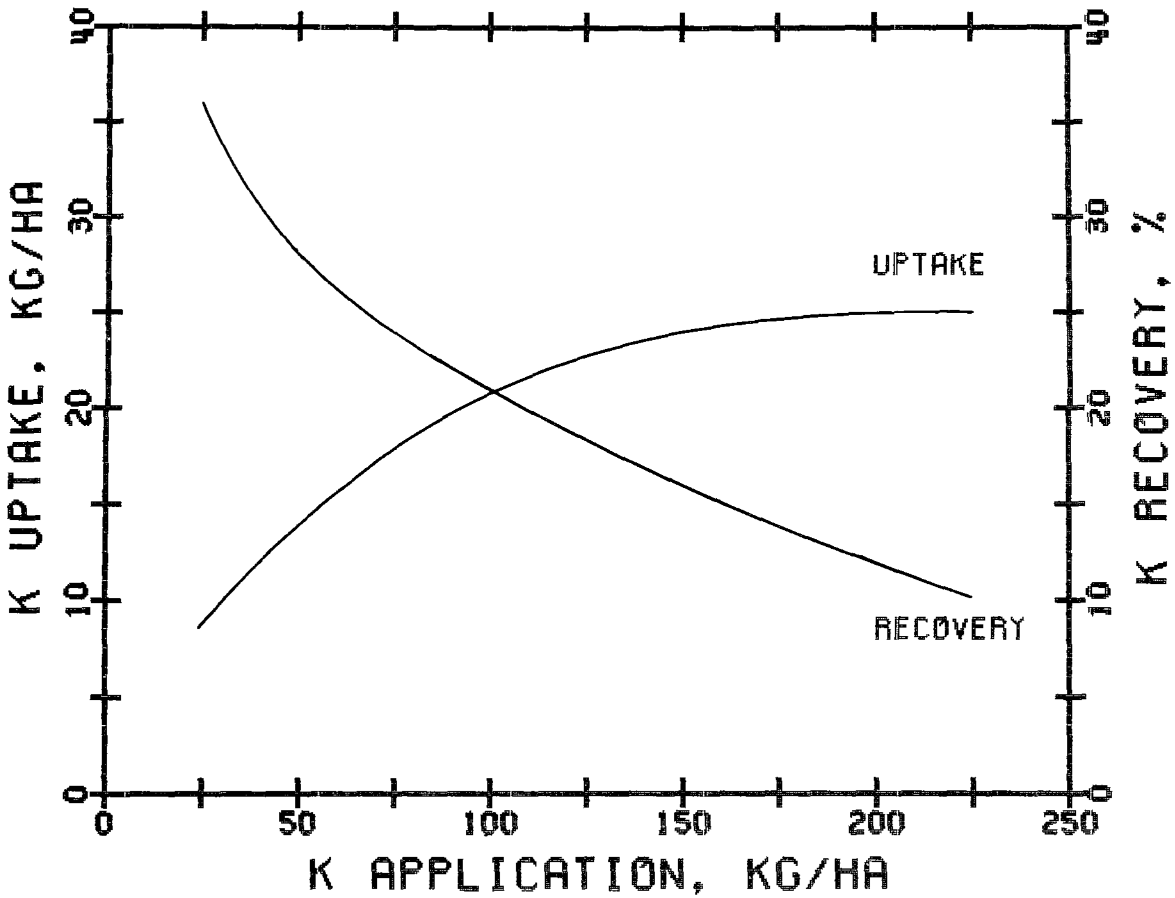

Figure 54. Estimated potassium recovery by corn grain.

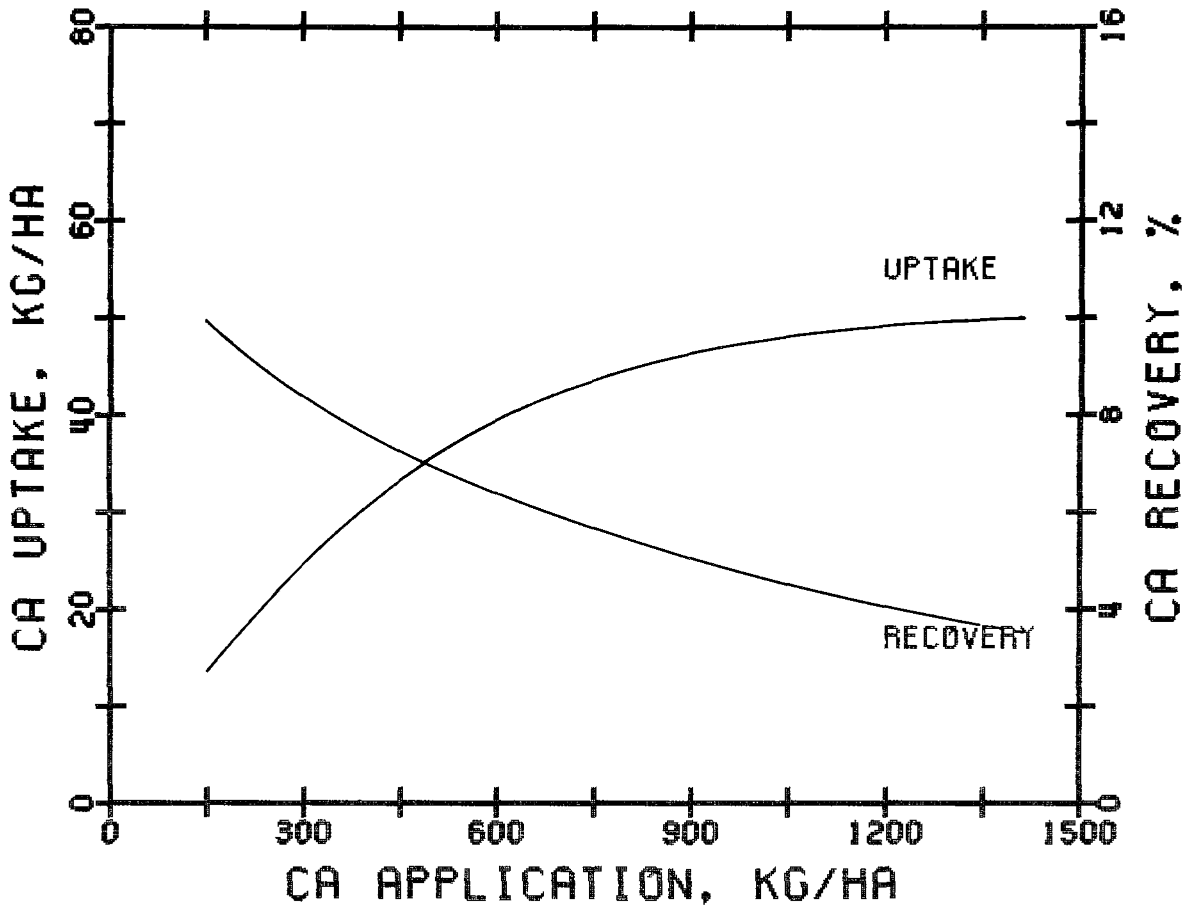

Figure 55. Estimated calcium recovery by corn grain.

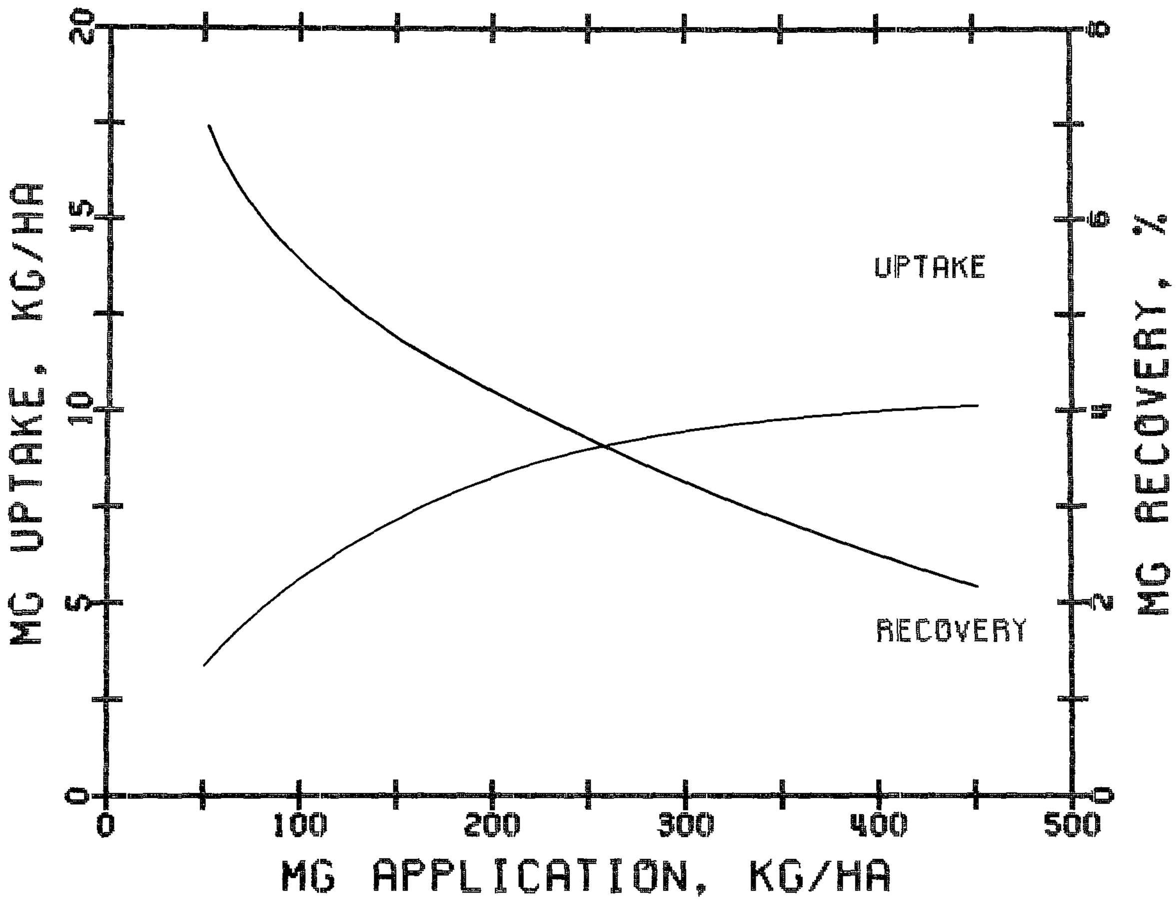

Figure 56. Estimated magnesium recovery by corn grain.

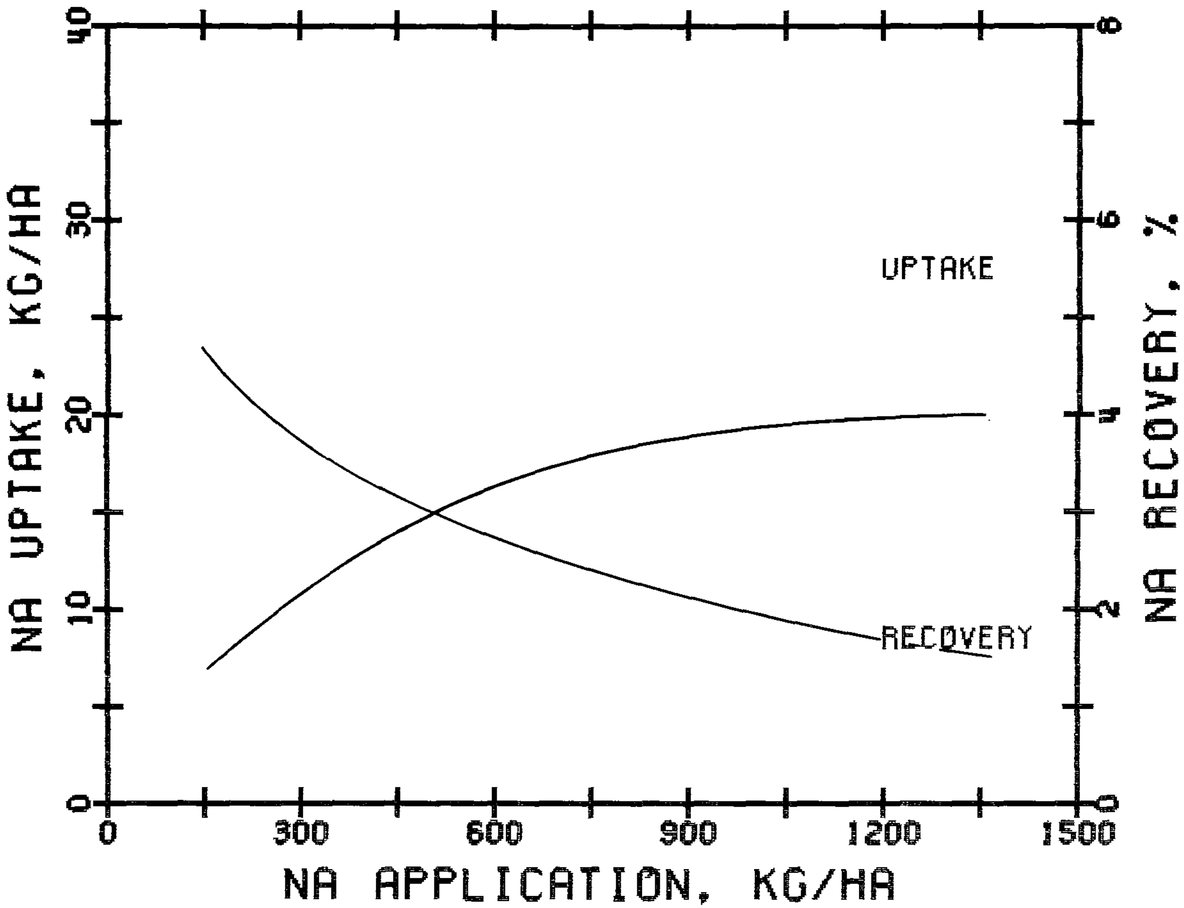

Figure 57. Estimated sodium recovery by corn grain.

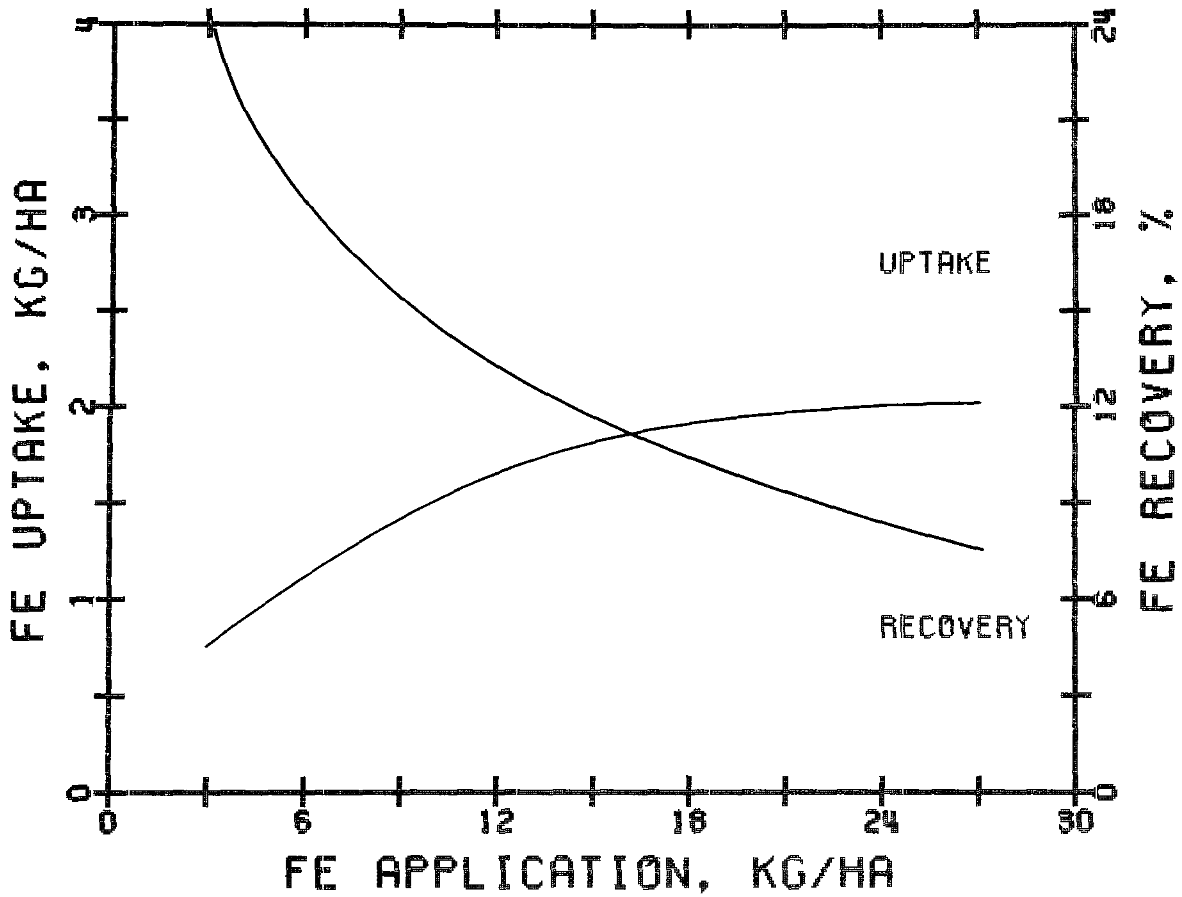

Figure 58. Estimated iron recovery by corn grain.

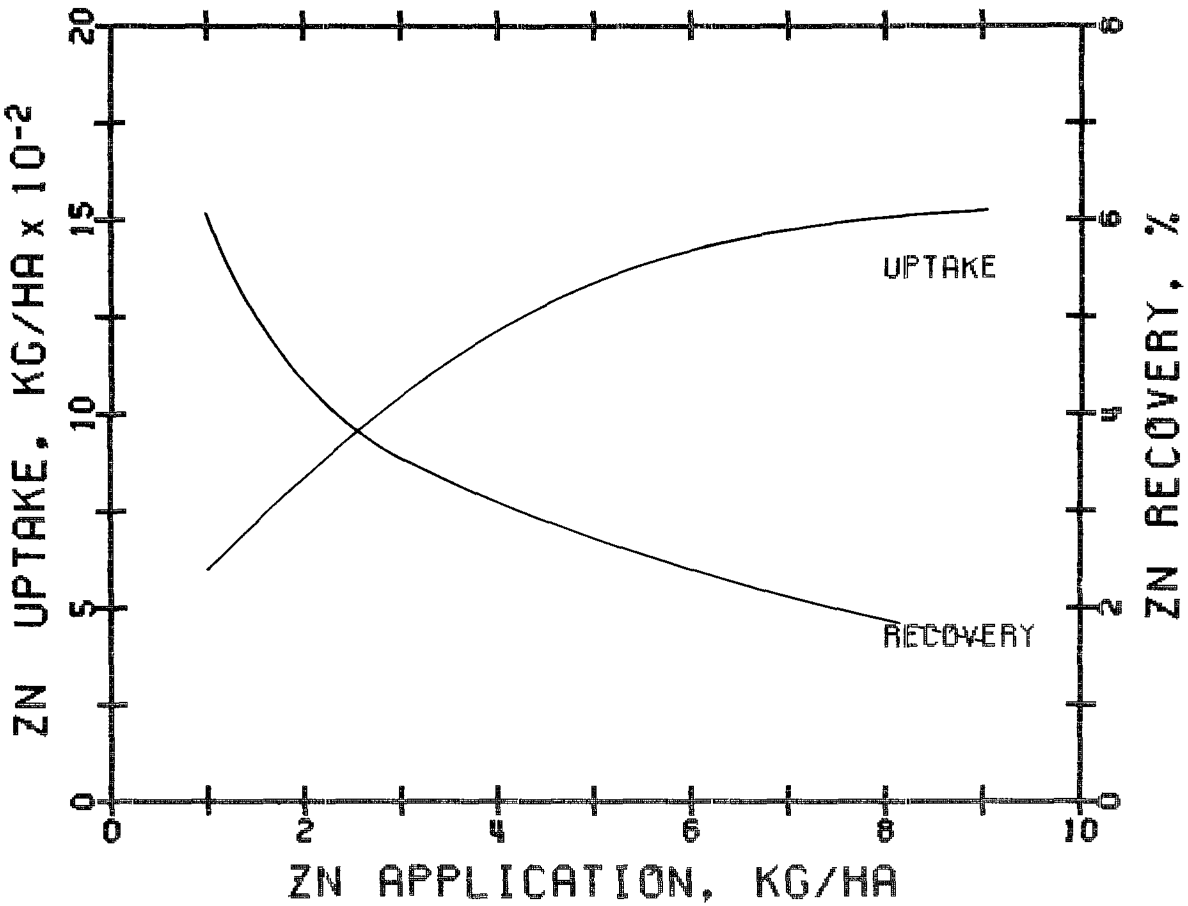

Figure 59. Estimated zinc recovery by corn grain.

For N application of 200 kg/ha (180 lb/acre), the yield of dry corn was 8 mtons/ha (3.6 tons/acre), from Figure 51. For a moisture content of 15%, this corresponded to 9.4 mtons/ha (150 bu/acre).

Kenaf

Dry matter yields of kenaf showed weak coupling with application rate (Figure 60). Estimates based on the present study were below those of Pepper and Prine (1969), but in both cases only one harvest was obtained with Everglades 41 variety. Killinger (1967) reported similar yields to those of Pepper and Prine (1969) with this variety. The study of Killinger (1967) showed a nitrogen content of 2.0% at 123 kg/ha applied N, compared to an estimated value of 1% or less at that rate for this study. Apparently N uptake by kenaf was much weaker under broadcast application than banded application, as used by Killinger (1967). This probably accounted for low recovery efficiencies (Figure 61) estimated from the present work. As with other crops, K uptake exceeded application at lower rates (Figure 63), indicating a possible need for supplemental K. Karbassi and Killinger (1966) showed a positive response of kenaf to K addition. Kenaf also showed high demand for Fe (Figure 67). All elements, except K, were supplied in adequate quantities (Figures 60-68).

A yield of 6 mtons/ha (2.7 tons/acre) of dry forage was estimated at 250 kg/ha (220 lb/acre) of applied N (Figure 60). This corresponded to 33 mtons/ha (15 tons/acre) of greenchop at 18% dry matter.

Rye

Dry matter yield showed an appreciable increase with application rate (Figure 69). These estimates of yield agreed closely with results of Morris and Jackson (1959) and Morris and Reese (1962) in Georgia. Nitrogen uptake (Figure 70) also agrees closely with values from Parks et al. (1970). As with several of the summer crops, at lower application rates, rye shows K uptake exceeding application (Figure 72). This indicates potential K deficiency and need for supplemental K. Other elements appear to be supplied in adequate quantities (Figures 70-77). Beneficial effects of the trace elements Fe and Zn (Figures 76 and 77) occur, since appreciable fractions of these are taken up by the rye.

With adequate moisture and nutrients, rye should be harvested about 3 times. Since the yield of dry forage at 160 kg/ha (140 lb/acre) applied N was 3.5 mtons/ha (1.6 tons/acre) from Figure 69, the corresponding yield of greenchop (20% dry matter) was 18 mtons/ha (7.8 tons/acre).

Ryegrass

Estimates of dry matter yields (Figure 78) agreed closely with results from Mislevy and Dantzman (1974) in Florida. Uptake of N (Figure 79) also agreed with Mislevy and Dantzman (1974). Nitrogen content of 2.5 to 3.5% is in the range given by Hylton et al. (1965), and showed an increase with application rate. Content of other nutrients estimated here were: P = 0.75, K = 1.5, Ca = 0.5 and Mg = 0.25%. Values reported for these elements by

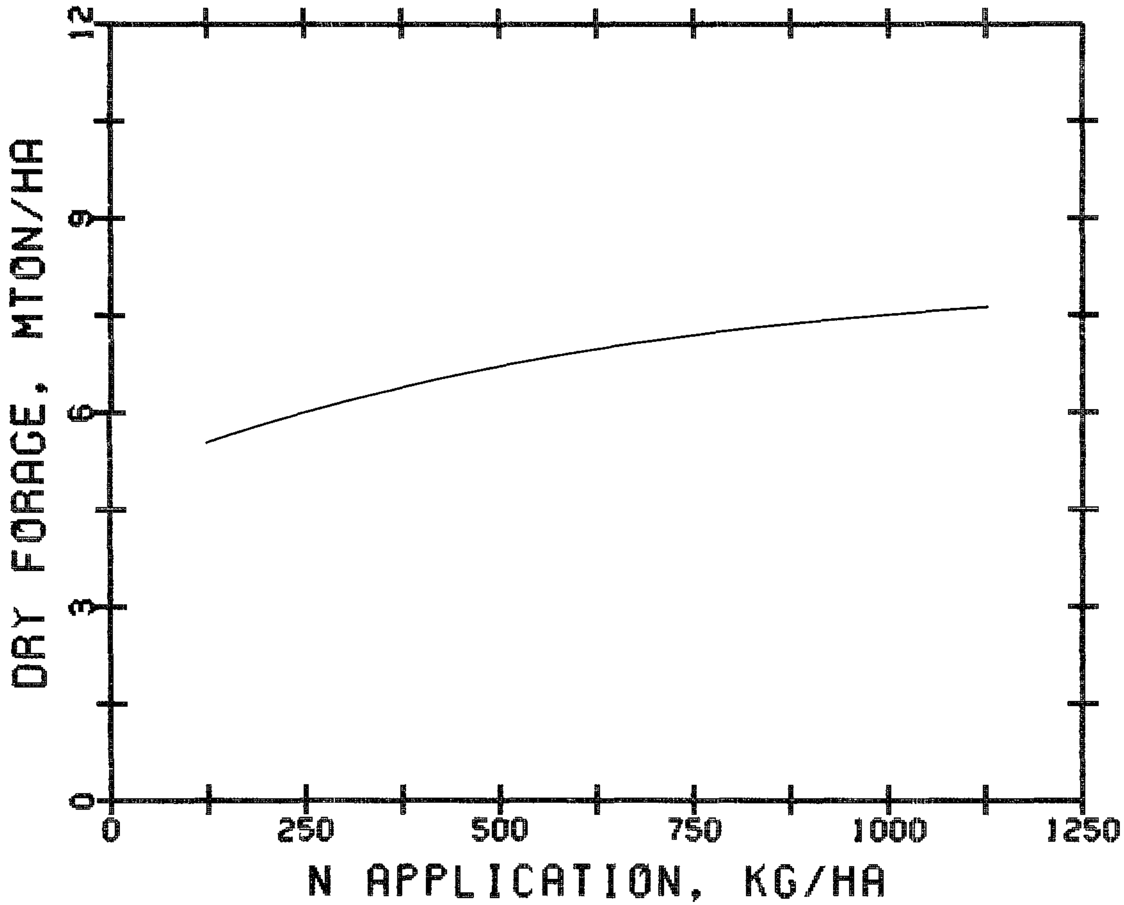

Figure 60. Estimated yield response of kenaf.

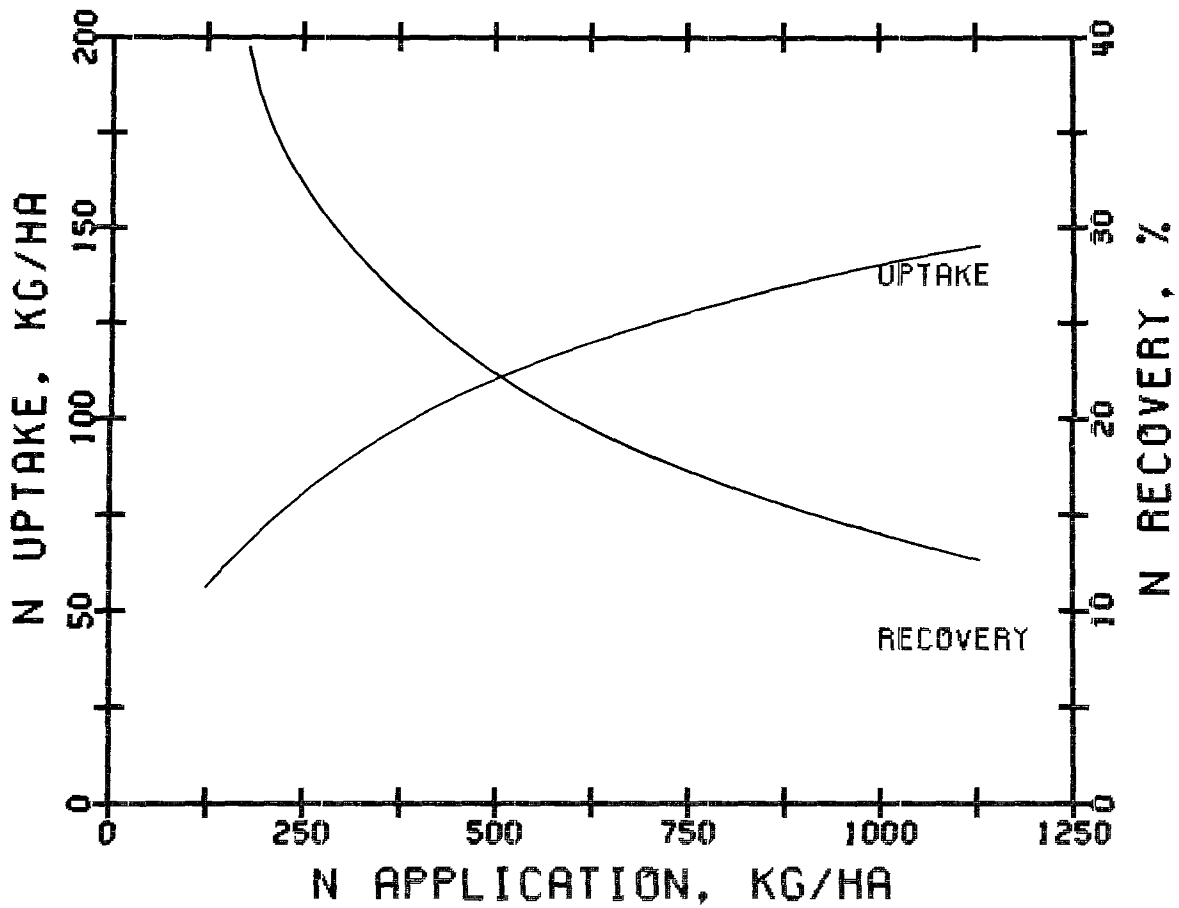

Figure 61. Estimated nitrogen recovery by kenaf.

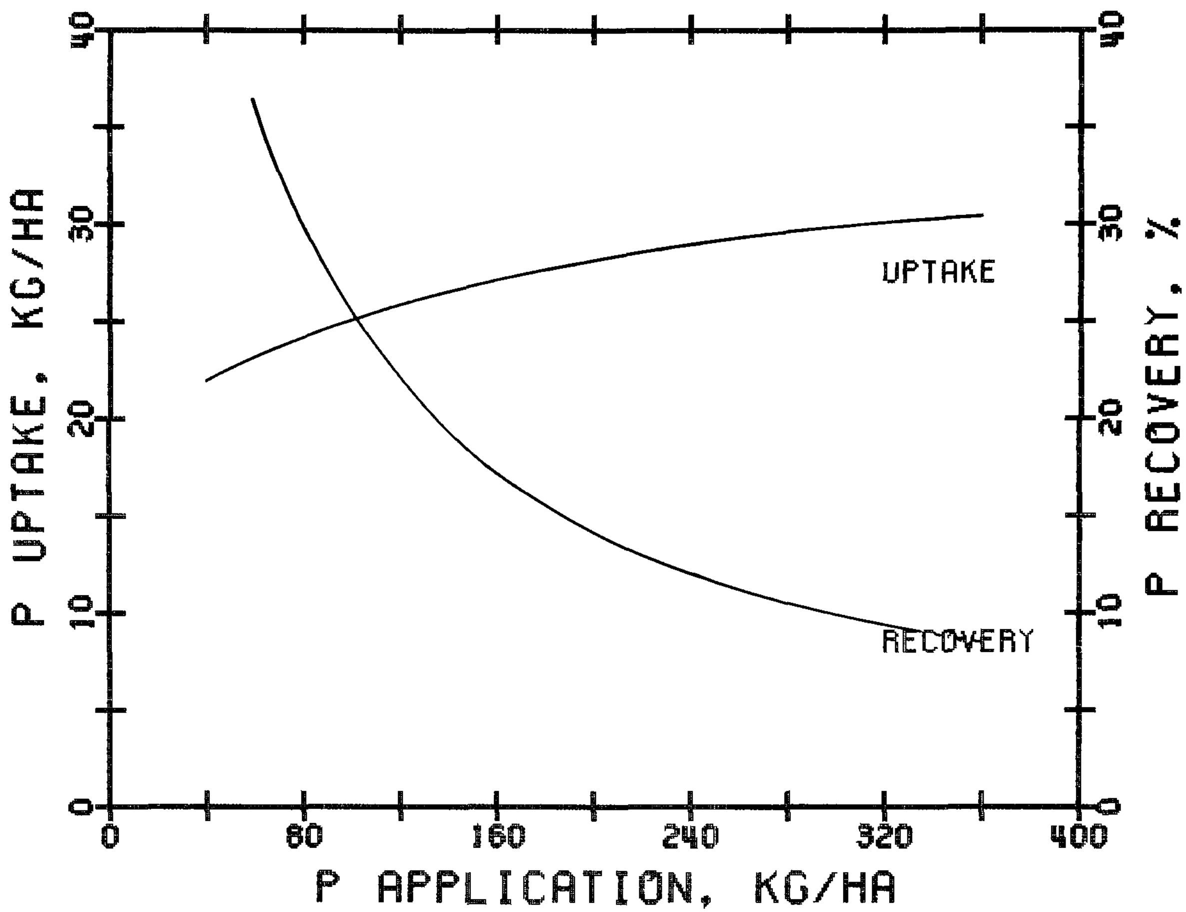

Figure 62. Estimated phosphorus recovery by kenaf.

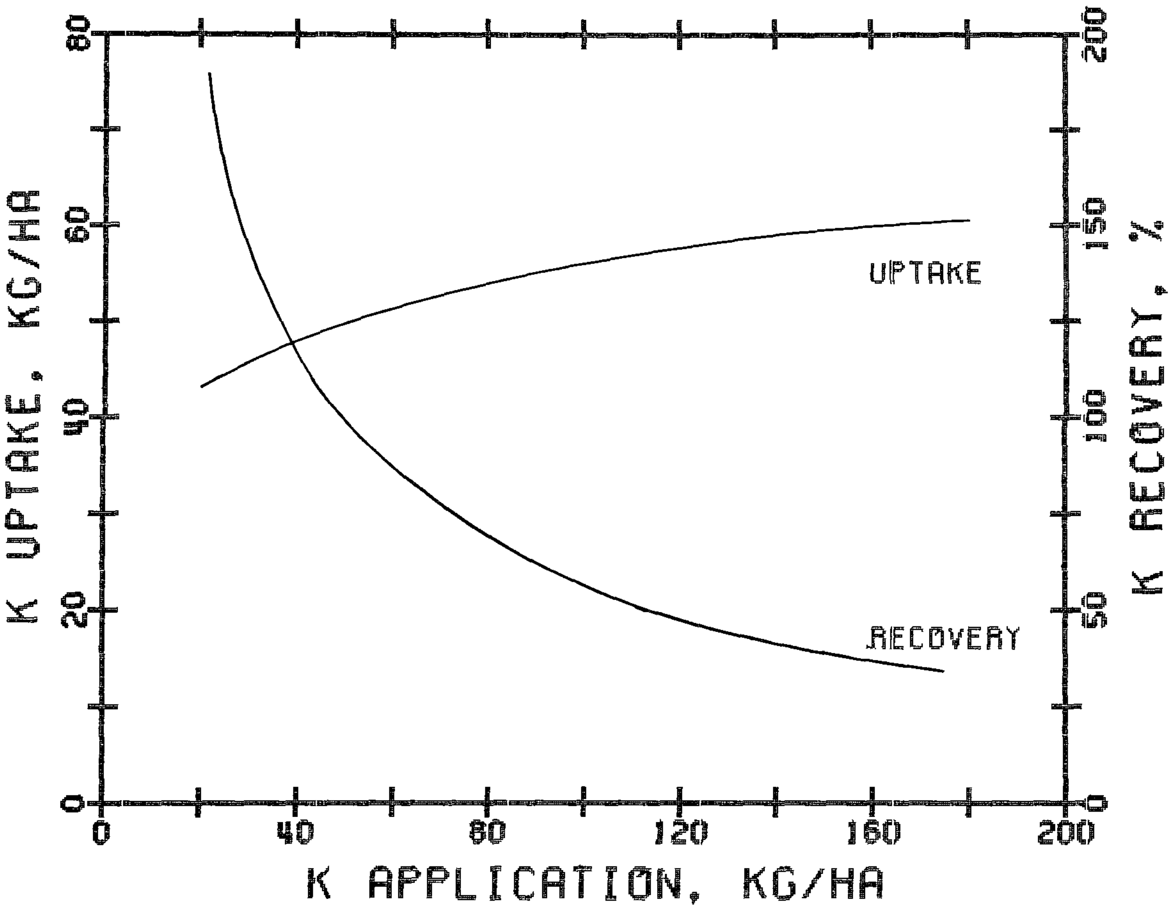

Figure 63. Estimated potassium recovery by kenaf.

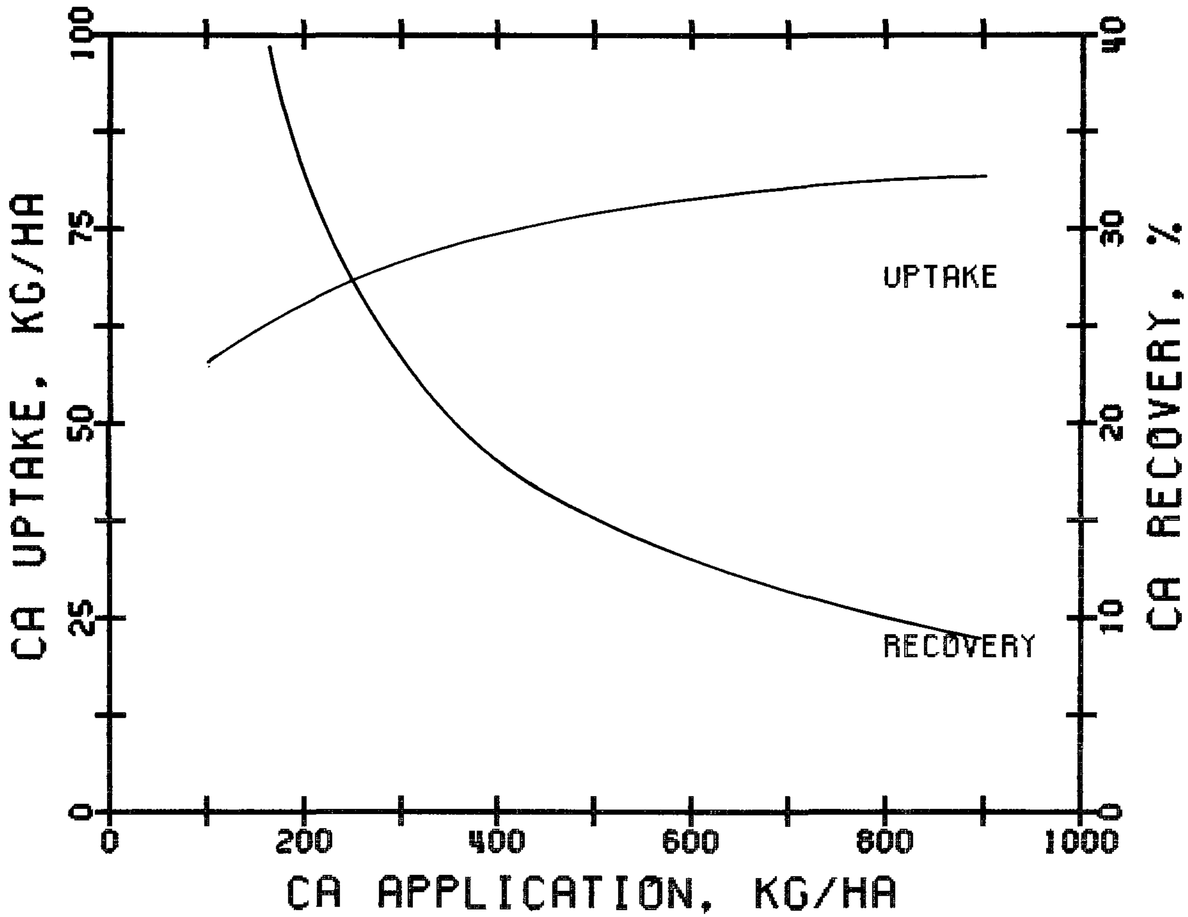

Figure 64. Estimated calcium recovery by kenaf.

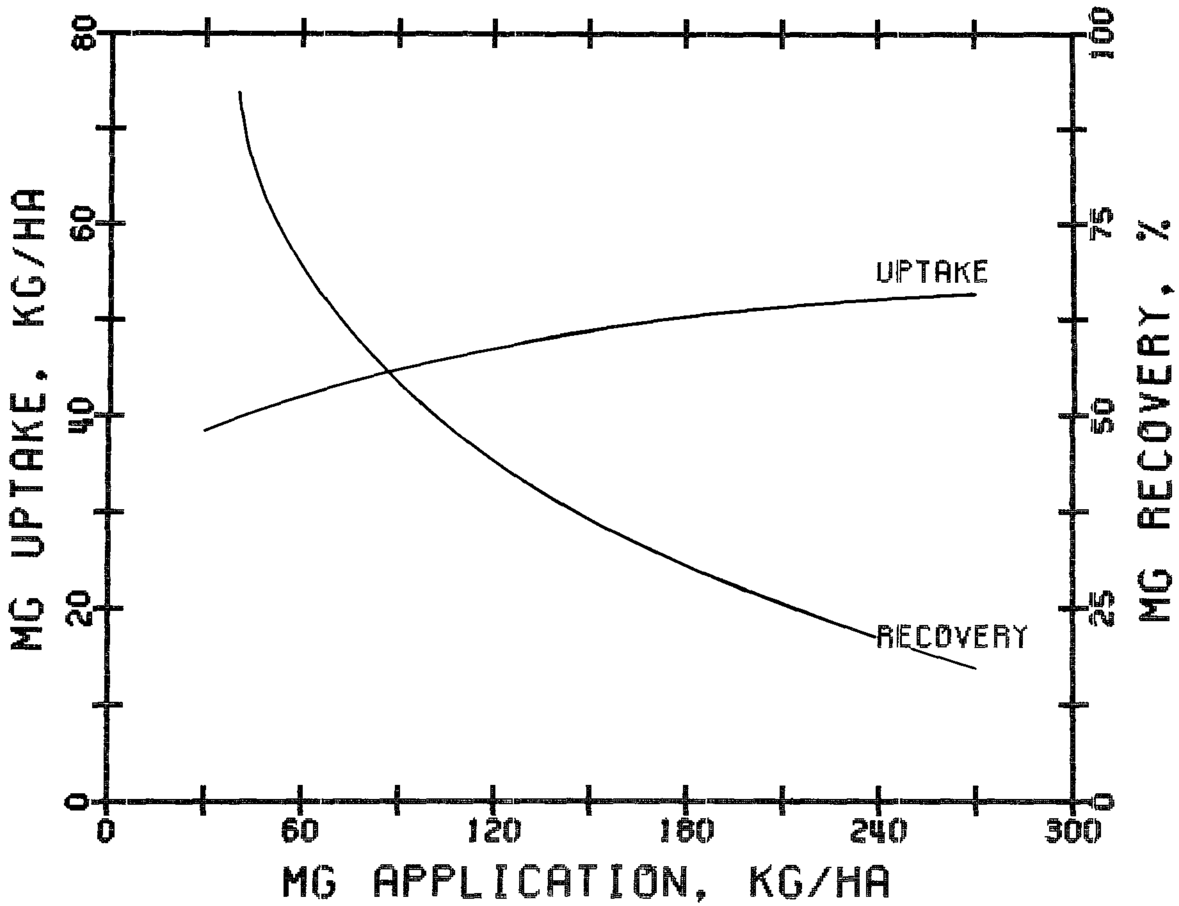

Figure 65. Estimated magnesium recovery by kenaf.

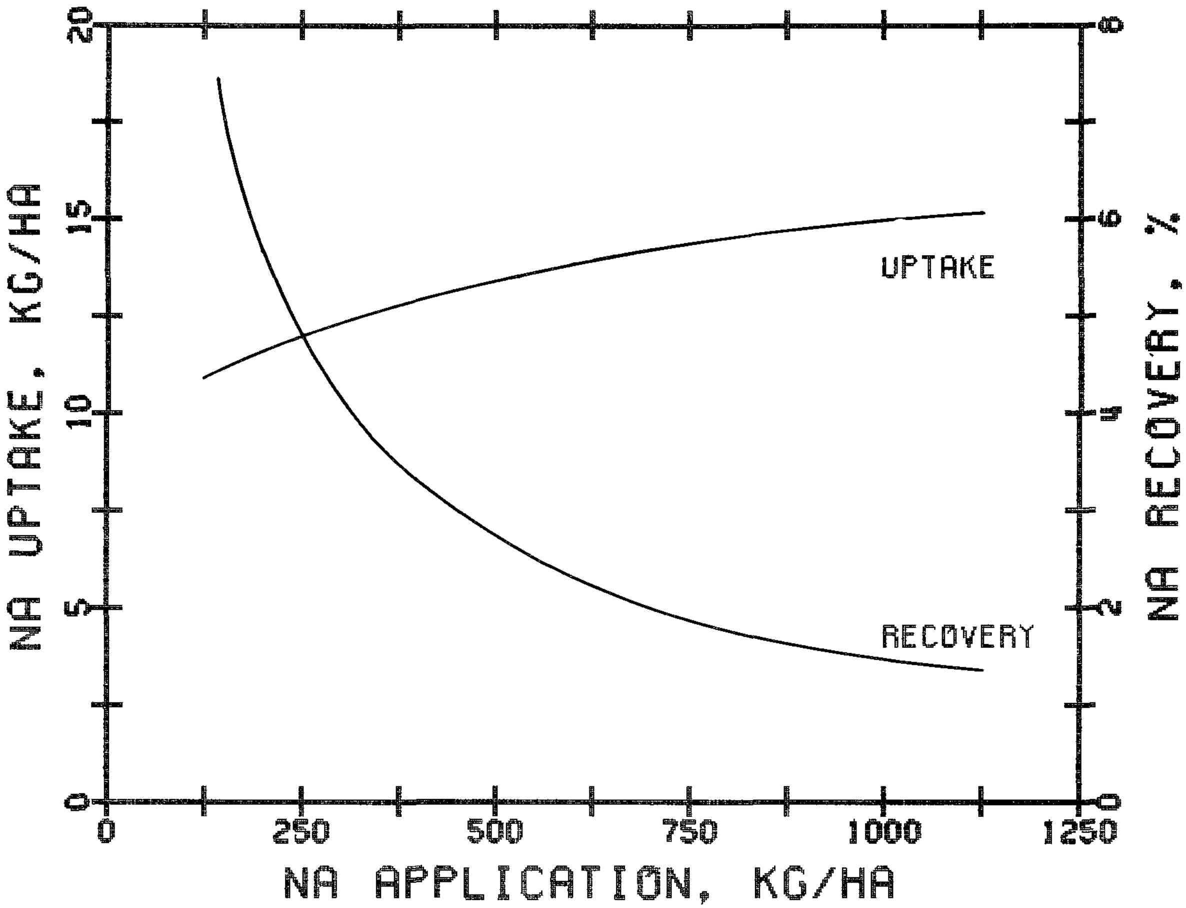

Figure 66. Estimated sodium recovery by kenaf.

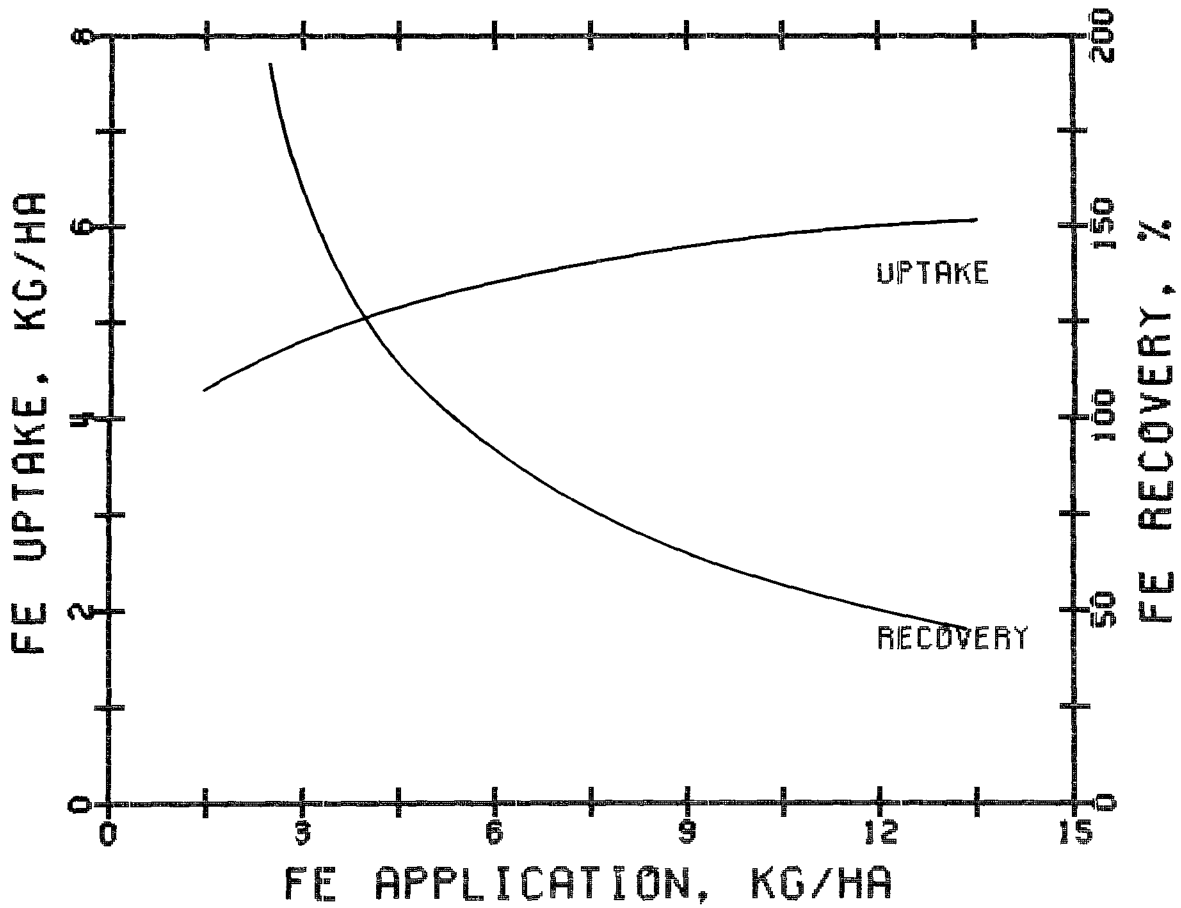

Figure 67. Estimated iron recovery by kenaf.

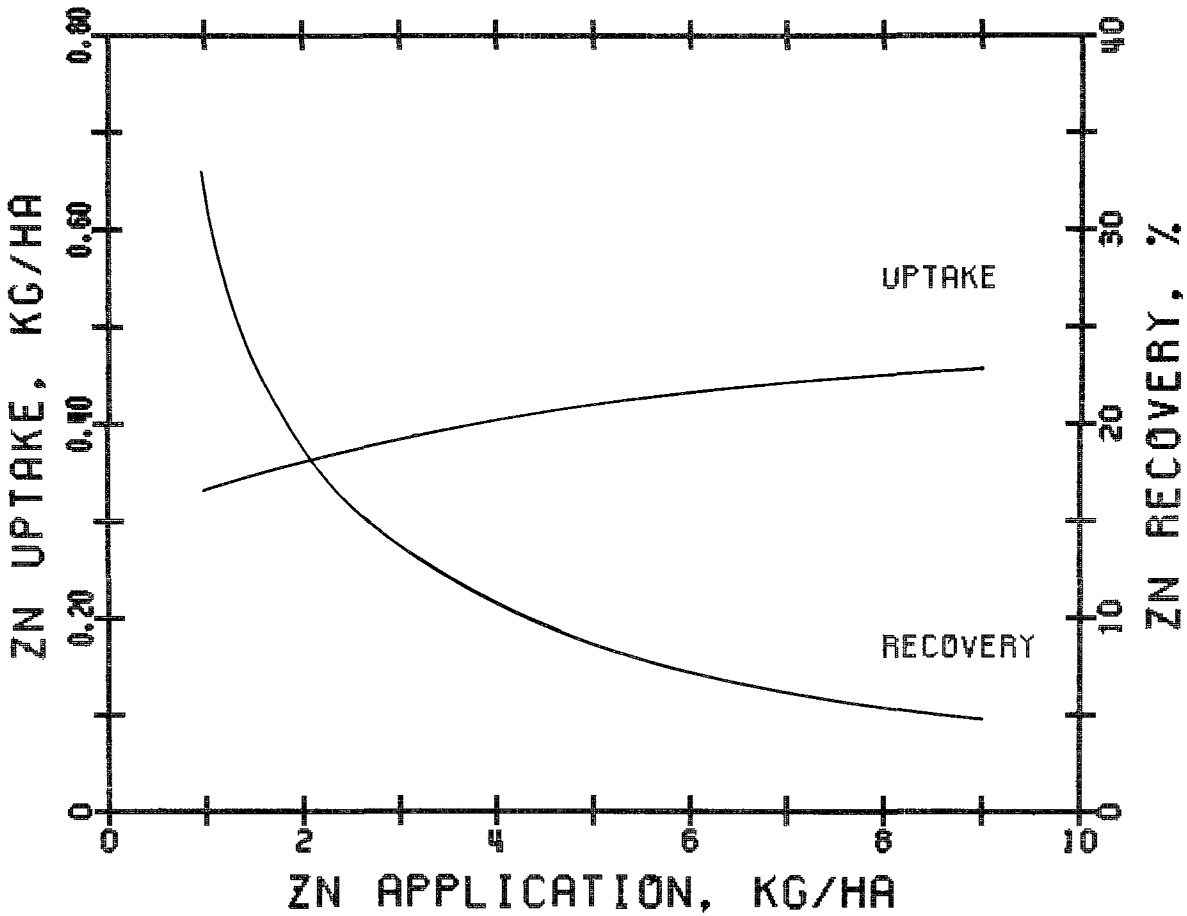

Figure 68. Estimated zinc recovery by kenaf.

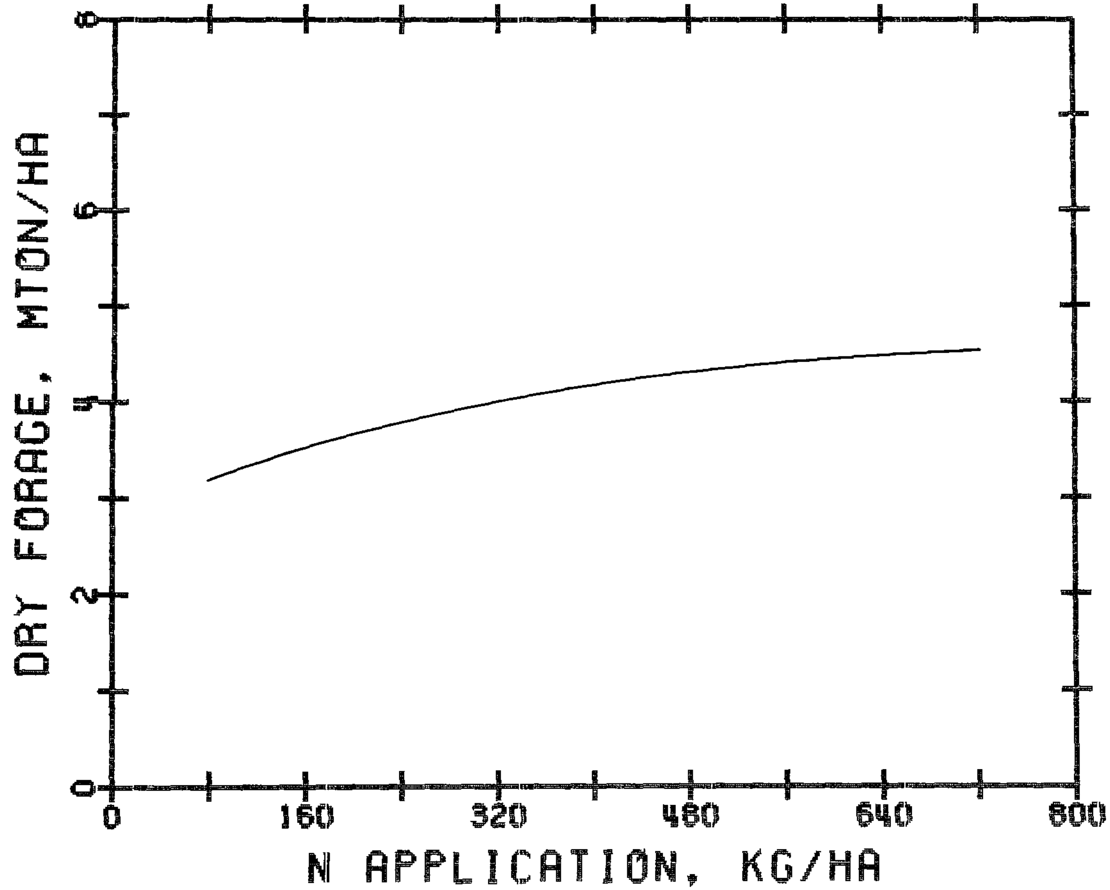

Figure 69. Estimated yield response of rye.

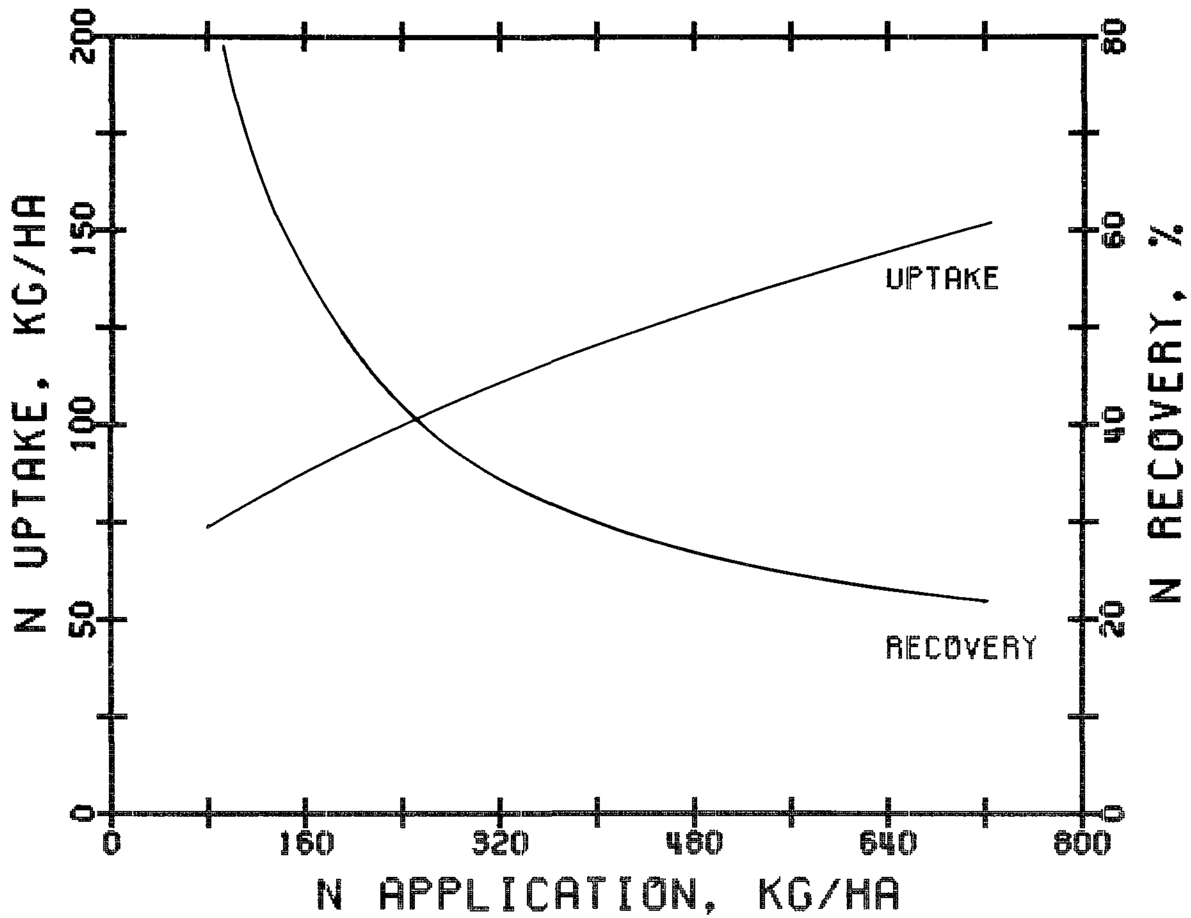

Figure 70. Estimated nitrogen recovery by rye.

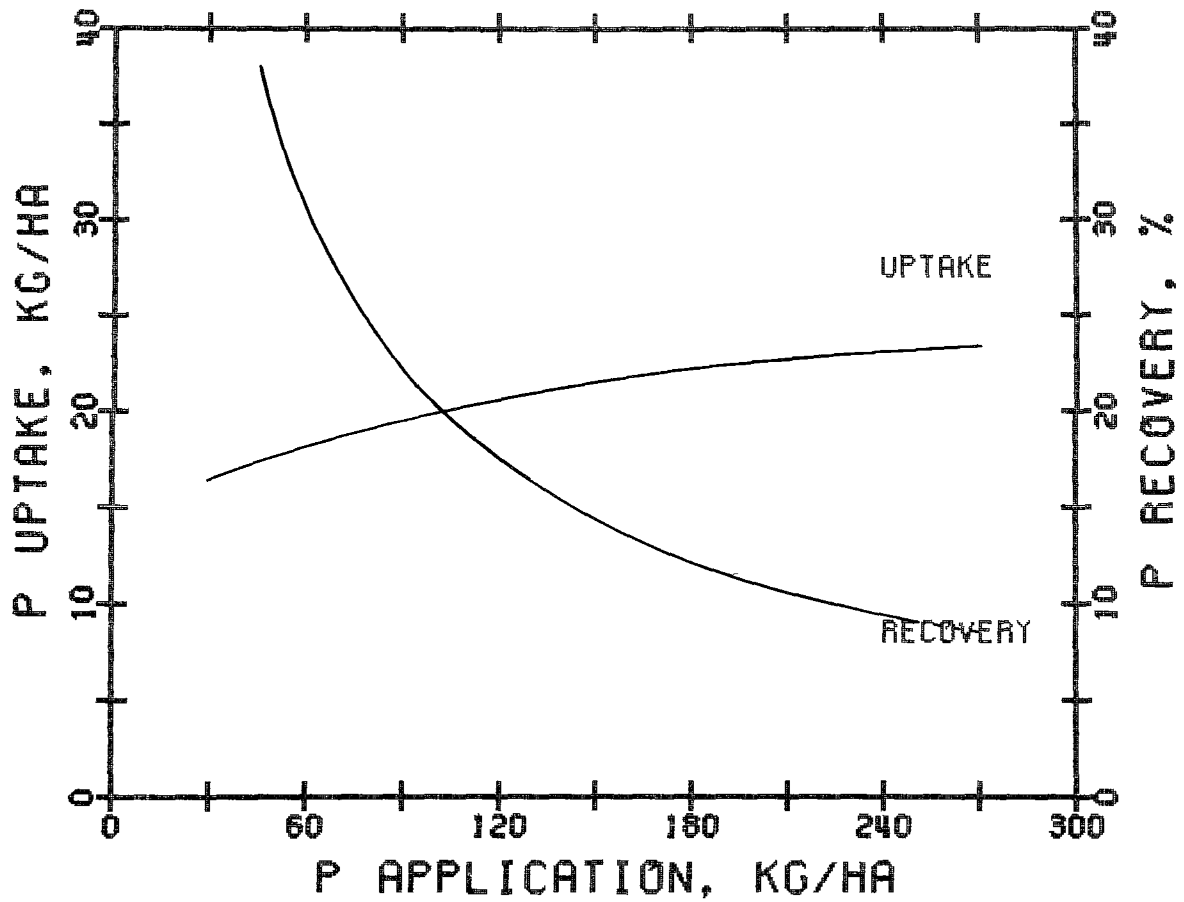

Figure 71. Estimated phosphorus recovery by rye.

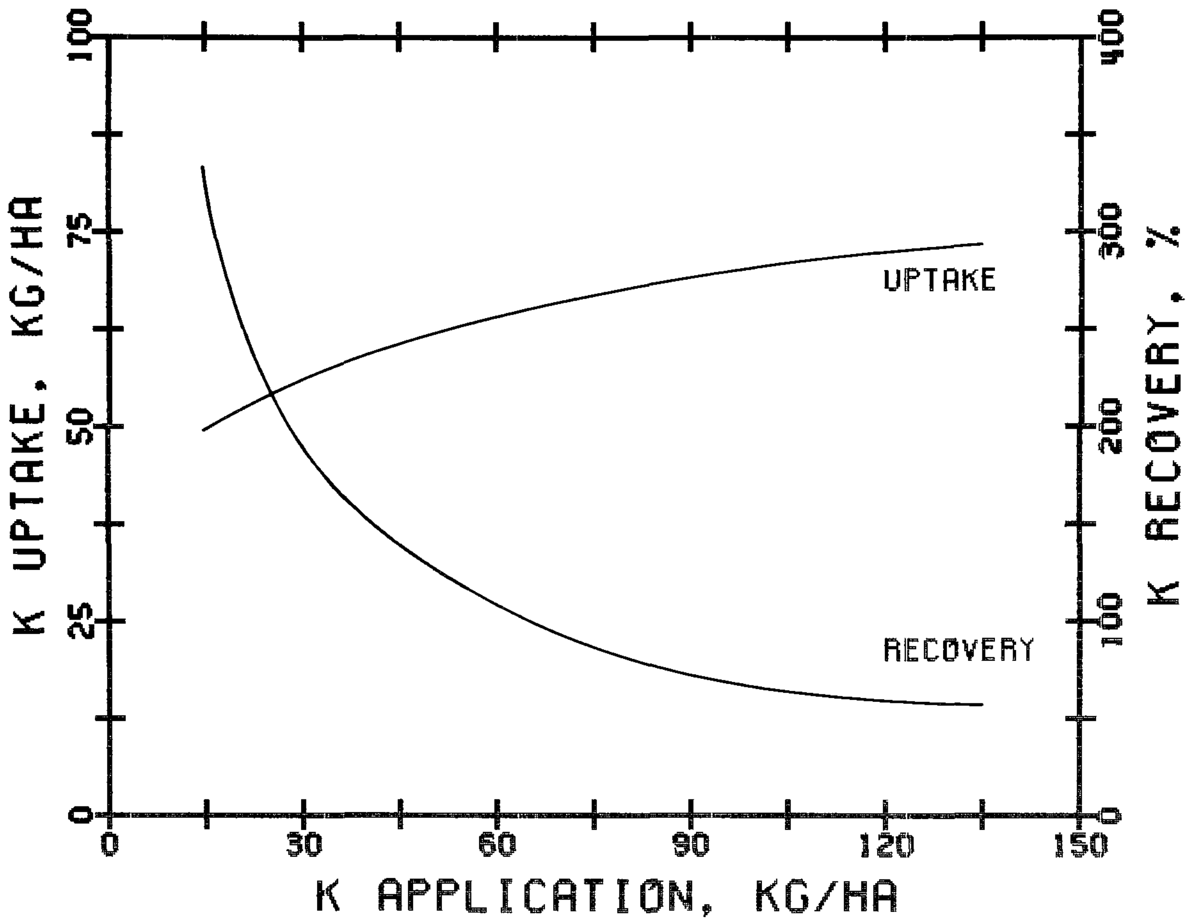

Figure 72. Estimated potassium recovery by rye.

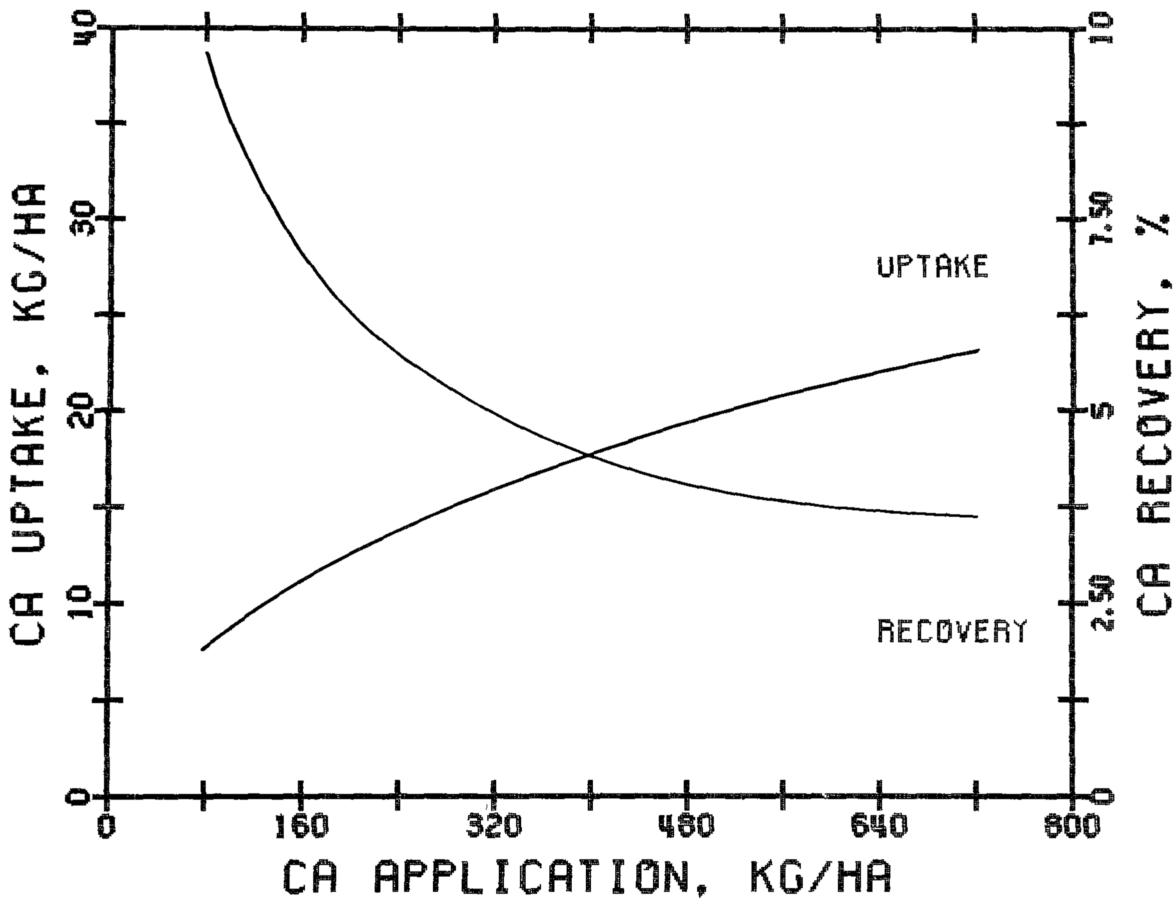

Figure 73. Estimated calcium recovery by rye.

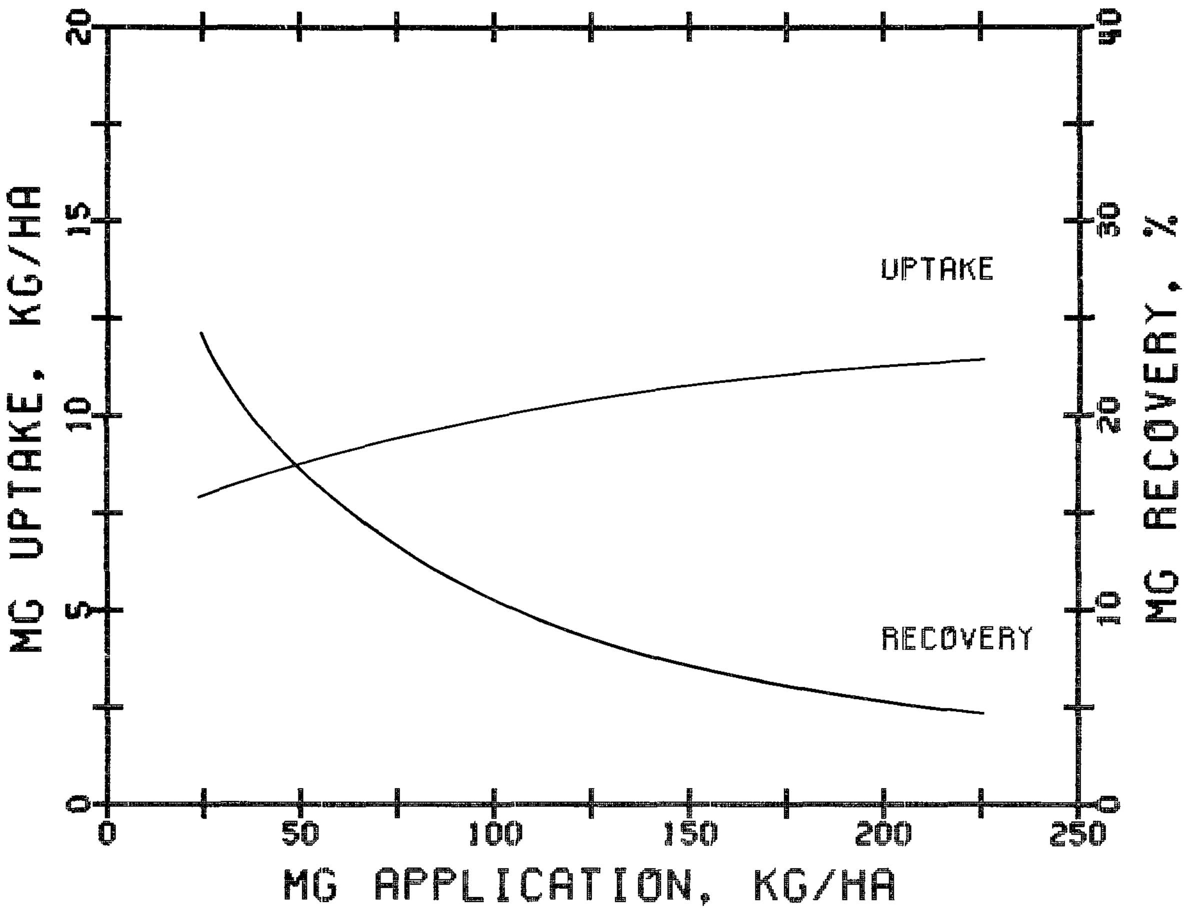

Figure 74. Estimated magnesium recovery by rye.

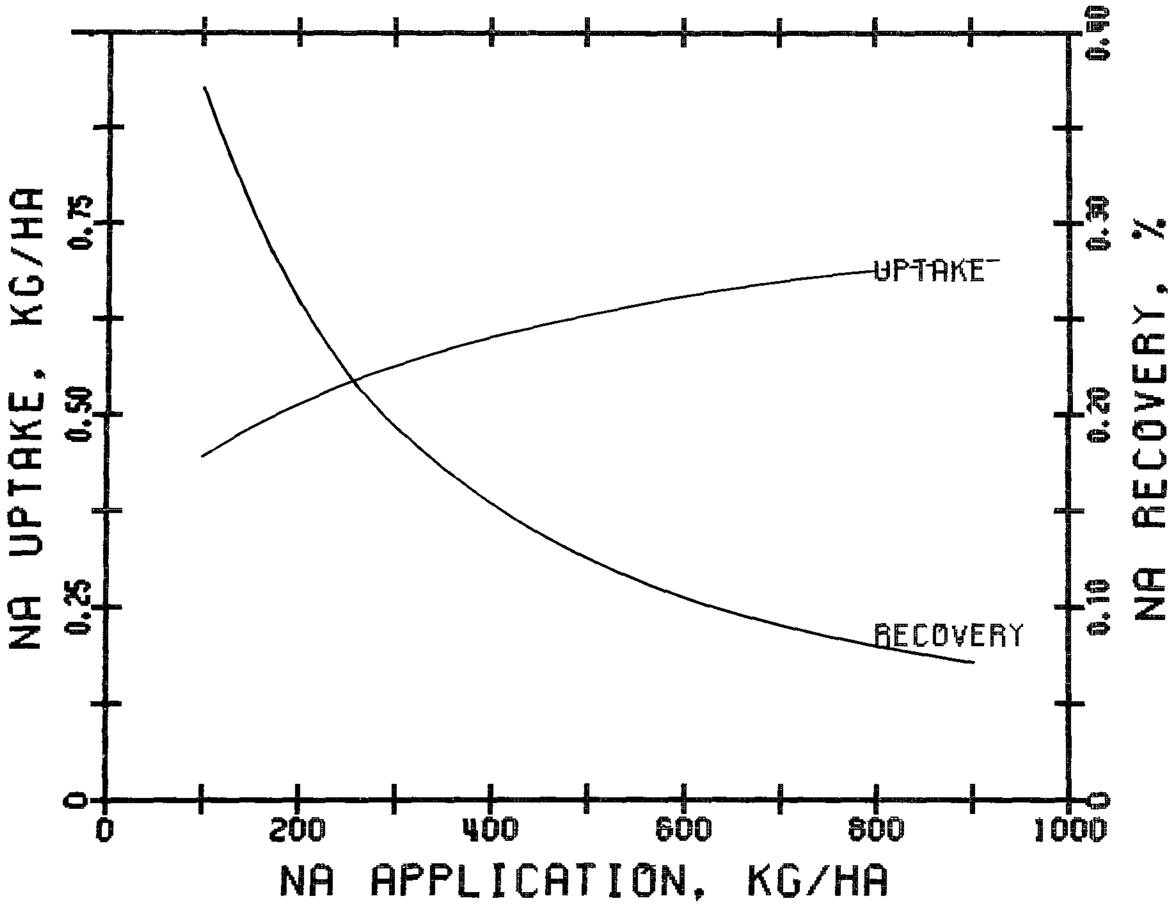

Figure 75. Estimated sodium recovery by rye.

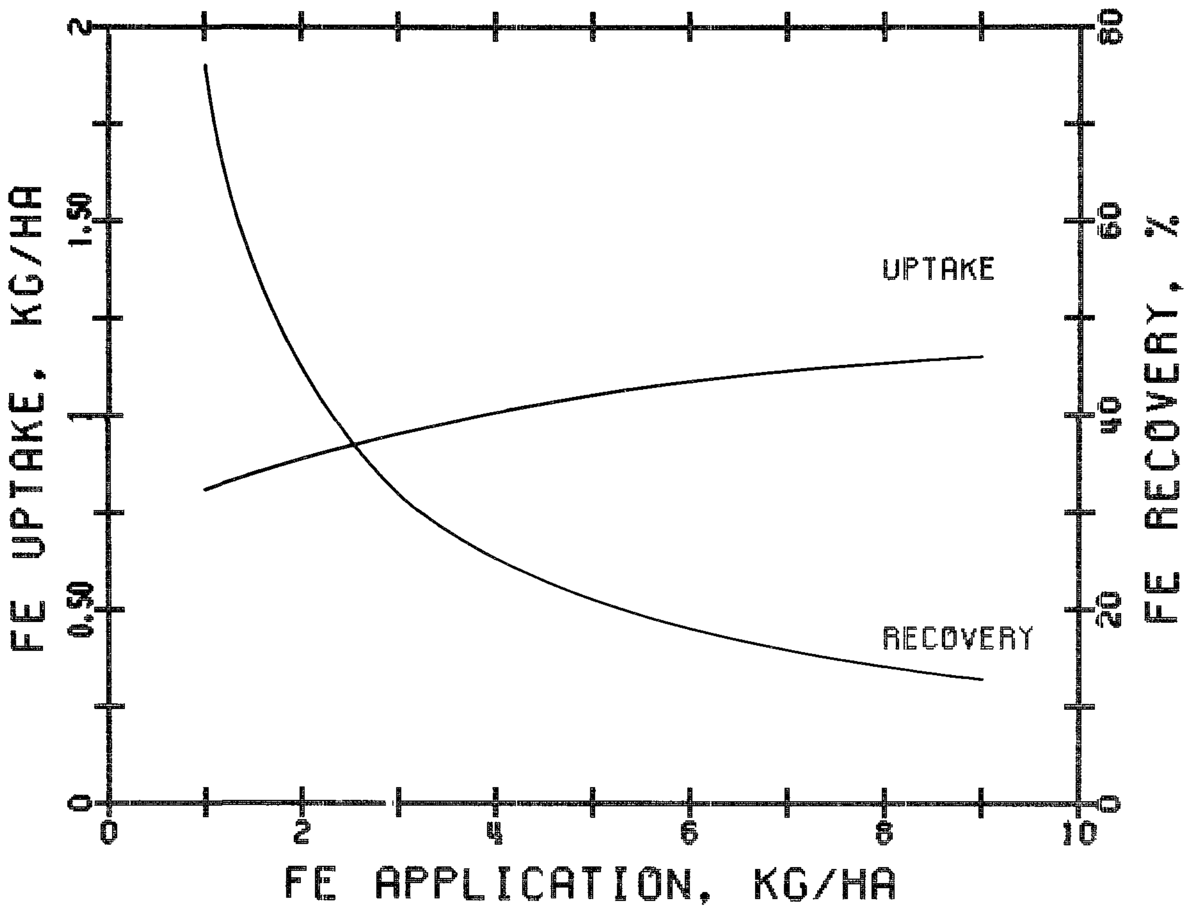

Figure 76. Estimated iron recovery by rye.

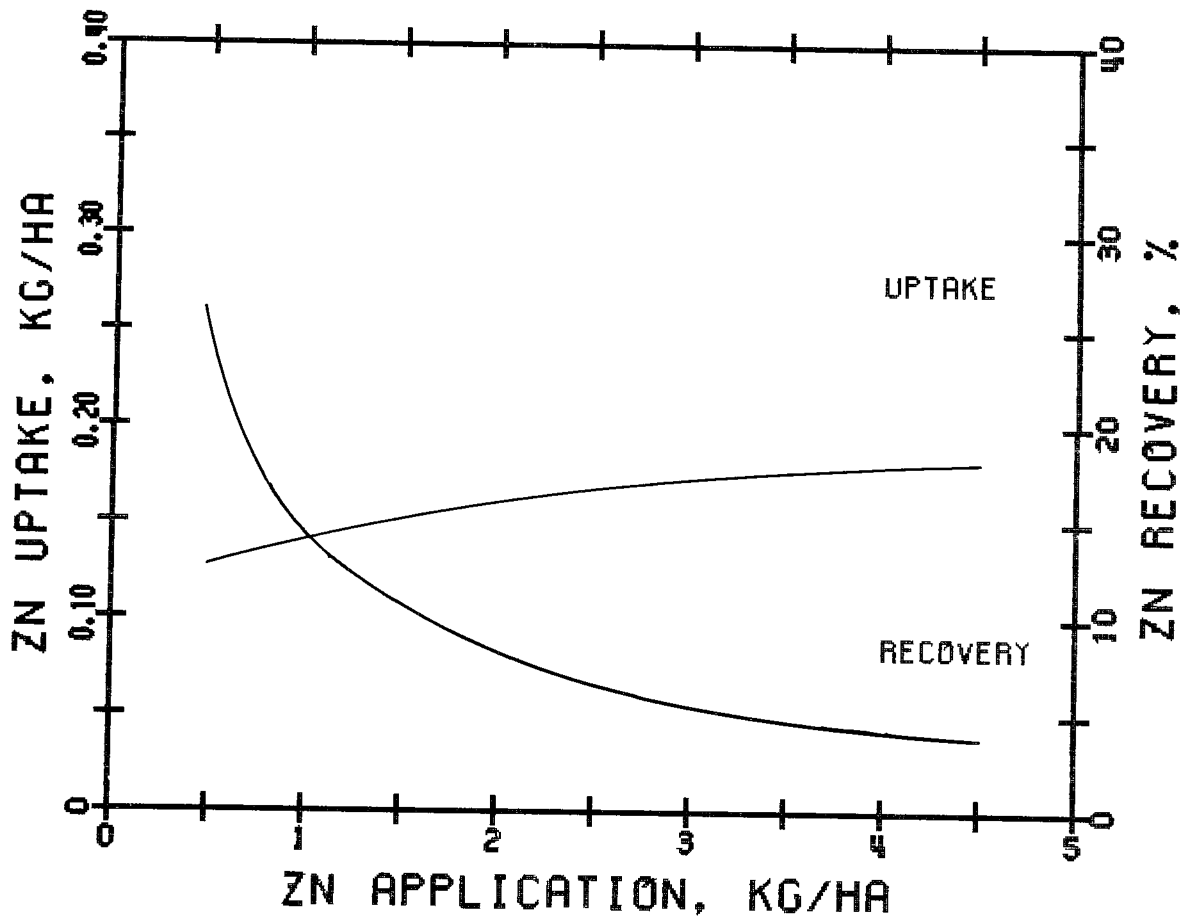

Figure 77. Estimated zinc recovery by rye.

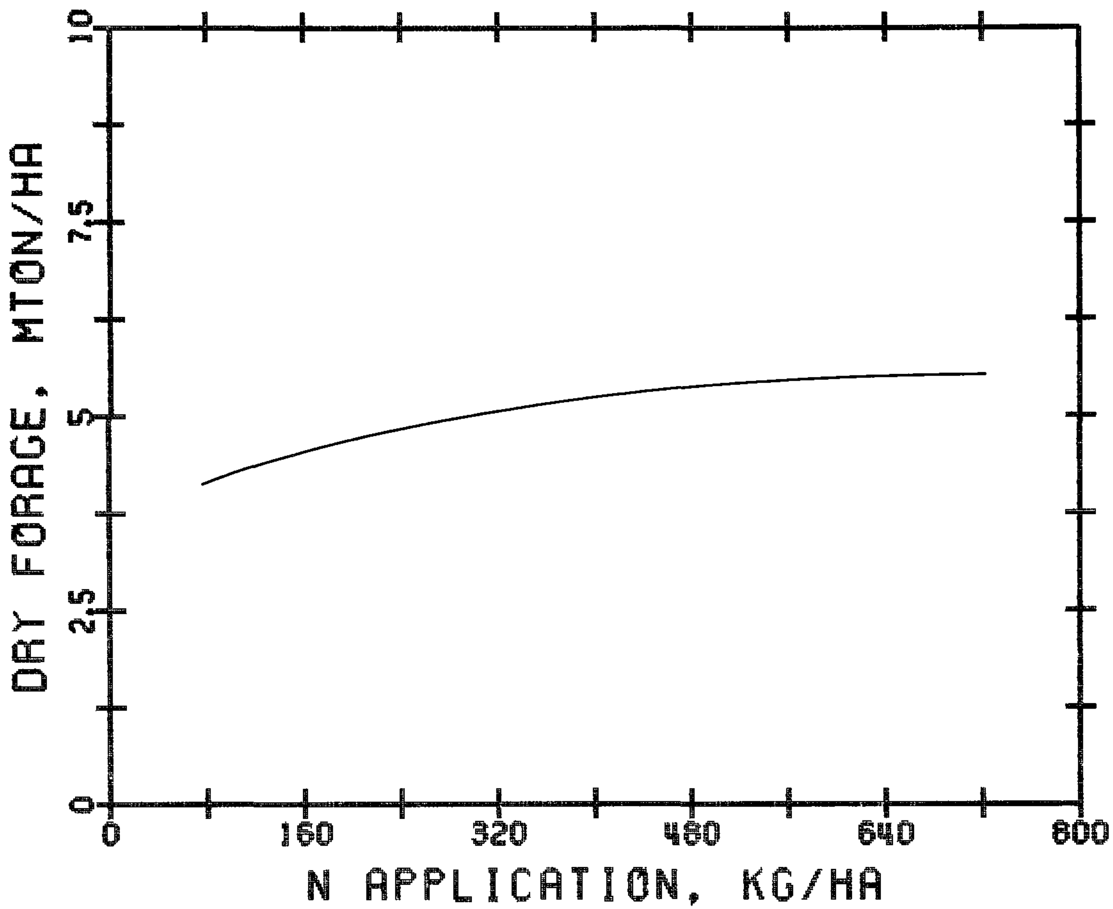

Figure 78. Estimated yield response of ryegrass.

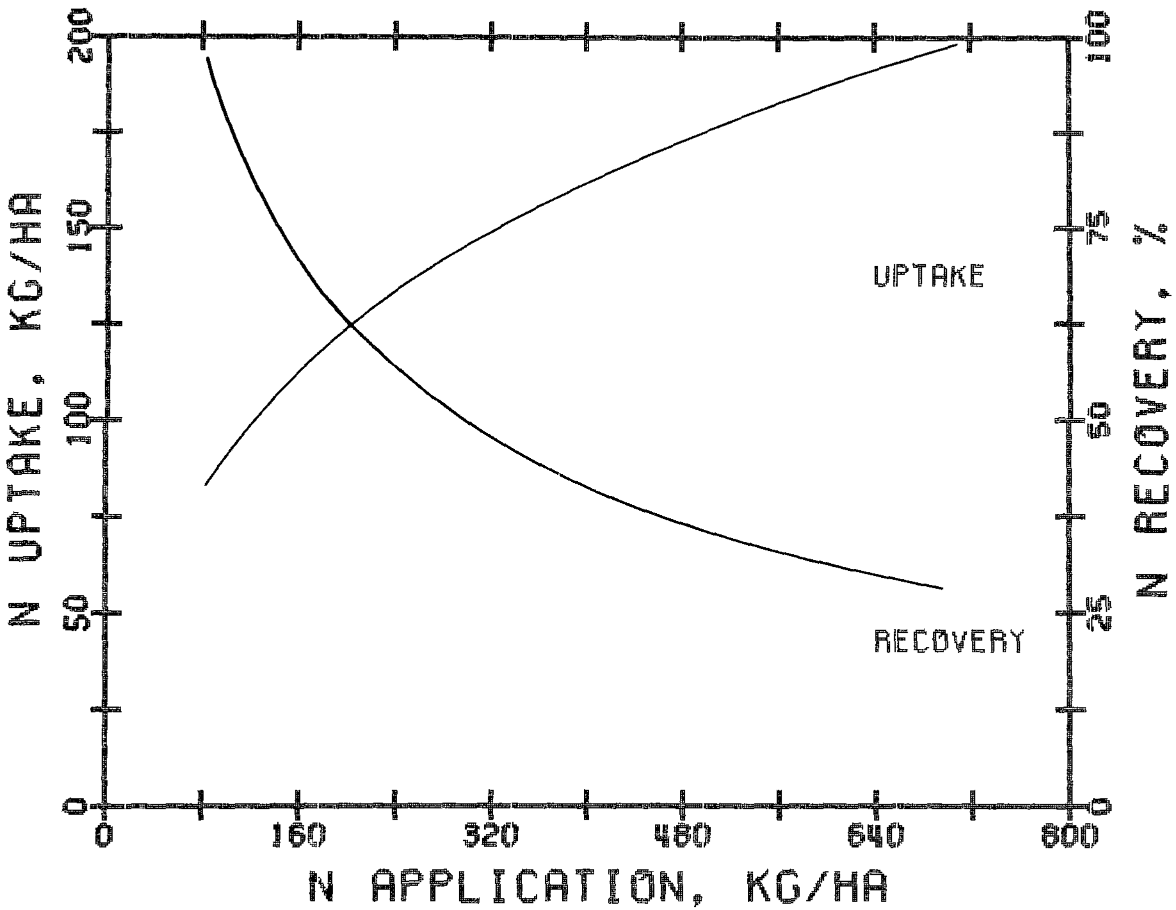

Figure 79. Estimated nitrogen recovery by ryegrass.

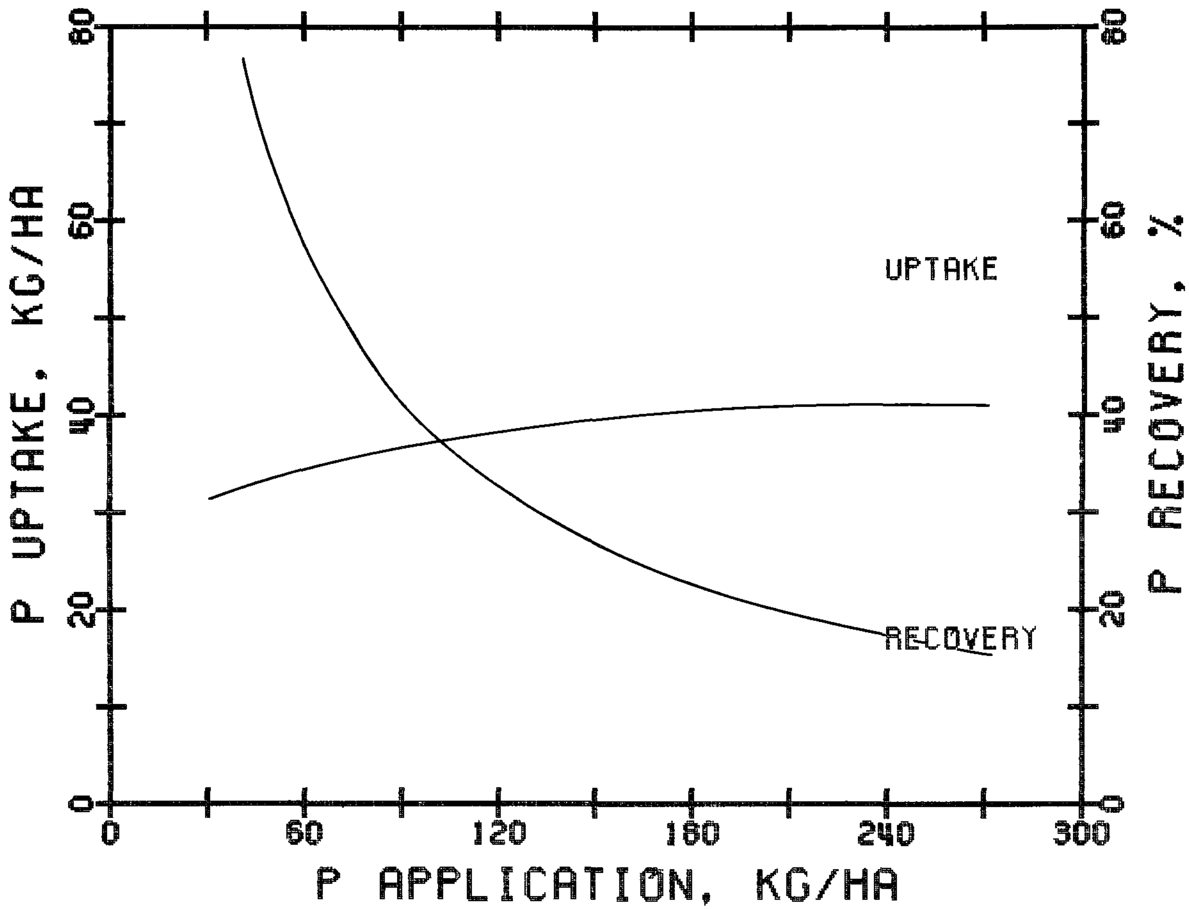

Figure 80. Estimated phosphorus recuvery by ryegrass.

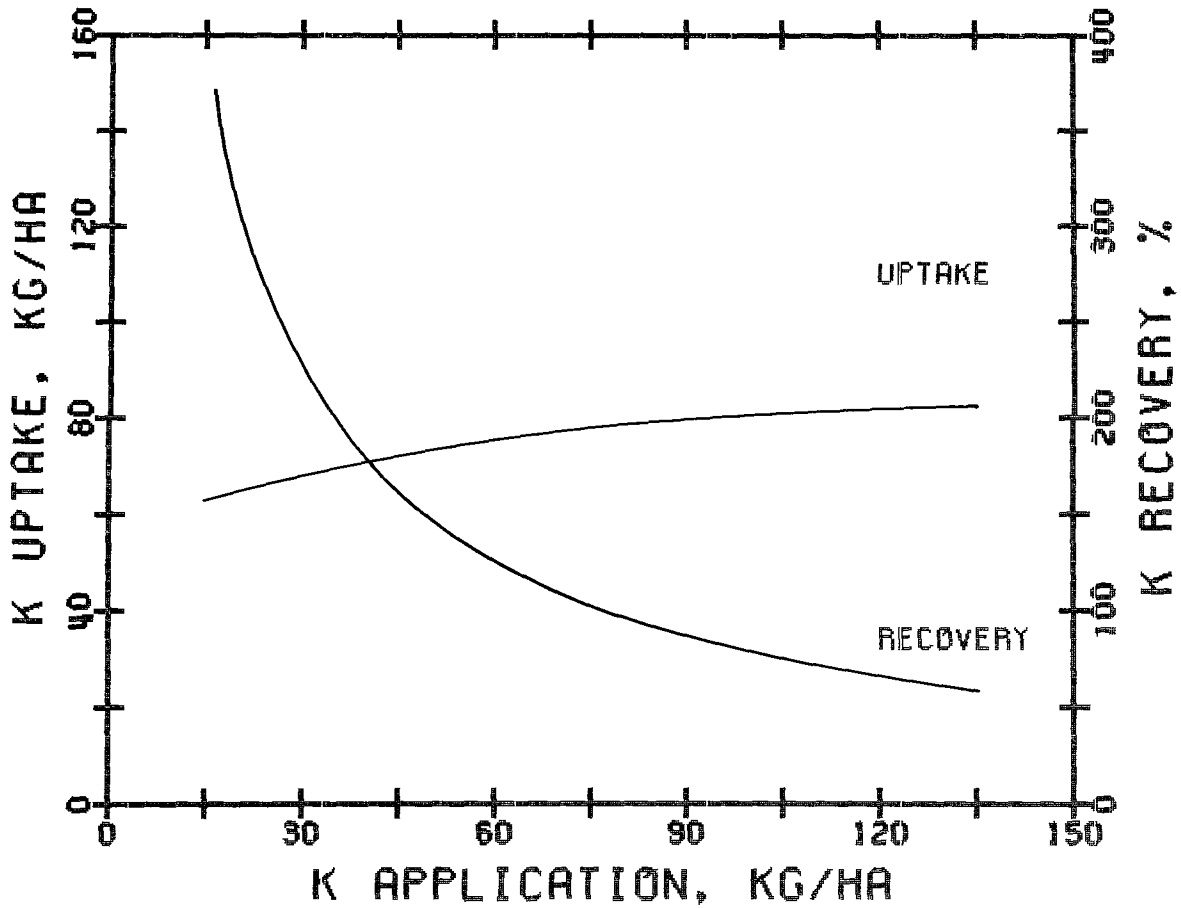

Figure 81. Estimated potassium recovery by ryegrass.

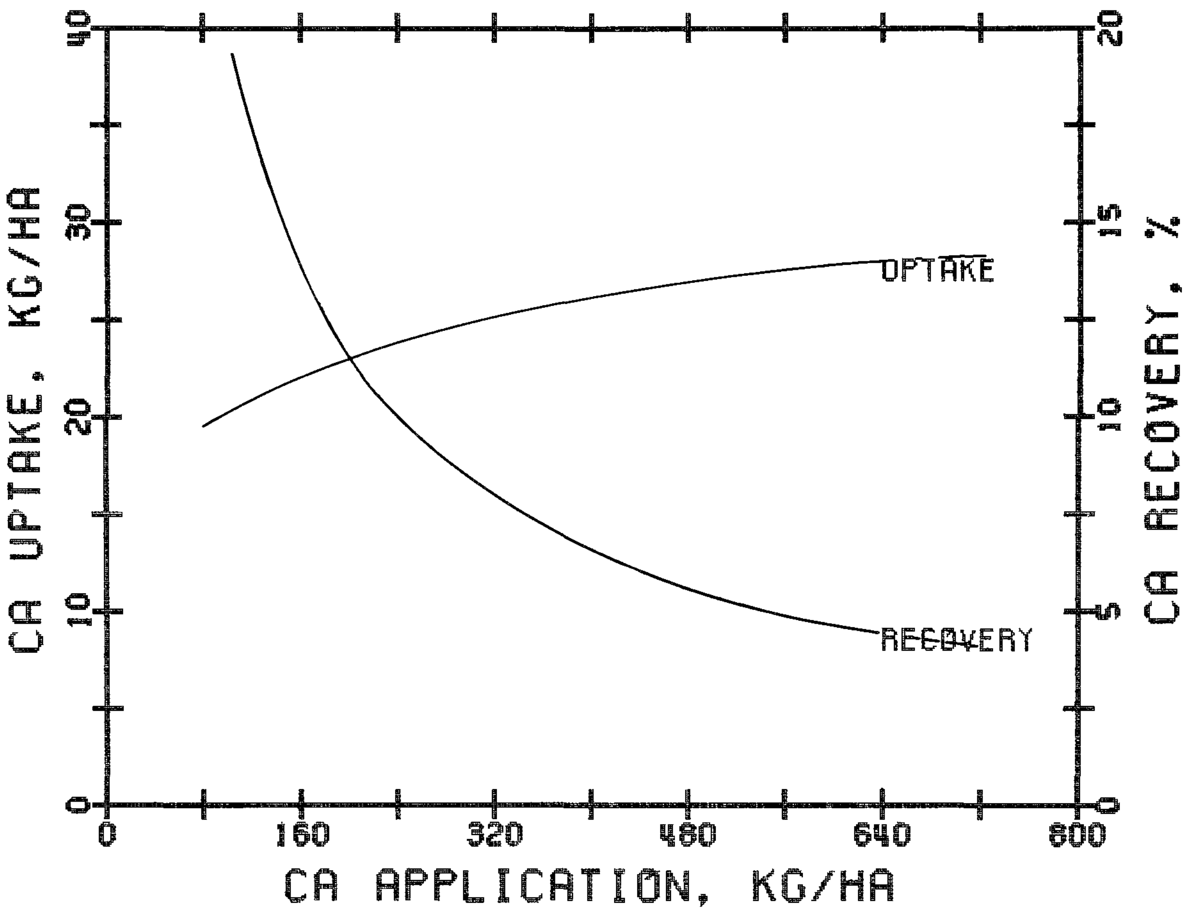

Figure 82. Estimated calcium recovery by ryegrass.

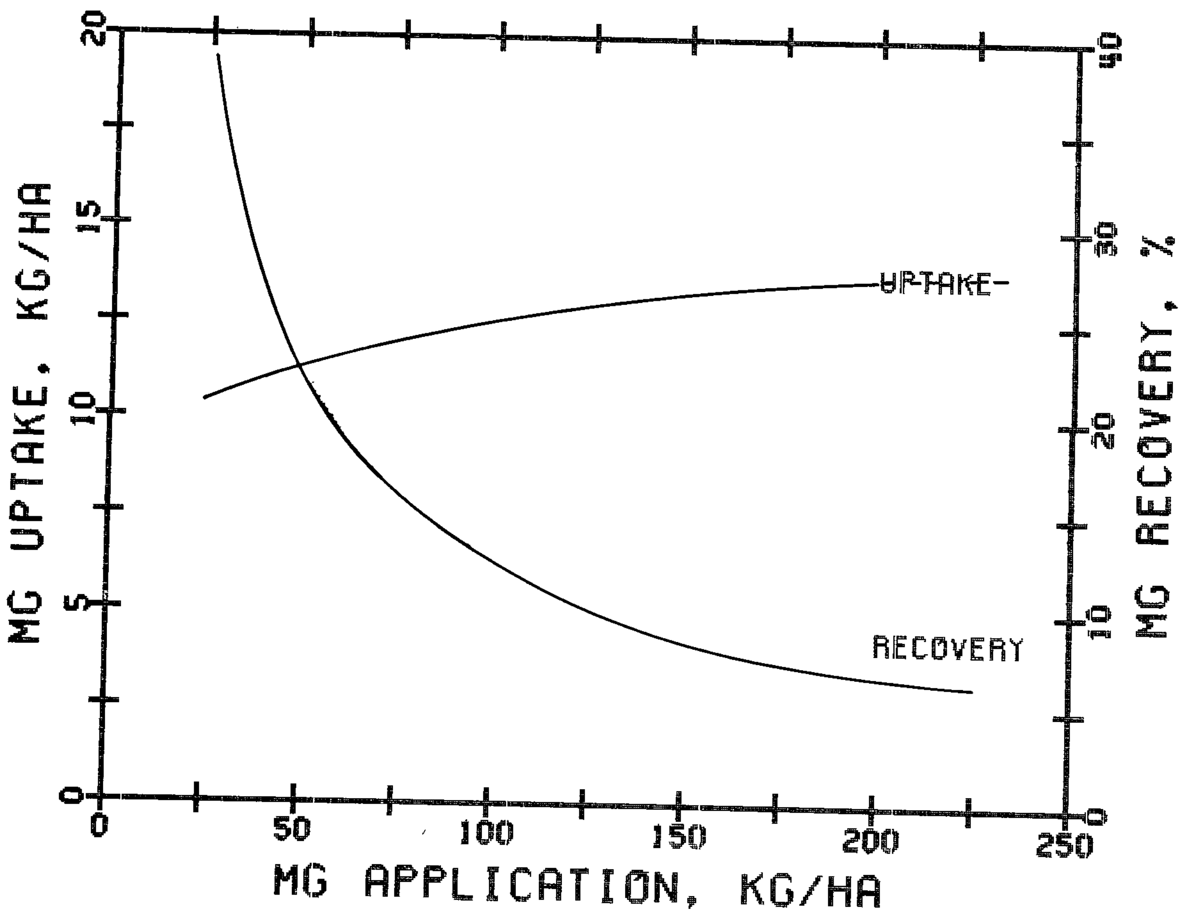

Figure 83. Estimated magnesium recovery by ryegrass.

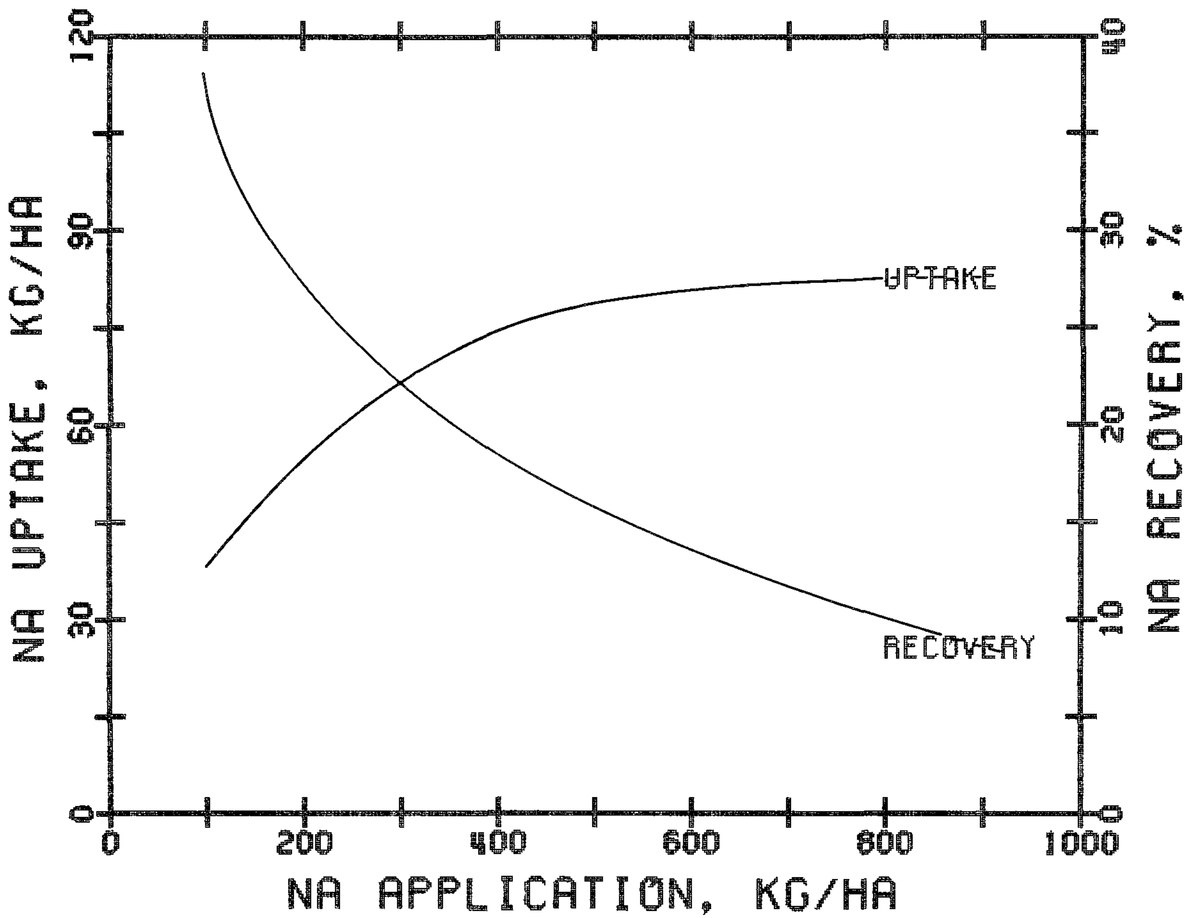

Figure 84. Estimated sodium recovery by ryegrass.

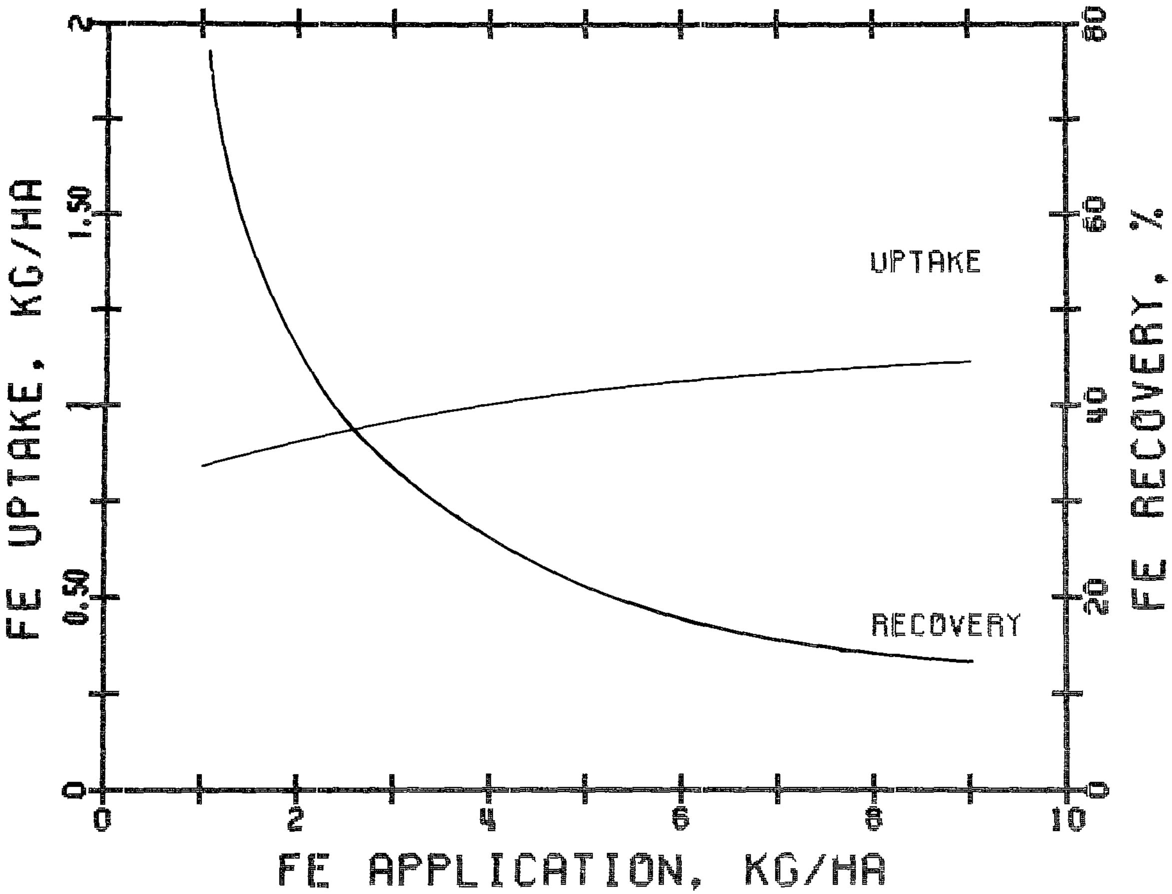

Figure 85. Estimated iron recovery by ryegrass.

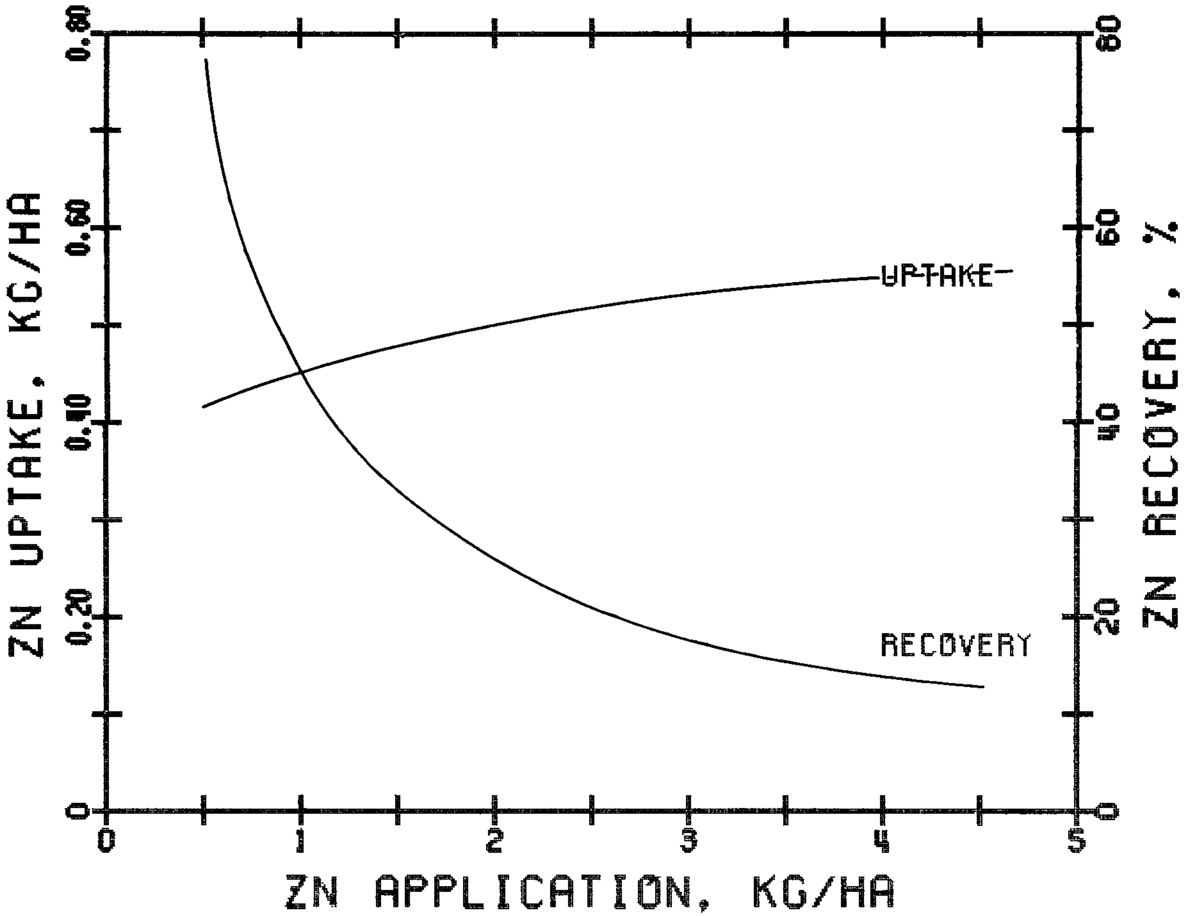

Figure 86. Estimated zinc recovery by ryegrass.

Parks and Fisher (1958) were approximately: P = 0.25%, K = 3.0%, Ca = 0.7% and Mg = 0.5%. These differences probably reflected differences in chemical ratios applied, soil characteristics and crop variety. As with rye, K uptake exceeded application (Figure 81) at the lower rates, indicating potential deficiency and need for supplemental K. Other elements appeared to be available in adequate amounts (Figures 79-86). A beneficial effect was provided by Fe and Zn as with rye.

Three cuttings would be expected. At 160 kg/ha (140 lb/acre) of applied N, yield of dry forage was estimated to be 4 mtons/ha (1.8 tons/acre) from Figure 78. The corresponding yield of greenchop (15% dry matter) was 27 mtons/ha (12 tons/acre).

GROWTH RESPONSE OF CROPS

Introduction

In 1972, field experiments were conducted to measure plant growth and nitrogen uptake with age under effluent irrigation. The crops studied and their varieties are listed in Table 23. Plots were 30 m x 30 m (100 ft x 100 ft). Irrigation rates were 50, 100, 150 and 200 mm/week at an intensity of 13 mm/hr (0.5 in./hr) following the schedule in Table 24. All plots were prepared by disking, plowing and disking. All crops were planted on April 23, 1972 in 0.9 m x 30 m (3 ft x 100 ft) rows. Seeding rates were as follows: corn 17 kg/ha, sorghum x sudangrass - 11 kg/ha and kenaf - 11 kg/ha. Beginning in the fourth week after planting, duplicate samples, 91.5 cm x 91.5 cm in size, were clipped from each plot. Samples were weighed, chopped, dried at 70°C for 24 hours, and weighed again. Composite samples were ground in a Wiley mill and triplicate 0.500 g samples were analyzed for Kjeldahl_N (USEPA 1971). Composite effluent samples were collected each week and analyzed for Kjeldahl-N (USEPA, 1971) and for NO_3-N.

Some aspects of this study have been discussed elsewhere (Overman and Nguy, 1975 and Overman, 1975).

Results

Measurements and estimates were made of green weight, dry matter content, dry weight, nitrogen content, nitrogen uptake and nitrogen recovery. Estimates were made of harvest time for optimum nitrogen recovery.

Corn - Pioneer 3369 A

Forage data were collected for irrigation rates of 50, 100, 150 and 200 mm/week. Yield of green forage increased with age (Table 25-28). Dry matter content showed a concurrent increase, while N content decreased (Figure 87a). The crop showed a resultant increase in dry forage with age and also with irrigation rate (Figure 87b). These trends have been reported by Bar-Yosef and Kafkafi (1972).

TABLE 23. CROPS AND VARIETIES USED IN GROWTH STUDY

Crop	Variety
Corn	Pioneer 3369A McNair 440V
Sorghum x sudangrass	Asgrow Grazer S
Kenaf	Everglades 41

TABLE 24. IRRIGATION SCHEDULE FOR GROWTH STUDY

Rate mm/week	Dose mm/irrigation	Application day of week
50	50	Wed.
100	50	Tues., Thurs.
150	50	Mon., Wed., Fri.
200	50	Mon., Tues., Thurs., Fri.

TABLE 25. GROWTH RESPONSE OF CORN (PIONEER 3369A) AT 50 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
25	0.41	11.8	0.048	3.36	1.6
32	1.12	12.2	0.14	3.68	5.1
39	2.00	11.7	0.23	2.64	6.1
47	5.72	12.2	0.70	2.71	19
53	14.7	10.6	1.56	1.51	24
60	20.6	12.0	2.48	1.50	37
67	31.6	16.4	5.19	1.25	65
77	30.5	20.8	6.34	0.95	60
84	25.9	24.4	6.31	1.11	70
95	50.0	21.4	10.7	1.70	182

TABLE 26. GROWTH RESPONSE OF CORN (PIONEER 3369A) AT 100 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
25	0.48	12.5	0.060	3.36	2.0
32	2.21	11.1	0.24	3.48	8.3
39	5.28	10.3	0.54	3.28	18
47	12.0	9.7	1.16	2.88	33
53	27.5	11.0	3.02	-	-
60	43.5	13.6	5.91	1.85	109
67	52.5	14.6	7.65	1.28	98
77	59.4	19.6	11.6	1.22	141
84	64.8	22.4	14.5	1.06	154
95	65.4	20.0	13.1	1.41	185

TABLE 27. GROWTH RESPONSE OF CORN (PIONEER 3369A) AT 150 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
25	0.54	12.1	0.065	3.43	2.2
32	2.01	10.4	0.21	3.37	7.1
39	4.20	10.2	0.43	3.27	14
47	12.9	10.2	1.32	2.30	30
53	25.8	9.0	2.32	-	-
60	41.1	12.2	5.00	2.44	122
67	48.3	13.8	6.67	1.49	99
77	69.0	19.4	13.4	1.31	175
84	87.0	25.8	22.5	1.33	300
95	64.4	20.3	13.1	1.28	168

TABLE 28. GROWTH RESPONSE OF CORN (PIONEER 3369A) AT 200 MM/WEEK

Age days	Dry Weight mtons/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
25	0.65	18.5	0.12	3.61	4.3
32	2.04	14.1	0.29	3.71	11
39	5.16	11.2	0.58	3.37	20
47	16.1	11.0	1.77	2.52	45
53	31.0	9.8	3.04	2.32	70
60	43.0	15.2	6.53	2.63	172
67	62.8	14.0	8.80	1.31	115
77	75.0	16.4	12.3	1.29	159
84	99.8	20.0	20.0	1.51	302
95	70.0	17.6	12.3	1.46	180

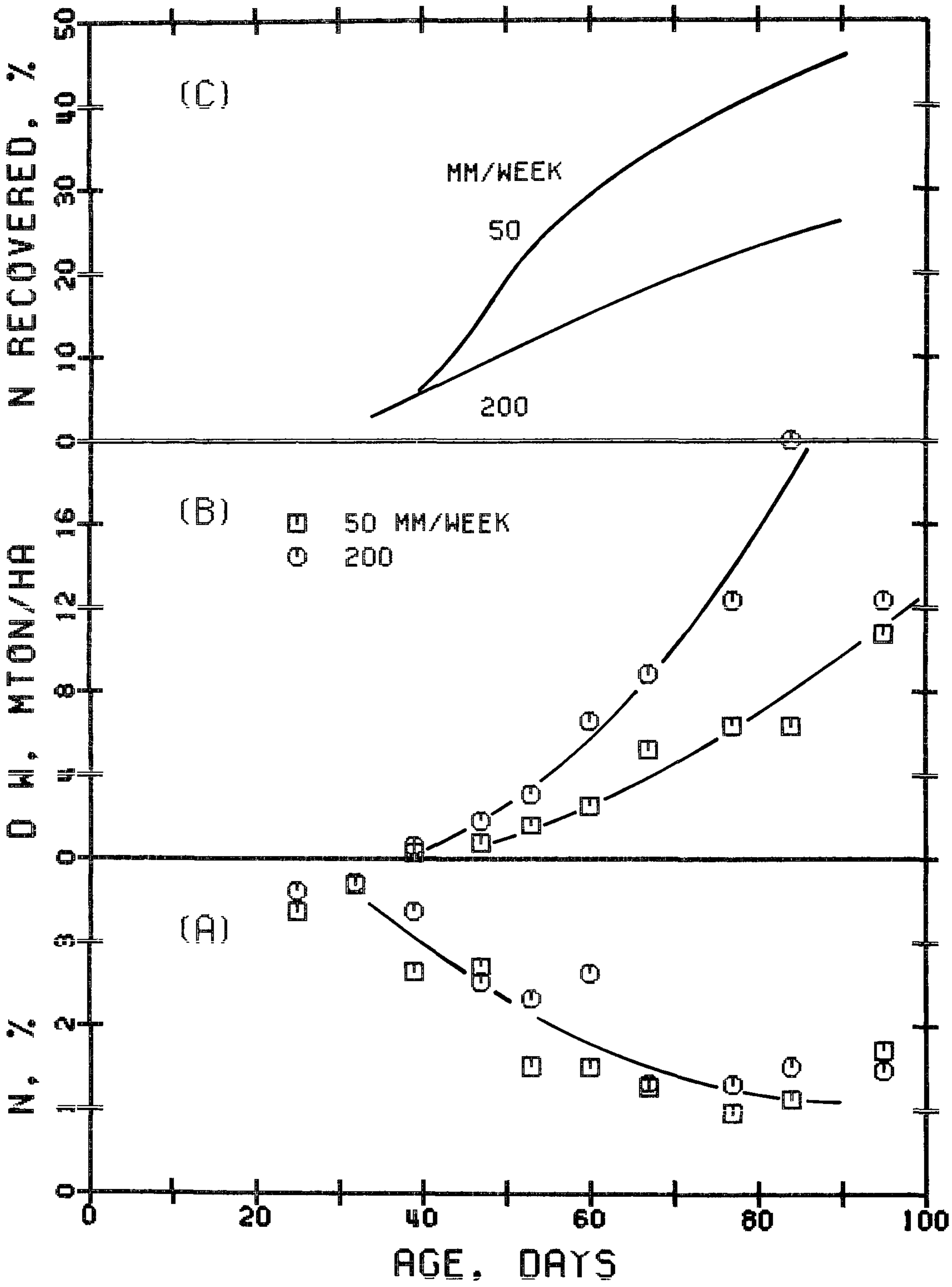

Figure 87. Response of nitrogen content, dry weight and nitrogen recovery for corn (Pioneer 3369A).

TABLE 29. ESTIMATED YIELD AND NITROGEN RESPONSE OF CORN (PIONEER 3369A) AT 50 AND 200 MM/WEEK

		50 mm/week		200 mm/week	
Age days	N %	Dry Weight mton/ha	N kg/ha	Dry Weight mton/ha	N kg/ha
30	3.80	-	-	-	-
35	3.40	0.05	2	0.3	10
40	3.00	0.2	6	0.7	21
45	2.60	0.5	13	1.4	36
50	2.25	1.1	25	2.3	52
55	1.95	1.8	35	3.7	72
60	1.70	2.7	46	5.6	95
65	1.50	3.7	56	7.6	114
70	1.35	4.7	64	10.0	135
75	1.25	5.8	73	12.7	159
80	1.20	7.1	85	15.7	188
85	1.15	8.3	96	18.8	216
90	1.10	9.7	107	22.1	242

TABLE 30. ESTIMATED NITROGEN RECOVERY BY CORN (PIONEER 3369A) AT 50 AND 200 MM/WEEK

	50 mm/week			200 mm/week		
Age days	Harvested kg/ha	Applied kg/ha	Recovered %	Harvested kg/ha	Applied kg/ha	Recovered %
35	2	90	2	10	360	3
40	6	103	6	21	412	5
45	13	116	11	36	464	8
50	25	129	19	52	516	10
55	35	142	25	72	568	13
60	46	155	30	95	620	15
65	56	168	33	114	672	17
70	64	180	36	135	720	19
75	73	193	38	159	772	21
80	85	206	41	188	824	23
85	96	219	44	216	876	25
90	107	232	46	242	928	26

Due to the scatter obtained for both N content and dry weights, smooth curves were visually fitted to the data. A single curve was used for N content (Figure 87a), while separate curves were drawn for dry weights (Figure 87b). Values from these curves were then used to estimate N uptake with age (Table 29). Applied N from planting to a particular age was estimated from the average N content of the effluent for the crop season, irrigation rate and time of irrigation. Recovery of N was then calculated as the ratio of harvested to applied (Table 30). Recovery increased with age and was lower for 200 mm/week than for 50 mm/week (Figure 87c). This latter result is in agreement with yield data presented above. For 50 mm/week, recovery efficiency reached approximately 50% at 90 days. The crop had not reached maximum N recovery, even at 90 days.

Corn - McNair 440 V

Green and dry forage yields increased with age and irrigation rate (Tables 31-34). Dry matter content rose, while N content declined with age. Nitrogen uptake showed a general increase with age and irrigation rate.

Estimates of N content were obtained from Figure 88a. Similarly, estimates of dry forage were taken from Figure 88b for 50 and 200 mm/week. These values were then combined to estimate N uptake (Table 35). Nitrogen recovery was finally calculated (Table 36) for 50 and 200 mm/week. Recovery increased with time (Figure 88c) and was higher at the lower application rate. The corn approached its maximum N recovery at 80 days, but never reached 50%.

Sorghum x Sudangrass

Samples were only collected for the first harvest period. Green and dry forage yields increased with age and irrigation rate (Tables 37-40), while N content showed a decrease. Crop uptake of N increased with age and with irrigation rate.

Estimates of N content (Figure 89a) and dry weight (Figure 89b) were combined to calculate N uptake at 50 and 200 mm/week (Table 41) and N recovery (Table 42). Recovery increased with age (Figure 89c), and reached a peak around 65 to 70 days. Efficiency of recovery was greater for the lower irrigation rate, but only reached approximately 25%.

From these results a harvest age of around 9 weeks appears optimum for the first cutting.

Kenaf

Yields of green and dry forage increased with age and with irrigation rate (Table 43-46). Even though N content decreased with age, N uptake showed an increase with age and irrigation rate. Estimates of N content (Figure 90a) and dry weight (Figure 90b) for 50 and 200 mm/week were combined to calculate N uptake by kenaf (Table 47). Nitrogen recovery was then calculated (Table 48) with age at 50 and 200 mm/week. Curves of N recovery (Figure 90c) showed definite peaks around 70 days, reaching 30% recovery for 50 mm/week and only about 10% for 200 mm/week. Optimum harvest time appears to be about 10 weeks.

TABLE 31. GROWTH RESPONSE OF CORN (MCNAIR 440V) AT 50 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
26	0.22	13.5	0.030	3.61	1.1
33	0.68	11.5	0.078	4.09	3.2
40	2.05	19.0	0.39	2.58	10
48	9.12	12.8	1.17	3.07	36
54	9.39	15.8	1.48	1.46	22
61	13.3	18.4	2.45	3.17	78
68	20.1	15.4	3.10	0.89	28
77	21.0	19.4	4.07	1.33	54
85	22.1	21.2	4.68	0.78	37

TABLE 32. GROWTH RESPONSE OF CORN (MCNAIR 440V) AT 100 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
26	0.25	11.9	0.030	3.89	1.2
33	1.78	11.4	0.20	3.63	7.3
40	3.33	13.1	0.44	3.35	15
48	13.6	10.4	1.41	3.02	42
54	18.4	11.4	2.10	1.94	41
61	37.9	15.8	5.99	2.51	150
68	40.5	12.4	5.02	1.35	68
77	51.8	19.6	10.2	1.57	160
85	37.3	20.0	7.46	-	-

TABLE 33. GROWTH RESPONSE OF CORN (MCNAIR 440V) AT 150 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
26	0.35	11.9	0.042	4.29	1.8
33	1.94	11.7	0.23	4.15	10
40	3.04	12.0	0.36	3.77	14
48	10.3	10.4	1.07	2.87	31
54	22.0	10.8	2.38	2.55	61
61	48.0	15.0	7.20	1.84	132
68	45.6	14.0	6.38	1.53	211
77	41.2	19.2	7.91	1.85	146
85	47.3	19.8	9.36	-	-

TABLE 34. GROWTH RESPONSE OF CORN (MCNAIR 440V) AT 200 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
26	0.31	23.1	0.072	3.18	2.3
33	1.01	13.6	0.14	4.30	6.0
40	2.36	15.7	0.37	3.71	14
48	7.83	7.9	0.62	2.05	13
54	19.4	13.6	2.64	2.97	78
61	30.3	14.6	4.42	1.09	48
68	42.5	13.4	5.70	1.39	79
77	56.7	14.8	8.39	1.21	102
85	46.6	17.6	8.20	-	-

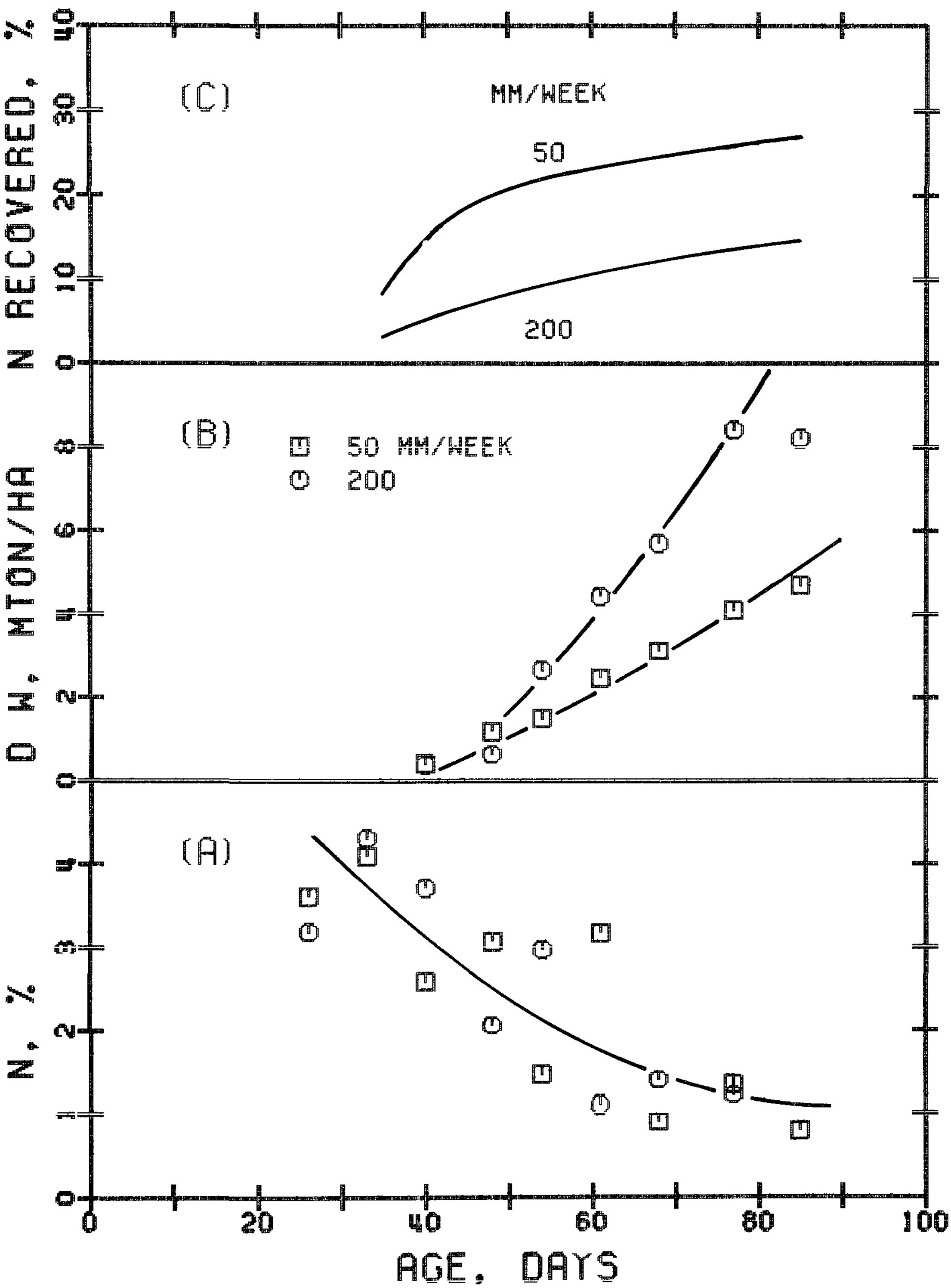

Figure 88. Response of nitrogen content, dry weight and nitrogen recovery for corn (McNair 440V).

TABLE 35. ESTIMATED YIELD AND NITROGEN RESPONSE OF CORN (MCNAIR 440V) AT 50 AND 200 MM/WEEK

Age days	N %	50 mm/week		200 mm/week	
		Dry Weight mton/ha	N kg/ha	Dry Weight mton/ha	N kg/ha
30	4.00	-	-	-	-
35	3.50	0.2	7	0.3	11
40	3.05	0.5	15	0.6	18
45	2.65	0.8	21	1.1	29
50	2.30	1.2	28	1.9	44
55	1.95	1.6	31	2.8	55
60	1.70	2.1	36	3.9	66
65	1.50	2.6	39	5.1	77
70	1.35	3.2	43	6.4	87
75	1.25	3.8	48	7.8	98
80	1.10	4.5	54	9.3	112

TABLE 36. ESTIMATED NITROGEN RECOVERY BY CORN (MCNAIR 440V) AT 50 AND 200 MM/WEEK

Age days	Harvested kg/ha	Applied kg/ha	Recovered %	Harvested kg/ha	Applied kg/ha	Recovered %
35	7	90	8	11	360	3.1
40	15	103	15	18	412	4.4
45	21	116	18	29	464	6.2
50	28	129	22	44	516	8.5
55	31	142	22	55	568	9.7
60	36	155	23	66	620	11
65	39	168	23	77	672	11
70	43	180	24	87	720	12
75	48	193	25	98	772	13
80	54	206	26	112	824	14

TABLE 37. GROWTH RESPONSE OF SORGHUM X SUDANGRASS AT 50 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
27	0.29	16.3	0.047	3.99	1.9
34	1.01	14.8	0.15	3.67	5.5
41	2.62	8.0	0.21	3.41	7.2
49	5.52	13.2	0.73	2.62	19.1
55	12.2	14.0	1.71	1.74	30.0
62	27.1	16.0	4.34	1.37	59.5
69	19.6	16.6	3.25	1.28	41.6

TABLE 38. GROWTH RESPONSE OF SORGHUM X SUDANGRASS AT 100 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
27	0.25	15.4	0.015	4.39	0.66
34	1.36	14.1	0.19	4.05	7.7
41	3.70	8.9	0.33	3.19	10.5
49	8.52	11.8	1.00	2.75	27.5
55	17.8	15.0	2.67	2.00	53.4
62	25.7	15.0	3.86	1.60	61.8
69	35.2	14.6	5.14	1.42	73.0

TABLE 39. GROWTH RESPONSE OF SORGHUM X SUDANGRASS AT 150 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
27	0.34	15.8	0.054	4.21	2.3
34	1.49	12.9	0.19	3.69	7.0
41	3.25	9.4	0.31	3.75	11.6
49	8.46	15.2	1.29	2.87	37.0
55	17.1	15.2	2.60	2.30	59.8
62	29.7	15.8	4.69	1.60	75.0
69	35.8	16.0	5.73	1.53	87.7

TABLE 40. GROWTH RESPONSE OF SORGHUM X SUDANGRASS AT 200 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
27	0.43	12.7	0.054	4.93	2.7
34	1.44	13.3	0.19	3.95	7.5
41	3.47	7.5	0.26	3.75	9.8
49	8.64	10.6	0.92	2.52	23.2
55	21.8	14.8	3.22	2.41	77.6
62	32.4	14.6	4.73	1.53	72.4
69	37.4	18.0	6.73	1.32	88.8

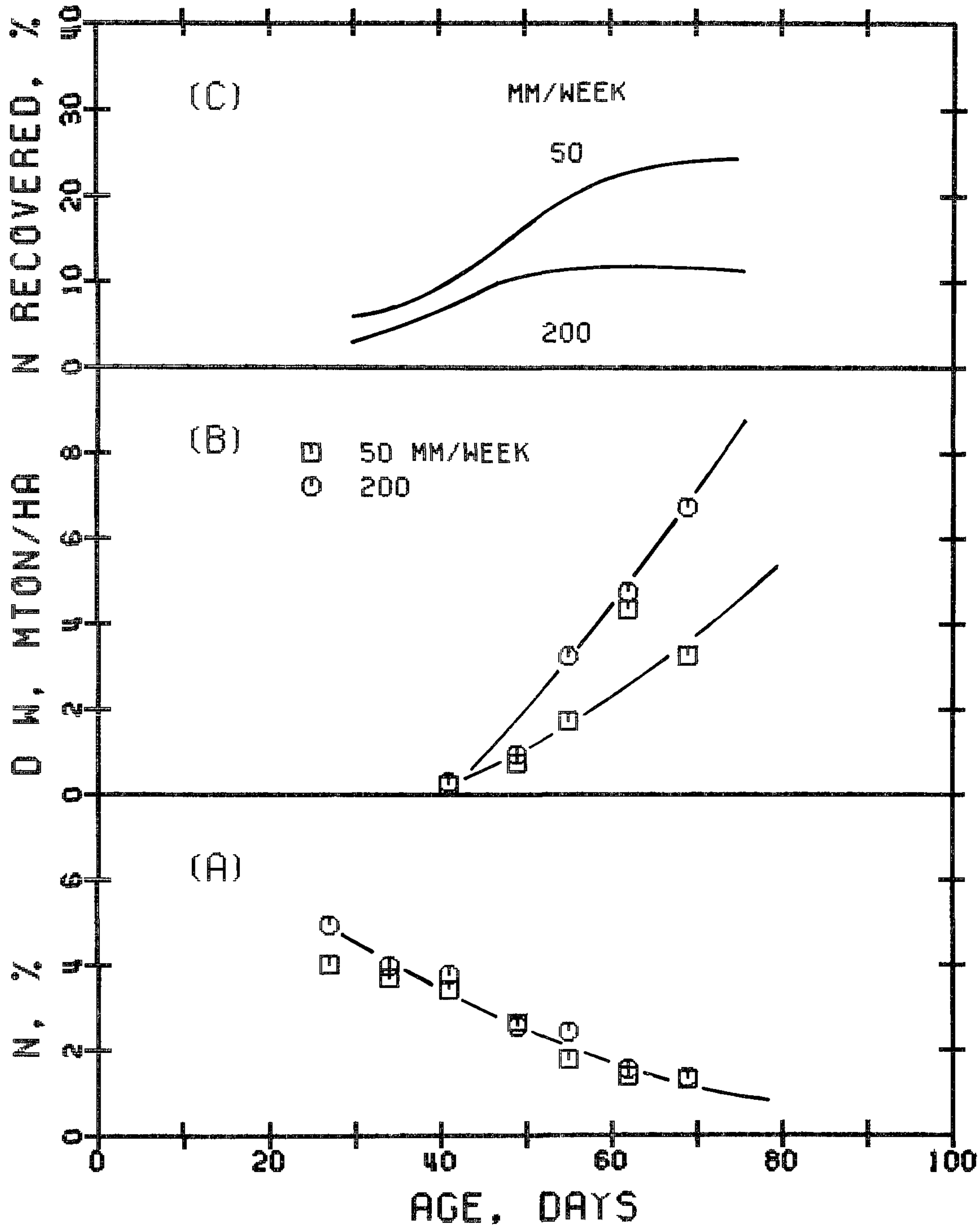

Figure 89. Response of nitrogen content, dry weight and nitrogen recovery for sorghum x sudangrass.

TABLE 41. ESTIMATED YIELD AND NITROGEN RESPONSE OF SORGHUM X SUDANGRASS AT 50 AND 200 MM/WEEK

		50 mm/week		200 mm/week	
Age days	N %	Dry Weight mton/ha	N kg/ha	Dry Weight mton/ha	N kg/ha
30	4.50	0.10	5	0.25	9
35	3.90	0.15	6	0.40	16
40	3.40	0.25	9	0.80	27
45	2.90	0.50	15	1.40	41
50	2.40	0.85	20	2.20	53
55	2.00	1.40	28	3.20	64
60	1.65	2.10	35	4.35	72
65	1.35	2.90	39	5.65	76
70	1.15	3.70	41	7.00	81
75	1.00	4.65	47	8.55	86

TABLE 42. ESTIMATED NITROGEN RECOVERY BY SORGHUM X SUDANGRASS AT 50 AND 200 MM/WEEK

	50 mm/week			200 mm/week		
Age days	Harvested kg/ha	Applied kg/ha	Recovered %	Harvested kg/ha	Applied kg/ha	Recovered %
30	5	77	6	9	308	3
35	6	90	7	16	360	4
40	9	103	9	27	412	7
45	15	116	13	41	464	9
50	20	129	16	53	516	10
55	28	142	20	64	568	11
60	35	155	23	72	620	12
65	39	168	23	76	672	12
70	41	180	23	81	720	11
75	47	193	24	86	772	11

TABLE 43. GROWTH RESPONSE OF KENAF AT 50 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
28	0.51	11.8	0.060	4.89	2.9
35	1.34	11.2	0.15	4.24	6.4
42	5.75	11.6	0.67	3.17	21.2
50	6.72	13.4	0.90	3.27	29.4
56	11.0	12.4	1.36	2.73	37.1
63	12.7	16.0	2.03	1.73	35.1
70	26.8	8.0	2.14	1.86	39.8
78	28.5	15.4	4.39	1.58	69.4
85	27.2	15.8	4.30	1.42	61.1
98	45.5	18.6	8.46	1.23	104.0

TABLE 44. GROWTH RESPONSE OF KENAF AT 100 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
28	0.47	11.4	0.054	5.03	2.7
35	1.70	10.2	0.17	4.44	7.5
42	7.70	6.8	0.52	3.38	17.6
50	8.58	8.5	0.73	3.03	22.1
56	13.9	10.8	1.50	2.89	43.4
63	18.6	15.0	2.79	1.94	54.1
70	24.6	9.4	2.31	1.81	41.8
78	28.6	18.2	5.21	1.92	100.0
85	28.0	19.4	5.43	2.28	124.0
98	51.9	16.8	8.72	1.72	150.0

TABLE 45. GROWTH RESPONSE OF KENAF AT 150 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
28	0.68	10.7	0.073	3.78	2.8
35	1.96	10.1	0.20	3.72	7.4
42	7.34	6.5	0.47	3.35	15.7
50	9.96	6.1	0.61	3.35	20.4
56	12.6	11.2	1.41	3.56	50.2
63	12.4	14.2	1.76	2.18	38.4
70	21.4	9.6	2.05	1.74	35.7
78	16.5	19.8	3.27	1.15	37.6
85	27.8	21.6	6.00	1.25	75.0
98	42.3	15.6	6.60	2.60	172.0

TABLE 46. GROWTH RESPONSE OF KENAF AT 200 MM/WEEK

Age days	Green Weight mton/ha	Dry Matter %	Dry Weight mton/ha	N %	N kg/ha
0	0	-	0	-	0
28	0.83	10.1	0.080	4.88	3.9
35	2.46	10.0	0.25	4.24	10.6
42	6.43	10.8	0.69	2.79	19.2
50	11.1	8.4	0.93	4.19	39.0
56	16.2	11.0	1.78	3.17	56.4
63	22.2	13.0	2.89	2.22	64.2
70	26.5	10.6	2.81	1.10	30.9
78	32.7	16.0	5.23	3.12	163.0
85	40.3	17.8	7.17	2.84	204.0
98	51.1	16.7	8.53	1.90	162.0

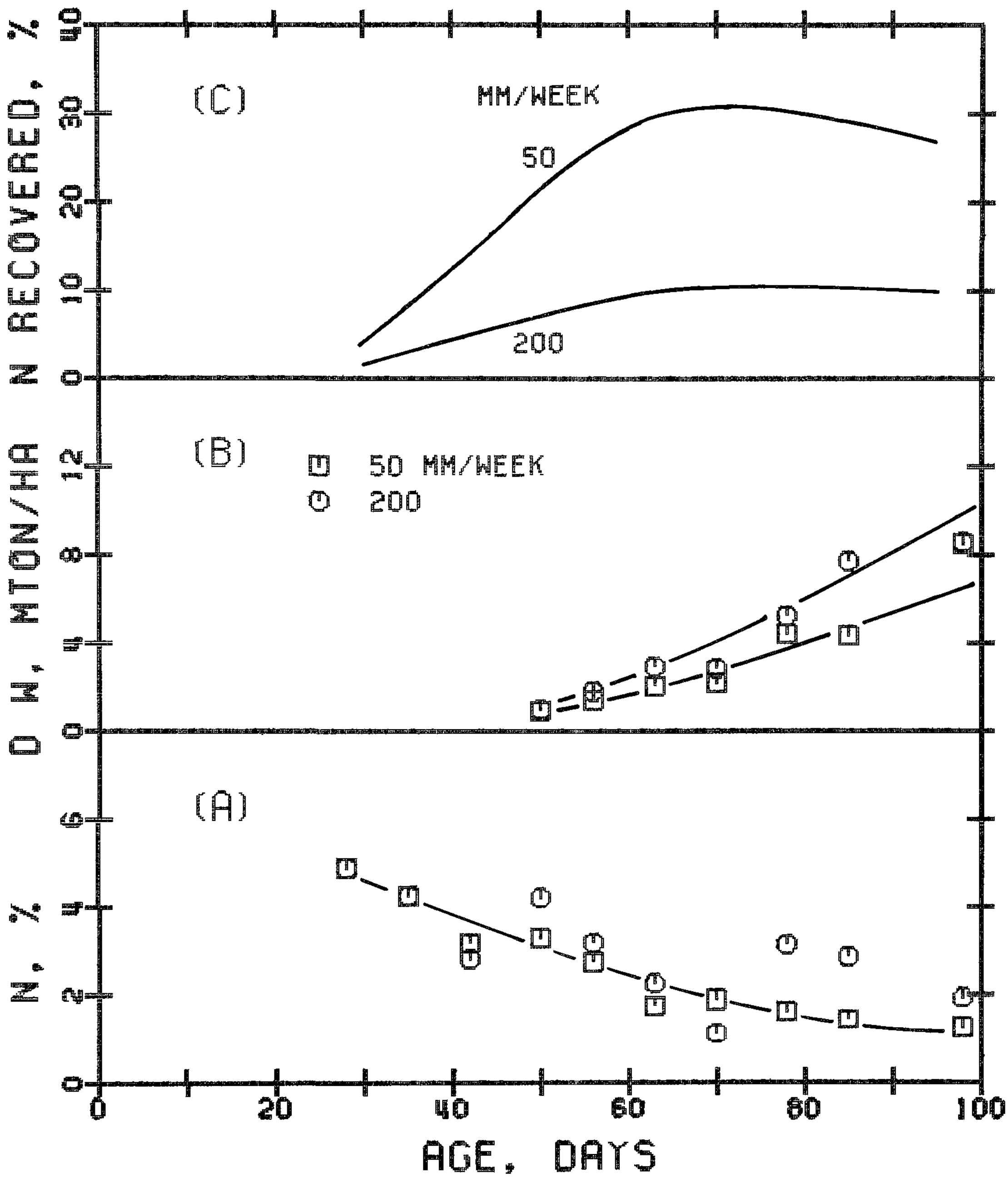

Figure 90. Response of nitrogen content, dry weight and nitrogen recovery for kenaf.

TABLE 47. ESTIMATED YIELD AND NITROGEN RESPONSE OF KENAF AT 50 AND 200 MM/WEEK

		50 mm/week		200 mm/week	
Age days	N %	Dry Weight mton/ha	N kg/ha	Dry Weight mton/ha	N kg/ha
30	4.75	0.06	3	0.10	5
35	4.35	0.18	8	0.25	11
40	3.95	0.30	12	0.45	18
45	3.55	0.55	20	0.80	28
50	3.20	0.90	29	1.20	38
55	2.85	1.30	37	1.70	48
60	2.50	1.75	44	2.35	59
65	2.25	2.25	51	3.10	69
70	1.95	2.85	56	3.90	76
75	1.70	3.45	59	4.85	82
80	1.50	4.05	61	5.80	87
85	1.35	4.70	63	6.85	92
90	1.20	5.35	64	7.90	95
95	1.10	6.00	66	8.95	98

TABLE 48. ESTIMATED NITROGEN RECOVERY BY KENAF AT 50 AND 200 MM/WEEK

	50 mm/week			200 mm/week		
Age days	Harvested kg/ha	Applied kg/ha	Recovered %	Harvested kg/ha	Applied kg/ha	Recovered %
30	3	77	4	5	308	1.6
35	8	90	9	11	360	3.1
40	12	103	12	18	412	4.4
45	20	116	17	28	464	6.0
50	29	129	22	38	516	7.4
55	37	142	26	48	568	8.5
60	44	155	28	59	620	9.5
65	51	168	30	69	672	10.3
70	56	180	31	76	720	10.6
75	59	193	31	82	772	10.6
80	61	206	30	87	824	10.6
85	63	219	29	92	876	10.5
90	64	232	28	95	928	10.2
95	66	245	27	98	980	10.0

Summary

The crops studied showed a lag time of 30-40 days in their growth curves. Ragland et al. (1965) reported similar results with corn. Dry matter yield increased with age, while N content decreased. Bar-Yosef and Kafkafi (1972) observed similar response with corn. Nitrogen recovery by the crops showed a continual increase throughout the study period. Estimates were made of harvest age for optimum N recovery (Table 49). For Pioneer 3369 A corn

TABLE 49. ESTIMATED HARVEST AGE FOR OPTIMUM NITROGEN RECOVERY

Crop	Age, weeks
Corn	
Pioneer 3369 A	>13
McNair 440V	12
Sorghum x Sudangrass	9
Kenaf	10

this value exceeded 13 weeks, with 14 weeks being a good estimate. The value for sorghum x sudangrass represented the first harvest only. The second harvest would be about the same, while the third harvest would cover a shorter period due to reduced growth later in the season.

Effluent irrigation had two beneficial effects on crop growth - addition of nutrients and reduction of soil moisture stress. Higher levels of applied N produced greater uptake of N, in agreement with findings of Parks et al. (1970). Parks and Knetsch (1959) observed higher yields at reduced moisture tension. However, N recovery efficiency decreased with application rate, with 50% recovery obtained at approximately 50 mm/week (2 in./week).

GROWTH RESPONSE OF TREES

Field plots were established at Tallahassee by W. H. Smith and D. M. Post, School of Forest Resources and Conservation, University of Florida. The study was aimed at screening several species as to their suitability for wastewater irrigation on well drained sandy soil. Growth response was measured on several species (Table 50) over a three year period (Smith and Evans, 1977, and Smith et al., 1978).

Tree heights were measured 1, 2 and 3 years after planting. Average values from the three plots receiving 50, 100 and 200 mm/week were averaged and graphed to show growth trends (Figures 91-94). Cottonwood showed the most rapid growth (Figure 91) during the 3-year period. Cottonwood, sycamore, black locust, green ash, chinese elm, and tulip poplar exhibited linear growth

(Figures 91 and 92). Sweetgum, bald cypress and red cedar showed decreasing growth rates (Figure 93), while loblolly pine showed a rapid increase in growth rate during the 3-year period.

All of the species reported appeared to be suitable for effluent irrigation.

TABLE 50. TREES IRRIGATED AT TALLAHASSEE

Common Name	Scientific Name
Cottonwood	*Populus deltoides*
Sycamore	*Platanus occidentalis*
Black locusts	*Robinia pseudoacacia*
Green ash	*Fraxinus pennsylvanica*
Chinese elm	*Ulmus parvifolia*
Tulip poplar	*Liriodendron tulipifera*
Sweetgum	*Liquidambar styraciflua*
Bald cypress	*Taxodium distichum*
Red cedar	*Juniperus silicicola*
Loblolly pine	*Pinus taeda*

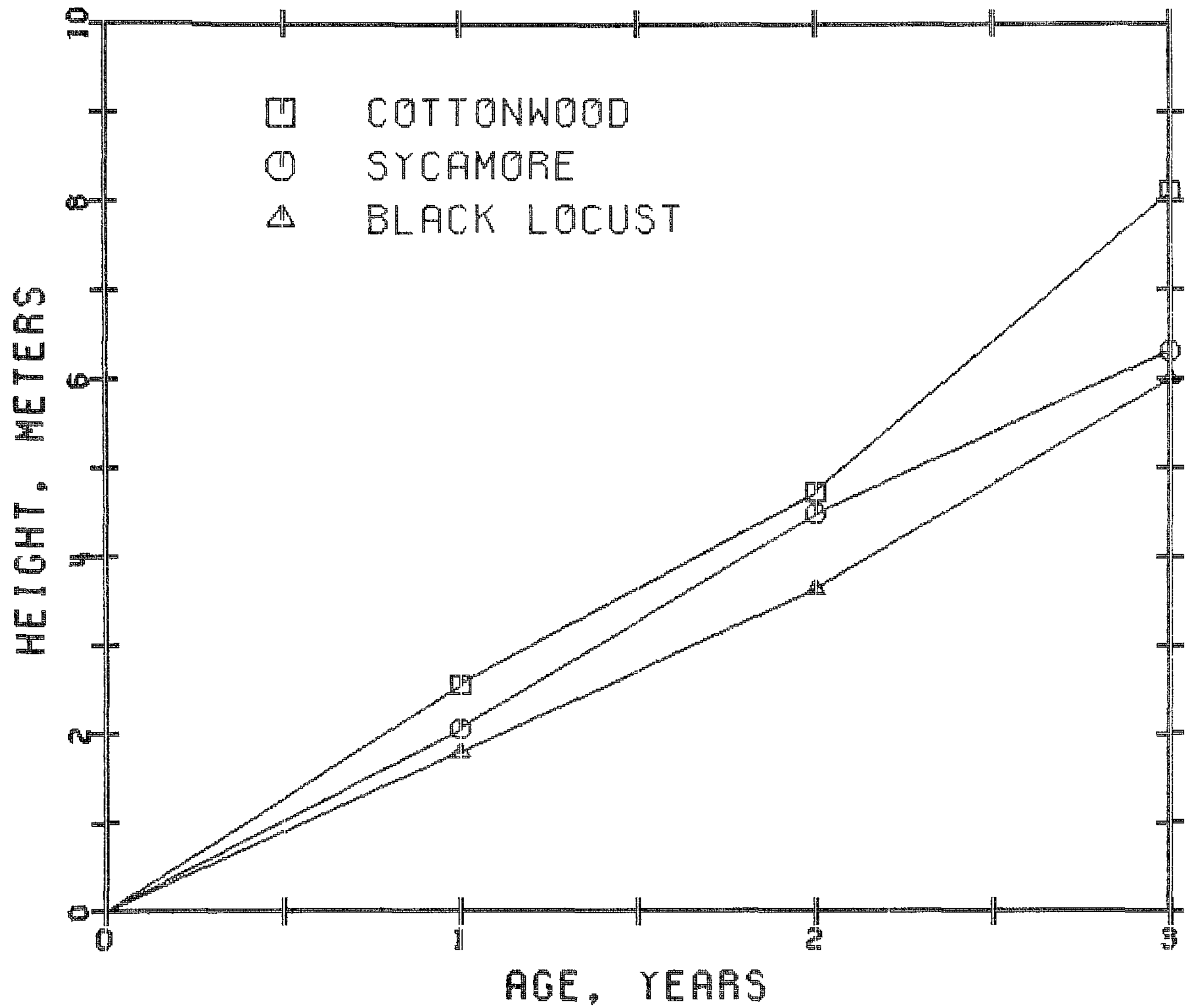

Figure 91. Growth response of Cottonwood, Sycamore and Black Locust to effluent irrigation.

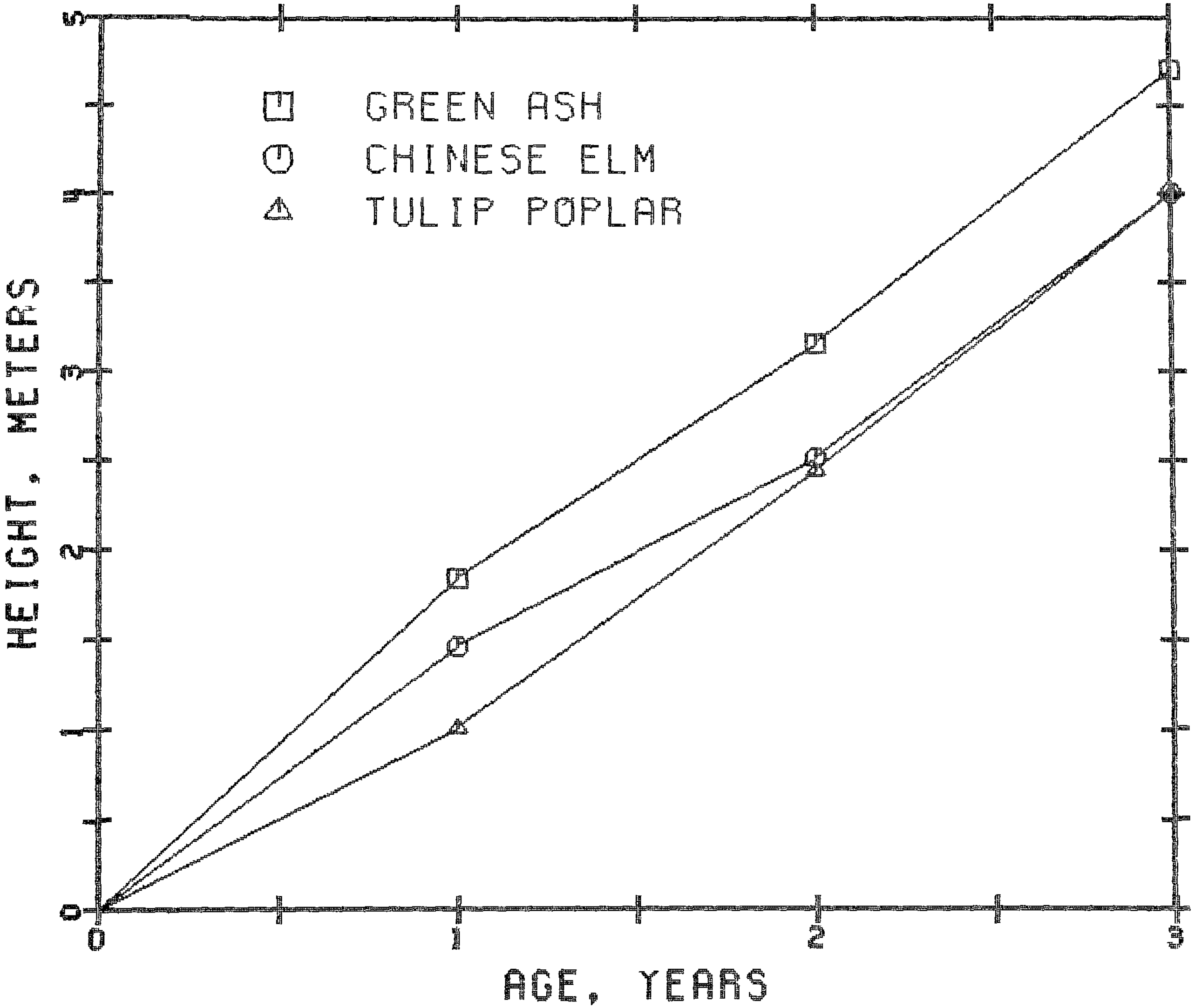

Figure 92. Growth response of Green Ash, Chinese Elm and Tulip Poplar to effluent irrigation.

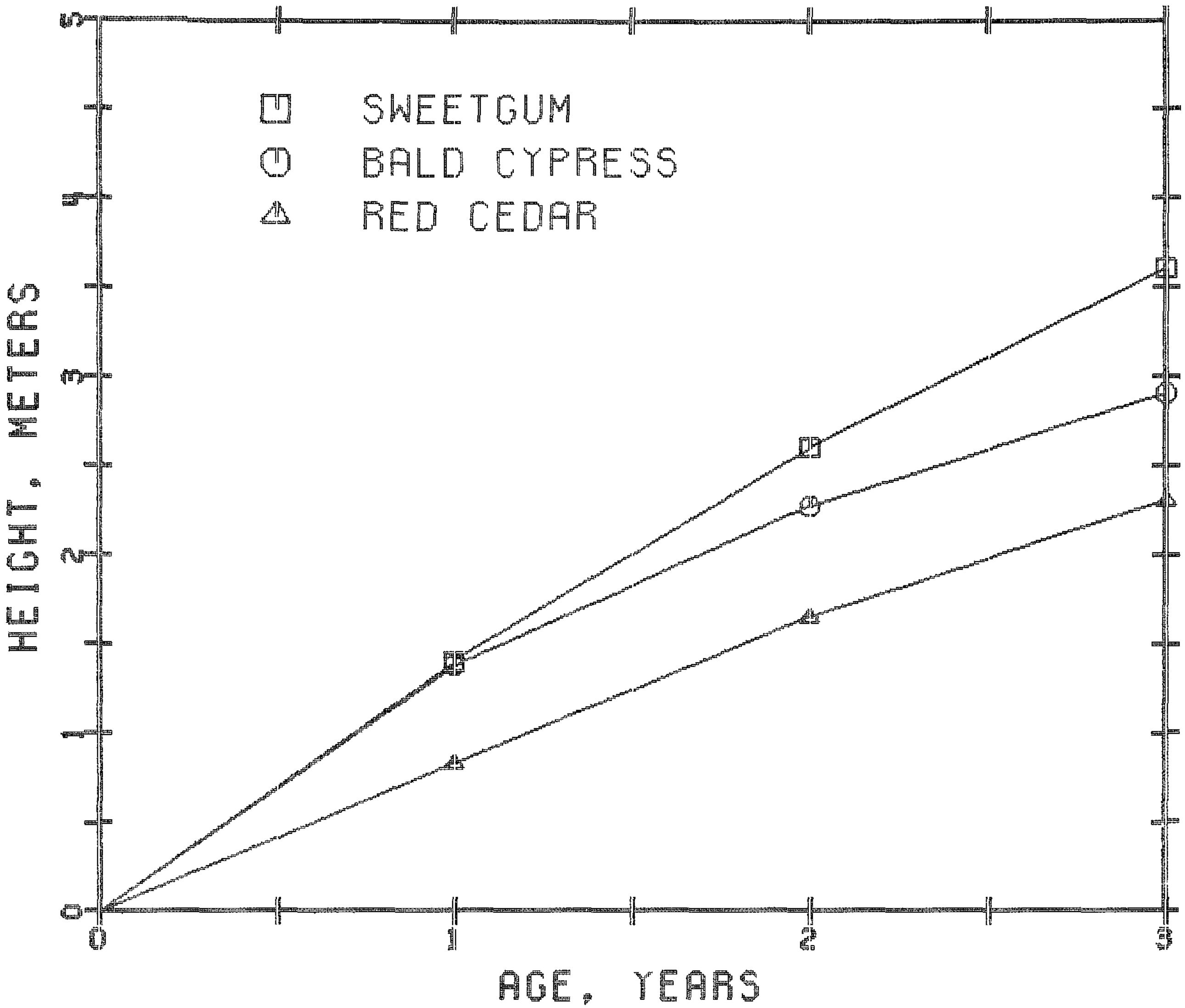

Figure 93. Growth response of Sweetgum, Bald Cypress and Red Cedar to effluent irrigation.

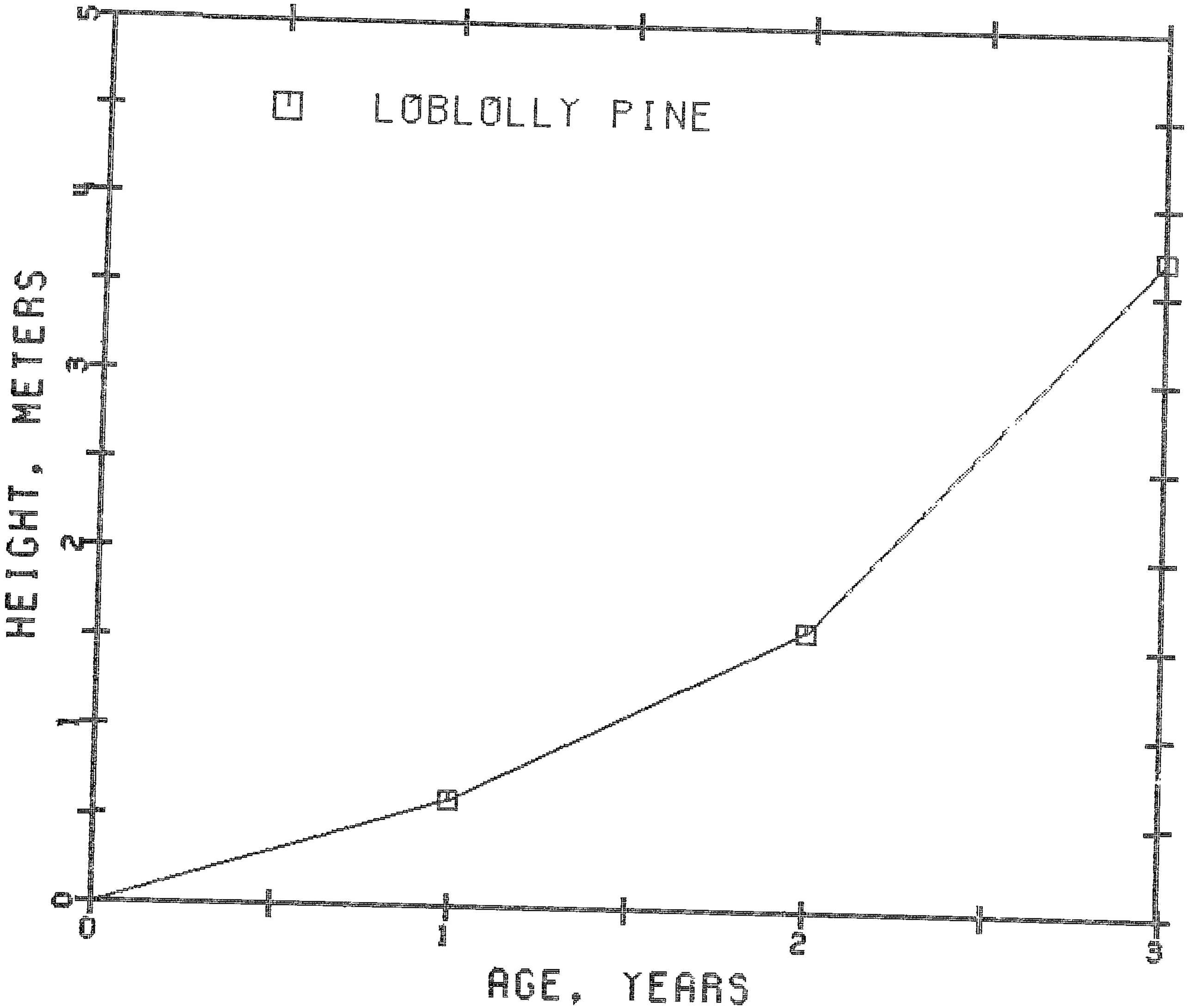

Figure 94. Growth response of Loblolly Pine to effluent irrigation.

SECTION 7

ANALYSIS OF TRANSPORT PROCESSES

INTRODUCTION

Laboratory experiments were conducted to clarify the interplay among various processes operating in the field system. Attention was focused on phosphorus and cations (including NH_4^+) because of their particular importance to water quality and to plant growth. Crop response under effluent irrigation was influenced by the availability of N, P and K in the soil solution for crop uptake through the root system. For N and K this availability was related to cation exchange - transfer between solution and surface phases. For P, anion exchange and chemical reaction were the critical factors. Measurements were made to quantify the rates of some of the processes and to establish correlations among the processes of convection, dispersion, exchange and chemical reaction. In both phosphorus fixation and cation exchange, mathematical models were developed of transport and kinetic components to provide an analytical framework. Results from these laboratory studies were used to aid in explaining field results.

PHOSPHORUS TRANSPORT

In Section 5 it was observed that phosphorus in wastewater applied to land decreased in concentration as the water percolated down through the soil, and that ammonium acetate extractable phosphorus also decreased with depth. Two models were developed to quantify the relevant processes involved. Cho et al. (1970), Novak et al. (1975), Novak and Adriano (1975) and Monke et al. (1974) previously applied the theory of convective diffusion to phosphorus movement in soil. This analysis focused on the coupling among the various processes and quantified the kinetics of fixation in this study of effluent irrigation.

Flow experiments were conducted in a packed-bed reactor. The reactor was constructed from acrylic plastic 4.7-cm ID and 10 cm in length. End plates were grooved to allow uniform entry and exit of solution. Filter paper was used at each end to confine the soil. Sampling ports were installed at depths of 2, 4, 6 and 8 cm. Lakeland fine sand was dried in a forced air oven at 105°C for 24 hours and then packed into the reactor to a bulk density of 1.73 g/cm^3. The reactor was then purged with CO_2 gas to displace other gases, followed by saturation with degassed distilled water. Stock solution of KH_2PO_4 containing 10 mg/ℓ P was fed to the reactor with a peristaltic pump at pore velocities of 0.118, 0.256, 0.539 and 0.900 cm/min. Flow was continued until phosphorus concentration reached a steady value. Orthophosphate was determined by the stannous chloride reduction method (APHA, 1971).

Equilibrium Model

This model included four processes: convection, dispersion, adsorption and reaction. Concentration in a volume increment changed due to convection, or mass flow, of the solution through the increment. Concentration gradients, partly due to nonuniform flow velocity in the pores, caused mixing due to diffusion. Adsorption and desorption at particle surfaces induced changes in solution concentration. Finally, chemical reactions, in solution or on the particle surfaces, caused changes in solution concentration. A dispersed flow model of this system for one dimension was given by (Smith, 1970):

$$\bar{D}\frac{\partial^2 C}{\partial z^2} - \bar{V}\frac{\partial C}{\partial z} - \varepsilon r - \varepsilon\frac{\partial S}{\partial t} - \varepsilon\frac{\partial C}{\partial t} = 0 \tag{1}$$

where C = solute concentration in the liquid phase
z = depth in the bed
t = time
r = chemical reaction
S = solute concentration in the adsorbed phase
$\bar{D}$ = dispersion coefficient for the bed
$\bar{V}$ = volume flux through the bed
ε = porosity of the bed

Here V was taken as constant with depth and time. A first order chemical reaction with coefficient k was assumed so that

$$r = kC \tag{2}$$

Equilibrium adsorption was assumed to be linear with exchange coefficient R so that

$$S = RC \tag{3}$$

The utility of these assumptions for the packed bed reactor was determined from the experimental results. Combination of Equations (1) - (3) yielded

$$D\frac{\partial^2 C}{\partial z^2} - V\frac{\partial C}{\partial z} - kC - (1 + R)\frac{\partial C}{\partial t} = 0 \tag{4}$$

where $D = D/\varepsilon$ and $V = V/\varepsilon$ were pore dispersion coefficient and pore velocity, respectively. Initial and boundary conditions to be used in the system were

$$z > 0 \qquad C = 0 \qquad t = 0 \tag{5}$$

$$z = 0 \qquad C = C_0 \qquad t \geq 0 \tag{6}$$

$$z \to \infty \qquad C \to 0 \qquad t \geq 0 \tag{7}$$

where C_0 was the feed concentration for the reactor. This system of equations was reduced to the dimensionless form

$$\frac{\partial^2\phi}{\partial\xi^2} - 2\alpha\frac{\partial\phi}{\partial\xi} - \beta^2\phi - \frac{\partial\phi}{\partial\tau} = 0 \tag{8}$$

with

$$\xi > 0 \qquad \phi = 0 \qquad \tau = 0 \tag{9}$$

$$\xi = 0 \qquad \phi = 1 \qquad \tau \geq 0 \tag{10}$$

$$\xi \to \infty \qquad \phi \to 0 \qquad \tau \geq 0 \tag{11}$$

where

$$\phi = \frac{C}{C_0} \qquad \xi = \frac{z}{\ell} \qquad \tau = \frac{D}{\ell^2}\frac{t}{1+R}$$

$$\alpha = \frac{\ell V}{2D} \qquad \beta = \ell\sqrt{\frac{k}{D}}$$

using ℓ as a characteristic length. The steady state and transient solutions were, respectively, (Overman et al., 1976)

$$\phi_s = \exp\left[-\left(\sqrt{\alpha^2+\beta^2} - \alpha\right)\xi\right] \tag{12}$$

and

$$\phi = \frac{1}{2}\exp\left[-\left(\sqrt{\alpha^2+\beta^2} \quad \alpha\right)\xi\right] \times$$

$$\left[\exp\left(2\sqrt{\alpha^2+\beta^2}\,\xi\right) \times \mathrm{erfc}\left(\frac{\xi}{2\sqrt{\tau}} + \sqrt{(\alpha^2+\beta^2)\tau}\right)\right.$$

$$\left. + \,\mathrm{erfc}\left(\frac{\xi}{2\sqrt{\tau}} - \sqrt{(\alpha^2+\beta^2)\tau}\right)\right] \tag{13}$$

where subscript s refers to steady state and *erfc* represents the complimentary error function. It was convenient for purposes of analysis to define the dimensionless variables

$$Z = \sqrt{1+\gamma}\,\frac{V}{2D}\,z \qquad T = (1+\gamma)\frac{V^2}{4D}\frac{t}{1+R}$$

and the dimensionless parameter

$$\gamma = \frac{\beta^2}{\alpha^2} = \frac{4kD}{V^2}$$

Equations (12) and (13) were then converted to the form

$$\phi_s = \exp \left[- \frac{\sqrt{1 + \gamma} - 1}{\sqrt{1 + \gamma}} Z \right] \tag{14}$$

and

$$\frac{\phi}{\phi_s} = \frac{1}{2} \left[\exp(2Z) \, \mathrm{erfc} \left(\frac{Z}{2\sqrt{T}} + \sqrt{T} \right) + \mathrm{erfc} \left(\frac{Z}{2\sqrt{T}} - \sqrt{T} \right) \right] \tag{15}$$

Equation (14) predicted a logarithmic distribution of phosphate at steady state, i.e. a graph of C_s/C_0 (log scale) versus depth (linear scale) should yield a straight line. Equation (15) was used to plot $\phi/\phi_s = C/C_s$ versus T with Z as a parameter, or, C/C_s versus Z with T as a parameter. With no chemical reaction ($k = 0$), $\gamma = 0$ and $C_s = C_0$ for all depths, as expected.

For the special case $\gamma << 1$, it was shown by Taylor series expansion that Equation (14) reduced to

$$\frac{C_s}{C_o} \simeq \exp \left(- \frac{k}{V} z \right) \tag{16}$$

and that

$$Z \simeq \frac{V}{2D} z \qquad T \simeq \frac{V^2}{4D} \frac{t}{1 + R}$$

Steady state distributions are shown in Figure 95 for the four velocities. Distributions were logarithmic as predicted by Equation (12). Values of the reaction coefficient k were estimated from the slopes of these lines using Equation (16). The dependence of k on velocity is illustrated in Figure 96a.

Estimates of D and R were obtained from the transient data. Equation (15) was fitted to data as follows. From a plot of C/C_s versus t for a particular depth and velocity, estimates were made of times $t_{0.2}$, $t_{0.5}$ and $t_{0.7}$ corresponding to $C/C_s = 0.2$, 0.5 and 0.7, respectively. Values of $T_{0.2}$, $T_{0.5}$ and $T_{0.7}$ were obtained for these same values of C/C_s from Equation (15) for a range of values of Z. The value of Z which satisfied the equality

$$\frac{T_{0.7} - T_{0.2}}{T_{0.5}} = \frac{t_{0.7} - t_{0.2}}{t_{0.5}}$$

was selected as the proper value. An estimate of D was then obtained from $D \simeq Vz/2Z$. For example, with $z = 2$ cm and $V = 0.118$ cm/min, $Z = 9.6$

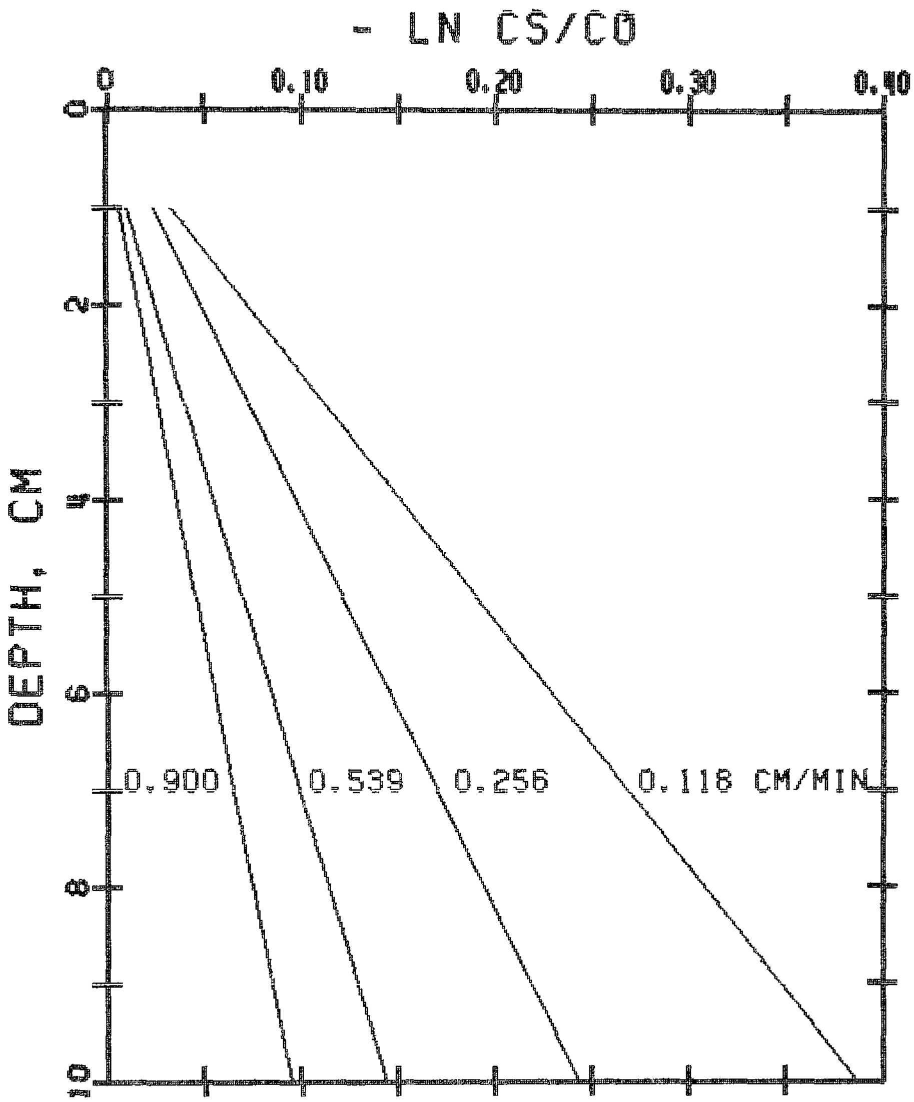

Figure 95. Steady state distributions of phosphorus for the packed-bed reactor.

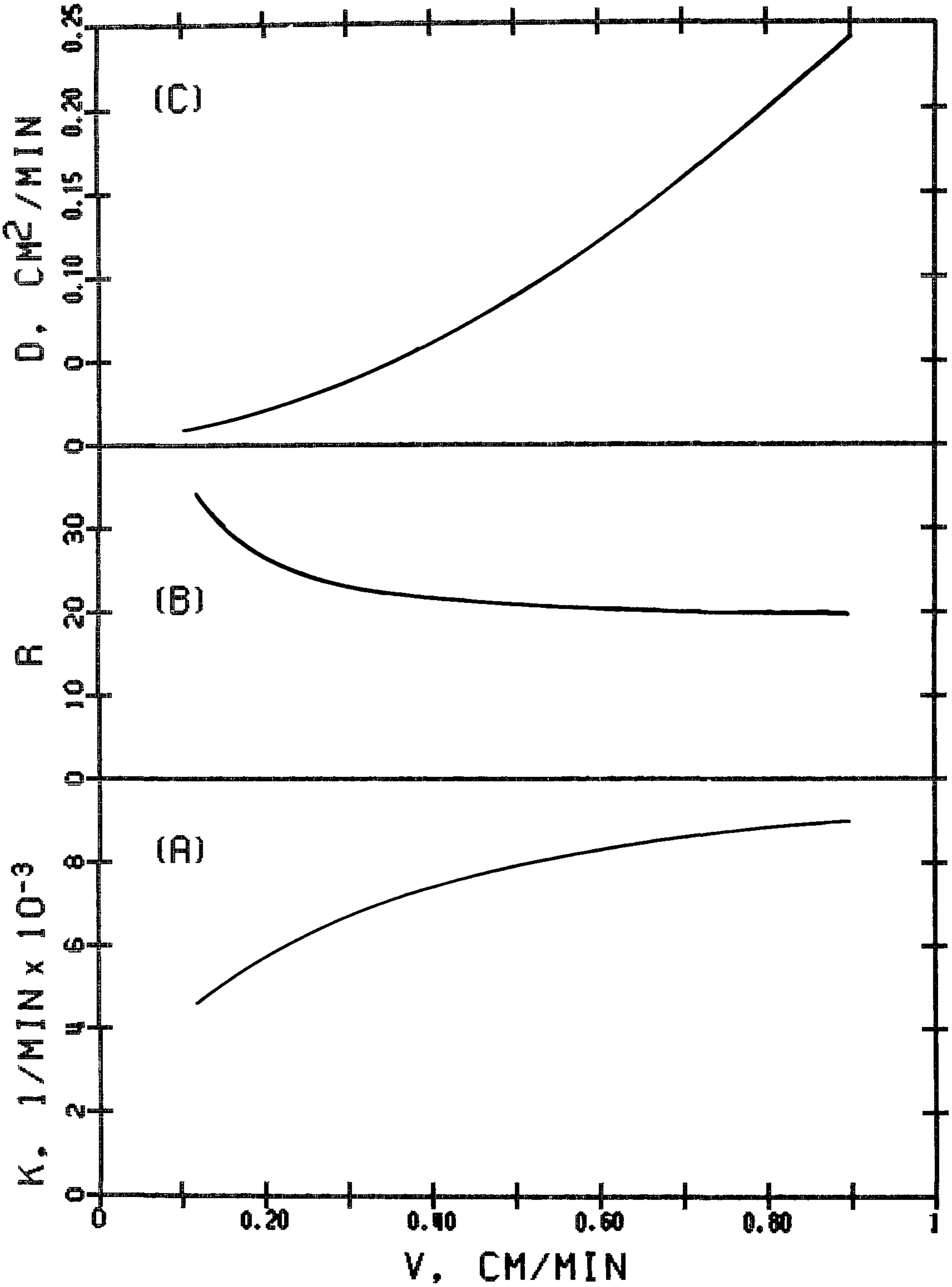

Figure 96. Dependence of reaction, exchange and dispersion coefficients on velocity for the equilibrium model of phosphorus transport

was obtained. The corresponding value of D was 0.012 cm^2/min. At each velocity the four values of D were averaged. Variation of D with velocity is shown in Figure 96c. From the definitions of Z and T it was shown that

$$\frac{Z^2}{T} = \frac{z^2}{D^*t} \tag{17}$$

where $D^* = D/(1 + R)$. Estimates of D* were obtained by substituting appropriate values into Equation (17). For example, with z = 2 cm and V = 0.118 cm/min, Z = 9.6 and $T_{0.5}/t_{0.5}$ = 0.0076 1/min, so that D* = 0.00033 cm^2/min. It follows that R = 36. At each velocity the four values of R were averaged. The trend of R with velocity is shown in Figure 96b.

The various coefficients showed strong dependence upon pore velocity. An asymptotic increase in k with V was apparent (Figure 96a). This suggested that the reaction was not homogeneous (solution phase) as implied in the model, but was heterogeneous (solid phase) and that k approached a limiting value at higher velocities. At the lower velocities reaction was limited by diffusion of reactants to the particle surface (Smith, 1970). Variation of R with V (Figure 96b) indicated that adsorption and desorption coefficients had different velocity dependence, so that their ratio changed with velocity. At higher velocities this ratio approached a constant value, which implied that their velocity dependence assumed similar form in the upper range. Dependence of both k and R on V brought the equilibrium assumption into question, which led to the global model, as discussed in the next section. Levich (1962) pointed out that surface reactions should be included as a boundary condition. However, geometric complexity of the solution/solid interface necessitated including these effects as a sink term. The dispersion coefficient showed a more-than-linear increase with velocity (Figure 96c). Bear (1972) has discussed some of the proposed correlations between D and V, including linear and quadratic types. The observed dependence reflected in part description of a multi-dimensional transport by a one-dimensional model.

The assumption that $\gamma << 1$ was justified, since γ = 0.0163, 0.0122, 0.0112 and 0.0108 at velocities of 0.118, 0.256, 0.539 and 0.900 cm/min, respectively, were calculated from appropriate values of k and D. This simplified the calculations considerably.

As mentioned in Section 5, a field plot was irrigated continuously for three days in July, 1970 at an intensity of 1.25 cm/hr. At the end of three days, soil solution samples were collected and analyzed for orthophosphate. The distribution was logarithmic (Figure 13), as predicted above. The slope of the regression line was 0.0401 1/cm. For this velocity, a water content of 0.16 was estimated from Overman and West (1972). The corresponding pore velocity was estimated to be V = 0.13 cm/min. From Equation (16) the rate constant was calculated to be k = (0.0401)(0.13) = 0.0052/min. This value agreed closely with the corresponding value from Figure 96a.

The dispersed flow model with equilibrium exchange and first order chemical reaction agreed closely with both steady state and transient results. Observed steady state distributions were logarithmic, as predicted. Reaction coefficients for laboratory and field studies agreed rather closely. However, correlations of reaction and exchange coefficients with velocity suggested that the assumption of equilibrium between solution and adsorbed phases was not entirely justified. A more detailed description of the surface component seemed desirable.

Kinetic Model

In this model the assumption of equilibrium between solution and surface phases was removed and the chemical reaction was assumed to occur on the particle surface. Thus the problem became one of heterogeneous kinetics (multiphase system) in contrast to homogeneous kinetics (single phase system). For equilibrium exchange, the heterogeneous system may be treated as an equivalent homogeneous system. This explains the apparent success of the equilibrium model discussed above. The kinetic component for this model was written in the global sense (Smith, 1970), i.e. without regard to intermediate steps between bulk solution and the adsorbed phase. This implicitly assumed that transfer to and from surfaces was kinetically controlled and not limited by external diffusion. By assuming reversible adsorption followed by an essentially irreversible reaction on the surface, the kinetic scheme was written as

$$C \underset{k_d}{\overset{k_a}{\rightleftharpoons}} A \xrightarrow{k_r} F \qquad (18)$$

where A = solute concentration in adsorbed phase
F = solute concentration in fixed phase
k_a = adsorption coefficient
k_d = desorption coefficient
k_r = reaction coefficient

Adsorption, desorption and reaction were all assumed to follow first order kinetics and the kinetic equations were written as

$$\frac{\partial S}{\partial t} = k_a C - k_d A \qquad (19)$$

and

$$\frac{\partial A}{\partial t} = k_a C - k_d A - k_r A \qquad (20)$$

Concentration of the adsorbed phase was expressed on a solution volume basis.

The transport equation for one-dimensional dispersed flow was written as

$$\overline{D} \frac{\partial^2 C}{\partial z^2} - \overline{V} \frac{\partial C}{\partial z} - \varepsilon \frac{\partial S}{\partial t} - \varepsilon \frac{\partial C}{\partial t} = 0 \qquad (21)$$

Initial and boundary conditions were

$$z > 0 \qquad C = 0 \qquad t = 0 \tag{22}$$

$$z = 0 \qquad C = C_o \qquad t \geq 0 \tag{23}$$

$$z \rightarrow \infty \qquad C \rightarrow 0 \qquad t \geq 0 \tag{24}$$

$$z > 0 \qquad A = 0 \qquad t = 0 \tag{25}$$

In the development of the model the dispersion term was neglected. Justification for this follows below. Equations (19) and (21) were combined to give

$$V \frac{\partial C}{\partial z} + \frac{\partial C}{\partial t} + k_a C - k_d A = 0 \tag{26}$$

where $V = \overline{V}/\varepsilon$.

Steady state distributions were obtained

$$A_s = KC_s \tag{27}$$

and

$$C_s = C_o \exp\left(-\frac{k}{V} z\right) \tag{28}$$

where

$$K = \frac{k_a}{k_d + k_r} \tag{29}$$

and

$$k = k_r K \tag{30}$$

For the case of no adsorption ($k_a = 0$) the equations yielded $A_s = 0$ and $C_s = C_o$, as expected. With adsorption, but no reaction ($k_r = 0$), the results were $C_s = C_o$, as expected.

By using definitions

$$C^* = \frac{C}{C_s} \qquad A^* = \frac{A}{A_s} \qquad z^* = \frac{z}{\ell} \qquad t^* = \frac{Vt}{\ell}$$

$$\alpha = \frac{k_d}{k_a} K^2 \qquad \beta = \frac{\ell k_a}{VK}$$

Equations (26) and (20) were written as

$$\frac{\partial C^*}{\partial z^*} + \frac{\partial C^*}{\partial t^*} + \alpha\beta(C^* - A^*) = 0 \tag{31}$$

and

$$\frac{\partial A^*}{\partial t^*} = \beta(C^* - A^*) \tag{32}$$

subject to the conditions

$$z^* > 0 \qquad C^* = 0 \qquad t^* = 0 \tag{33}$$

$$z^* = 0 \qquad C^* = 1 \qquad t^* \geq 0 \tag{34}$$

$$z^* \to \infty \qquad C^* \to 0 \qquad t^* \geq 0 \tag{35}$$

$$z^* > 0 \qquad A^* = 0 \qquad t^* = 0 \tag{36}$$

Overman et al. (1978) solved Equations (31) - (36) and obtained

$$\frac{A}{A_s} = \beta \exp(-\alpha\beta z^*) \int_0^{t^*-z^*} \exp(-\beta\ ) \ I_o \sqrt{4\alpha\beta^2 z^* y}\ dy \tag{37}$$

and

$$\frac{C}{C_s} = \frac{A}{A_s} + \exp(-\alpha\beta z^*) \exp[-\beta(t^* - z^*)] \ I_o \sqrt{4\alpha\beta^2 z^*(t^* - z^*)} \tag{38}$$

and

$$\frac{A}{A_s} = \frac{C}{C_s} = 0 \qquad t^* < z^* \tag{39}$$

where I_o was the modified Bessel function of first kind and zeroth order. For a system with no adsorption ($\alpha = 0$), Equation (38) reduced to plug flow, viz.

$$t < \frac{z}{V} \qquad C = 0 \tag{40}$$

$$t > \frac{z}{V} \qquad C = C_o \tag{41}$$

as expected.

Values for k_a and k_d were estimated from the transient data. From a graph of C/C_s versus t, the time corresponding to $C/C_s = 0.5$ was estimated. Then t* was calculated, using the appropriate pore velocity and sampling depth. Then $K = t^* - 1$ was assumed. With $k_r << k_d$, this gave $k_a/k_d = t^* - 1$.

Values of k_a and k_d were then chosen, subject to this constraint, until the calculated curve agreed with the data. This procedure was followed for all depths and velocities.

The model predicted a logarithmic distribution at steady state, as given by Equation (28). By using the slopes from Figure 95 , estimates were obtained for k_r from Equation (30). This relationship established the relationship between the apparent coefficient for the homogeneous reaction and the coefficient for the heterogeneous reaction.

All three kinetic coefficients varied with velocity (Figure 97). Since each curve showed asymptotic response, an empirical equation

$$k = k_m \left[1 - \exp(-\lambda V) \right] \tag{42}$$

was fitted for each process, where k_m and λ were curve fitting parameters. The resulting equations were:

$$k_a = 3.12 \left[1 - \exp(-3.71\ V)\right] \tag{43}$$

$$k_d = 0.170 \left[1 - \exp(-2.71\ V)\right] \tag{44}$$

and

$$k_r = 0.000520 \left[1 - \exp(-2.53\ V)\right] \tag{45}$$

These equations indicated that the rates followed the order adsorption > desorption > reaction. Since R for the equilibrium model was related to k_a and k_d for the kinetic model by

$$R = \frac{k_a}{k_d} \tag{46}$$

Equation (46) was used to calculate R for various velocities. The values were 23.9, 23.5, 20.6 and 19.0 at 0.118, 0.256, 0.539 and 0.900 cm/min, respectively. The decrease in R with V was related to the different velocity dependence of k_a and k_d.

In the kinetic model, a global scheme was used which neglected any intermediate steps between bulk solution and adsorbed phases. An alternative possibility was that transfer from solution to the surface was diffusion limited (Smith, 1970) in which case solution concentration adjacent to the particle surface was lower than in bulk solution. At higher velocity mass transfer (by diffusion) was greatly enhanced, so that adsorption became the limiting step. This coupling, then, gave rise to asymptotic increase of the global coefficients to maxima. This line of analysis is being continued in another study.

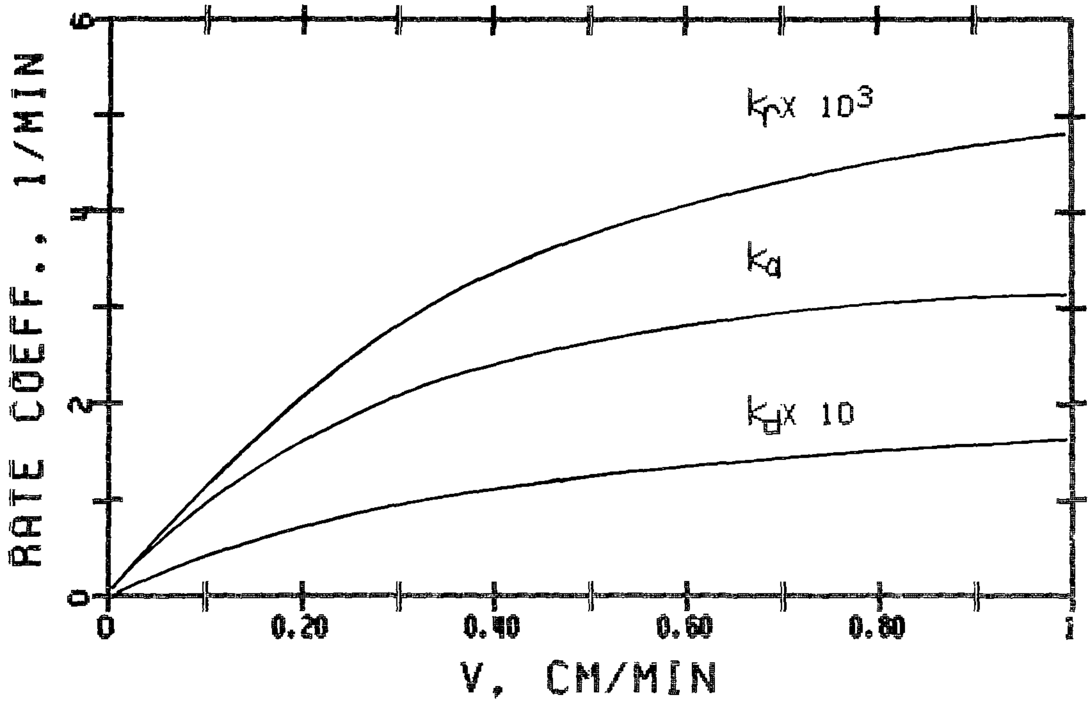

Figure 97. Dependence of adsorption, desorption and reaction coefficients on velocity for the kinetic model of phosphorus transport.

Characteristic times for the processes of convection, dispersion, adsorption, desorption and reaction were defined from Equations (19) - (21). The times were:

$$\text{convection} \qquad \tau_c = \frac{\ell}{V} \tag{47}$$

$$\text{dispersion} \qquad \tau_D = \frac{\ell^2}{D} \tag{48}$$

$$\text{adsorption} \qquad \tau_a = \frac{1}{k_a} \tag{49}$$

$$\text{desorption} \qquad \tau_d = \frac{1}{k_d} \tag{50}$$

$$\text{reaction} \qquad \tau_r = \frac{1}{k_r} \tag{51}$$

These values were calculated for the 2-cm depth, where dispersion showed the greatest relative importance. Values of D from the equilibrium model and the kinetic coefficients from the kinetic model were used. Comparison of values in Table 51 showed that dispersion and reaction were slow compared to convection, adsorption and desorption. Hence, neglecting these terms in the transient analysis was justified. Of course, reaction was relevant to the steady state analysis. The insignificance of dispersion was also indicated by the fact that at one pore volume C/C_s was less than 0.01 for all cases.

Analysis of phosphorus transport with the kinetic model gave good description of both steady state and transient response. The model predicted a logarithmic distribution at steady state, as was observed experimentally both in the laboratory and the field. Estimates of adsorption, desorption and reaction coefficients showed that all three varied in an asymptotic manner with velocity. It was concluded that at lower velocities mass transfer to the particle surface was diffusion controlled, while at higher velocities surface kinetics was controlling. Calculation of characteristic times showed that dispersion was negligible compared to the other processes, which justified use of Equation (26).

PHOSPHORUS KINETICS

Batch studies were conducted to elaborate the details associated with the kinetic scheme, Equation (18), used in the kinetic model of phosphorus transport. Since this model assumed that phosphate molecules were adsorbed onto a surface, then the number of adsorption sites per molecule was an important parameter in the process.

Various aspects of phosphorus fixation in soils were discussed previously by Hemwall (1957), Ulrich et al. (1962), Hsu (1964), Tandon and Kurtz (1968), Rajan and Fox (1972), Probert and Larsen (1972), and Kuo and Lotze (1974).

TABLE 51. VALUES OF RATE COEFFICIENTS AND CHARACTERISTIC TIMES AT 2-CM DEPTH

Parameter	Numerical Value			
V cm/min	0.118	0.256	0.539	0.900
D cm^2/min	0.0122	0.0329	0.0515	0.239
k_a 1/min	1.10	2.00	2.75	3.00
k_d 1/min	0.031	0.079	0.110	0.184
k_r 1/min	0.00013	0.00024	0.00039	0.00046
τ_c min	16.9	7.8	3.7	2.2
τ_D min	328	122	78	17
τ_a min	0.91	0.50	0.36	0.33
τ_d min	32	13	9	5
τ_r min	7700	4200	2600	2200

In all the rate studies reported, a two-stage sequence was observed--a fast initial drop in solution phosphate followed by a slower decrease. Probert and Larsen (1972) concluded that the fast step resulted from exchange between solution and solid phases, while the slower step reflected incorporation of phosphorus into the solid phase. Hsu (1964) concluded that the fast step related to adsorption of phosphate onto colloidal aluminum hydroxide and iron hydroxide in the soil and that the slow step was caused by adsorption of phosphate onto surfaces of hydroxides and oxides which formed during the experiment.

Enfield and Bledsoe (1975) applied several kinetic models in estimating phosphorus fixing capacity of soils.

Development of the Model

Preliminary experiments were conducted in a batch reactor with several combinations of soil mass and initial concentration of phosphorus. If the kinetic model of Equation (18) was correct, then the graph of relative phosphorus concentration versus time should be unaffected by soil mass. It was observed that changing the soil mass did shift the plot; viz, that increased soil mass in the reactor increased the rate of disappearance of solution phosphorus. This observation indicated that at least one step in the process was not first order. In fact, the results suggested that adsorption could be described by second order kinetics. The kinetic model adopted was (Overman and Chu, 1977a)

$$P + S \underset{k_d}{\overset{k_a}{\rightleftharpoons}} A \xrightarrow{k_r} F + S \qquad (52)$$

where P = concentration of phosphorus in solution
S = concentration of adsorptive sites in the soil
A = concentration of adsorbed phosphorus
F = concentration of fixed phosphorus
k_a = kinetic coefficient for adsorption
k_d = kinetic coefficient for desorption
k_r = kinetic coefficient for reaction

All concentrations were expressed on a volume basis. Equation (52) represented a case of heterogeneous catalysis, and was recognized as an example of Langmuir-Hinshelwood kinetics (Laidler, 1950). Adsorption was assumed to follow second order kinetics, while desorption and reaction were assumed to be first order processes. For a closed batch reactor the rate of gain of phosphorus in solution was described by

$$\frac{dP}{dt} = -k_a SP + k_d A \qquad (53)$$

Because the nonlinear nature of Equation (53) presented difficulties for obtaining a mathematical solution, it was decided to utilize an open reactor with a steady input of phosphorus, r. The appropriate kinetic equations for this reactor were:

$$\frac{dP}{dt} = r - k_a SP + k_d A \tag{54}$$

and

$$\frac{dA}{dt} = k_a SP - k_d A - k_r A \tag{55}$$

subject to

$$S = S_o - A \tag{56}$$

where S_o was the total concentration of adsorptive sites in the reactor. Equation (56) resulted from the catalytic nature of Equation (52).

For steady state conditions Equations (54) - (56) reduced to

$$0 = r - k_a S_s P_s + k_d A_s \tag{57}$$

$$0 = k_a S_s P_s - (k_d + k_r) A_s \tag{58}$$

and

$$S_s = S_o = A_s \tag{59}$$

where subscript s referred to steady state. Combination of Equations (57) - (59) yielded

$$S_s = \frac{S_o}{1 + \frac{k_a}{k_d + k_r} P_s} \tag{60}$$

and

$$r = \frac{k_r S_o P_s}{\frac{k_d + k_r}{k_a} + P_s} \tag{61}$$

Using the definitions

$$K = \frac{k_d + k_r}{k_a} \tag{62}$$

and

$$r_m = k_r S_o \tag{63}$$

Equations (60) and (61) were reduced to

$$S_s = \frac{S_o}{1 + \frac{P_s}{K}} \tag{64}$$

and

$$r = \frac{r_m P_s}{K + P_s} \tag{65}$$

It was noted that r_m was the upper limit for r and that at $P_s = K$, $r = r_m/2$. The catalytic form of Equation (52) led to the hyperbolic relationship between feed rate and steady state phosphorus concentration given by Equation (65). In fact, achievement of a steady state required that Equation (52) be catalytic in nature. Equation (65) showed the same form as the Michaelis-Menton relationship in enzyme kinetics (Aiba et al., 1965).

Effect of Soil/Solution Ratio

Experiments were conducted in a batch reactor at 25°C and at a pH of 5. At the beginning of each run a selected quantity of H_3PO_4 was diluted to 500 ml with deionized water, adjusted to pH = 5 and placed in the reactor. A selected quantity of soil was then added to the reactor. During the experiment a paddle stirrer kept the soil suspended while a solution of H_3PO_4 was injected into the reactor at a constant rate of 3.16 mℓ/hr with a syringe pump. The pH was controlled at 5 with a two-way pH controller by suspending the electrodes in the reactor. Checks of the electrodes at the beginning and end of each run verified their stability. Lakeland fine sand was collected from the 30-60 cm depth at Tallahassee in an area which had received neither effluent nor fertilizer. This soil was known to contain < 5% silt, < 5% clay and a large amount of iron and aluminum (Hortenstine, 1966). Experiments were conducted with 100, 150, 200 and 250 g soil, which had been dried at 105°C in a forced air oven for 24 hr, in 500 ml of solution. Samples were collected at 1/2-, 1-, 1 1/2-, 2-, 2 1/2-, 3-, 4-, 5-, and 6-hr periods and immediately filtered through 0.45 μm Millipore filters, with prefilters to remove larger particles, to stop the reaction and for chemical analysis. Orthophosphate was determined by stannous chloride reduction (APHA, 1971). It was found in preliminary experiments that beginning with a phosphate solution in the reactor enhanced the approach to steady state. In all the runs phosphate concentration in the reactor reached steady state within 2 hr. In several cases, the syringe pump was stopped after 6 hr to show that phosphorus did decay rapidly toward zero. Volumes added by the pump or removed by sampling were negligible. Experiments were conducted at pH = 5 so that essentially all the phosphate occurred as $H_2PO_4^-$.

Equation (65) was used to fit the experimental data, using the weighted statistical procedure of Wilkinson (1961). Four rates of phosphorus addition were used for each soil/solution ratio. The data did follow the predicted trends (Figure 98). Furthermore, the upper limit increased with soil mass,

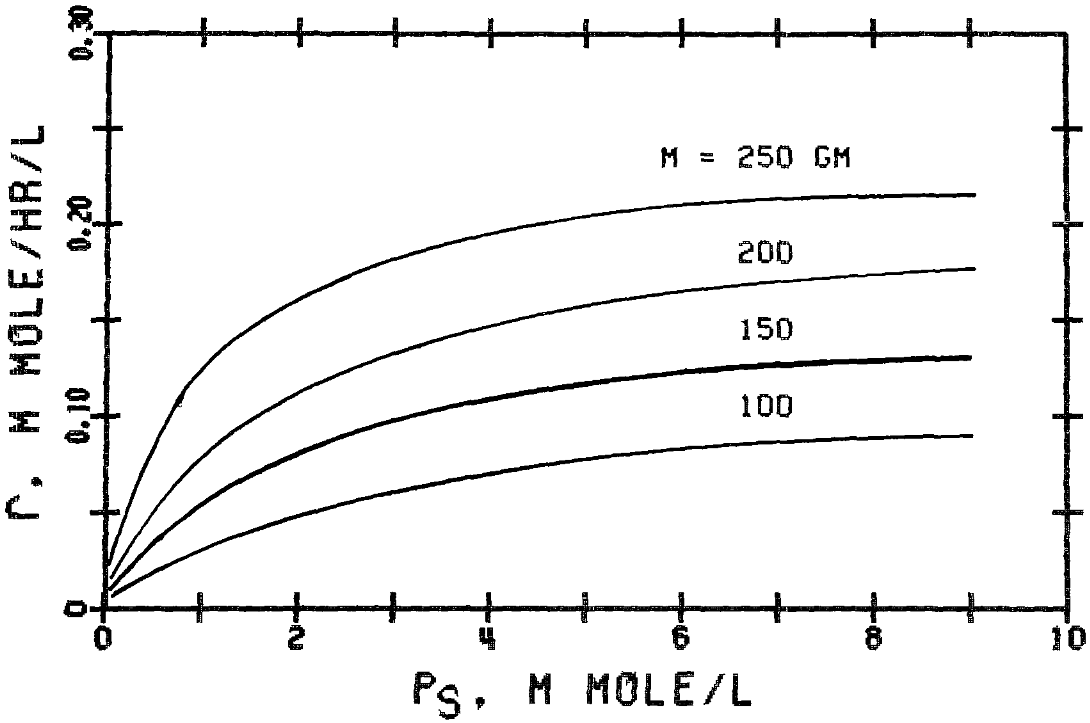

Figure 98. Effect of soil mass on steady state phosphorus fixation in the batch reactor.

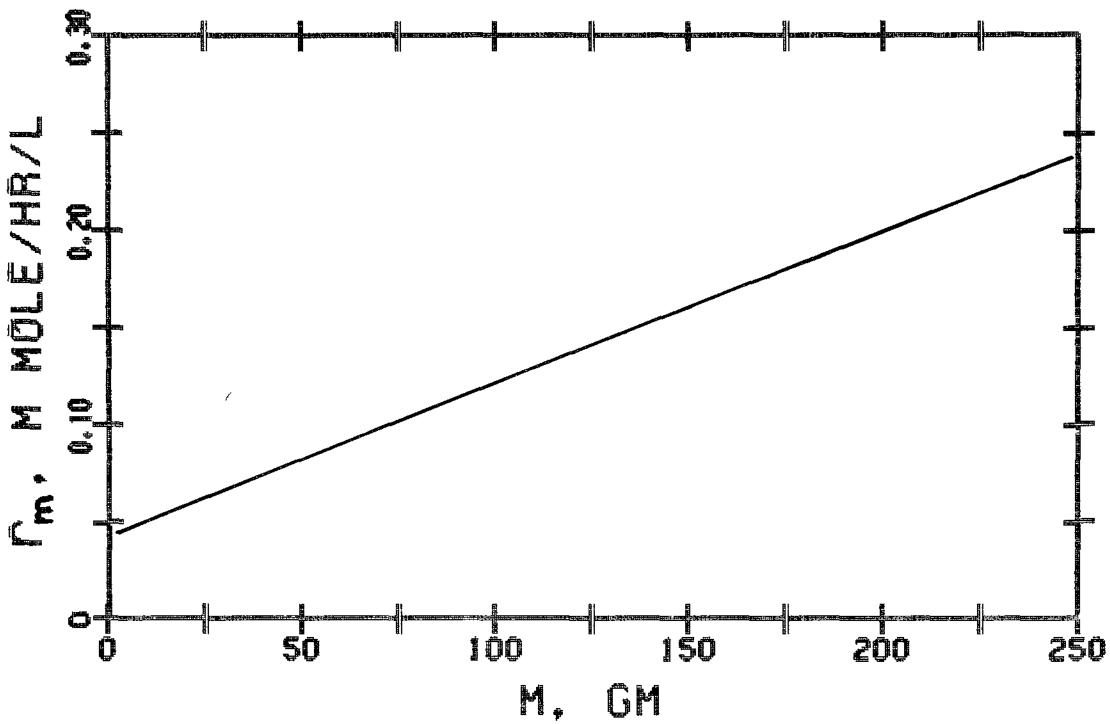

Figure 99. Dependence on maximum phosphorus fixation rate on soil mass.

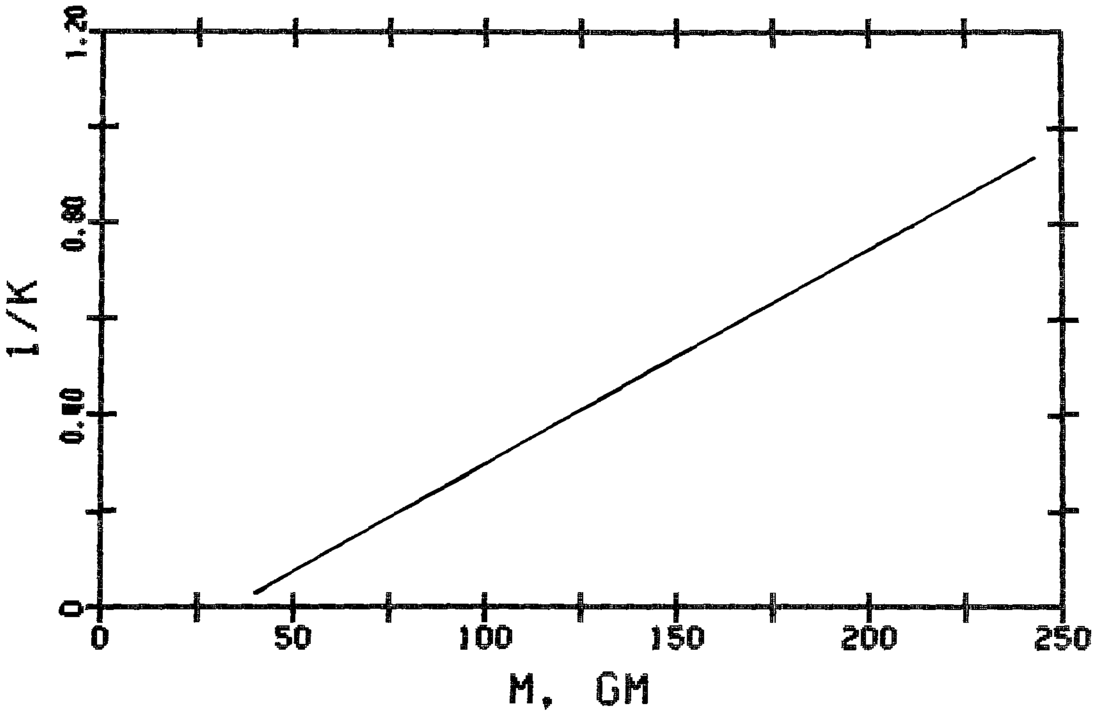

Figure 100. Dependence on equilibrium constant of phosphorus fixation on soil mass.

as predicted by Equation (13). The graph of r_m versus soil mass showed a linear increase (Figure 99), as predicted by Equation (63). However, the graph showed a nonzero intercept. This suggested that the solution reaction between phosphate and slightly soluble aluminum (Hsu, 1975) was significant. At constant pH this reaction was expected to be first order in P_s and independent of soil mass. This effect was later verified. The equilibrium constant was also shown to vary with soil mass (Figure 100). The reason for this was not clear and remained unexplained.

Effect of pH

Additional steady state batch experiments were conducted to show the dependence of r_m and K on pH (Overman and Chu, 1977 b). Experiments were conducted at pH = 2, 3, 5, 7 and 8. Four rates of phosphorus addition were used at each pH. In all runs 250 g of Lakeland fine sand was used in 500 ml solution. Stirring and pH control were as noted above.

Equation (65) was again used to fit the data (Figure 101). The analysis gave values for r_m and K at each pH. These curves at first appeared confusing, however, further analysis revealed their meaning. Values of r_m showed a decrease with an increase in pH (Figure 102). This trend follows that observed by Muljadi et al. (1966), Chen et al. (1973), Rajan et al. (1974) and Hsu (1975). Hsu (1975) suggested that OH^- competed strongly with $H_2PO_4^-$ for adsorption by aluminum and iron compounds in the soil. The graph of 1/K versus pH showed a distribution very similar to that of the $H_2PO_4^-$ fraction (Figure 103). For pH 2-8, $H_2PO_4^-$ and $HPO_4^=$ were the dominant forms of phosphate This was interpreted to mean that k_a changed with pH. The adsorption process was written in terms of elemental P, but Figure 103 suggested that in fact $H_2PO_4^-$ was the relevant phosphate ion, by assuming that $k_a \propto H_2PO_4^-$. Muljadi et al. (1966) and Rajan et al. (1974) also concluded that $H_2PO_4^-$ was the form involved in adsorption. The shift between distributions in Figure 103 resulted from the suspension effect of a pH value of approximately 0.2 in the batch reactor.

Effect of Solution Reaction

In the analysis above the batch process was treated as heterogeneous catalysis. Hsu (1975) showed that phosphate reacted in solution with aluminum. Consequently, Equation (54) was modified to include a first order homogeneous reaction so that

$$\frac{dP}{dt} = r - k'P - k_a SP + k_d A \qquad (66)$$

where k' was the first order rate coefficient (Overman and Chu, 1977 c). Equations (55) and (56) remained the same. For steady state conditions it was shown that

$$r = k'P_s + \frac{r_m P_s}{K + P_s} \qquad (67)$$

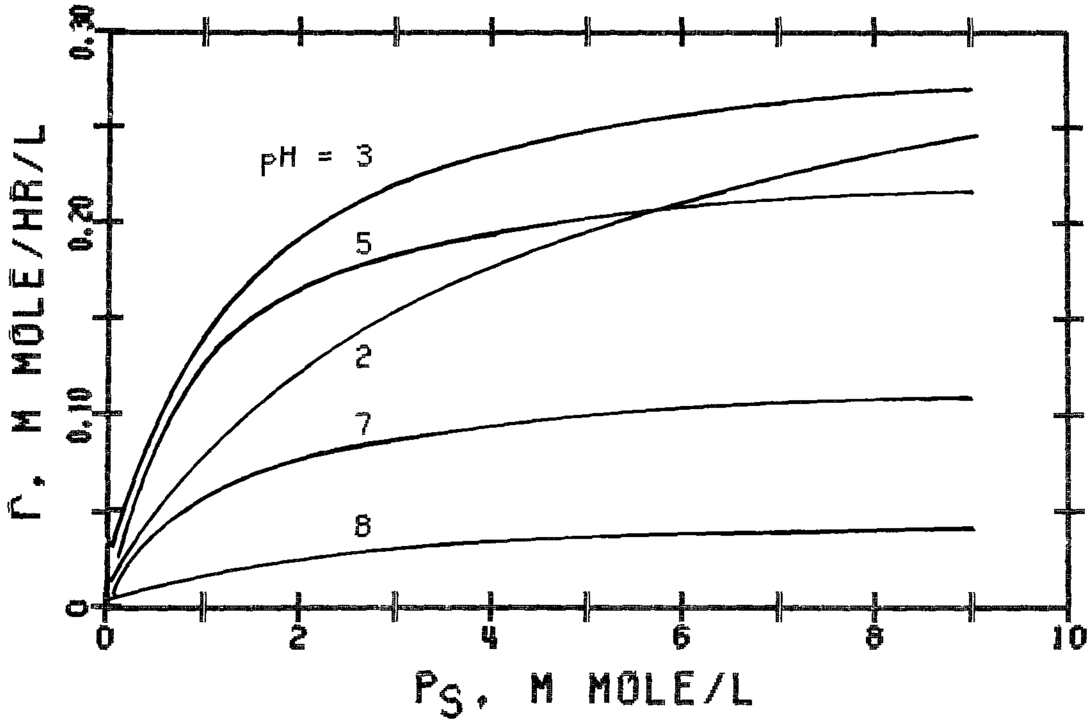

Figure 101. Effect of pH on steady state phosphorus fixation in the batch reactor.

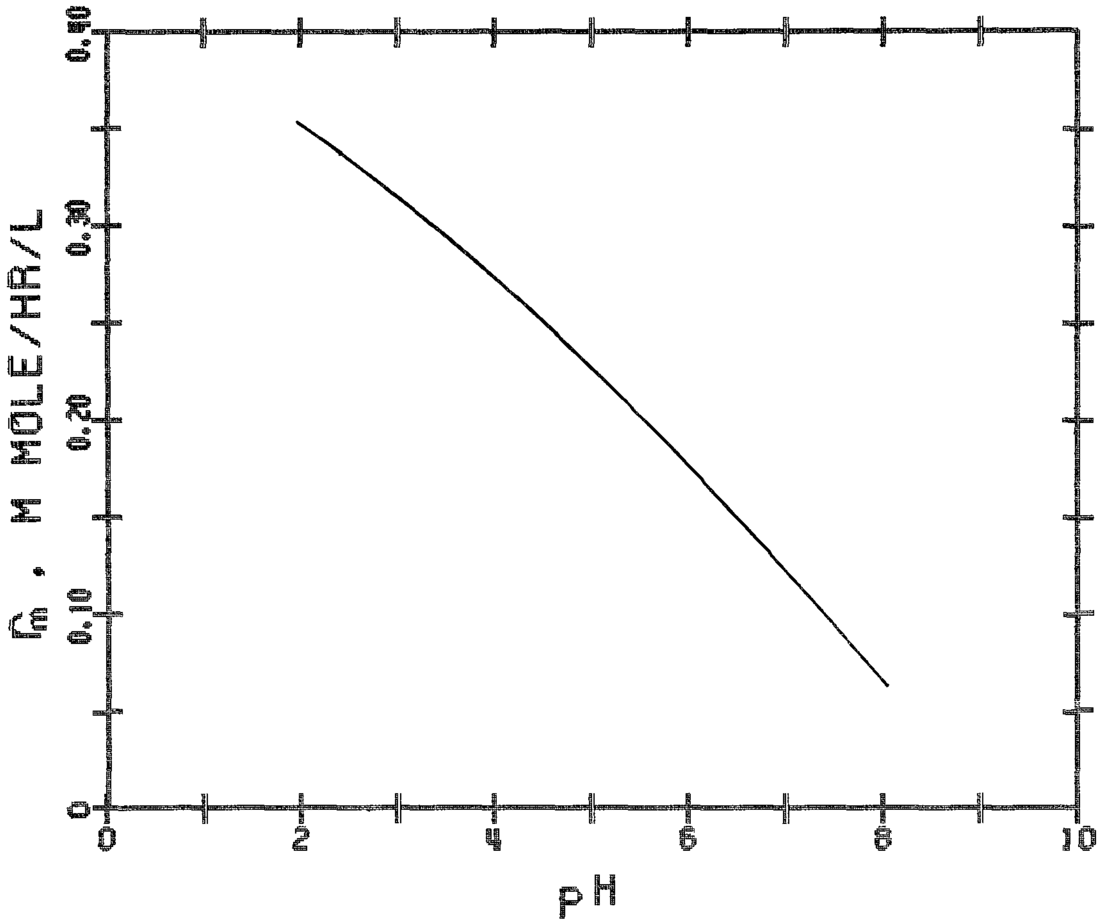

Figure 102. Dependence of maximum phosphorus fixation rate on pH.

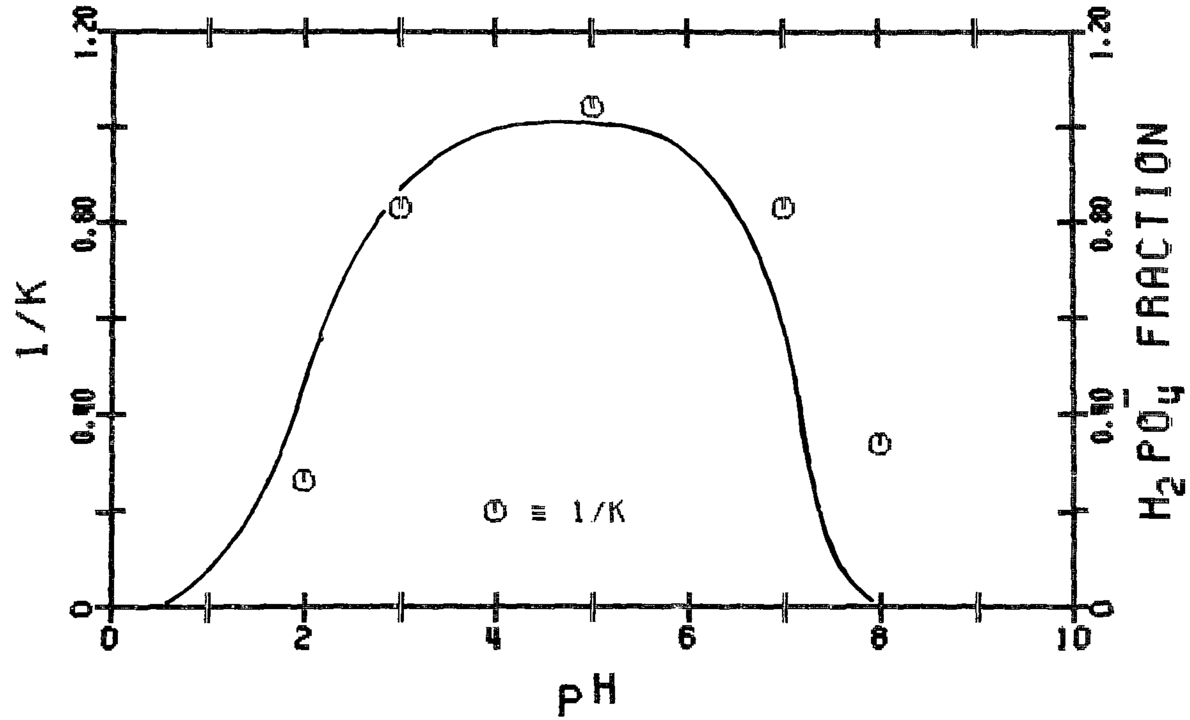

Figure 103. Dependence of equilibrium constant for phosphorus fixation on pH.

where r_m and K were defined as before. Using the definition

$$r' = r - k'P_s \tag{68}$$

Equation (67) was written as

$$r' = \frac{r_m P_s}{K + P_s} \tag{69}$$

Equation (69) was of the same form as Equation (65), so r_m and K were evaluated by the same procedure as before.

Values of k' were chosen until the plot of r_m versus soil mass passed through the origin. With k' = 0.003/hr the graph was linear and passed through the origin. This result conformed with Equation (63), since the correlation between S_0 and soil mass was expected to be linear with a zero intercept. The correlation between r and P_s (Figure 104) was described very well by Equation (67). These curves did not approach maxima because of the homogeneous reaction, which continued to increase with P_s.

Summary

The kinetics of phosphorus fixation was studied in a batch reactor operated in the steady state mode. A kinetic model was developed which included both heterogeneous and homogeneous processes. Langmuir-Hinselwood kinetics was used to describe the heterogeneous process, while the homogeneous component employed first order kinetics. Results from the steady state experiments agreed with the assumption of heterogeneous catalysis. Apparently adsorptive sites in the soil acted to catalyze chemical reaction between phosphate and some other component. Results at different pH values identified $H_2PO_4^-$ as the pertinent phosphate ion involved in the heterogeneous step. The expected linear correlation between the maximum rate of surface reaction and soil was verified.

Dependence of phosphorus fixation on pH and soil mass was explained very well with the proposed kinetic model. It did not estimate phosphorus fixation capacity of soil. The very difficult task of identifying the chemical mechanism was not achieved in this study.

In the model for phosphorus transport, the kinetic component assumed first order kinetics, given by Equation (19). This assumption was justified in the packed-bed reactor since an excess of adsorptive sites was present and the number of adsorbed molecules was very small compared to the number of sites. For this reason the second order process reduced to pseudo first order.

CATION TRANSPORT

In the effluent irrigation system cation exchange was important in processes such as nitrification ($NH_4^+ \rightarrow NO_3^-$) and nutrient uptake by plants. A model of cation transport was utilized to establish coupling between ion

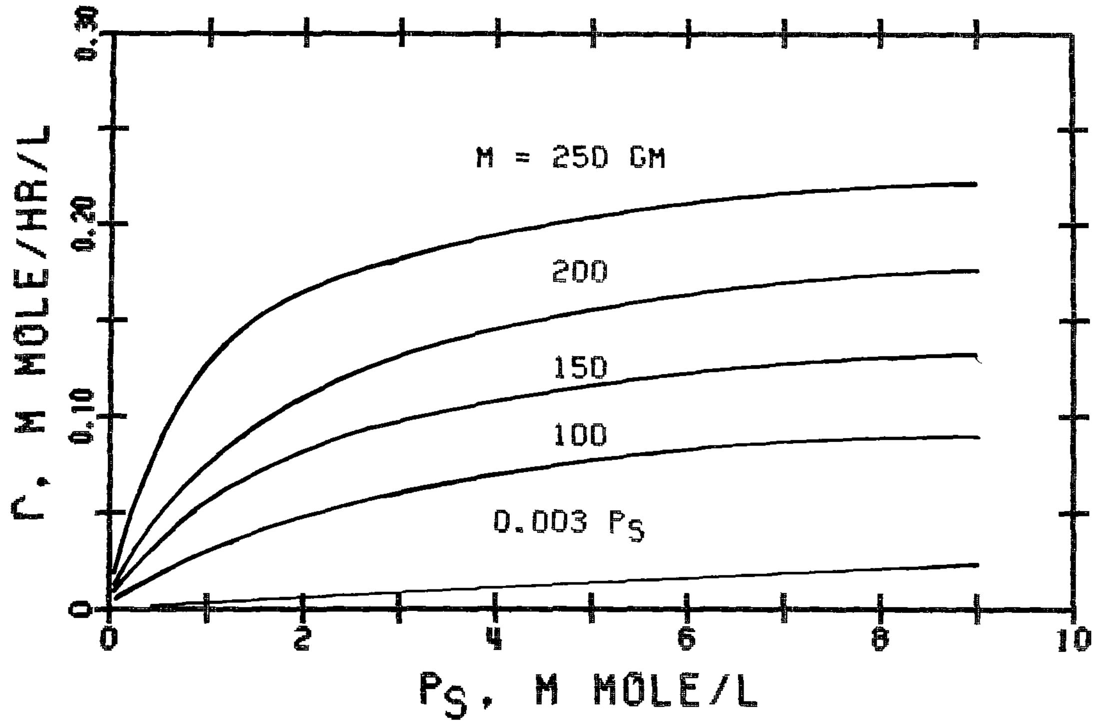

Figure 104. Effect of solution reaction on steady state phorphorus fixation in a batch reactor.

exchange and convection. Components of the model included convection, dispersion and cation exchange. Measurements were made on a univalent/univalent system. The cations K^+ and NH_4^+ were chosen because of their similar ionic mobilities.

Cation Exchange Model

A reversible ion exchange model was assumed for the univalent-univalent system (Hiester and Vermuelen, 1952)

$$C + B \cdot S \underset{k_B}{\overset{k_C}{\rightleftharpoons}} C \cdot S + B \tag{70}$$

where C = solution concentration on the inflow cation
B = solution concentration of the outflow cation
$C \cdot S$ = surface concentration of the inflow cation
$B \cdot S$ = surface concentration of the outflow cation
k = exchange coefficient

and the subscript refers to the appropriate cation. Cation exchange was assumed to be controlled by mass action, so that the kinetic equation

$$\frac{\partial C \cdot S}{\partial t} = k_C C\ (B \cdot S) - k_B B\ (C \cdot S) \tag{71}$$

was used, where t was the time. The analysis was simplified by assuming constant and uniform ionic strength throughout the experiments, so that, by electrical neutrality

$$B + C = A = \text{constant} \tag{72}$$

where A was the solution concentration of anion. It was further assumed that the cation exchange capacity of the soil, Q, was constant, so that

$$B \cdot S + C \cdot S = Q \tag{73}$$

and

$$B + C = C_0 \tag{74}$$

where C_0 was the feed concentration of the cation. Combination of Equations (71) - (74) yielded

$$\frac{\partial q}{\partial t} = k_C C\ (Q - q) - k_B\ (C_o - C)\ q \tag{75}$$

where $q = C \cdot S$. The initial condition was

$$q = 0 \qquad \text{at } t = 0 \tag{76}$$

Solution of Equation (75) required an auxiliary relationship of some type. For the packed-bed reactor this consisted of a mass balance for the cation in the solution phase.

Cation Transport Model

A dispersed flow model (Smith, 1970) was used for the packed bed reactor, and for one dimensional flow was written as

$$D \frac{\partial^2 C}{\partial z^2} - V \frac{\partial C}{\partial z} = \frac{\partial C}{\partial t} + \frac{\rho}{\varepsilon} \frac{\partial (C \cdot S)}{\partial t} \tag{77}$$

with the conditions

$$z > 0 \qquad C = 0 \qquad t = 0 \tag{78}$$

$$z = 0 \qquad C = C_o \qquad t \geq 0 \tag{79}$$

$$z \rightarrow \infty \qquad C \rightarrow 0 \qquad t \geq 0 \tag{80}$$

where z = depth in the reactor
D = pore dispersion coefficient
V = pore velocity
ρ = bulk density of soil
ε = porosity.

In the analysis $C \cdot S$ was written as mass of cation/mass of soil. Equations (75) - (80) constituted the system to be solved. However, it was convenient to convert the system to dimensionless form with the definitions

$$C^* = \frac{C}{C_o} \qquad q^* = \frac{q}{Q} \qquad z^* = \frac{z}{\ell} \qquad t^* = \frac{vt}{\ell}$$

$$\eta = \frac{D}{\ell v} \qquad \alpha = \frac{\ell k_c C_o}{v} \qquad \beta = \frac{\rho Q}{\varepsilon C_o} \qquad K = \frac{k_C}{k_B}$$

where ℓ was a characteristic length. Equations (75) - (80) were converted to

$$\eta \frac{\partial^2 C^*}{\partial z^{*2}} - \frac{\partial C^*}{\partial z^*} = \frac{\partial C^*}{\partial t^*} + \beta \frac{\partial q^*}{\partial t^*} \tag{81}$$

with

$$z^* > 0 \qquad C^* = 0 \qquad t^* = 0 \tag{82}$$

$$z^* = 0 \qquad C^* = 1 \qquad t^* \geq 0 \tag{83}$$

$$z^* \rightarrow \infty \qquad C^* \rightarrow 0 \qquad t^* \geq 0 \tag{84}$$

and

$$\frac{\partial q^*}{\partial t^*} = \alpha [C^* (1 - q^*) - \frac{1}{K} (1 - C^*) q^*] \qquad (85)$$

with

$$z^* > 0 \qquad q^* = 0 \qquad t^* = 0 \qquad (86)$$

For the special case of symmetric exchange ($k_C = k_B = k$), Equation (85) reduced to

$$\frac{\partial q^*}{\partial t^*} = \alpha [C^* - q^*] \qquad (87)$$

Equations (81) - (86) were solved by finite differences, using the Crank-Nicolson implicit procedure (Gupta and Greenkorn, 1973).

Response Curves

Experiments were conducted in a packed-bed reactor, 4.8 cm ID and 10 cm in length. The end plates were grooved to provide more uniform flow at the ends. After drying in a forced air oven at 105°C for 24 hr, Lakeland fine sand was packed in the reactor to a bulk density of 1.66 g/cm^3 and porosity of 0.376. After purging with CO_2 to displace insoluble gases, the reactor was saturated with deionized water. Several pore volumes of 1 N NH_4Cl were passed through to saturate the exchange complex with NH_4^+ ions. This was followed by several pore volumes of NH_4Cl solution of appropriate feed concentration and pH = 6.5. Flow rates were controlled with a peristaltic pump with speed control. Whole discrete outflow samples were collected with a fraction collector. Samples were analyzed for NH_4^+ by spectrophotometer, K^+ by flame photometer and Cl^- by coulometric titration. Experiments were conducted by switching between KCl and NH_4Cl of the same molar concentration and at pH = 6.5. Measurements of Cl^- showed that its concentration remained constant throughout a run. Measurements of the two cations established that Equation (74) was satisfied.

Output curves were all of the type shown in Figure 105. The amount of cation in exchange was estimated from a mass balance for the particular cation; viz,

$$\text{In} + \text{Pores (initial)} = \text{Out} + \text{Pores (final)} + \text{Exchange} \qquad (88)$$

Mass in (moles) was calculated from feed concentration (moles/ℓ), flow rate (cm^3/min) and total time (min). Mass-out was calculated from concentration (moles/ℓ) for the fraction, flow rate (cm^3/min) and time between fractions (min), and summing over all fractions. Mass in the pores was calculated from concentration (moles/ℓ) and pore volume (cm^3). Exchange quantity was divided by soil mass in the reactor to obtain Q (meq/100 g). Values were averaged for the inflow and outflow cations to obtain a value of Q for use in the model In all cases inflow and outflow values were within 10% of each other. In the analysis, exchange was assumed to be symmetric ($k_C = k_B = k$), since NH_4^+ and K^+

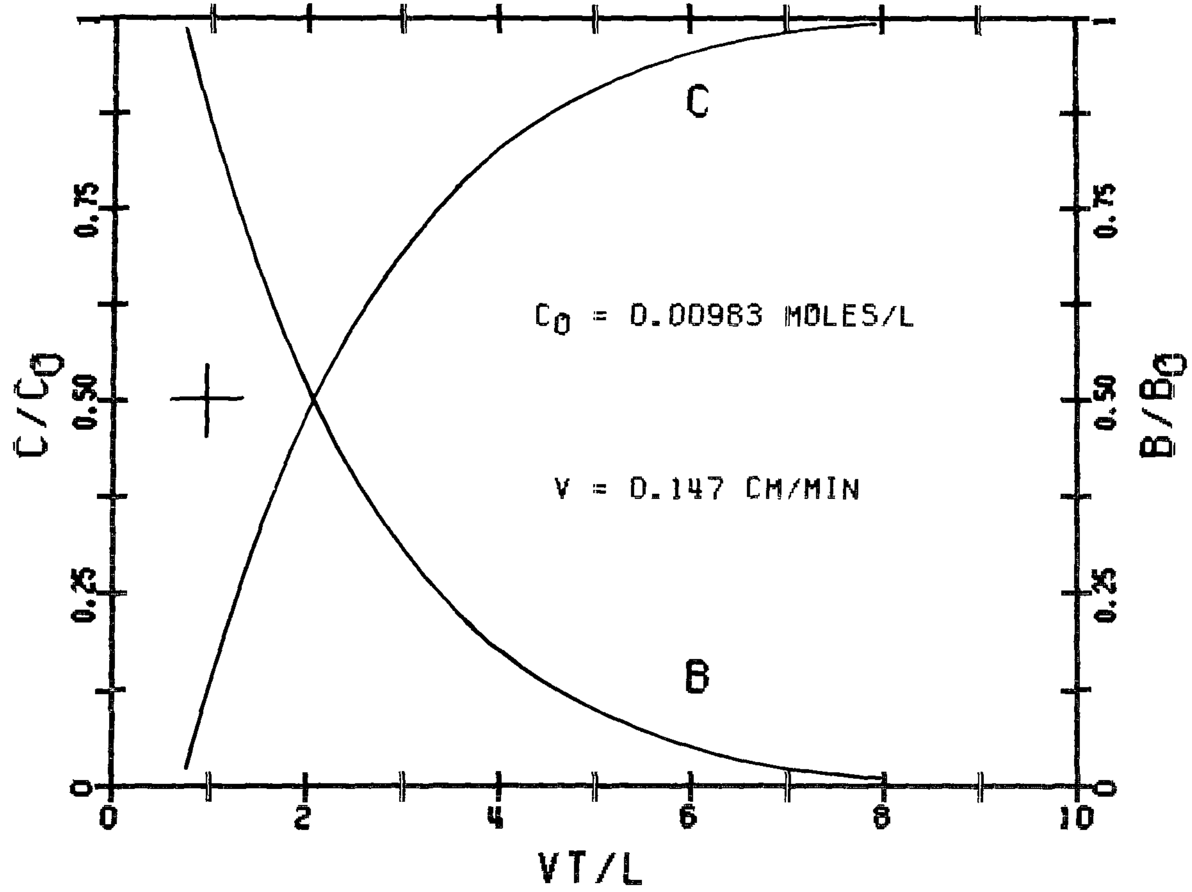

Figure 105. Typical outflow curves for NH_4^+/K^+ transport in a packed bed reactor.

both had the same ionic diffusion coefficients, and Equation (87) was used. Values for k and D were chosen to obtain good agreement between data and the model. It was observed that the influence of dispersion was primarily limited to the early portion of the curves. Exchange, on the other hand, influenced the entire curve. Reversal of the cations with the same feed concentration and velocity gave curves which superimposed throughout the runs, which showed that exchange between NH_4^+ and K^+ was symmetric.

Coupling of D and k with V

Response curves for a feed concentration of $C_0 \simeq 0.01$ moles/ℓ and velocities of 0.147, 0.297 and 0.588 cm/min all followed the shape of Figure 105, and superimposed very closely over most of the curve. The early portions disagreed slightly. A graph of the parameters showed that k versus V was linear, while D versus V was quadratic (Figure 106). These correlations explained the superimposition of the three output curves over the upper portions.

The coupling between k and V was explained with elementary film theory (Smith, 1970). In the above analysis, Equation (71) was written as a global model, where solution concentrations represented bulk solution. Apparently the transfer from bulk solution to the particle surface was diffusion limited, so that solution concentration adjacent to the surface was lower than bulk concentration. For this system surface kinetics was fast compared to diffusion. This agreed with observations in a batch reactor where the characteristic time was found to be less than one minute, which established that surface kinetics of exchange was very fast. The diffusion limited transfer in the packed-bed reactor caused a lag between surface and solution phases (Figure 107). Lag was independent of velocity, due to linear coupling between convection and cation exchange.

Feed Concentration and System Response

Behavior of the response curves was strongly influenced by feed concentration (Figure 108). At low concentrations response time was governed by exchange, while at high concentrations convection and dispersion were the controlling processes. This behavior was inherent in the coupling between Equations (81) and (87).

Ionic strength had a major influence on the exchange coefficient (Figure 109). The decrease in the exchange coefficient with increased ionic strength probably resulted from compression of the electric double layer at the charged particle/solution interface (Gast, 1977), which increased the concentration gradient near the particle surface. This increased diffusion showed up as an increased exchange coefficient in the global model.

Cation exchange capacity increased with ionic strength (Figure 109). Melendez (1976) showed that this type of correlation was associated with colloids of metal oxides and hydroxides which possessed surfaces of constant potential rather than surfaces of constant charge. Hortenstine (1966) showed that Lakeland fine sand contained large quantities of aluminum and iron compounds.

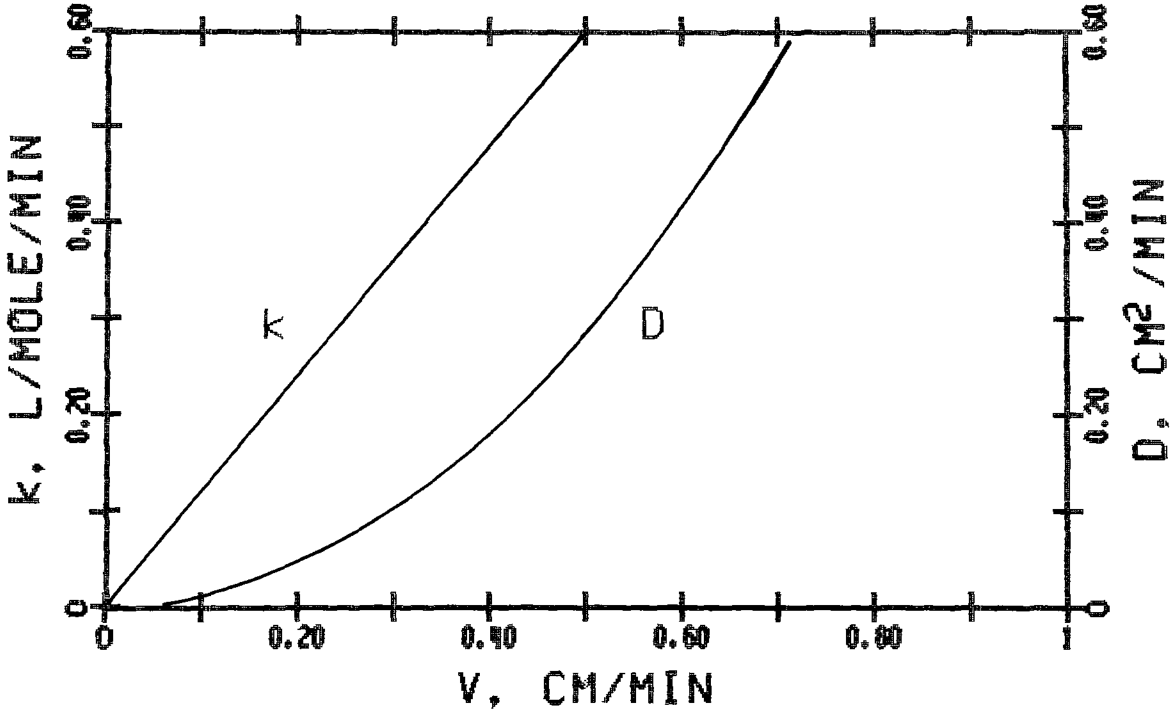

Figure 106. Dependence of exchange and dispersion coefficients on velocity for NH_4^+/K^+ transport.

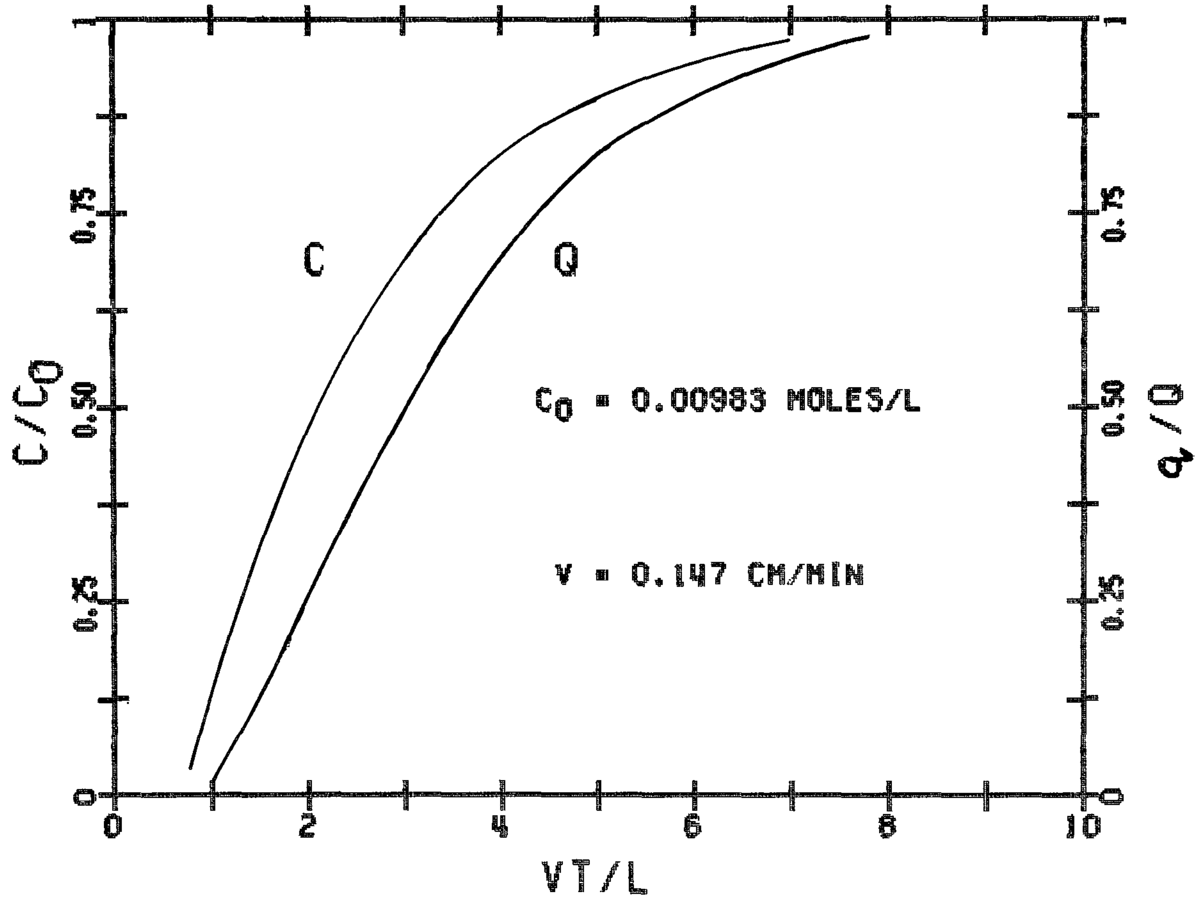

Figure 107. Lag between surface and solution concentration for NH_4^+/K^+ transport.

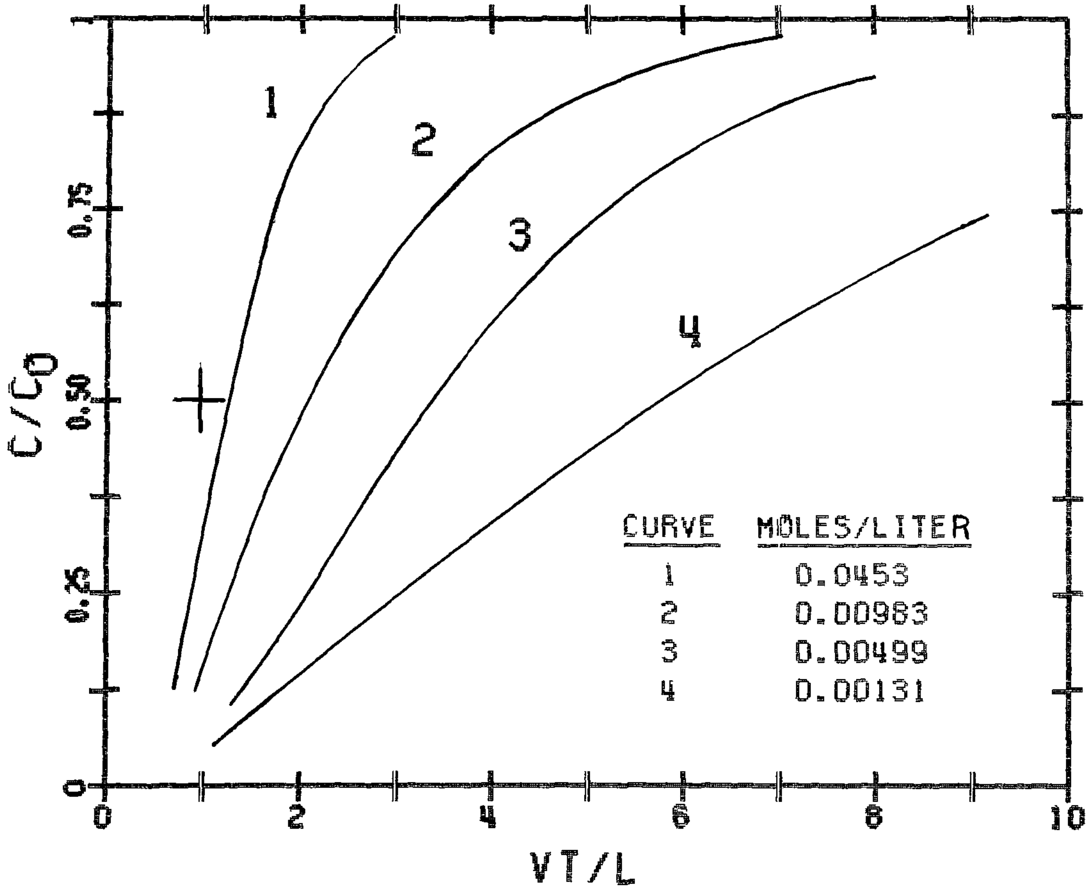

Figure 108. Effect of feed concentration on outflow curves for NH_4^+/K^+ transport.

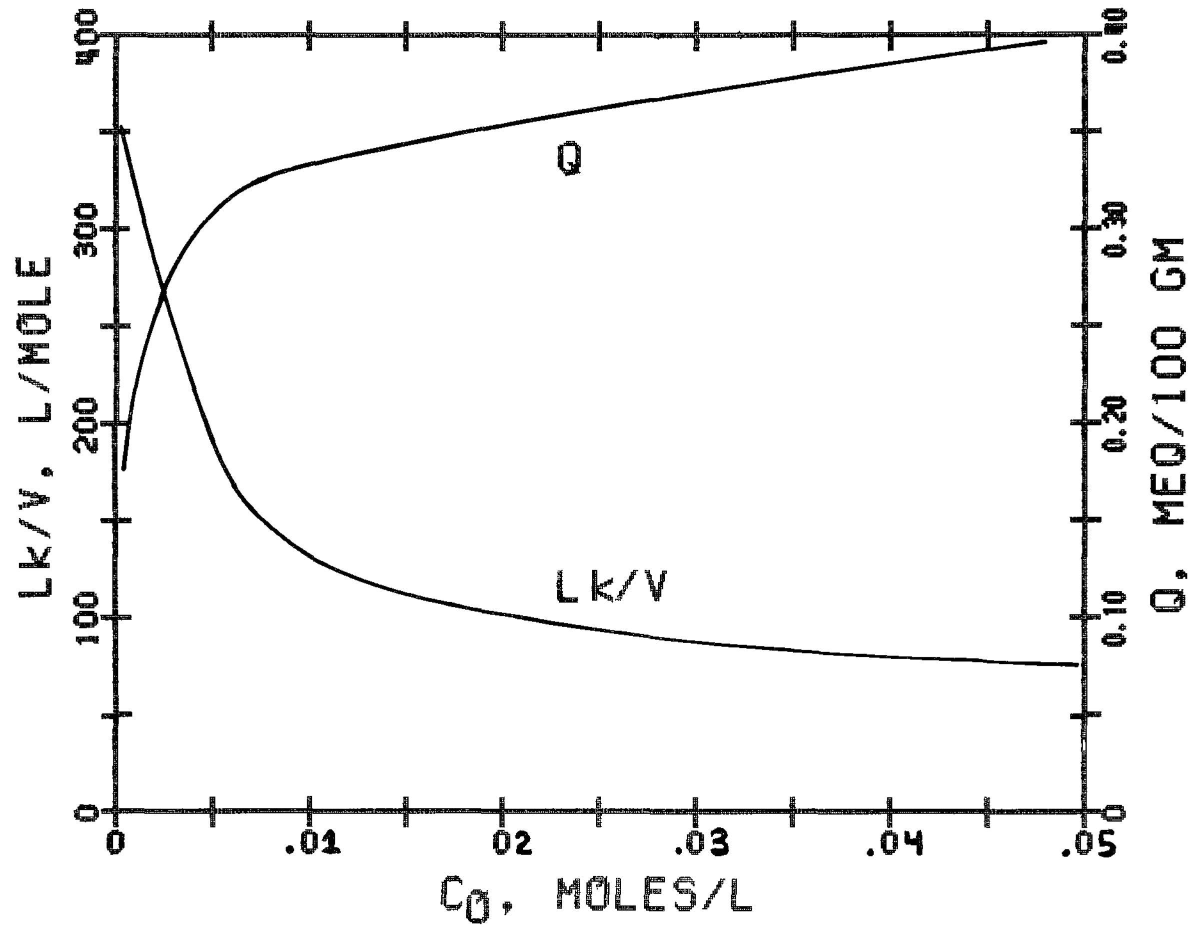

Figure 109. Effect of ionic strength on exchange coefficient and cation exchange capacity for NH_4^+/K^+ transport.

Summary

A transport model for the simple case of NH_4^+/K^+ was developed using the one dimensional dispersed flow equation and a reversible second order kinetic equation for exchange. For these two cations exchange was shown to be symmetric. The model described output curves very well for all feed concentrations and velocities. Coupling between the dispersion coefficient and velocity was shown to be quadratic, so that dispersion assumed greater importance at higher velocities. Dependence of the exchange coefficient on velocity was linear, which indicated that exchange was limited by diffusion of cations to and from the particle surface. Batch measurements verified that surface kinetics was fast compared to mass transfer in solution. These results suggested that exchange of cations such as NH_4^+ and K^+ under field conditions was closely related to convection, i.e. during irrigation exchange rates increased and then slowed down after irrigation ceased and water percolation rate diminished.

Several effects of feed concentration were noted. At low concentrations response time was controlled by exchange, while at high concentration dispersion became more important. The role of feed concentration resulted from the second order kinetics of exchange. The exchange coefficient decreased with increased ionic strength, due to compression of the electric double layer. Cation exchange capacity increased with ionic strength due to the presence of colloids of aluminum and iron in Lakeland soil. Even for this apparently simple system of NH_4^+/K^+ exchange, there was a complex interplay of several factors in the system.

From these studies on cation transport and exchange it was concluded that nitrification (bacterial conversion of exchangeable NH_4^+ to NO_3^-) would be enhanced with higher solution concentration of NH_4^+ and in soils with higher cation exchange capacity. This suggested that nitrogen uptake by the crops at Tallahassee was limited by the low cation exchange capacity of Lakeland fine sand (less than 5 meq/100 g) and that it was lower for the effluent used (total N < 40 mg/ℓ) than would have occurred with effluent of higher N concentration.

SECTION 8

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APPENDIX A

RESULTS FOR CROP YIELDS AND NUTRIENT RECOVERY

INTRODUCTION

Detailed results for the various crops and years are presented in this appendix because of the voluminous amount of data. Results are presented by years due to commonality of wastewater characteristics and cultural practices. A summary of results by crops is presented in Section 6 to relate data from different years. In this report, mton is used to denote metric tons, as distinguished from English tons, to minimize confusion. For each year the crop varieties are listed since yields and chemical composition may vary widely among varieties of the same crop.

1971 SUMMER CROPS

The two crops used were sorghum x sudangrass (Asgrow Grazer-S) and kenaf (Everglades 41). Following plowing and disking, the plots (30 m x 30 m) were planted in 0.9 m (3 ft) rows, with a seeding rate of 11 kg/ha (10 lb/acre). Planting and harvesting followed the schedule shown in Table A-1. Irrigation rates were 25, 50, 100 and 200 mm/week. Green weights were measured for each

TABLE A-1. FIELD SCHEDULE FOR SUMMER 1971

Operation	Crop	
	Sorghum x sudangrass	Kenaf
Planting	4/7/71	4/9/71
Harvesting		
1st	6/16/71	6/16/71
2nd	8/25/71	9/27/71

plot by collecting all the vegetation. From each batch 1 kg composite samples were taken, dried in a forced air oven at 70°C for 24 hr, weighed again and ground in a Wiley mill. Duplicate 1 g samples were analyzed for Kjeldahl-N (USEPA, 1971). Other nutrients were measured from 0.5 g samples digested in 15 ml HNO_3 and 10 ml $HClO_4$, made up to 50 ml with deionized water. Chemical analyses included P by $SnCl_2$ (APHA, 1971), K and Na by flame emission, and all others by atomic absorption. Effluent samples were analyzed by the same methods.

Chemical characteristics of the effluent were measured weekly on composite samples. Average values for the period 4/71-9/71 are shown in Table 6. Effluent pH averaged 7.6 while nitrogen composition was 74% NH_4-N, 13% NO_3-N and 13% organic N. Since these samples were not analyzed for P, K, Ca, Mg, and Na, values for the period 4/72-9/72 were used.

Sorghum x Sudangrass

The crop showed positive response to effluent irrigation. Yields of green forage as well as dry forage showed an increase with application rate, as shown in Table A-2. Dry matter content remained essentially constant, for

TABLE A-2. YIELD AND DRY MATTER OF SORGHUM X SUDANGRASS - 1971

Rate mm/week	25	50	100	200
		1st Harvest		
Green Weight, mtons/ha	23.7	26.9	32.9	39.9
Dry Matter, %	21.2	18.1	18.8	20.4
Dry Weight, mtons/ha	5.04	4.86	6.18	8.13
		2nd Harvest		
Green Weight, mtons/ha	18.6	23.7	25.3	31.4
Dry Matter, %	21.9	23.6	21.7	23.3
Dry Weight, mtons/ha	4.08	5.60	5.49	7.28
		Net		
Green Weight, mtons/ha	42.3	50.6	58.2	71.3
Dry Matter, %	21.5	20.7	20.0	21.6
Dry Weight, mtons/ha	9.12	10.46	11.67	15.41

an average composite value of approximately 21%. These results compare closely with fertility trials in Gainesville, Florida (Agronomy Mimeo Report, 1971) with this same variety where 228 kg/ha of applied N produced 58.8 mtons/ha.

By combining dry yields (Table A-2) and nutrient composition (Table A-3), crop uptake of the various elements was calculated (Table A-4). Nutrient uptake of all elements (except Fe and Zn) showed an increase with irrigation rate. A positive correlation between uptake and application rate of nutrients may be seen from Table A-4. All of these illustrated the response of diminishing returns, i.e. succeeding increments of nutrient applied produced smaller and smaller increments of uptake. This in turn led to decreasing efficiency of recovery. Figure A-1 illustrates these features for nitrogen. For example, an irrigation rate of 25 mm/week (1 in./week) provided 88 kg/ha N

TABLE A-3. NUTRIENT COMPOSITION OF SORGHUM X SUDANGRASS - 1971

Rate	mm/week	25	50	100	200
			1st Harvest		
N		0.89	0.94	0.86	1.30
P		0.42	0.67	0.54	0.76
K		0.29	0.43	0.26	0.21
Ca	%	0.39	0.46	0.46	0.77
Mg		0.53	0.67	0.72	1.01
Na		0.16	0.21	0.12	0.19
Fe		0.0091	0.0065	0.0100	0.0390
Zn		0.0037	0.0038	0.0026	0.0054
			2nd Harvest		
N		1.04	1.14	1.50	1.20
P		0.75	0.80	1.00	0.66
K		0.98	1.12	0.96	0.85
Ca	%	0.50	0.50	1.55	0.58
Mg		0.57	0.64	0.95	0.65
Na		0.18	0.10	0.36	0.15
Fe		0.0380	0.0140	0.0200	0.0130
Zn		0.0041	0.0053	0.0097	0.0042
			Net		
N		0.96	1.05	1.17	1.25
P		0.57	0.74	0.67	0.71
K		0.60	0.80	0.59	0.51
Ca	%	0.44	0.48	0.97	0.68
Mg		0.55	0.65	0.83	0.84
Na		0.18	0.15	0.23	0.17
Fe		0.0220	0.0105	0.0147	0.0195
Zn		0.0039	0.0045	0.0059	0.0048

TABLE A-4. NUTRIENT UPTAKE BY SORGHUM X SUDANGRASS - 1971

Rate	mm/week	25	50	100	200
			1st Harvest		
N		45	46	54	105
P		21	33	33	62
K		15	21	16	17
Ca	kg/ha	20	22	28	63
Mg		27	33	44	82
Na		9.0	10.2	7.4	15.5
Fe		0.46	0.31	0.62	3.17
Zn		0.19	0.18	0.16	0.44
			2nd Harvest		
N		43	64	83	87
P		31	45	55	48
K		40	63	53	62
Ca	kg/ha	20	28	85	42
Mg		23	36	52	47
Na		7.4	5.6	19.7	11.0
Fe		1.54	0.78	1.10	0.95
Zn		0.17	0.29	0.53	0.30
			Total		
N		88	110	137	192
P		52	78	88	110
K		55	84	69	79
Ca	kg/ha	40	50	113	105
Mg		50	69	97	129
Na		16.4	15.8	27.1	26.5
Fe		2.00	1.09	1.72	4.12
Zn		0.36	0.47	0.69	0.74

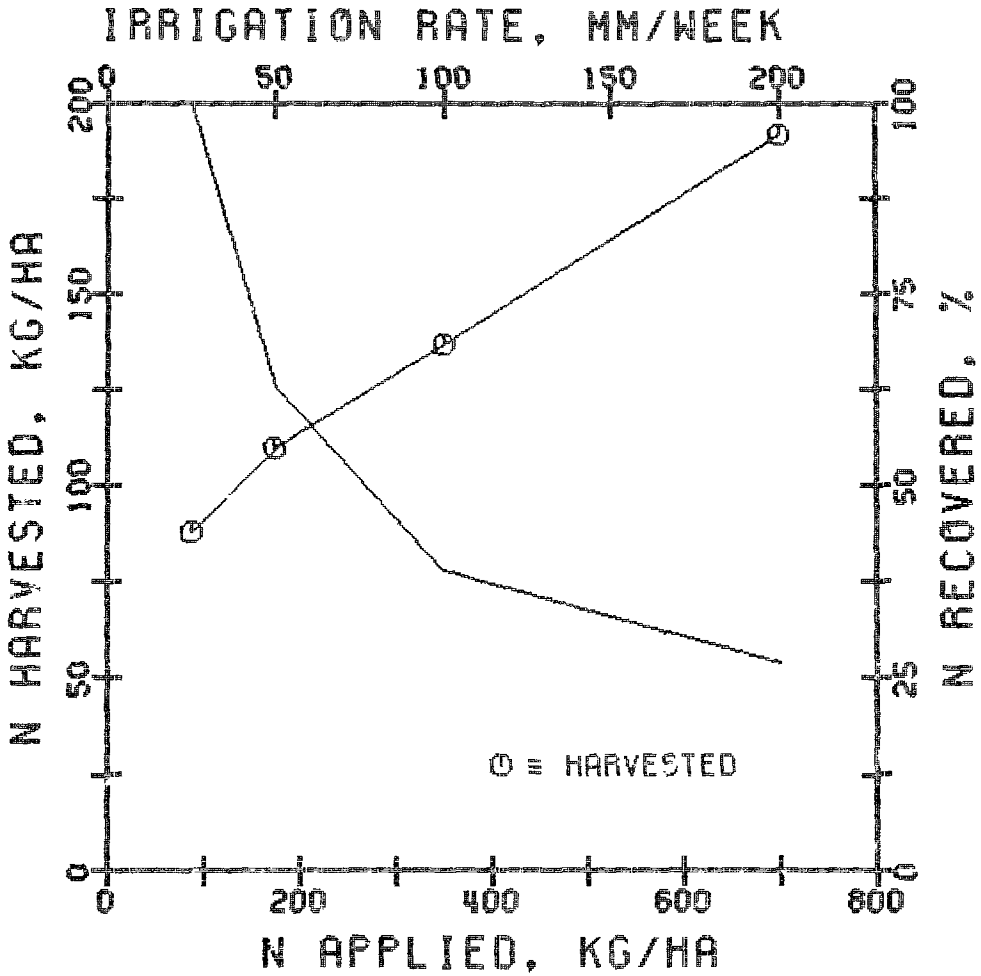

Figure A-1. Nitrogen recovery by sorghum x sudangrass.

TABLE A-5. NUTRIENT RECOVERY BY SORGHUM X SUDANGRASS - 1971

Rate	mm/week	25	50	100	200
			Harvested, kg/ha		
N		88	110	137	192
P		52	78	88	110
K		55	84	69	79
Ca		40	50	113	105
Mg		50	69	97	129
Na		16.4	15.8	27.1	26.5
			Applied, kg/ha		
N		88	175	350	700
P		42	85	170	340
K		21	42	85	170
Ca		112	225	450	900
Mg		31	62	125	250
Na		122	245	490	980
			Recovered, %		
N		100	63	39	27
P		120	92	52	32
K		260	200	81	46
Ca		36	22	25	12
Mg		160	110	78	52
Na		13.0	6.4	5.5	2.7

with a corresponding uptake of 88 kg/ha N, for a recovery efficiency of 100%. Increasing the application rate to 50 mm/week (2 in./week) raised the values to 175 kg/ha N applied, 110 kg/ha harvested and 63% recovery.

From Table A-5 it appears that most elements were supplied in adequate quantity in the effluent. The major exception to this was K. At 25 mm/week recovery was 260%. For a soil low in available K, as Lakeland fine sand is, a deficiency of K could eventually occur. Supplemental K might then be required. It has been pointed out that effluent is deficient in K for producing forage crops (Kardos, et al., 1974).

It should be pointed out that response of a crop to added nutrients depends upon nutrient reserves in the soil. From this work, Overman and Evans (1978) estimated soil reserves of N, P and K of 56, 45 and 45 kg/ha, respectively. Such values do not seem unusual, since the plots had carried a grass cover under irrigation with effluent (no grass removal) for five prior years. However, under crop harvest, these reserves of N and K would likely diminish.

In normal practice, two or three harvests of sorghum x sudangrass would be expected. A third harvest failed for lack of weed control.

Kenaf

Yield results are shown in Table A-6. Both green and dry yields increased with irrigation rate, while dry matter content decreased slightly. These results agreed closely with fertility trials in Gainesville, Florida (Pepper and Prine, 1969) with this variety, where 190 kg/ha N applied produced 11 mton/ha of oven dry material.

TABLE A-6. YIELD AND DRY MATTER OF KENAF - 1971

Rate mm/week	25	50	100	200
		1st Harvest		
Green Weight, mtons/ha	19.7	28.4	29.6	39.6
Dry Matter, %	15.0	13.9	15.3	16.9
Dry Weight, mtons/ha	2.96	3.94	4.52	6.70
		2nd Harvest		
Green Weight, mtons/ha	27.8	30.5	30.7	40.1
Dry Matter, %	28.0	25.6	22.6	19.2
Dry Weight, mtons/ha	7.77	7.80	6.92	7.71
		Net		
Green Weight, mtons/ha	47.5	58.9	60.3	79.7
Dry Matter, %	22.6	19.9	19.0	18.1
Dry Weight, mtons/ha	10.7	11.7	11.4	14.4

TABLE A-7. NUTRIENT COMPOSITION OF KENAF - 1971

Rate	mm/week	25	50	100	200
			1st Harvest		
N		1.49	1.46	1.34	2.73
P		0.90	0.78	0.86	0.68
K		0.28	0.27	0.28	0.24
Ca	%	1.91	1.60	1.70	1.76
Mg		1.02	0.92	1.02	0.96
Na		0.28	0.25	0.33	0.24
Fe		0.0150	0.0170	0.0150	0.0250
Zn		0.0049	0.0044	0.0059	0.0039
			2nd Harvest		
N		0.74	0.90	1.06	2.34
P		0.74	0.80	0.88	0.62
K		0.86	0.93	1.25	3.62
Ca	%	1.38	1.49	1.40	2.22
Mg		0.75	0.85	0.85	0.82
Na		0.22	0.25	0.40	0.23
Fe		0.0120	0.0140	0.0200	0.0340
Zn		0.0076	0.0082	0.0094	0.0064
			Net		
N		0.94	1.09	1.16	2.52
P		0.78	0.79	0.87	0.65
K		0.70	0.71	0.96	2.05
Ca	%	1.52	1.53	1.52	2.01
Mg		0.82	0.87	0.92	0.88
Na		0.24	0.25	0.37	0.23
Fe		0.0128	0.0150	0.0180	0.0300
Zn		0.0069	0.0069	0.0080	0.0052

TABLE A-8. NUTRIENT UPTAKE BY KENAF - 1971

Rate	mm/week	25	50	100	200
			1st Harvest		
N		44	57	60	183
P		27	31	39	46
K		8	11	13	16
Ca	kg/ha	56	63	77	118
Mg		30	36	46	64
Na		8.3	9.9	14.9	16.1
Fe		0.45	0.67	0.67	1.68
Zn		0.15	0.17	0.27	0.26
			2nd Harvest		
N		57	71	73	180
P		57	62	61	48
K		67	72	97	279
Ca	kg/ha	107	116	97	171
Mg		58	66	59	63
Na		17.1	19.5	27.7	17.7
Fe		0.93	1.09	1.39	2.62
Zn		0.59	0.64	0.65	0.49
			Total		
N		101	128	133	363
P		84	93	100	94
K		75	83	110	186
Ca	kg/ha	163	179	174	289
Mg		88	102	105	127
Na		25.4	29.4	42.6	33.8
Fe		1.38	1.73	2.06	4.30
Zn		0.74	0.81	0.92	0.75

TABLE A-9. NUTRIENT RECOVERY BY KENAF - 1971

Rate	mm/week	25	50	100	200
			Harvested, kg/ha		
N		101	128	133	363
P		84	93	100	94
K		75	83	110	186
Ca		163	179	174	289
Mg		88	102	105	127
Na		25.4	29.4	42.6	33.8
			Applied, kg/ha		
N		106	212	425	850
P		52	103	206	412
K		26	52	103	206
Ca		138	275	550	1100
Mg		39	78	157	314
Na		151	302	605	1210
			Recovered, %		
N		95	60	31	43
P		160	90	48	23
K		290	160	110	140
Ca		120	65	32	26
Mg		220	130	67	41
Na		17.0	9.7	7.0	2.8

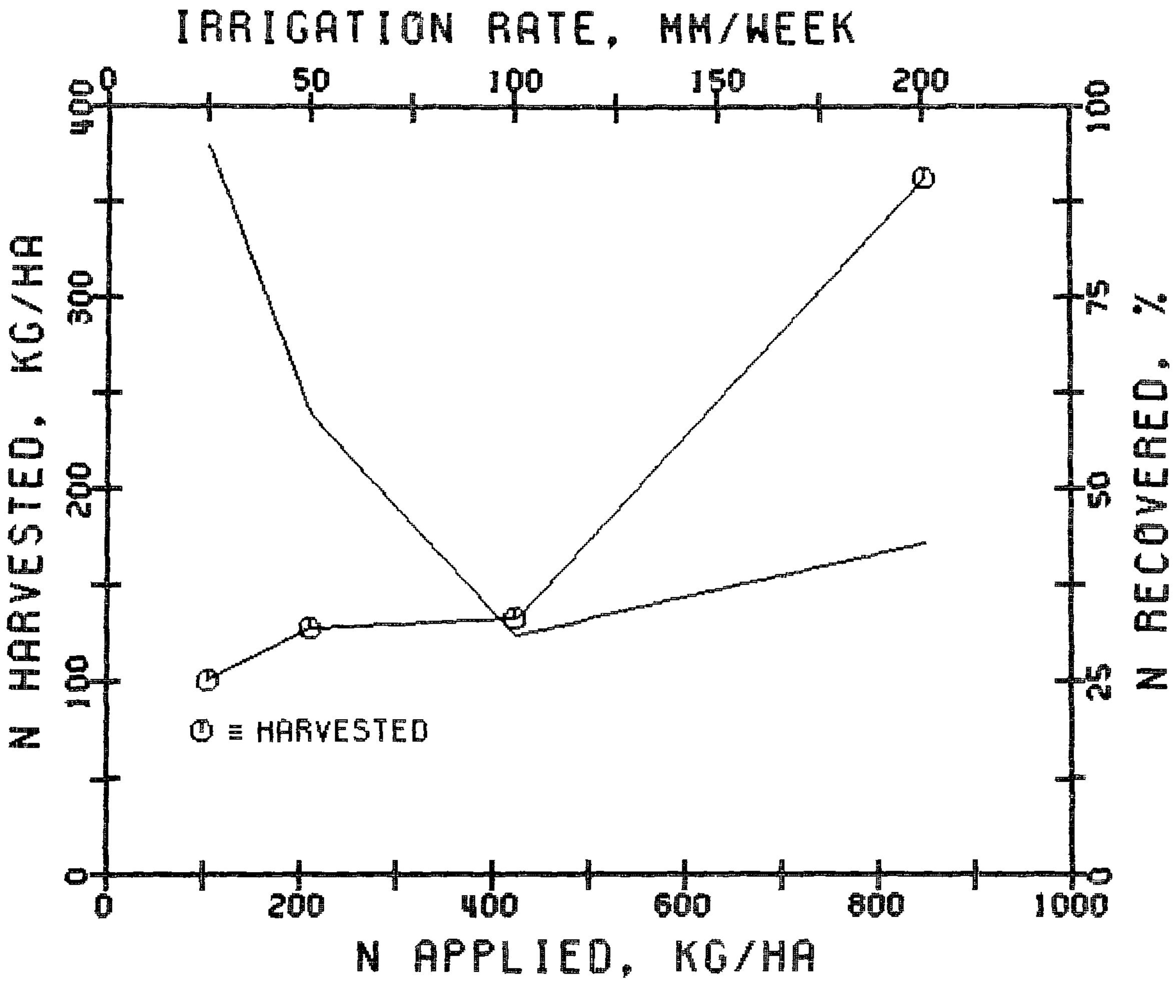

Figure A-2. Nitrogen recovery by kenaf - 1971.

Combination of dry yields (Table A-6) and nutrient composition (Table A-7) provided estimates of nutrient uptake (Table A-8). Increased application of all nutrients led to increased uptake. Recovery efficiency (Table A-9, Fig. A-2) decreased with application rate for all elements measured. As with sorghum x sudangrass, a K deficiency may occur under extended periods of low irrigation rates (<50 mm/week). Overman and Evans (1978) estimated soil reserves of N, P and K of 56, 73 and 56 kg/ha, respectively, which agrees reasonably well with the values estimated from the sorghum x sudangrass data. Under continuing harvest, these reserves of N and K would be depleted.

Potential uses for kenaf have been discussed by Killinger (1967, 1969).

1971 WINTER CROPS

Rye (Wrens Abruzzi) and ryegrass (Florida Rust Resistant) were selected for winter crops. Earlier attempts with oats failed, apparently due to disease problems. All plots were disked, plowed and disked again. Both crops were drilled at a rate of 1.7 hl/ha (2 bu/acre) on October 22, 1971. Plots were harvested in January 1972, but data was invalid due to malfunction of a weighing device. Plots were harvested again March 17, 1972. Green weights were recorded and 0.5 kg composite samples collected and dried at 60°C. All other procedures were the same as for the summer crops. Crop growth was quite vigorous.

Effluent values from Table 6 were used for the period 10/71-3/72. Missing values were approximated as those of 4/72-10/72.

<u>Rye</u>

Results in Table A-10 show that green and dry yields increased with irrigation rate, while dry matter content decreased, i.e. higher irrigation

TABLE A-10. YIELD AND COMPOSITION OF RYE - 1971

Rate	mm/week	6	12	25	50
Green Weight, mtons/ha		6.97	8.11	11.8	15.3
Dry Matter, %		19.3	19.0	17.1	14.7
Dry Weight, mtons/ha		1.35	1.54	2.02	2.24
N		4.21	4.61	4.62	4.79
P		0.68	0.69	1.05	0.94
K		2.80	2.88	2.80	3.10
Ca	%	0.52	0.49	1.15	1.02
Mg		0.23	0.24	0.46	0.43
Na		0.28	0.25	1.40	0.35
Fe		0.110	0.067	0.020	0.032
Zn		0.0092	0.0095	0.0067	0.0170

produced forage of higher moisture content. Nitrogen content of the rye was quite high, since it was harvested in the dough stage after seed head formation, and showed an increase with irrigation rate. Again, the curve of diminishing returns is well illustrated by this data (Table A-11). Due to the low application rates, efficiency of recovery was quite high, where N recovery exceeded 100% (Fig. A-3) for all rates. The likelihood of K deficiency is strongly indicated here, since recovery exceeded 100%.

TABLE A-11. NUTRIENT RECOVERY BY RYE - 1971

Rate	mm/week	6	12	25	50
			Harvested, kg/ha		
N		57	71	93	108
P		9	11	21	21
K		38	44	57	70
Ca		7	8	23	23
Mg		3.1	3.7	9.3	9.6
Na		3.8	3.8	2.8	7.8
			Applied, kg/ha		
N		12	25	50	100
P		6	12	24	48
K		3	6	12	24
Ca		16	32	65	130
Mg		5	9	18	36
Na		18	35	70	140
			Recovered, %		
N		470	290	190	110
P		150	88	88	44
K		1200	730	470	290
Ca		43	23	36	18
Mg		67	40	50	26
Na		21	11	4	5

Ryegrass

Green and dry yields of ryegrass (Table A-12) also showed a positive response to irrigation, with dry matter content showing a sizable decrease. At 50 mm/week the forage was very wet (89% water). Also, the N content was somewhat lower than for rye. In fact, nutrient recovery was lower for ryegrass (Table A-13) than for rye, in spite of the higher yields. Efficiency of N recovery decreased rapidly with irrigation rate (Fig. A-4), but remained quite high.

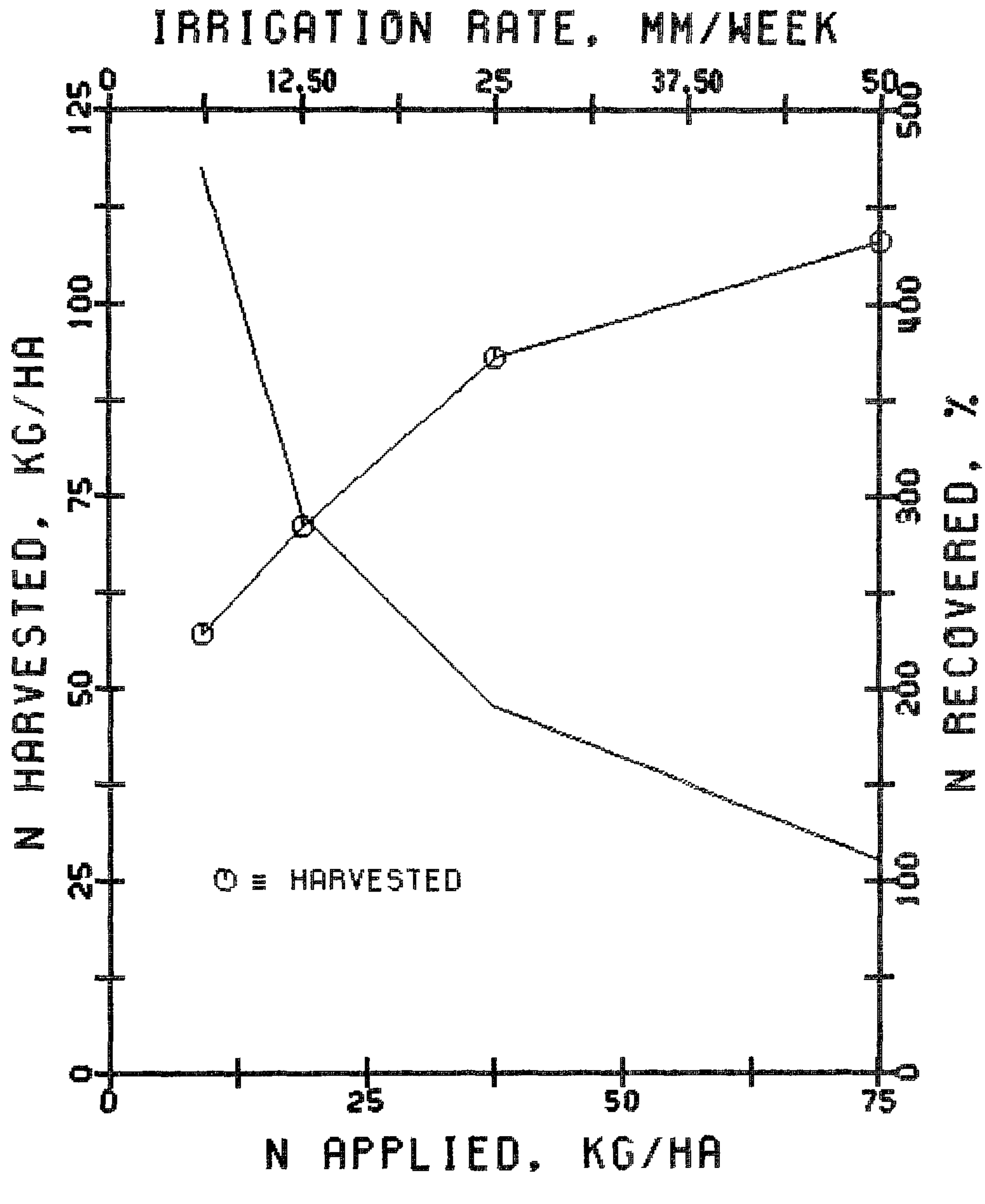

Figure A-3. Nitrogen recovery by Rye - 1971.

TABLE A-12. YIELD AND COMPOSITION OF RYEGRASS - 1971

Rate mm/week	6	12	25	50
Green Weight, mtons/ha	11.8	10.7	12.9	21.0
Dry Matter, %	20.1	18.5	16.3	11.0
Dry Weight, mtons/ha	2.38	1.98	2.11	2.31
N	1.97	2.03	2.35	2.75
P	1.06	1.00	0.77	1.17
K	3.18	2.78	2.82	2.08
Ca %	1.10	1.12	0.74	0.95
Mg	0.45	0.44	0.34	0.32
Na	0.72	1.15	1.28	1.50
Fe	0.028	0.021	0.042	0.015
Zn	0.0125	0.0091	0.0158	0.0036

TABLE A-13. NUTRIENT RECOVERY BY RYEGRASS - 1971

Rate mm/week	6	12	25	50
		Harvested, kg/ha		
N	47	40	50	64
P	25	20	16	27
K	76	55	59	48
Ca	26	22	16	22
Mg	10.7	8.7	7.2	7.4
Na	17	23	27	35
		Applied, kg/ha		
N	12	25	50	100
P	6	12	24	48
K	3	6	12	24
Ca	16	32	65	130
Mg	5	9	18	36
Na	18	35	70	140
		Recovered, %		
N	380	160	100	65
P	420	160	67	56
K	2500	900	490	200
Ca	160	68	24	17
Mg	230	95	39	20
Na	97	63	38	24

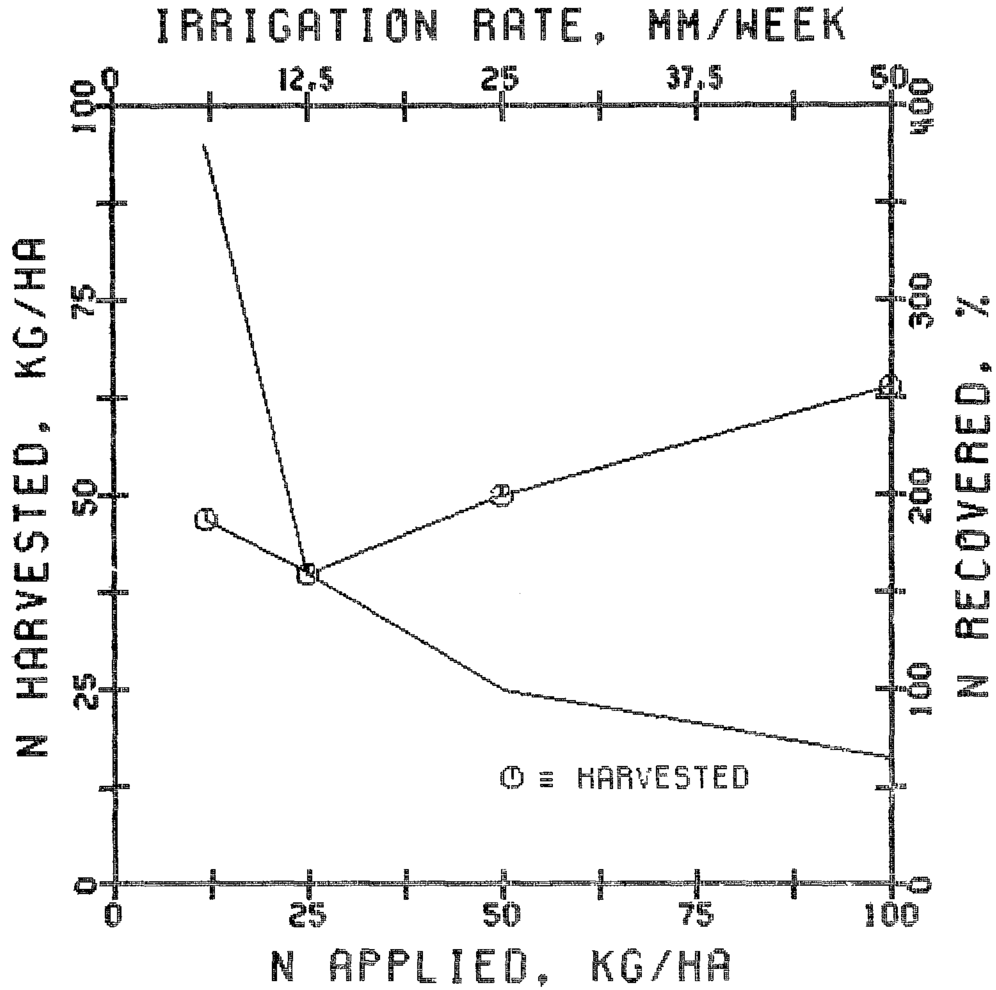

Figure A-4. Nitrogen recovery by ryegrass - 1971.

1972 SUMMER CROPS

Crops included sorghum x sudangrass (Asgrow Grazer-S), kenaf (Everglades 41), corn (McNair 440 V for silage and Pioneer 3369 A for grain), and pearl millet (Tiflate). All plots were disked, plowed and disked again. Planting, cultivation and harvests followed the schedule in Table A-14. All crops were

TABLE A-14. FIELD SCHEDULE FOR SUMMER 1972

Crop	Planting	Cultivation	Harvesting
Sorghum x sudangrass	3/23/72	4/27/72 6/8/72	6/7/72 7/27/72 9/26/72
Kenaf	3/23/72	4/27/72	7/7/72
Corn Silage	3/23/72	4/27/72	6/21/72
Corn Grain	3/23/72	4/27/72	9/7/72
Pearl Millet	4/13/72	4/27/72	7/3/72 9/28/72

planted in 0.9 m (3 ft) rows with a length of 30 m (100 ft). Four rows of pearl millet were planted and harvested, with weights being recorded for the inner two rows, only. All other plantings contained 14 rows. Seeding rates were as follows: sorghum x sudangrass - 11 kg/ha, kenaf - 11 kg/ha, corn silage - 11 kg/ha, corn grain - 17 kg/ha, and pearl millet - 11 kg/ha. Analytical procedures followed those outlined above for the 1971 summer crops.

Duplicates of each crop (except pearl millet) were planted, and each irrigation rate was duplicated so that single and split application could be made to compare crop yields and nutrient uptake under the two methods. Split applications were made as outlined in Table A-15. Results for these studies have been discussed elsewhere (Overman, 1975 and Overman, 1978).

Chemical characteristics of the effluent for the period 4/72-9/72 are shown in Table 6. Irrigation rates were 50, 100, 150 and 200 mm/week.

Sorghum x Sudangrass - Single Applications

Three harvests were made. Yields for the third cutting were lower due to decreased solar radiation and temperature during this period of the year (Table A-16). Both green and dry weights increased with irrigation rate, while dry matter content remained essentially constant. The third harvest also showed slightly lower nitrogen (protein) content than the other two

TABLE A-15. SCHEDULE FOR SPLIT APPLICATIONS*

Rate mm/week	Applications per week	Irrigation days
50	1	Wed.
100	2	Tues., Thurs.
150	3	Mon., Wed., Fri.
200	4	Mon., Tues., Thurs., Fri.

* Each increment included 50 m application.

TABLE A-16. YIELD AND DRY MATTER OF SORGHUM X SUDANGRASS WITH SINGLE APPLICATIONS - 1972

Rate mm/week	50	100	150	200
		1st Harvest		
Green Weight, mtons/ha	27.8	27.3	31.1	34.3
Dry Matter, %	16.2	15.7	16.6	16.0
Dry Weight, mtons/ha	4.50	4.30	5.17	5.49
		2nd Harvest		
Green Weight, mtons/ha	28.7	41.0	32.7	35.6
Dry Matter, %	19.1	18.7	18.8	18.4
Dry Weight, mtons/ha	5.49	7.66	6.14	6.56
		3rd Harvest		
Green Weight, mtons/ha	5.3	21.6	25.1	25.8
Dry Matter, %	25.0	23.0	25.0	23.5
Dry Weight, mtons/ha	1.34	4.97	6.27	6.05
		Net		
Green Weight, mtons/ha	61.8	89.9	88.9	95.7
Dry Matter, %	18.3	18.9	19.7	18.9
Dry Weight, mtons/ha	11.3	16.9	17.6	18.1

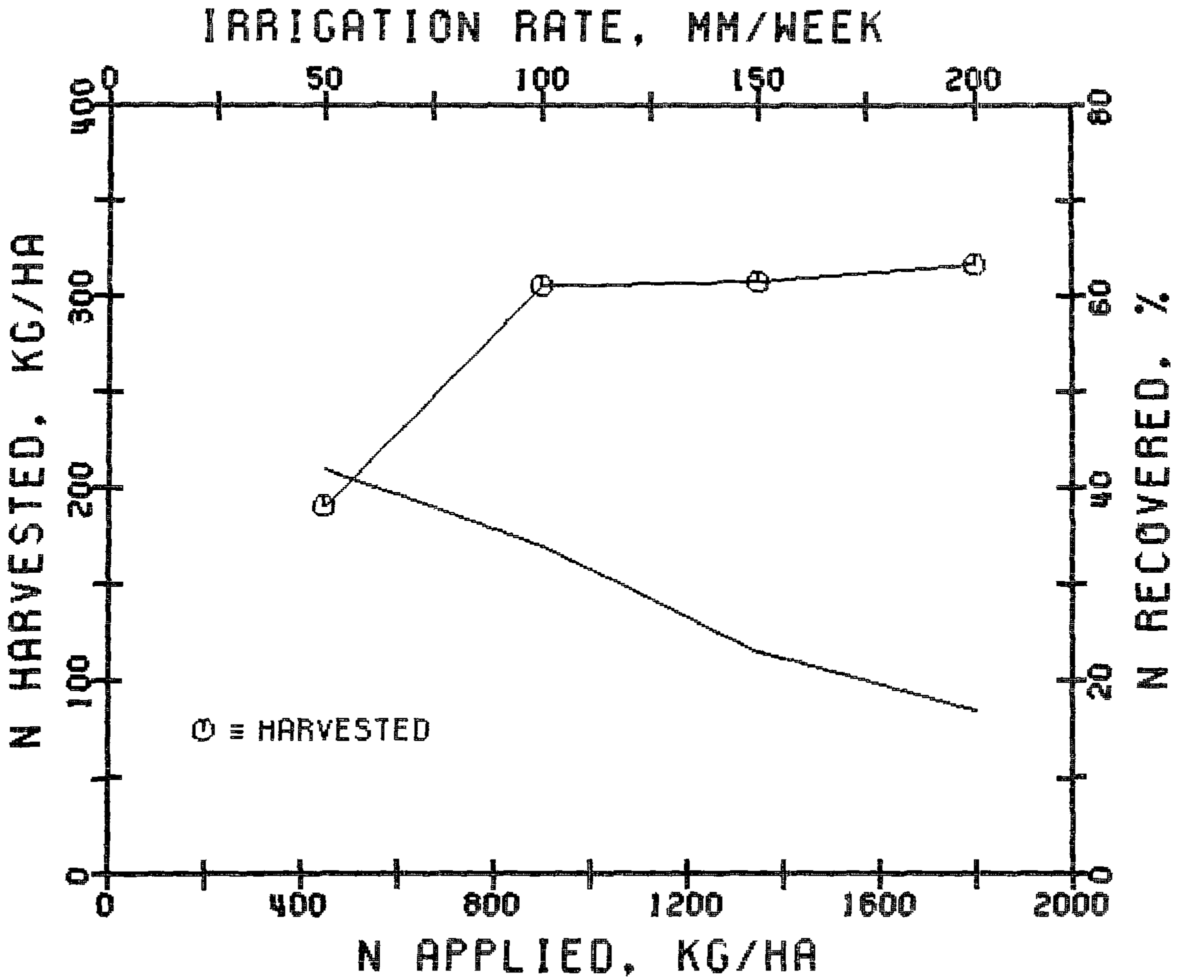

Figure A-5. Nitrogen recovery by sorghum x sudangrass with single applications - 1972.

TABLE A-17. NUTRIENT COMPOSITION OF SORGHUM X SUDANGRASS WITH SINGLE APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
			1st Harvest		
N		1.46	1.91	2.12	1.95
P		0.43	0.44	0.38	0.37
K		1.06	1.15	1.04	0.96
Ca	%	0.62	0.61	0.72	0.62
Mg		0.55	0.80	0.76	0.58
Na		0.018	0.020	0.025	0.035
Fe		0.015	0.045	0.064	0.014
			2nd Harvest		
N		1.90	1.94	1.68	1.71
P		0.44	0.33	0.29	0.32
K		0.78	0.82	0.92	1.00
Ca	%	0.60	0.49	0.52	0.64
Mg		0.59	0.64	0.70	0.75
Na		0.030	0.035	0.032	0.035
Fe		0.019	0.023	0.029	0.040
			3rd Harvest		
N		1.59	1.51	1.52	1.61
P		0.39	0.29	0.28	0.27
K		0.90	0.83	0.80	0.80
Ca	%	0.65	0.47	0.47	0.43
Mg		0.49	0.44	0.48	0.52
Na		0.033	0.030	0.030	0.025
Fe		0.020	0.015	0.020	0.036
			Net		
N		1.69	1.81	1.75	1.75
P		0.42	0.35	0.32	0.32
K		0.91	0.91	0.91	0.92
Ca	%	0.61	0.52	0.55	0.56
Mg		0.56	0.63	0.64	0.62
Na		0.026	0.029	0.030	0.032
Fe		0.017	0.026	0.036	0.030

TABLE A-18. NUTRIENT UPTAKE BY SORGHUM X SUDANGRASS WITH SINGLE APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
			1st Harvest		
N		66	82	110	108
P		19	19	20	20
K		48	49	54	53
Ca	kg/ha	28	26	37	34
Mg		25	35	39	31
Na		0.8	0.8	1.3	1.9
Fe		0.7	1.9	3.4	0.8
			2nd Harvest		
N		104	149	103	112
P		24	26	18	21
K		42	63	56	66
Ca	kg/ha	32	38	31	31
Mg		32	49	43	49
Na		1.7	2.7	2.0	2.4
Fe		1.0	1.8	1.8	2.6
			3rd Harvest		
N		21	75	95	97
P		6	15	18	17
K		12	41	50	48
Ca	kg/ha	9	24	29	26
Mg		7	22	30	31
Na		0.4	1.5	1.9	1.6
Fe		0.2	0.8	1.2	2.1

TABLE A-19. NUTRIENT RECOVERY BY SORGHUM X SUDANGRASS WITH SINGLE APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
			Harvested, kg/ha		
N		191	306	308	317
P		49	60	56	58
K		102	153	160	167
Ca		69	88	97	91
Mg		64	106	112	111
Na		2.9	5.0	5.2	5.9
Fe		1.9	4.5	6.4	5.5
			Applied, kg/ha		
N		450	900	1350	1800
P		155	310	465	620
K		62	125	187	250
Ca		410	820	1230	1640
Mg		120	240	360	480
Na		492	985	1477	1970
Fe		6	12	18	24
			Recovered, %		
N		42	34	23	17
P		31	19	12	9
K		130	99	69	54
Ca		17	11	8	6
Mg		53	44	31	23
Na		0.6	0.5	0.4	0.3
Fe		30	36	34	22

(Table A-17). Nutrient uptake for all elements increased with irrigation rate for all harvests (Table A-18). While total nutrient uptake for the season increased with irrigation rate (Table A-19), efficiency of recovery decreased for all elements. The trend is illustrated in Figure A-5.

Sorghum x Sudangrass - Split Applications

Green and dry yields increased with irrigation rate for all three harvests (Table A-20). Dry matter content remained essentially constant.

TABLE A-20. YIELD AND DRY MATTER OF SORGHUM X SUDANGRASS WITH SPLIT APPLICATIONS - 1972

Rate mm/week	50	100	150	200
		1st Harvest		
Green Weight, mtons/ha	21.6	36.5	42.6	45.7
Dry Matter, %	16.4	16.4	14.9	14.0
Dry Weight, mtons/ha	3.53	5.96	6.34	6.41
		2nd Harvest		
Green Weight, mtons/ha	17.2	25.3	34.5	42.8
Dry Matter, %	18.6	18.0	16.2	16.0
Dry Weight, mtons/ha	3.20	4.55	5.58	6.85
		3rd Harvest		
Green Weight, mtons/ha	5.7	14.5	34.3	36.5
Dry Matter, %	20.5	23.0	21.5	20.0
Dry Weight, mtons/ha	1.16	3.34	7.37	7.30
		Net		
Green Weight, mtons/ha	44.5	76.4	111.3	125.0
Dry Matter, %	17.8	18.1	17.3	16.5
Dry Weight, mtons/ha	7.9	13.8	19.3	20.6

Nutrient content values (Table A-21) were similar to those obtained for single applications. Nutrient uptake increased with irrigation rate (Table A-22) for all elements. Efficiency of recovery decreased with application rate (Table A-23), and showed similar values for split and single applications. Recoveries were relatively low due to the high level of N application (Fig. A-6).

TABLE A-21. NUTRIENT COMPOSITION OF SORGHUM X SUDANGRASS WITH SPLIT APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
			1st Harvest		
N		1.47	1.93	1.89	1.70
P		0.47	0.36	0.45	0.38
K		1.15	0.98	1.11	1.20
Ca	%	0.52	0.54	0.58	0.52
Mg		0.74	0.74	0.84	0.69
Na		0.030	0.040	0.060	0.058
Fe		0.024	0.018	0.019	0.017
			2nd Harvest		
N		1.65	1.92	2.25	2.27
P		0.57	0.50	0.34	0.42
K		0.95	0.88	0.91	0.96
Ca	%	0.82	0.66	0.54	0.88
Mg		0.74	0.75	0.64	0.74
Na		0.032	0.035	0.045	0.035
Fe		0.021	0.033	0.018	0.028
			3rd Harvest		
N		1.64	1.85	1.44	1.63
P		0.39	0.43	0.29	0.29
K		1.22	1.08	0.79	0.95
Ca	%	0.71	0.74	0.61	0.64
Mg		0.79	0.74	0.42	0.49
Na		0.062	0.050	0.040	0.045
Fe		0.022	0.072	0.013	0.013
			Net		
N		1.56	1.91	1.82	1.86
P		0.50	0.42	0.35	0.36
K		1.08	0.97	0.93	1.04
Ca		0.65	0.63	0.58	0.69
Mg		0.74	0.74	0.63	0.63
Na		0.035	0.040	0.048	0.045
Fe		0.023	0.036	0.017	0.019

TABLE A-22. NUTRIENT UPTAKE BY SORGHUM X SUDANGRASS WITH SPLIT APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
			1st Harvest		
N		52	115	120	109
P		17	21	28	25
K		40	58	71	77
Ca	kg/ha	18	32	37	34
Mg		26	44	54	44
Na		1.1	2.4	3.8	3.7
Fe		0.9	1.1	1.2	1.1
			2nd Harvest		
N		53	87	125	156
P		18	22	19	29
K		30	40	50	66
Ca	kg/ha	26	30	30	60
Mg		24	34	36	50
Na		1.0	1.6	2.5	2.4
Fe		0.7	1.5	1.0	1.9
			3rd Harvest		
N		19	62	106	119
P		4	15	21	21
K		15	36	58	69
Ca	kg/ha	8	25	45	47
Mg		9	25	31	36
Na		0.7	1.7	2.9	3.2
Fe		0.2	2.4	1.0	0.9

TABLE A-23. NUTRIENT RECOVERY BY SORGHUM X SUDANGRASS WITH SPLIT APPLICATIONS - 1972

Rate mm/week	50	100	150	200
		Harvested, kg/ha		
N	124	264	351	384
P	39	58	68	75
K	85	134	179	212
Ca	52	87	112	141
Mg	59	103	121	130
Na	2.8	5.7	9.2	9.3
Fe	1.8	5.0	3.2	3.9
		Applied, kg/ha		
N	450	900	1350	1800
P	155	310	465	620
K	62	125	187	250
Ca	410	820	1230	1640
Mg	120	240	360	480
Na	492	985	1477	1970
Fe	6	12	18	24
		Recovered, %		
N	27	29	26	21
P	25	19	13	12
K	110	87	77	69
Ca	13	11	9	9
Mg	48	42	33	27
Na	0.6	0.6	0.6	0.5
Fe	29	39	17	16

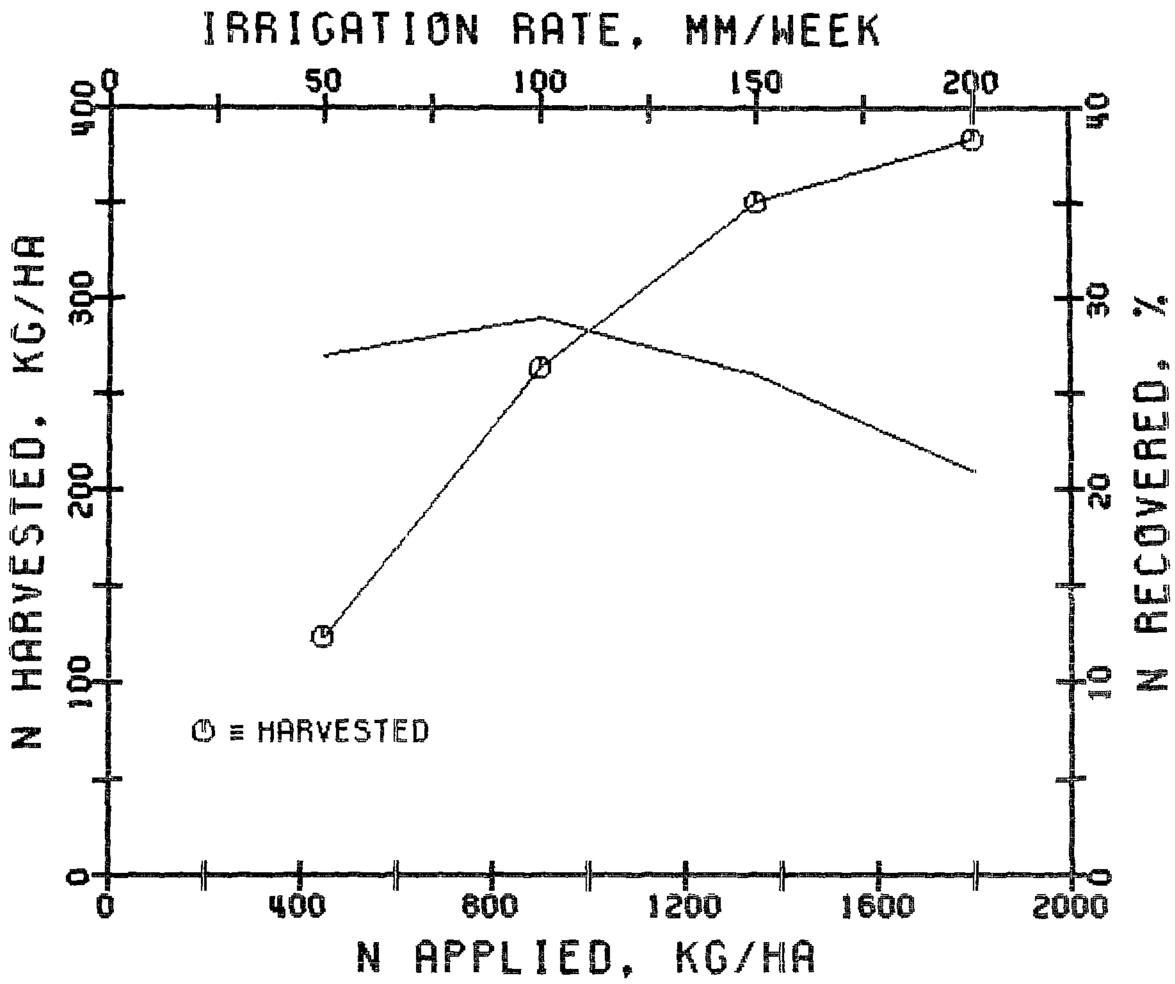

Figure A-6. Nitrogen recovery by sorghum x sudangrass with split applications - 1972.

Kenaf - Single Applications

Only one harvest of kenaf was obtained in 1972; the crop simply failed to regenerate adequately following the first cutting. Both green and dry yields increased with irrigation rate (Table A-24), while dry matter content

TABLE A-24. YIELD AND COMPOSITION OF KENAF WITH SINGLE APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
Green Weight, mtons/ha		35.4	41.0	40.3	49.7
Dry Matter, %		17.6	16.4	16.8	17.2
Dry Weight, mtons/ha		6.23	6.72	6.76	8.56
N		1.38	1.57	1.69	1.99
P		0.43	0.36	0.40	0.30
K		0.92	0.39	1.05	0.98
Ca	%	1.14	1.01	1.07	1.06
Mg		0.78	0.78	0.80	0.74
Na		0.11	0.13	0.16	0.15
Fe		0.140	0.099	0.099	0.040

remained essentially constant. Nitrogen content showed a slight increase with application rate. Crop uptake of N increased with irrigation rate, while uptake decreased for Fe and remained essentially unchanged for the other elements. Nitrogen recovery (Figure A-7) was low due to the single harvest obtained. Recovery was considerably higher in 1971 when two cuttings were obtained. Recovery of K was 140% at an irrigation rate of 50 mm/week, which indicated that the effluent was deficient in K at this rate. Results from 1971 (Table A-9) showed this same effect. Iron was also slightly deficient at 50 mm/week, but was adequate at higher rates. Crop uptake of N increased with irrigation rate (Table A-25), while N recovery showed a decrease (Figure A-7).

TABLE A-25. NUTRIENT RECOVERY BY KENAF WITH SINGLE APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
			Harvested, kg/ha		
N		86	105	114	170
P		27	25	27	20
K		57	26	71	66
Ca		71	68	72	72
Mg		48	53	54	49
Na		6.8	8.7	10.8	10.1
Fe		8.7	6.6	6.6	2.7
			Applied, kg/ha		
N		235	470	705	940
P		85	170	255	340
K		40	80	120	160
Ca		212	425	637	850
Mg		62	125	187	250
Na		205	510	715	1020
Fe		3.2	6.5	9.7	13.0
			Recovered, %		
N		37	22	16	18
P		32	15	11	6
K		140	32	58	41
Ca		33	16	11	8
Mg		77	42	29	20
Na		2.7	1.7	1.4	1.0
Fe		270	100	68	21

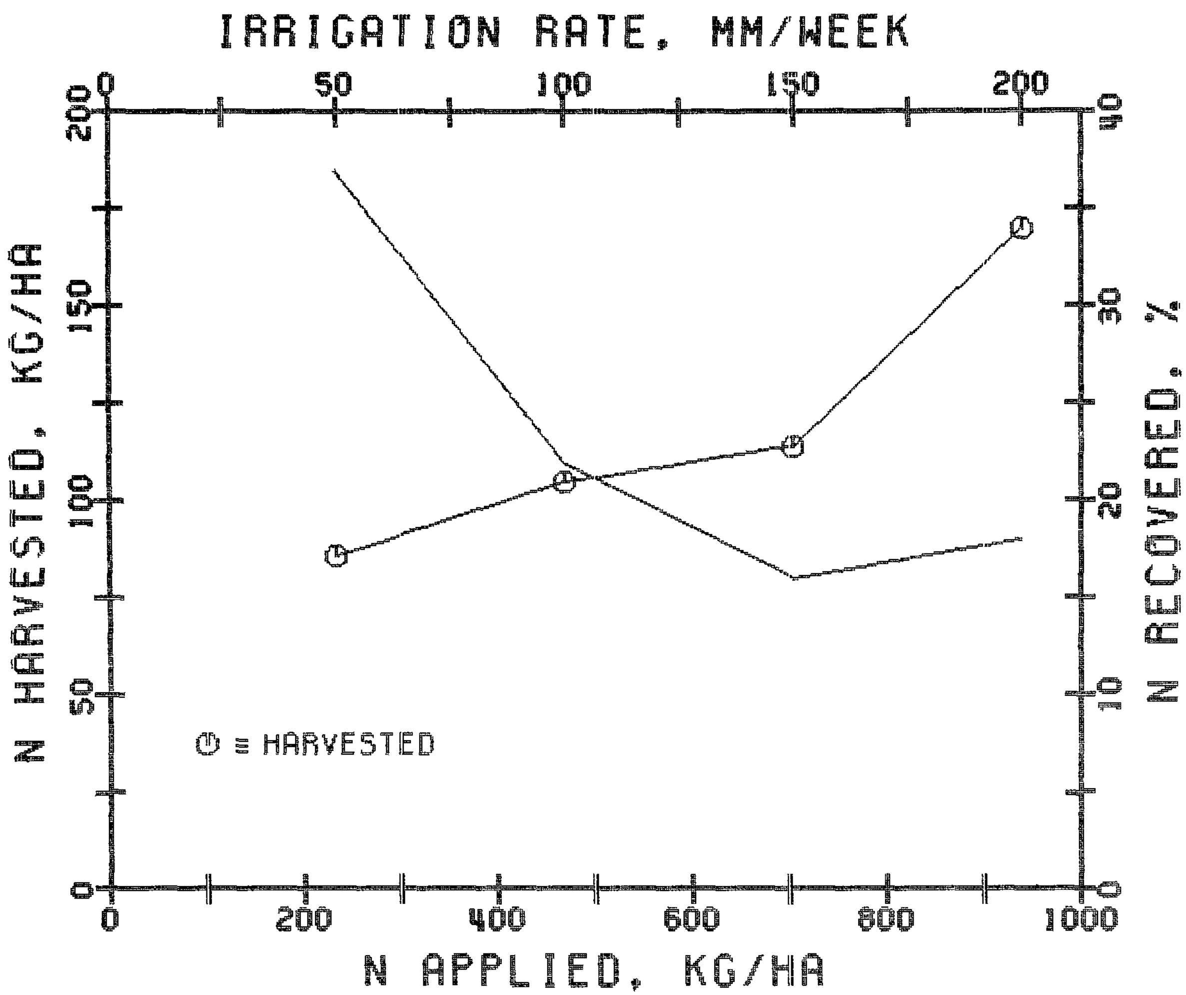

Figure A-7. Nitrogen recovery by kenaf with single applications - 1972.

Kenaf - Split Applications

Green and dry yields showed erratic trends with irrigation rate (Table A-26). Dry matter content showed a decrease, while N content showed an increase. Nutrient uptake values were somewhat erratic (Table A-27), but N showed a slight increase with irrigation rate. Efficiency of recovery decreased for all elements (Figure A-8). Values of N recovery were similar for split and single applications.

TABLE A-26. YIELD AND COMPOSITION OF KENAF WITH SPLIT APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
Green Weight, mtons/ha		41.0	39.4	32.3	44.1
Dry Matter, %		17.8	16.7	16.0	15.6
Dry Weight, mtons/ha		7.30	6.59	5.17	6.90
N		1.19	1.63	1.73	1.78
P		0.40	0.36	0.37	0.31
K		0.78	0.80	0.78	0.92
Ca	%	1.18	1.19	1.15	1.17
Mg		0.71	0.65	0.72	0.59
Na		0.15	0.20	0.26	0.27
Fe		0.080	0.082	0.080	0.110

TABLE A-27 . NUTRIENT RECOVERY BY KENAF WITH SPLIT APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
			Harvested, kg/ha		
N		87	108	90	123
P		29	24	19	21
K		57	53	40	64
Ca		86	78	59	81
Mg		52	43	37	40
Na		11	13	13	19
Fe		5.8	5.4	4.1	7.6
			Applied, kg/ha		
N		235	470	705	940
P		85	170	255	340
K		40	80	120	160
Ca		212	425	637	850
Mg		62	125	187	250
Na		255	510	765	1020
Fe		3.2	6.5	9.7	13.0
			Recovered, %		
N		37	23	13	13
P		35	14	8	6
K		140	65	33	40
Ca		40	18	9	10
Mg		82	34	20	16
Na		4.3	2.6	1.7	1.8
Fe		180	83	43	59

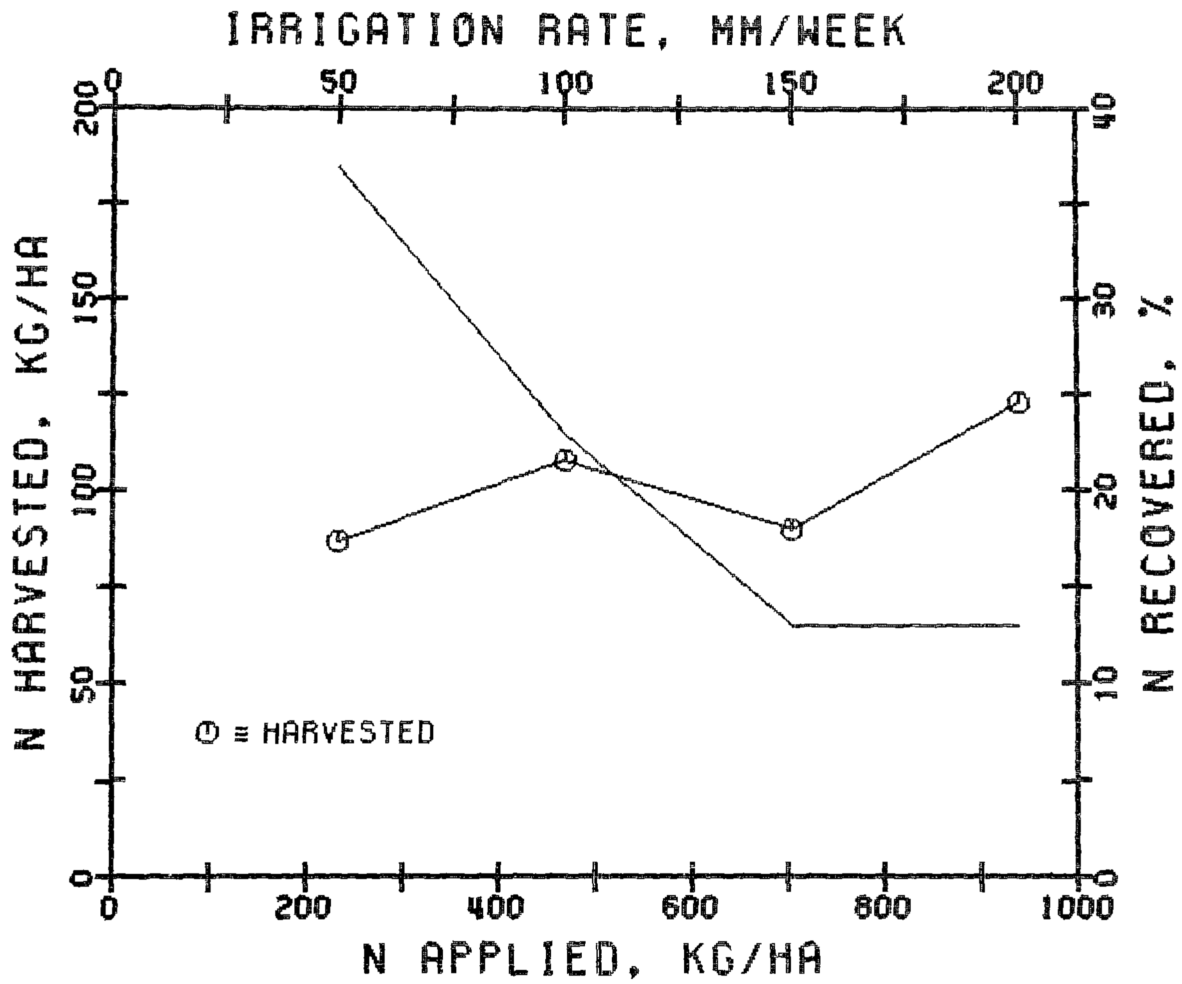

Figure A-8. Nitrogen recovery by kenaf with split applications - 1972.

Corn Grain - Single Applications

Yields of grain were adjusted to a standard dry matter content of 15.5%. Yields showed a strong response to irrigation rate (Table A-28). Nitrogen content also increased, while other elements remained essentially constant. Nutrient uptake of all elements increased with irrigation rate (Table A-29), while efficiency of uptake decreased for all elements, including N (Figure A-9).

TABLE A-28. YIELD AND COMPOSITION OF CORN GRAIN WITH SINGLE APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
Yield	mtons/ha	5.98	8.78	9.72	10.66
N		1.34	1.40	1.42	1.62
P		-	-	-	-
K		0.25	0.22	0.23	0.20
Ca	%	0.42	0.50	0.52	0.51
Mg		-	-	-	-
Na		0.15	0.25	0.20	0.22

TABLE A-29. NUTRIENT RECOVERY BY CORN GRAIN WITH SINGLE APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
			Harvested, kg/ha		
N		80	123	138	173
P		-	-	-	-
K		15	19	22	21
Ca		25	44	50	54
Mg		-	-	-	-
Na		9	22	19	23
			Applied, kg/ha		
N		290	580	870	1160
P		102	204	306	408
K		49	98	147	196
Ca		262	524	786	1048
Mg		78	157	235	314
Na		312	625	937	1250
			Recovered, %		
N		28	21	16	15
P		-	-	-	-
K		31	19	15	11
Ca		9.5	8.4	6.4	5.2
Mg		-	-	-	-
Na		2.9	3.5	2.0	1.8

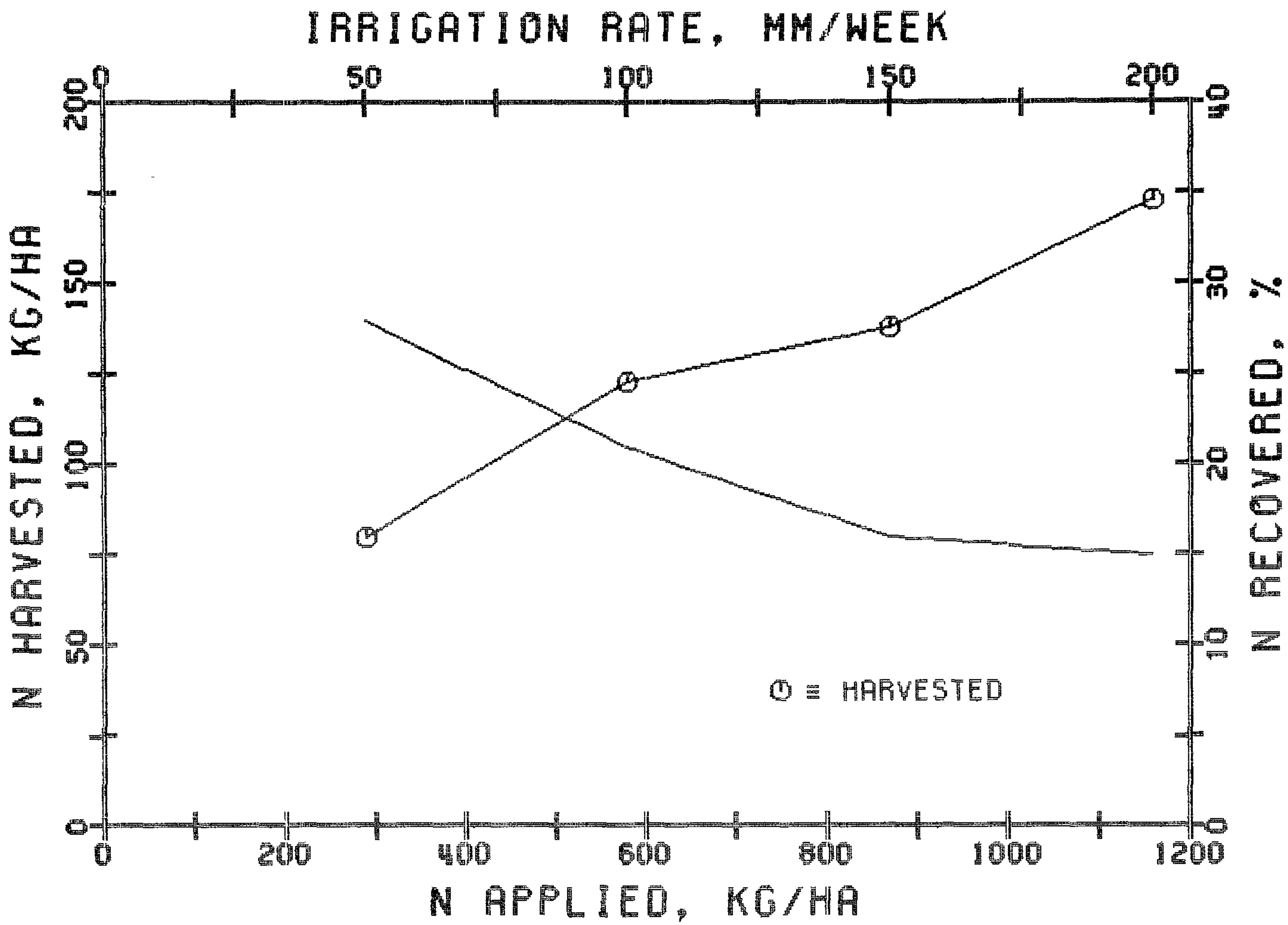

Figure A-9. Nitrogen recovery by corn grain with single application - 1972.

Corn Grain - Split Applications

Yields of grain showed a strong increase with irrigation rate (Table A-30) and were similar to those from single applications. Nitrogen content also increased, while other elements showed a decrease. Uptake of N increased with irrigation rate (Table A-31), and showed similar values to single applications. Recovery efficiency of N (Figure A-10) showed a general decline with application rate.

TABLE A-30. YIELD AND COMPOSITION OF CORN GRAIN WITH SPLIT APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
Yield	mtons/ha	4.52	8.72	10.66	10.04
N		1.26	1.42	1.48	1.75
P		-	-	-	-
K		0.25	0.25	0.25	0.25
Ca	%	0.74	0.58	0.50	0.43
Mg		-	-	-	-
Na		0.35	0.25	0.20	0.15

TABLE A-31. NUTRIENT RECOVERY BY CORN GRAIN WITH SPLIT APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
			Harvested, kg/ha		
N		57	124	158	176
P		-	-	-	-
K		11	22	27	25
Ca		33	50	53	43
Mg		-	-	-	-
Na		16	22	21	15
			Applied, kg/ha		
N		290	580	870	1160
P		102	204	306	408
K		49	98	147	196
Ca		262	524	786	1048
Mg		78	157	235	314
Na		312	625	937	1250
			Recovered, %		
N		20	21	18	15
P		-	-	-	-
K		22	22	18	13
Ca		13	9.5	6.7	4.1
Mg		-	-	-	-
Na		5.1	3.5	2.2	1.2

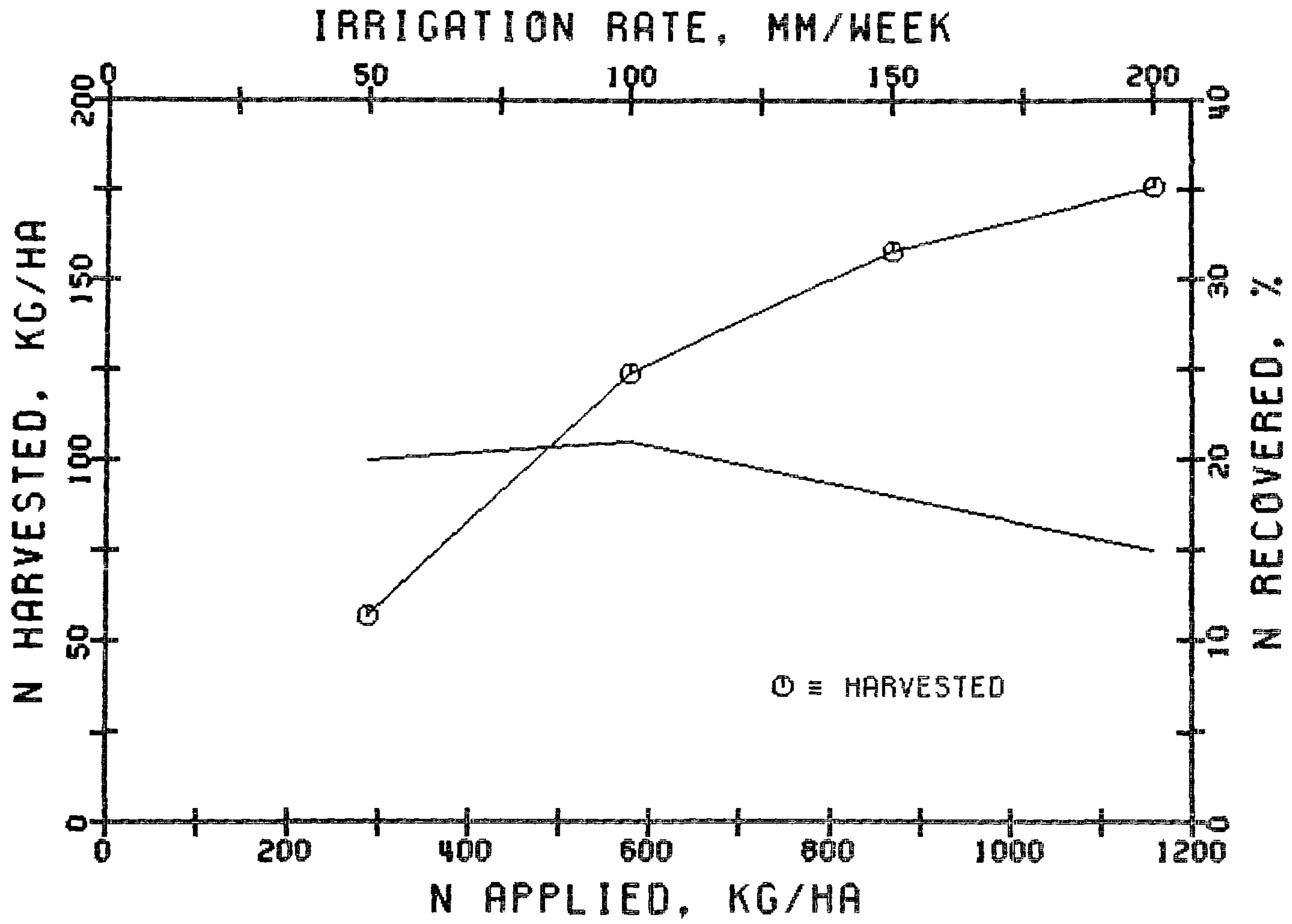

Figure A-10. Nitrogen recovery by corn grain with split applications - 1972.

Corn Silage - Single Applications

Corn was harvested for silage when the grain reached the hard dent stage, 13 weeks after planting. Green and dry yields increased with irrigation rate (Table A-32), while dry matter content remained essentially constant. Content of N also showed an increasing trend. Uptake of N increased with application rate (Table A-33), while recovery efficiency decreased (Figure A-11).

TABLE A-32. YIELD AND COMPOSITION OF CORN SILAGE WITH SINGLE APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
Green Weight, mtons/ha		33.2	39.2	45.0	50.8
Dry Matter, %		18.9	17.2	18.4	18.4
Dry Weight, mtons/ha		6.27	6.74	8.29	9.36
N		1.51	1.74	1.81	1.63
P		0.44	0.42	0.38	0.37
K		0.90	0.95	0.68	0.80
Ca	%	0.41	0.34	0.42	0.26
Mg		0.49	0.54	0.55	0.50
Na		0.040	0.045	0.110	0.038
Fe		0.025	0.045	0.070	0.030

TABLE A-33. NUTRIENT RECOVERY BY CORN SILAGE WITH SINGLE APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
			Harvested, kg/ha		
N		95	118	150	152
P		28	29	31	35
K		56	64	56	75
Ca		26	22	35	25
Mg		30	36	46	47
Na		2.5	3.0	9.1	3.6
Fe		1.6	3.0	5.7	2.8
			Applied, kg/ha		
N		200	400	600	800
P		70	140	210	280
K		31	62	93	134
Ca		174	358	532	716
Mg		54	108	162	216
Na		215	430	645	860
Fe		3	6	9	12
			Recovered, kg/ha		
N		48	29	25	19
P		40	21	15	12
K		170	95	56	56
Ca		14.4	6.2	6.5	3.4
Mg		56	33	28	22
Na		1.1	0.7	1.4	0.4
Fe		53	50	63	23

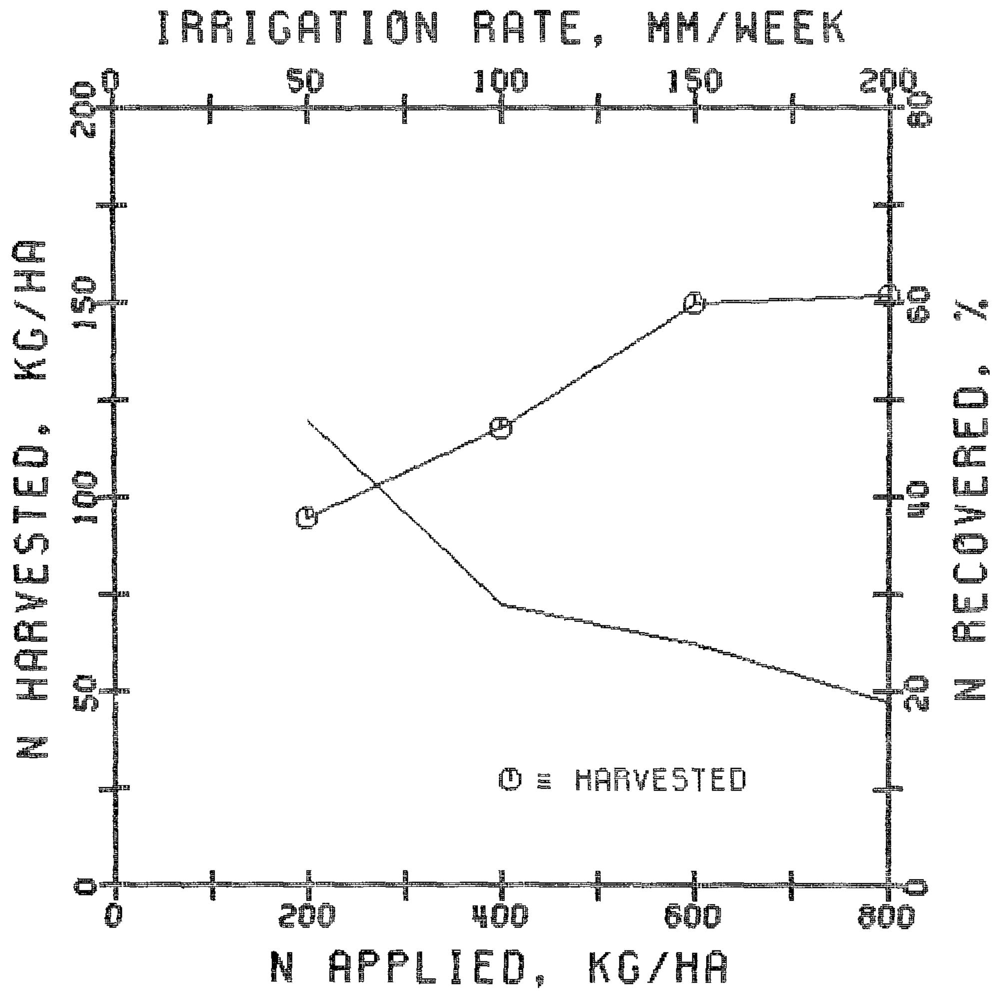

Figure A-11. Nitrogen recovery by corn silage with single applications - 1972.

Corn Silage - Split Applications

Green and dry yields increased with irrigation rate (Table A-34), while dry matter content showed a slight decrease. Content of N also increased. Nitrogen uptake increased with application rate (Table A-35), while efficiency of recovery generally decreased (Figure A-12). Recoveries were similar for split and single applications. This indicated no advantage to the more frequent irrigations.

TABLE A-34. YIELD AND COMPOSITION OF CORN SILAGE WITH SPLIT APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
Green Weight, mtons/ha		20.2	39.6	44.8	45.7
Dry Matter, %		19.0	18.0	17.4	16.8
Dry Weight, mtons/ha		3.83	7.15	7.80	7.66
N		1.10	1.65	1.64	1.63
P		0.46	0.44	0.45	0.44
K		0.92	0.95	0.88	0.90
Ca	%	0.36	0.34	0.31	0.29
Mg		0.56	0.43	0.49	0.45
Na		0.045	0.062	0.065	0.078
Fe		0.027	0.035	0.021	0.018

TABLE A-35. NUTRIENT RECOVERY BY CORN SILAGE WITH SPLIT APPLICATIONS - 1972

Rate	mm/week	50	100	150	200
			Harvested, kg/ha		
N		43	118	128	124
P		18	32	35	34
K		35	68	68	69
Ca		13	25	25	22
Mg		21	30	38	35
Na		1.7	4.5	5.0	5.9
Fe		1.0	2.6	1.7	1.3
			Applied, kg/ha		
N		200	400	600	800
P		70	140	210	280
K		31	62	93	134
Ca		174	358	532	716
Mg		54	108	162	216
Na		215	430	645	860
Fe		3	6	9	12
			Recovered, %		
N		21	29	21	16
P		26	23	17	12
K		100	100	68	52
Ca		7.5	6.9	4.6	3.1
Mg		40	28	24	16
Na		0.78	1.00	0.78	0.69
Fe		37	46	20	12

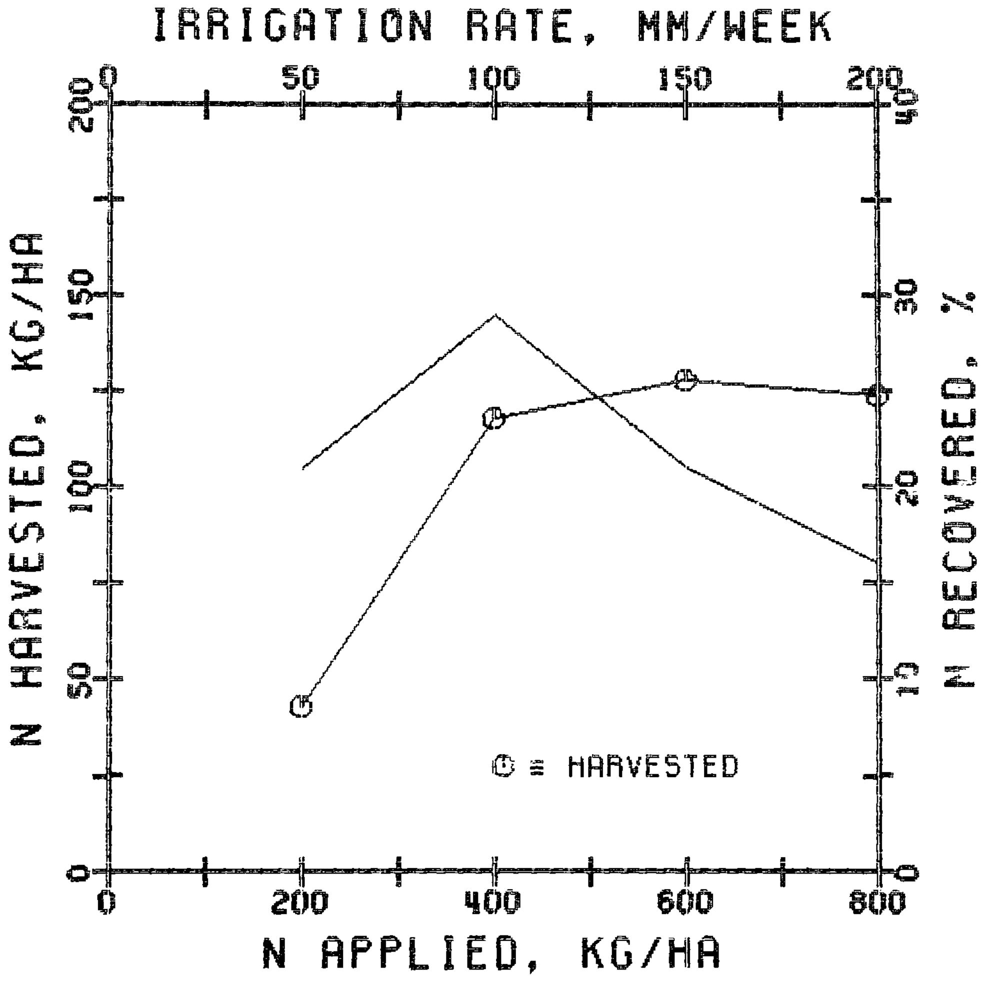

Figure A-12. Nitrogen recovery by corn silage with split applications - 1972.

Pearl Millet

Plots were harvested two times during the season. Green and dry yields were somewhat erratic (Table A-36) but tended to remain constant with irrigation rate. Dry matter content showed a decreasing trend. Nitrogen content increased with irrigation rate (Table A-37). Uptake of N by the crop showed an increase with application rate (Table A-38), while efficiency of recovery decreased (Table A-39 and Figure A-13). Results from this experiment have been reported elsewhere (Overman, 1975).

TABLE A-36. YIELD AND DRY MATTER OF PEARL MILLET - 1972

Rate mm/week	50	100	150	200
		1st Harvest		
Green Weight, mtons/ha	24.2	46.8	47.5	66.8
Dry Matter, %	15.9	14.1	12.5	12.8
Dry Weight, mtons/ha	3.85	6.61	5.94	8.53
		2nd Harvest		
Green Weight, mtons/ha	72.8	80.2	64.1	71.9
Dry Matter, %	19.5	17.5	17.5	16.5
Dry Weight, mtons/ha	14.2	14.0	11.2	11.9
		Net		
Green Weight, mtons/ha	97	127	112	139
Dry Matter, %	18.6	16.3	15.4	14.7
Dry Weight, mtons/ha	18.1	20.6	17.1	20.4

TABLE A-37. NUTRIENT COMPOSITION OF PEARL MILLET - 1972

Rate	mm/week	50	100	150	200
			1st Harvest		
N		2.2	2.4	2.8	2.9
P		0.92	1.00	0.88	0.75
K		1.52	1.35	2.32	1.73
Ca		0.48	0.52	0.52	0.48
Mg	%	0.43	0.70	0.71	0.76
Na		0.035	0.050	0.090	0.110
Fe		0.105	0.046	0.051	0.031
Zn		0.0055	0.0050	0.0055	0.0048
Cu		0.0020	0.0015	0.0013	0.0010
			2nd Harvest		
N		1.8	2.3	2.7	2.5
P		0.73	0.70	0.73	0.68
K		1.15	1.42	1.52	1.71
Ca		0.39	0.48	0.53	0.60
Mg	%	0.51	0.50	0.53	0.58
Na		0.030	0.070	0.070	0.085
Fe		0.044	0.037	0.038	0.038
Zn		0.0040	0.0040	0.0052	0.0040
Cu		0.0010	0.0010	0.0008	0.0008
			Net		
N		1.9	2.3	2.7	2.7
P		0.78	0.80	0.78	0.70
K		1.23	1.40	1.80	1.71
Ca		0.41	0.49	0.52	0.55
Mg	%	0.50	0.56	0.59	0.65
Na		0.031	0.064	0.077	0.096
Fe		0.057	0.040	0.042	0.035
Zn		0.0043	0.0043	0.0053	0.0043
Cu		0.0012	0.0011	0.0009	0.0009

TABLE A-38. NUTRIENT UPTAKE BY PEARL MILLET - 1972

Rate	mm/week	50	100	150	200
			1st Harvest		
N		85	159	166	246
P		35	66	52	64
K		59	89	138	147
Ca		18	34	31	41
Mg	kg/ha	17	46	42	65
Na		1.3	3.4	5.4	9.5
Fe		4.0	3.0	3.0	2.7
Zn		0.21	0.34	0.32	0.40
Cu		0.077	0.100	0.077	0.085
			2nd Harvest		
N		255	323	302	297
P		104	98	82	81
K		164	199	170	203
Ca		55	67	59	71
Mg	kg/ha	72	70	59	69
Na		4.3	9.9	7.8	10.1
Fe		6.3	5.2	4.3	4.5
Zn		0.56	0.56	0.58	0.47
Cu		0.14	0.14	0.08	0.09
			Total		
N		340	482	468	543
P		139	164	134	145
K		223	288	308	350
Ca		73	101	90	112
Mg	kg/ha	89	116	101	134
Na		5.6	13.3	9.7	14.0
Fe		10.3	8.2	7.3	8.2
Zn		0.77	0.90	0.90	0.87
Cu		0.22	0.24	0.15	0.18

TABLE A-39. NUTRIENT RECOVERY BY PEARL MILLET - 1972

Rate mm/week	50	100	150	200
		Harvested, kg/ha		
N	340	482	468	534
P	139	164	134	145
K	223	288	308	350
Ca	73	101	90	112
Mg	89	116	101	134
Na	5.6	13.3	9.7	14.0
Fe	10.3	8.2	7.3	8.2
Zn	0.77	0.90	0.90	0.87
Cu	0.22	0.24	0.15	0.18
		Applied, kg/ha		
N	460	920	1380	1840
P	150	300	450	600
K	78	156	234	312
Ca	390	780	1170	1560
Mg	122	245	367	490
Na	500	1000	1500	2000
Fe	5	11	16	22
Zn	1.8	3.6	5.4	7.2
Cu	1.1	2.2	3.3	4.4
		Recovered, %		
N	74	52	34	30
P	93	54	30	24
K	280	185	130	110
Ca	19	13	8	7
Mg	73	47	27	27
Na	1.1	1.3	0.9	1.0
Fe	185	73	43	32
Zn	43	24	17	12
Cu	20	10	5	4

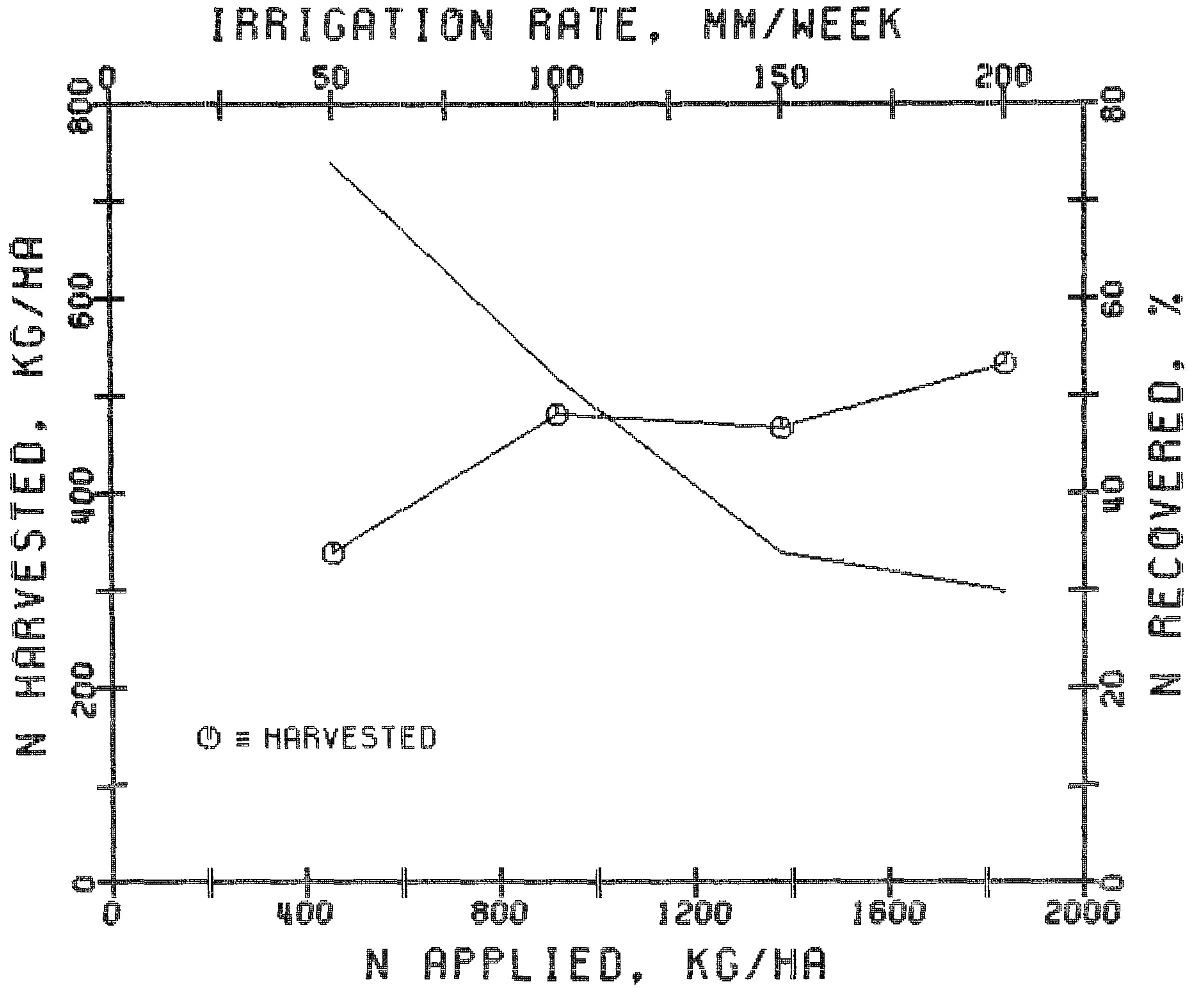

Figure A-13. Nitrogen recovery by pearl millet - 1972.

1972 WINTER CROPS

Rye (Wrens Abruzzi) and ryegrass (Florida Rust Resistant) were utilized as in 1971. All plots were prepared by disking, plowing and disking. Seeding rates were 1.7 hl/ha (2 bu/acre) for rye and 23 kg/ha (20 lb/acre) for ryegrass. All plots exhibited vigorous growth.

Effluent characteristics for the period 10/72-3/73 are shown in Table 6. Values for K, Ca, Mg and Na were approximated as those from the period 4/72-9/72.

Rye was harvested on March 22, 1973, and ryegrass on March 27. No plots were harvested in January due to unavailability of equipment. At irrigation rates of 75 and 100 mm/week, both rye and ryegrass showed considerable lodging due to high wind gusts just prior to harvest. Much of the vegetation in these plots was inaccessible to the forage harvester.

Forage samples were analyzed as outlined for 1971.

Rye

Green and dry yields declined sharply at the upper irrigation rates due to lodging. Dry matter content decreased with irrigation rate, while N content showed an increase (Table A-40). Nutrient uptake (Table A-41) also reflected the problem of lodging. However, uptake values at 25 and 50 mm/week were accurate due to negligible lodging and showed the typical upward trend. Recovery efficiencies (Figure A-14) obtained for the lower rates were more accurate.

TABLE A-40. YIELD AND COMPOSITION OF RYE - 1972

Rate	mm/week	25	50	75	100
Green Weight, mtons/ha		15.5	19.3	11.6	7.6
Dry Matter, %		25.5	23.6	22.4	20.9
Dry Weight, mtons/ha		3.95	4.55	2.60	1.59
N		1.84	1.96	2.34	2.56
P		0.76	0.84	0.78	0.88
K		2.02	2.21	2.50	2.30
Ca	%	0.52	0.49	0.56	0.56
Mg		0.31	0.35	0.35	0.44
Na		0.050	0.060	0.063	0.108
Fe		0.021	0.024	0.025	0.031
Al		0.010	0.010	0.010	0.015

TABLE A-41. NUTRIENT RECOVERY BY RYE - 1972

Rate	mm/week	25	50	75	100
			Harvested, kg/ha		
N		73	89	61	41
P		30	38	20	14
K		80	101	65	37
Ca		21	22	15	9
Mg		12	16	9	7
Na		2.0	2.7	1.6	1.7
Fe		0.83	1.09	0.65	0.49
Al		0.40	0.46	0.26	0.24
			Applied, kg/ha		
N		190	380	570	760
P		64	128	192	256
K		30	60	90	120
Ca		154	308	462	616
Mg		46	92	138	184
Na		188	376	564	752
			Recovered, kg/ha		
N		38	23	11	5
P		47	30	10	6
K		270	170	72	31
Ca		14	7	3	1
Mg		26	17	7	4
Na		1.1	0.7	0.3	0.2

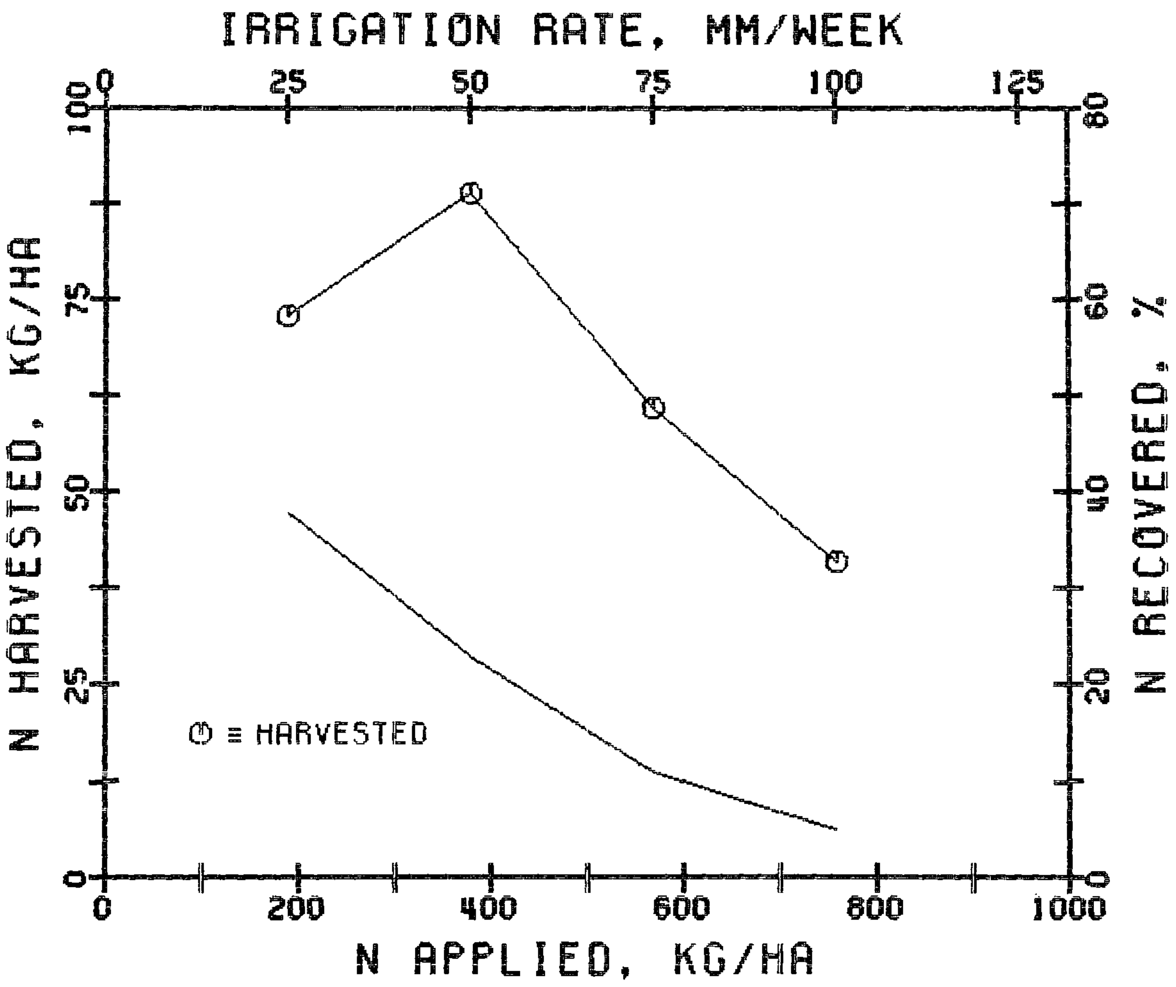

Figure A-14. Nitrogen recovery by rye - 1972.

Ryegrass

Lodging was also a problem for ryegrass at the higher irrigation rates, as shown by the green and dry yields (Table A-42). At irrigation rates of 25 and 50 mm/week, N uptake showed an increase (Table A-43), as expected. Recovery efficiency for N declined (Figure A-15) with application rate.

TABLE A-42. YIELD AND COMPOSITION OF RYEGRASS - 1972

Rate	mm/week	25	50	75	100
Green Weight, mtons/ha		30.4	32.3	27.8	24.2
Dry Matter, %		15.5	21.9	14.7	14.4
Dry Weight, mtons/ha		4.71	7.07	4.09	3.48
N		1.93	2.03	2.07	2.67
P		0.54	0.60	0.68	0.69
K		1.73	1.74	1.70	1.70
Ca	%	0.56	0.65	0.69	0.59
Mg		0.39	0.40	0.52	0.45
Na		0.25	0.51	0.84	1.18
Fe		0.032	0.038	0.047	0.041
Al		0.010	0.010	0.010	0.020

TABLE A-43. NUTRIENT RECOVERY BY RYEGRASS - 1972

Rate	mm/week	25	50	75	100
			Harvested, kg/ha		
N		91	144	85	93
P		25	42	28	24
K		81	123	70	59
Ca		26	46	28	21
Mg		18	28	21	16
Na		12	36	34	41
Fe		1.5	2.7	1.9	1.4
Al		0.47	0.71	0.41	0.70
			Applied, kg/ha		
N		190	380	570	760
P		64	128	192	256
K		30	60	90	120
Ca		154	308	462	616
Mg		46	92	138	184
Na		188	376	564	752
			Recovered, %		
N		48	38	15	12
P		39	33	15	9
K		270	200	78	49
Ca		17	15	6	3
Mg		39	30	15	9
Na		6.4	9.6	6.0	5.5

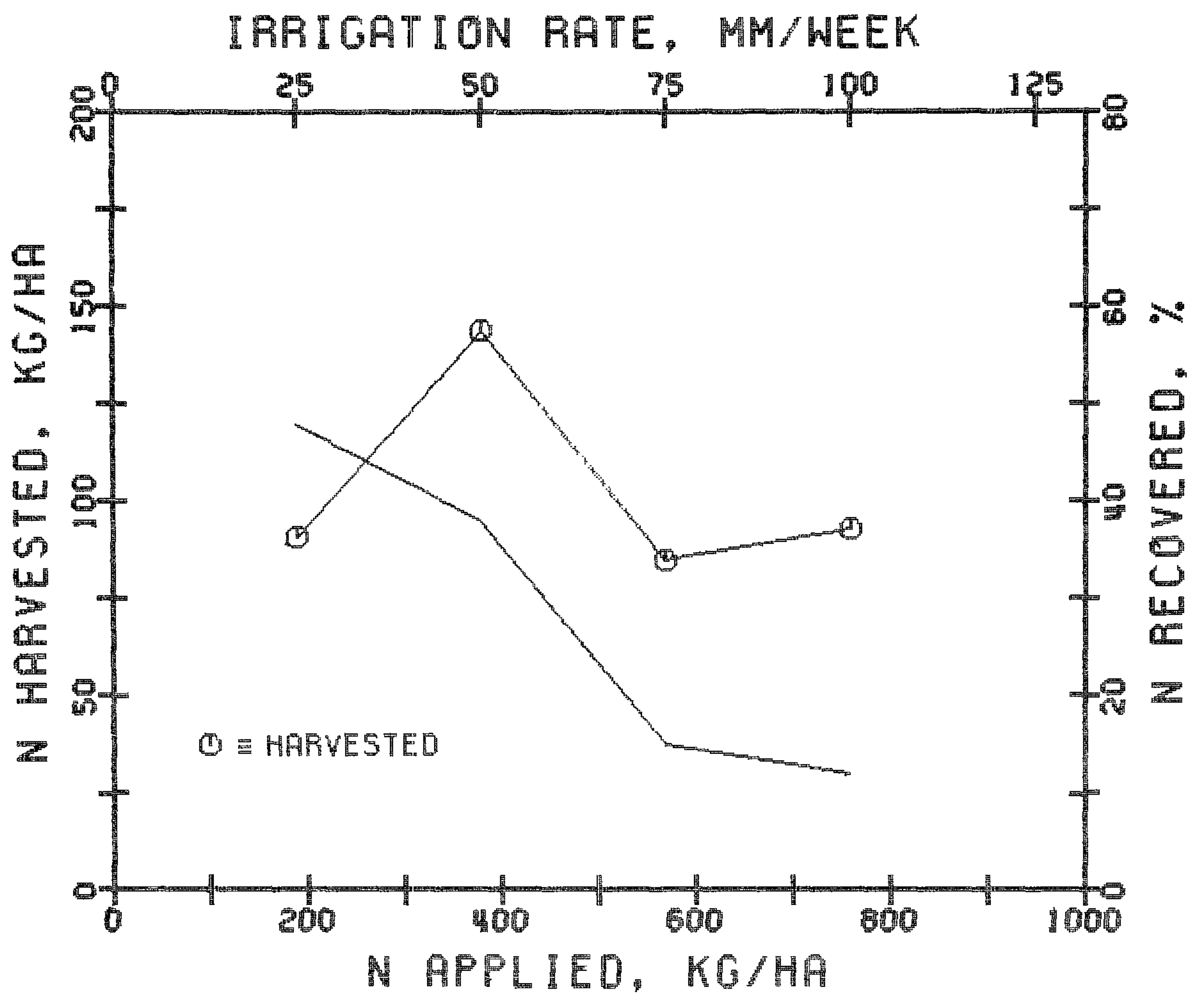

Figure A-15. Nitrogen recovery by ryegrass - 1972.

1973 SUMMER CROPS

Crops included sorghum x sudangrass (Asgrow Gazer-A), kenaf (Everglades 41), pearl millet (Asgrow Star), and corn (Pioneer 3369 A) for silage and for grain. All plots were disked, plowed and disked again. Planting and harvesting followed the schedule of Table A-44. Sorghum x sudangrass plots were rotovated on June 21, 1973, following the first harvest to control crabgrass. Corn was planted in 90 cm (36 in.) and 45 cm (18 in.) rows at seeding rates of 17 kg/ha and 34 kg/ha, respectively. Pearl millet was drilled (broadcast planted) at 28 kg/ha. Sorghum x sudangrass and kenaf were both planted in 90 cm rows at 11 kg/ha.

TABLE A-44. FIELD SCHEDULE FOR SUMMER 1973

Crop	Planting	Cultivation	Harvesting
Sorghum x sudangrass	4/11/73	6/22/73 8/30/73	6/21/73 8/29/73 10/24/73
Kenaf	4/11/73	7/11/73	7/10/73
Corn Silage	4/25/73		7/10/73
Corn Grain	4/25/73		8/30/73
Pearl Millet	4/25/73		6/21/73 8/29/73

Characteristics of the effluent for the period 4/73-9/73 are given in Table 6.

Sorghum x Sudangrass

Three harvests were obtained. Green and dry yields increased with irrigation rate (Table A-45), while dry matter content remained essentially constant. Nitrogen composition was independent of rate (Table A-46). Crop uptake of various elements increased with irrigation rate (Table A-47), while efficiency of recovery showed a decreasing trend (Table A-48 and Figure A-16).

TABLE A-45. YIELD AND DRY MATTER OF SORGHUM X SUDANGRASS - 1973

Rate mm/week	100	150	200
		1st Harvest	
Green Weight, mtons/ha	37.2	39.6	70.6
Dry Matter, %	17.0	16.3	16.5
Dry Weight, mtons/ha	6.32	6.47	11.65
		2nd Harvest	
Green Weight, mtons/ha	23.1	26.2	26.2
Dry Matter, %	23.0	24.2	23.4
Dry Weight, mtons/ha	5.31	6.34	6.14
		3rd Harvest	
Green Weight, mtons/ha	10.8	11.2	12.3
Dry Matter, %	20.3	20.1	21.5
Dry Weight, mtons/ha	2.20	2.26	2.64
		Net	
Green Weight, mtons/ha	71.1	77.0	109.1
Dry Matter, %	19.5	19.6	18.8
Dry Weight, mtons/ha	13.8	15.1	20.4

TABLE A-46. NUTRIENT COMPOSITION OF SORGHUM X SUDANGRASS - 1973

Rate	mm/week	100	150	200
			1st Harvest	
N		1.44	1.35	1.40
P		0.40	0.30	0.30
K		0.79	0.75	0.82
Ca		0.46	0.45	0.43
Mg	%	0.48	0.43	0.42
Na		0.100	0.130	0.120
Fe		0.0085	0.0132	0.0135
Zn		0.0047	0.0034	0.0040
Mn		0.00085	0.00050	0.00075
			2nd Harvest	
N		1.13	1.09	1.18
P		0.25	0.22	0.23
K		0.28	0.36	0.39
Ca		0.38	0.40	0.35
Mg	%	0.31	0.28	0.25
Na		0.220	0.180	0.225
Fe		0.0125	0.0095	0.0635
Zn		0.0063	0.0046	0.0175
Mn		0.00035	0.00075	0.00100
			3rd Harvest	
N		1.66	1.73	1.78
P		0.30	0.26	0.28
K		0.37	0.34	0.31
Ca		0.63	0.65	0.69
Mg	%	0.47	0.43	0.44
Na		0.240	0.245	0.185
Fe		0.0402	0.0322	0.0585
Zn		0.0022	0.0071	0.0043
Mn		0.00050	0.00075	0.00100
			Net	
N		1.35	1.30	1.38
P		0.33	0.26	0.28
K		0.53	0.53	0.62
Ca		0.46	0.49	0.44
Mg	%	0.41	0.37	0.37
Na		0.17	0.17	0.16
Fe		0.015	0.014	0.034
Zn		0.0049	0.0044	0.0081
Mn		0.00060	0.00064	0.00086

TABLE A-47. NUTRIENT UPTAKE BY SORGHUM X SUDANGRASS - 1973

Rate	mm/week	100	150	200
			1st Harvest	
N		91	87	163
P		25	19	35
K		50	49	96
Ca		29	29	50
Mg	kg/ha	30	28	49
Na		6.3	8.4	14.0
Fe		0.54	0.85	1.57
Zn		0.30	0.22	0.47
Mn		0.054	0.032	0.087
			2nd Harvest	
N		60	69	72
P		13	14	14
K		15	23	24
Ca		20	25	22
Mg	kg/ha	16	18	15
Na		11.6	11.4	13.8
Fe		0.66	0.60	3.90
Zn		0.34	0.29	1.08
Mn		0.019	0.048	0.061
			3rd Harvest	
N		36	39	47
P		7	6	7
K		8	8	8
Ca		14	19	18
Mg	kg/ha	10	10	12
Na		5.3	5.5	4.9
Fe		0.88	0.73	1.55
Zn		0.048	0.160	0.114
Mn		0.011	0.017	0.026

TABLE A-48. NUTRIENT RECOVERY BY SORGHUM X SUDANGRASS - 1973

Rate mm/week	100	150	200
	Harvested, kg/ha		
N	187	195	282
P	45	39	56
K	73	80	128
Ca	63	73	90
Mg	56	56	76
Na	23	25	33
Fe	2.1	2.2	7.0
Zn	0.69	0.67	1.66
	Applied, kg/ha		
N	670	1000	1340
P	245	370	490
K	195	290	390
Ca	1680	2520	3360
Mg	465	700	930
Na	1455	2180	2910
Fe	29	44	58
Zn	8.7	13.1	17.4
	Recovered, %		
N	28	20	21
P	18	11	11
K	37	28	33
Ca	3.7	2.9	2.7
Mg	12.0	8.0	8.2
Na	1.6	1.2	1.1
Fe	7.1	5.0	12.0
Zn	7.9	5.1	9.6

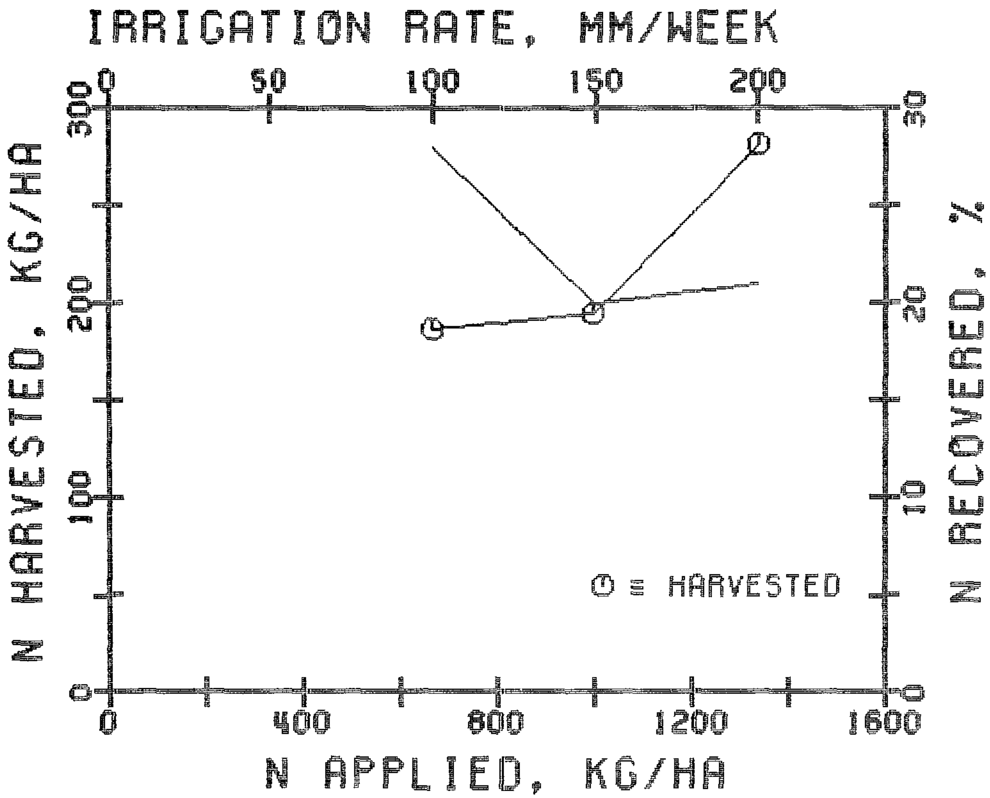

Figure A-16. Nitrogen recovery by sorghum x sudangrass - 1973.

Kenaf

As in 1972, the kenaf failed to regenerate after first harvest. Green and dry yields showed the characteristic increase with irrigation rate (Table A-49), while dry matter content decreased slightly. Nutrient composition was slightly erratic. Nitrogen uptake was essentially constant (Table A-50), while N recovery decreased rapidly with irrigation rate (Figure A-17).

TABLE A-49. YIELD AND COMPOSITION OF KENAF - 1973

Rate	mm/week	100	150	200
Green Weight, mtons/ha		24.6	26.4	27.6
Dry Matter, %		18.7	17.9	17.6
Dry Weight, mtons/ha		4.61	4.73	4.84
N		1.86	1.86	1.67
P		0.47	0.35	0.33
K		0.71	0.65	0.77
Ca	%	0.99	0.96	0.87
Mg		0.48	0.51	0.43
Na		0.142	0.114	0.109
Fe		0.0105	0.0045	0.0055
Zn		0.0065	0.0068	0.0056
Mn		0.0015	0.00085	0.00085

TABLE A-50. NUTRIENT RECOVERY BY KENAF - 1973

Rate	mm/week	100	150	200
			Harvested, kg/ha	
N		86	88	81
P		22	17	16
K		33	31	37
Ca		46	45	42
Mg		22	24	21
Na		66	54	53
Fe		4.8	2.1	2.7
Zn		3.0	3.2	2.7
Mn				
			Applied, kg/ha	
N		280	420	560
P		106	159	212
K		64	96	168
Ca		710	1070	1420
Mg		196	294	392
Na		620	930	1240
Fe		12	18	24
Zn		3.68	5.52	7.36
Mn		-	-	-
			Recovered, %	
N		31	21	14
P		21	10	8
K		51	32	22
Ca		6.4	4.2	3.0
Mg		11.2	8.2	5.3
Na		10.6	5.8	4.2
Fe		40	12	11
Zn		82	58	37
Mn		-	-	-

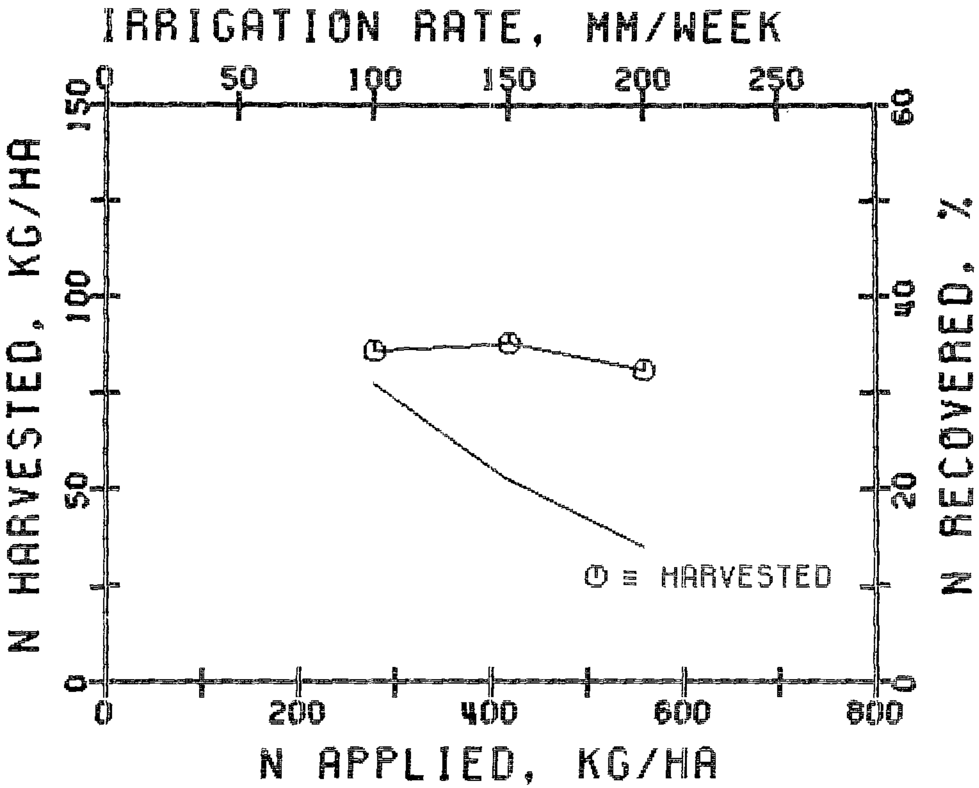

Figure A-17. Nitrogen recovery by kenaf - 1973.

Pearl Millet

Two cuttings were obtained. The first harvest was at 8 weeks of age. Some vegetation could not be harvested from the 200 mm/week plot due to lodging; the crop should have been harvested at 6 or 7 weeks after planting. Green and dry yields showed an upward trend with irrigation rate (Table A-51), while dry matter content showed a downward trend. Nitrogen content also tended upward (Table A-52). Crop uptake of N showed a slight increase of N with application rate (Table A-53). Efficiency of N recovery decreased in the typical manner (Table A-54, Figure A-18).

TABLE A-51. YIELD AND DRY MATTER OF PEARL MILLET (GAHI-1) - 1973

Rate mm/week	50	100	150	200
		1st Harvest		
Green Weight, mtons/ha	45.2	46.1	53.8	43.9
Dry Matter, %	14.3	12.6	12.1	12.3
Dry Weight, mtons/ha	6.47	5.82	6.50	5.40
		2nd Harvest		
Green Weight, mtons/ha	19.3	23.5	24.0	26.9
Dry Matter, %	25.1	25.7	23.9	23.2
Dry Weight, mtons/ha	4.84	6.03	5.71	6.23
		Net		
Green Weight, mtons/ha	64.5	69.6	77.8	70.8
Dry Matter, %	17.5	17.0	15.7	16.4
Dry Weight, mtons/ha	11.3	11.8	12.2	11.6

TABLE A-52. NUTRIENT COMPOSITION OF PEARL MILLET (GAHI-1) - 1973

Rate	mm/week	50	100	150	200
			1st Harvest		
N		1.58	1.62	1.78	1.89
P		0.81	0.86	0.70	0.60
K		0.89	1.02	1.00	1.11
Ca		0.39	0.43	0.44	0.50
Mg	%	0.63	0.70	0.67	0.70
Na		0.029	0.030	0.031	0.038
Fe		0.042	0.028	0.018	0.015
Zn		0.027	0.019	0.011	0.008
Mn		0.0032	0.0031	0.0032	0.0026
			2nd Harvest		
N		1.20	1.01	1.25	1.35
P		0.75	0.67	0.63	0.54
K		0.70	0.75	0.67	0.76
Ca		0.45	0.36	0.42	0.43
Mg	%	0.53	0.54	0.60	0.63
Na		0.009	0.010	0.012	0.010
Fe		0.0115	0.0045	0.0058	0.0042
Zn		0.0128	0.0062	0.0128	0.0072
Mn		0.0021	0.0011	0.0020	0.0014
			Net		
N		1.42	1.30	1.53	1.61
P		0.78	0.76	0.67	0.57
K		0.81	0.88	0.85	0.92
Ca		0.41	0.40	0.43	0.46
Mg	%	0.59	0.62	0.64	0.66
Na		0.021	0.020	0.022	0.023
Fe		0.029	0.016	0.012	0.009
Zn		0.021	0.013	0.012	0.008
Mn		0.0027	0.0021	0.0026	0.0020

TABLE A-53. NUTRIENT UPTAKE BY PEARL MILLET (GAHI-1) - 1973

Rate	mm/week	50	100	150	200
			1st Harvest		
N		102	94	115	103
P		52	50	45	32
K		58	60	65	60
Ca		25	25	29	27
Mg	kg/ha	41	41	44	38
Na		1.92	1.71	2.02	2.05
Fe		2.73	1.66	1.15	0.80
Zn		1.74	1.12	0.72	0.45
Mn		0.21	0.18	0.21	0.14
			2nd Harvest		
N		58	61	71	84
P		36	40	36	34
K		34	45	38	47
Ca		22	22	24	27
Mg	kg/ha	26	33	34	39
Na		0.44	0.63	0.68	0.65
Fe		0.56	0.27	0.34	0.26
Zn		0.62	0.37	0.73	0.45
Mn		0.10	0.07	0.11	0.09
			Total		
N		160	155	186	187
P		88	90	81	66
K		92	105	103	107
Ca		47	47	53	54
Mg	kg/ha	67	77	78	77
Na		2.36	2.34	2.70	2.70
Fe		3.29	1.93	1.49	1.06
Zn		2.36	1.49	1.45	0.90
Mn		0.31	0.25	0.32	0.23

TABLE A-54. NUTRIENT RECOVERY BY PEARL MILLET (GAHI-1) - 1973

Rate	mm/week	50	100	150	200
			Harvested, kg/ha		
N		160	155	186	187
P		88	90	81	66
K		92	105	103	107
Ca		47	47	53	54
Mg		67	77	78	77
Na		2.36	2.34	2.70	2.70
Fe		3.29	1.93	1.49	1.06
Zn		2.36	1.49	1.45	0.90
			Applied, kg/ha		
N		175	350	525	700
P		60	120	180	240
K		50	100	150	200
Ca		425	850	1275	1700
Mg		112	224	336	448
Na		365	730	1095	1460
Fe		5	11	16	22
Zn		1.7	3.4	5.1	6.8
			Recovered, %		
N		91	44	35	27
P		150	75	45	28
K		180	105	69	54
Ca		11.1	5.5	4.2	3.2
Mg		60	34	23	17
Na		0.65	0.32	0.25	0.18
Fe		66	18	9	5
Zn		140	44	28	13

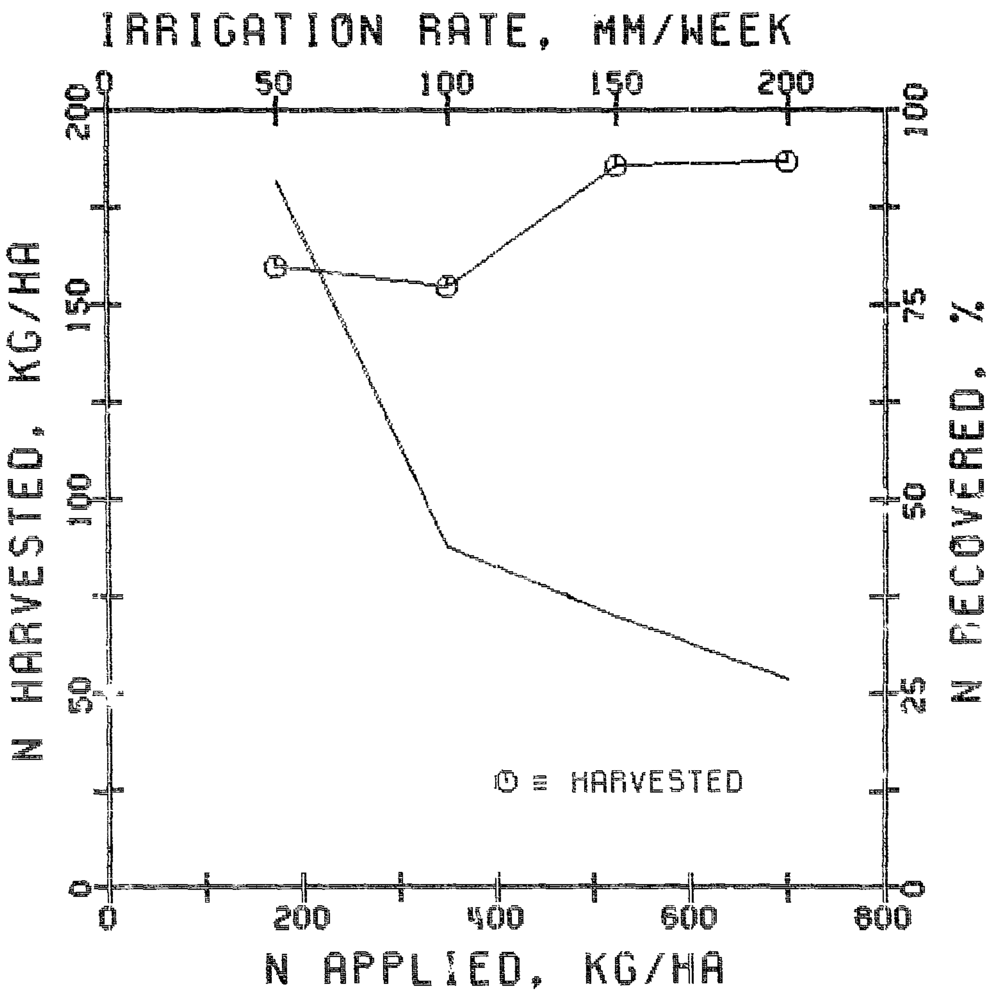

Figure A-18. Nitrogen recovery by pearl millet - 1973.

Corn Silage - 90 cm Rows

A plant density of approximately 45,000 plants/ha (18,000 plants/acre) was used. Both green and dry yields increased with irrigation rate (Table A-55), while dry matter content and N content remained essentially constant. Uptake of all elements showed an upward trend with application rate (Table A-56). Recovery efficiency for N decreased downward (Figures A-19) from 44% at 50 mm/week.

TABLE A-55. YIELD AND COMPOSITION OF CORN SILAGE IN 90 CM ROWS - 1973

Rate	mm/week	50	100	150	200
Green Weight, mtons/ha		23	26	34	35
Dry Matter, %		22.2	23.5	24.2	23.3
Dry Weight, mtons/ha		5.1	6.1	8.2	8.2
N		1.22	1.23	1.09	1.14
P		0.48	0.37	0.32	0.35
K		0.50	0.57	0.52	0.62
Ca	%	0.22	0.18	0.13	0.18
Mg		0.25	0.23	0.22	0.21
Na		0.0160	0.0150	0.0085	0.0170
Fe		0.0060	0.0060	0.0023	0.0060
Zn		0.0042	0.0045	0.0024	0.0044
Mn		0.00120	0.00085	0.00075	0.00085

TABLE A-56. NUTRIENT RECOVERY BY CORN SILAGE IN 90 CM ROWS - 1973

Rate mm/week	50	100	150	200
		Harvested, kg/ha		
N	62	75	89	93
P	24	23	26	29
K	26	35	43	51
Ca	11	11	11	15
Mg	13	14	18	17
Na	0.82	0.92	0.70	1.39
Fe	0.31	0.37	0.19	0.49
Zn	0.21	0.27	0.20	0.36
Mn	0.061	0.052	0.062	0.070
		Applied, kg/ha		
N	140	280	420	560
P	53	106	159	212
K	42	84	126	168
Ca	355	710	1060	1420
Mg	98	196	294	392
Na	310	620	930	1240
Fe	6	12	18	24
Zn	1.84	3.68	5.52	7.31
Mn	-	-	-	
		Recovered, %		
N	44	27	21	17
P	45	22	16	14
K	62	42	34	30
Ca	3.1	1.5	1.0	1.1
Mg	13	7.1	6.1	4.3
Na	0.26	0.15	0.08	0.11
Fe	5.2	3.1	1.1	2.0
Zn	11	7.3	3.6	4.9
Mn	-	-		-

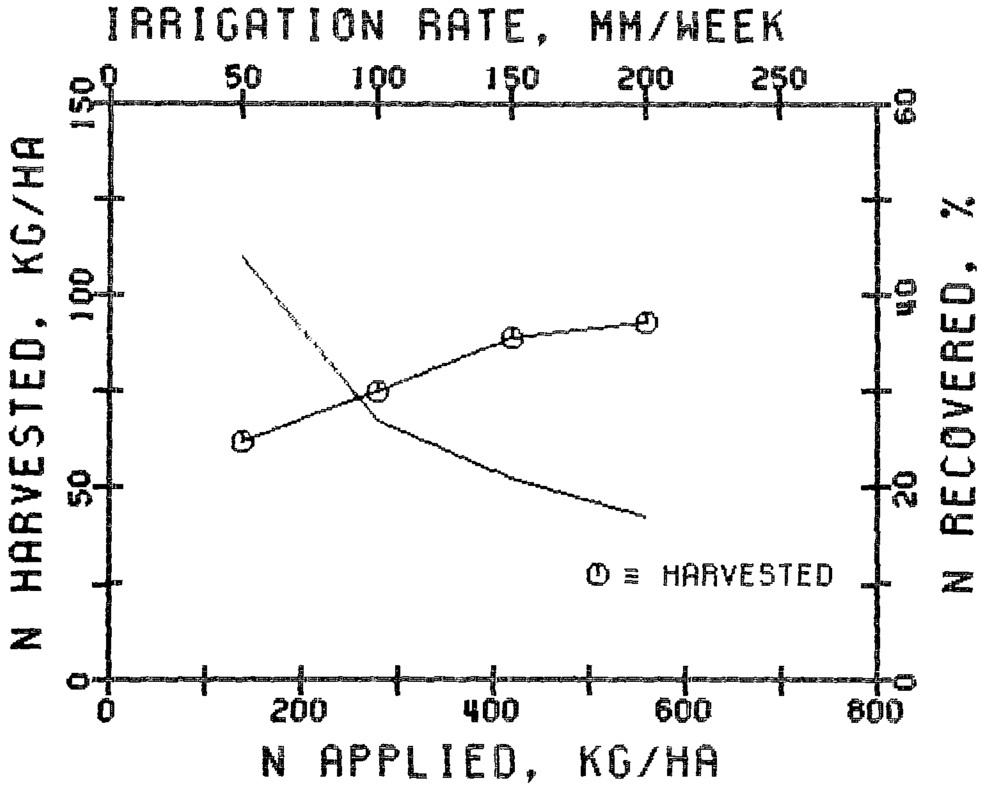

Figure A-19. Nitrogen recovery by corn silage in 90 cm rows - 1973.

Corn Silage - 45 cm Rows

Double planting was used to achieve a plant density of approximately 90,000 plants/ha (36,000 plants/acre). Increased irrigation rates caused higher green and dry yields (Table A-57), with dry matter content and N content remaining essentially constant. Crop uptake of all elements increased with application rate (Table A-58), with efficiency of recovery showing a decrease for N (Figure A-20).

TABLE A-57. YIELD AND COMPOSITION OF CORN SILAGE IN 45 CM ROWS - 1973

Rate	mm/week	50	100	150	200
Green Weight, mtons/ha		20.4	30.2	39.6	46.1
Dry Matter, %		19.0	19.5	20.8	19.2
Dry Weight, mtons/ha		4.0	5.7	8.2	8.9
N		1.42	1.45	1.31	1.56
P		0.56	0.43	0.40	0.40
K		0.62	0.64	0.54	0.67
Ca	%	0.28	0.23	0.25	0.27
Mg		0.30	0.26	0.29	0.27
Na		0.0225	0.0285	0.0130	0.0320
Fe		0.0162	0.0132	0.0058	0.0120
Zn		0.0051	0.0044	0.0050	0.0086
Mn		0.0017	0.0010	0.0011	0.0011

TABLE A-58. NUTRIENT RECOVERY BY CORN SILAGE IN 45 CM ROWS - 1973

Rate	mm/week	50	100	150	200
			Harvested, kg/ha		
N		57	83	107	139
P		22	25	33	36
K		25	36	44	60
Ca		11	13	21	24
Mg		12	15	24	24
Na		0.90	1.62	1.07	2.85
Fe		0.65	0.75	0.48	1.07
Zn		0.20	0.25	0.41	0.77
Mn		0.068	0.057	0.090	0.098
			Applied, kg/ha		
N		140	280	420	560
P		53	106	159	212
K		42	84	126	168
Ca		355	710	1060	1420
Mg		98	196	294	392
Na		310	620	930	1240
Fe		6	12	18	24
Zn		1.84	3.68	5.52	7.36
Mn		-	-	-	-
			Recovered, %		
N		41	30	25	25
P		42	24	21	17
K		60	43	35	36
Ca		3.1	1.8	2.0	1.7
Mg		12	7.7	8.2	6.1
Na		0.29	0.26	0.12	0.23
Fe		11	6.2	2.7	4.5
Zn		11	6.8	7.4	10.5
Mn		-	-	-	-

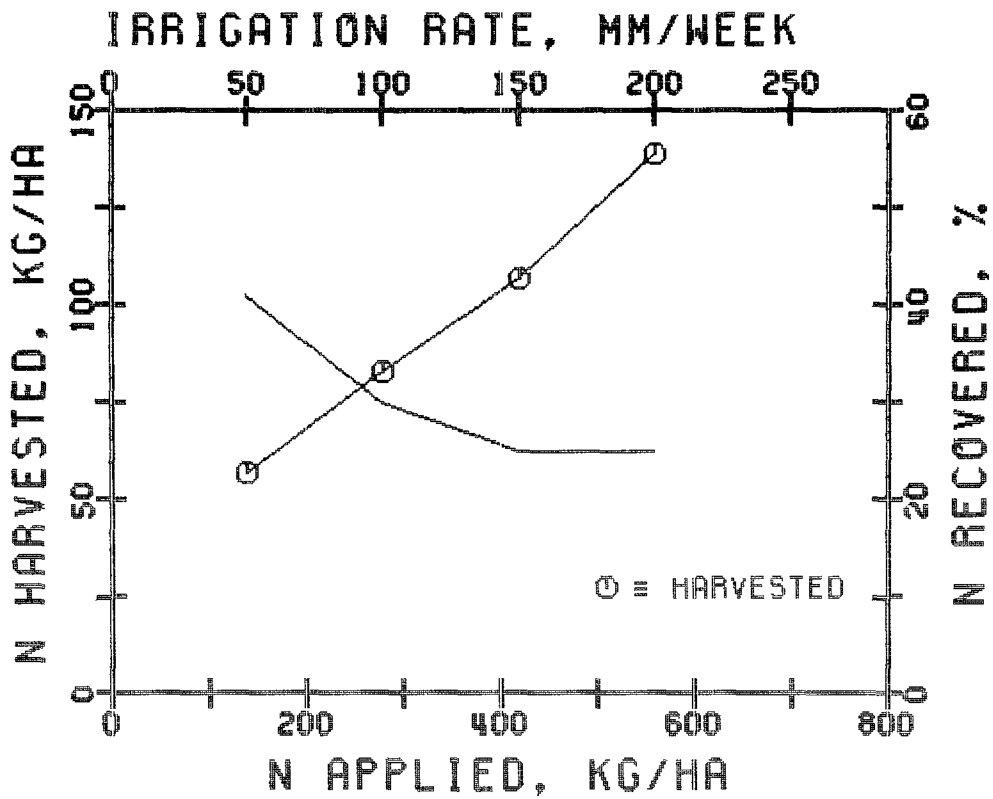

Figure A-20. Nitrogen recovery by corn silage in 45 cm rows - 1973.

Corn Grain

Corn was planted in 90 cm rows at a density of 45,000 plants/ha. Plots were harvested 18 weeks after planting. Green and dry weights showed a strong increase with irrigation rate (Table A-59), while dry matter content remained essentially constant. Nitrogen content also increased with rate. Calcium was not determined due to an oversight. Plant uptake of all elements increased with application rate (Table A-60). Efficiency of recovery of N showed a slight upward trend (Figure A-21), but was very low for all rates.

TABLE A-59. YIELD AND COMPOSITION OF CORN GRAIN IN 90 CM ROWS - 1973

Rate	mm/week	50	100	150	200
Green Weight, mtons/ha		1.68	2.91	5.38	6.83
Dry Matter, %		85.8	81.9	84.7	84.5
Dry Weight, mtons/ha		1.43	2.37	4.55	5.78
N		1.32	1.50	1.46	1.63
P		0.36	0.35	0.32	0.30
K		0.38	0.37	0.34	0.31
Ca	%	-	-	-	-
Mg		0.092	0.100	0.108	0.095
Na		0.0010	0.0005	0.0005	0.0015
Fe		0.0085	0.0101	0.0068	0.0145
Zn		0.0028	0.0016	0.0015	0.0014
Mn		0.0001	0.0007	0.0001	0.0001

TABLE A-60. NUTRIENT RECOVERY BY CORN GRAIN IN 90 CM ROWS - 1973

Rate	mm/week	50	100	150	200
			Harvested, kg/ha		
N		19	36	66	94
P		5.1	8.3	14.6	17.3
K		5.4	8.8	15.5	17.9
Ca		-	-	-	-
Mg		1.3	2.4	4.9	5.5
Na		0.014	0.012	0.023	0.087
Fe		0.12	0.24	0.31	0.84
Zn		0.040	0.038	0.068	0.081
Mn		0.001	0.017	0.005	0.006
			Applied, kg/ha		
N		140	280	420	560
P		52	105	157	210
K		32	64	96	168
Ca		355	710	1065	1420
Mg		98	195	293	390
Na		300	600	900	1200
Fe		6	12	18	24
Zn		1.8	3.7	5.5	7.4
Mn		-	-	-	-
			Recovered, %		
N		14	13	16	17
P		9.8	7.9	9.3	8.2
K		17	14	16	11
Ca		-	-	-	-
Mg		1.3	1.2	1.7	1.4
Na		0.005	0.002	0.003	0.007
Fe		2.0	2.0	1.7	3.5
Zn		2.2	1.0	1.2	1.1
Mn		-	-	-	-

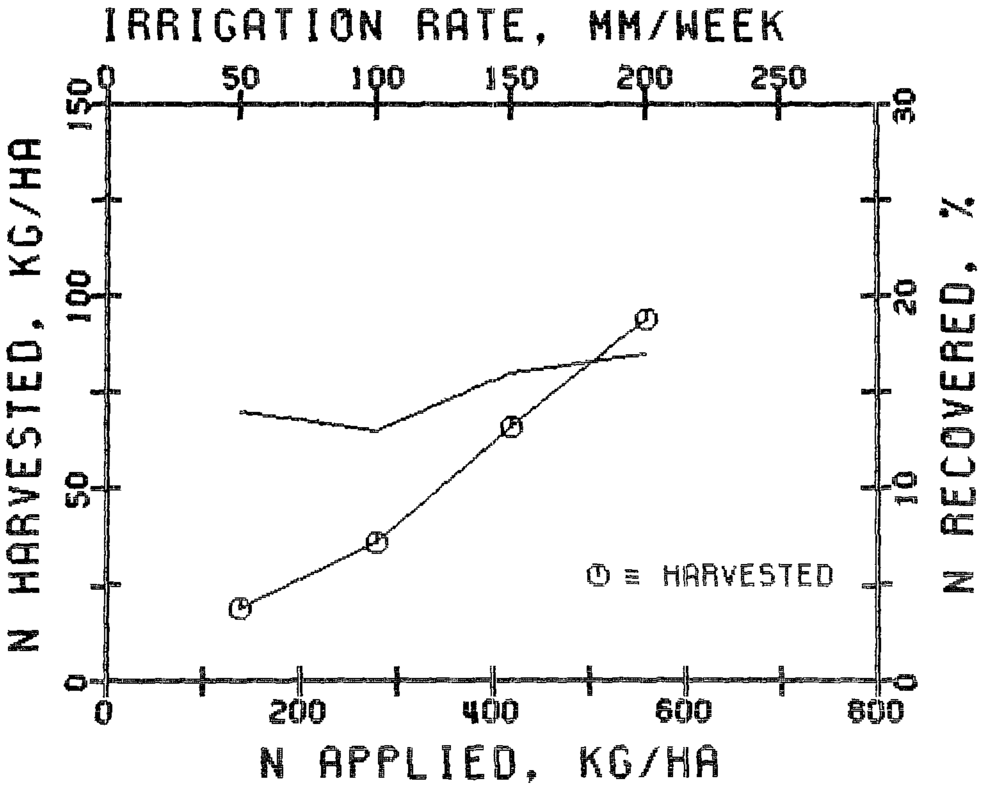

Figure A-21. Nitrogen recovery by corn grain in 90 cm rows - 1973.

1973 WINTER CROPS

Rye (Wrens Abruzzi) and ryegrass (Gulf Annual) were seeded at rates of 0.9 hl/ha (1 bu/acre) and 1.3 hl/ha (1.5 bu/acre), respectively, using a cultipacker seeder. Before planting, all plots were disked, plowed and disked again. Both crops grew vigorously and provided three cuttings. The schedule of planting and harvesting as shown Table A-61.

Effluent characteristics for this period are given in Table 6.

TABLE A-61. FIELD SCHEDULE FOR WINTER 1973

Operation	Date
Planting	11/7/73
Harvesting	
1st	1/17/74
2nd	2/13/74
3rd	4/4/74

Rye

Yields of green and dry forage showed an increase with irrigation rate (Table A-62), while dry matter content showed a slight downward trend. Nitrogen content showed a definite increase with irrigation rate (Table A-63), while other elements showed much smaller changes. Crop uptake of N showed a strong upward trend (Table A-64). Nitrogen recovery (Table A-65, Figure A-22) followed the characteristic decline with application. Uptake of K exceeded supply at 25 and 50 mm/week (Table A-65). This could lead to deficiency under prolonged practice.

TABLE A-62. YIELD AND DRY MATTER OF RYE - 1973

Rate mm/week	25	50	75	100
		1st Harvest		
Green Weight, mtons/ha	5.44	8.02	7.20	9.21
Dry Matter, %	17.8	13.8	15.8	16.0
Dry Weight, mtons/ha	0.97	1.11	1.15	1.47
		2nd Harvest		
Green Weight, mtons/ha	1.70	2.66	2.87	2.31
Dry Matter, %	23.3	20.8	20.0	19.9
Dry Weight, mtons/ha	0.39	0.56	0.57	0.46
		3rd Harvest		
Green Weight, mtons/ha	9.50	13.31	13.10	13.78
Dry Matter, %	25.2	22.0	20.4	20.4
Dry Weight, mtons/ha	2.39	2.93	2.67	2.81
		Net		
Green Weight, mtons/ha	16.6	24.0	23.3	25.3
Dry Matter, %	22.6	19.1	18.9	18.8
Dry Weight, mtons/ha	3.75	4.60	4.39	4.74

TABLE A-63. NUTRIENT CONTENT OF RYE - 1973

Rate	mm/week	25	50	75	100
			1st Harvest		
N		4.13	4.42	4.06	4.42
P		0.64	0.69	0.65	0.65
K		2.20	1.46	1.80	1.28
Ca		0.47	0.48	0.57	0.54
Mg	%	0.29	0.34	0.32	0.32
Na		0.021	0.026	0.018	0.026
Fe		0.040	0.027	0.098	0.092
Zn		0.0010	0.0022	0.0000	0.0072
Mn		0.0032	0.0015	0.0020	0.0020
Cu		0.0012	0.0013	0.0018	0.0020
			2nd Harvest		
N		3.18	3.61	4.01	4.18
P		0.52	0.50	0.51	0.56
K		1.46	1.51	1.55	1.57
Ca		0.36	0.39	0.45	0.46
Mg	%	0.26	0.30	0.31	0.31
Na		0.041	0.024	0.028	0.021
Fe		0.016	0.017	0.016	0.015
Zn		0	0	0	0
Mn		0.0030	0.0013	0.0010	0.0010
Cu		0.0010	0.0012	0.0010	0.0010
			3rd Harvest		
N		1.77	2.67	2.41	2.82
P		0.37	0.40	0.44	0.46
K		1.90	1.60	1.51	1.49
Ca		0.24	0.33	0.40	0.47
Mg	%	0.20	0.24	0.25	0.28
Na		0.012	0.009	0.012	0.009
Fe		0.020	0.016	0.010	0.010
Zn		0	0	0	0
Mn		0.00125	0.00075	0.00025	0.00050
Cu		0.00075	0.00075	0.00075	0.00075

(continued)

TABLE A-63. (continued)

Rate	mm/week	25	50	75	100
			Net		
N		2.53	2.83	3.06	3.54
P		0.45	0.49	0.51	0.53
K		1.93	1.55	1.59	1.43
Ca		0.31	0.38	0.45	0.49
Mg	%	0.23	0.27	0.28	0.29
Na		0.017	0.015	0.016	0.015
Fe		0.025	0.019	0.034	0.036
Zn		-	0	-	-
Mn		0.0019	0.0010	0.0008	0.0010
Cu		0.0009	0.0009	0.0010	0.0012

TABLE A-64. NUTRIENT UPTAKE BY RYE - 1973

Rate	mm/week	25	50	75	100
			1st Harvest		
N		40	50	47	65
P		6.2	7.7	7.5	9.6
K		21	16	21	19
Ca		4.6	5.3	6.6	7.9
Mg	kg/ha	2.8	3.8	3.7	4.7
Na		0.20	0.29	0.21	0.38
Fe		0.39	0.30	1.13	1.35
Zn		0.010	0.024	0	0.106
Mn		0.031	0.017	0.023	0.029
Cu		0.012	0.014	0.021	0.029
			2nd Harvest		
N		12	20	23	19
P		2.0	2.8	2.9	2.6
K		6	8	9	7
Ca		1.4	2.2	2.6	2.1
Mg	kg/ha	1.0	1.7	1.8	1.4
Na		0.16	0.13	0.16	0.10
Fe		0.062	0.095	0.091	0.069
Zn		0	0	0	0
Mn		0.0117	0.0073	0.0057	0.0046
Cu		0.0039	0.0067	0.0057	0.0046
			3rd Harvest		
N		42	78	64	79
P		9	12	12	13
K		45	47	40	42
Ca		5.7	9.7	10.7	13.2
Mg	kg/ha	4.8	7.0	6.7	7.9
Na		0.29	0.26	0.32	0.25
Fe		0.48	0.47	0.27	0.28
Zn		0	0	0	0
Mn		0.030	0.022	0.007	0.014
Cu		0.018	0.022	0.020	0.021

(continued)

TABLE A-64. (Continued)

Rate	mm/week	25	50	75	100
			Total		
N		94	148	134	163
P		17	23	22	25
K		72	71	70	68
Ca		12	17	20	23
Mg	kg/ha	8.6	12	12	14
Na		0.65	0.68	0.69	0.73
Fe		0.93	0.87	1.49	1.70
Zn		0.01	0.02	0	0.11
Mn		0.073	0.046	0.036	0.048
Cu		0.034	0.043	0.047	0.055

TABLE A-65. NUTRIENT RECOVERY BY RYE - 1973

Rate	mm/week	25	50	75	100
			Harvested, kg/ha		
N		94	148	134	163
P		17	23	22	25
K		72	71	70	68
Ca		12	17	20	23
Mg		8.6	12	12	14
Na		0.65	0.68	0.69	0.73
Fe		0.93	0.87	1.49	1.70
Zn		0.01	0.02	0	0.11
			Applied, kg/ha		
N		160	320	480	640
P		60	120	180	240
K		29	58	87	116
Ca		170	340	510	680
Mg		50	100	150	200
Na		190	380	570	760
Fe		2.3	4.7	7.0	9.4
Zn		1.0	2.1	3.1	4.2
			Recovered, %		
N		59	46	28	25
P		28	19	12	10
K		250	120	80	58
Ca		7.1	5.0	3.9	3.4
Mg		17	12	8	7
Na		0.34	0.18	0.12	0.10
Fe		40	19	21	18
Zn		1	1	-	3

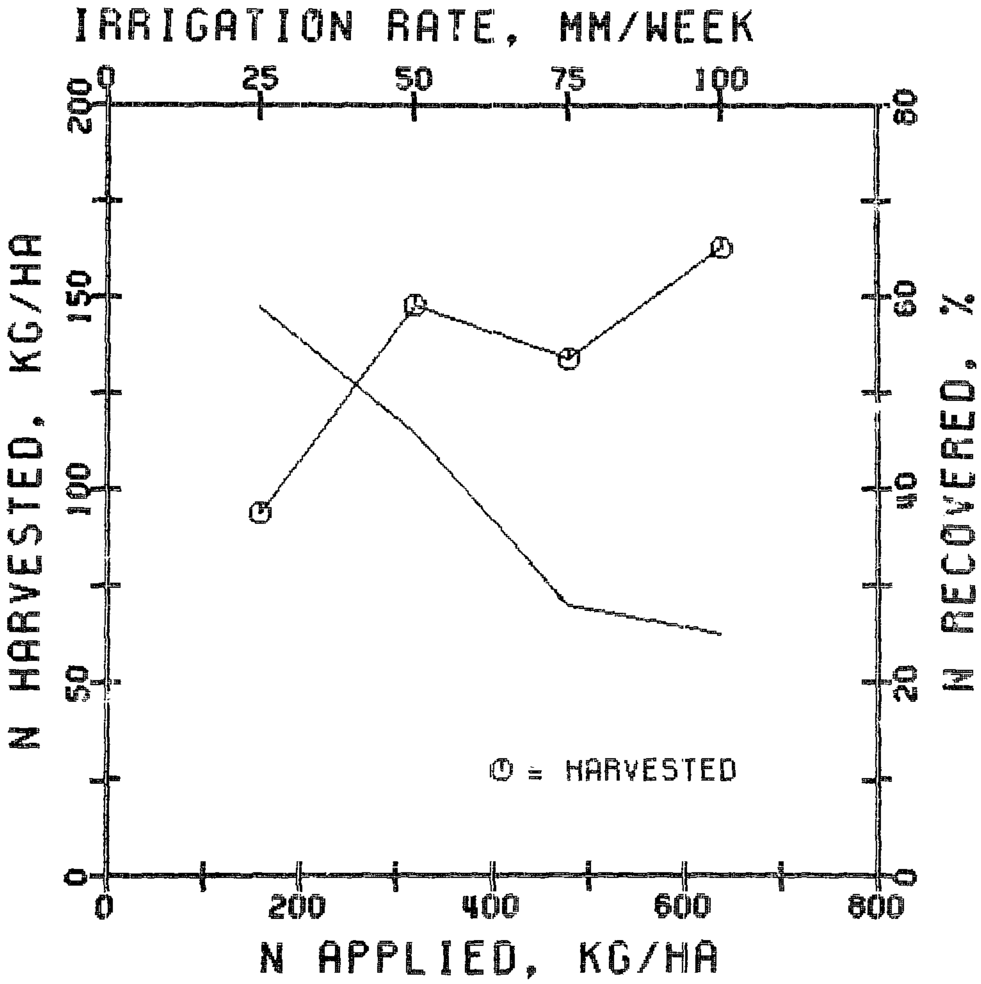

Figure A-22. Nitrogen recovery by rye - 1973.

Ryegrass

Increased irrigation rates produced higher yields of green and dry forage (Table A-66), with a slight decrease in dry matter content. Nitrogen content increased strongly with rate (Table A-67), while other elements showed only moderate changes. Crop uptake of N showed a strong upward trend with application rate (Table A-68), while recovery of all elements decreased (Table A-69). Figure A-23 shows the curve of diminishing returns for N.

TABLE A-66. YIELD AND DRY MATTER OF RYEGRASS 1973

Rate mm/week	25	50	75	100
		1st Harvest		
Green Weight, mtons/ha	4.2	12.4	12.5	12.9
Dry Matter, %	13.2	11.2	10.2	11.4
Dry Weight, mtons/ha	0.56	1.39	1.27	1.48
		2nd Harvest		
Green Weight, mtons/ha	6.9	8.8	9.5	9.7
Dry Matter, %	17.0	15.9	15.3	15.0
Dry Weight, mtons/ha	1.17	1.40	1.45	1.45
		3rd Harvest		
Green Weight, mtons/ha	17.2	15.9	20.3	21.4
Dry Matter, %	15.8	15.2	12.6	13.8
Dry Weight, mtons/ha	2.71	2.42	2.56	2.95
		Net		
Green Weight, mtons/ha	28.3	37.1	42.3	44.0
Dry Matter, %	15.7	14.0	12.5	13.4
Dry Weight, mtons/ha	4.44	5.21	5.28	5.88

TABLE A-67. NUTRIENT CONTENT OF RYEGRASS - 1973

Rate	mm/week	25	50	75	100
			1st Harvest		
N		3.83	4.13	4.04	4.12
P		0.93	0.92	0.86	0.80
K		1.71	1.71	1.68	1.68
Ca		0.45	0.41	0.48	0.44
Mg	%	0.25	0.25	0.29	0.25
Na		1.30	1.61	1.58	1.38
Fe		0.028	0.024	0.019	0.037
Zn		0	0	0	0
Mn		0.0022	0.0018	0.0020	0.0020
Cu		0.0022	0.0018	0.0020	0.0020
			2nd Harvest		
N		2.92	2.88	3.78	3.47
P		0.80	0.87	0.77	0.72
K		1.25	1.47	1.49	1.49
Ca		0.49	0.41	0.47	0.47
Mg	%	0.27	0.26	0.28	0.27
Na		1.23	1.61	1.75	1.74
Fe		0.033	0.023	0.023	0.036
Zn		0	0	0	0
Mn		0.0010	0.0015	0.0015	0.0015
Cu		0.0012	0.0013	0.0015	0.0015
			3rd Harvest		
N		2.11	3.09	3.36	3.20
P		0.67	0.82	0.72	0.66
K		1.24	1.49	1.57	1.38
Ca		0.63	0.46	0.49	0.48
Mg	%	0.26	0.29	0.26	0.25
Na		1.08	1.25	1.33	1.41
Fe		0.013	0.014	0.013	0.013
Zn		0	0	0	0
Mn		0.0020	0.0015	0.0015	0.0015
Cu		0.0008	0.0012	0.0012	0.0012

(continued)

TABLE A-67. (Continued)

Rate	mm/week	25	50	75	100
			Net		
N.		2.55	3.30	3.37	3.49
P		0.74	0.86	0.77	0.71
K		1.30	1.77	1.57	1.48
Ca		0.57	0.43	0.48	0.47
Mg	%	0.26	0.27	0.28	0.26
Na		1.15	1.44	1.50	1.48
Fe		0.020	0.019	0.017	0.025
Zn		0	0	0	0
Mn		0.0017	0.0016	0.0016	0.0016
Cu		0.0011	0.0014	0.0015	0.0015

TABLE A-68. NUTRIENT UPTAKE BY RYEGRASS - 1973

Rate	mm/week	25	50	75	100
			1st Harvest		
N		21	57	51	61
P		5.2	13	11	12
K		10	24	21	25
Ca		2.5	5.7	6.1	6.5
Mg	kg/ha	1.4	3.5	3.7	3.7
Na		7.3	22	20	20
Fe		0.16	0.33	0.24	0.55
Zn		0	0	0	0
Mn		0.012	0.025	0.025	0.030
Cu		0.012	0.025	0.025	0.030
			2nd Harvest		
N		34	40	55	50
P		9.4	12	11	10
K		15	21	22	22
Ca		5.7	5.7	6.8	6.8
Mg	kg/ha	3.2	3.6	4.1	3.9
Na		14	22	25	25
Fe		0.39	0.32	0.33	0.52
Zn		0	0	0	0
Mn		0.012	0.021	0.022	0.022
Cu		0.014	0.018	0.022	0.022
			3rd Harvest		
N		57	75	86	94
P		18	20	18	19
K		34	36	40	41
Ca		17	11	12	14
Mg	kg/ha	7.0	7.0	6.7	7.4
Na		29	30	34	42
Fe		0.35	0.34	0.33	0.38
Zn		0	0	0	0
Mn		0.054	0.036	0.038	0.044
Cu		0.020	0.029	0.031	0.035

(continued)

TABLE A-68. (Continued)

Rate	mm/week	25	50	75	100
			Total		
N		112	172	192	205
P		33	45	40	41
K		59	81	83	88
Ca		25	22	25	27
Mg	kg/ha	12	14	15	15
Na		50	74	79	87
Fe		0.90	0.99	0.90	1.45
Zn		0	0	0	0
Mn		0.078	0.082	0.085	0.096
Cu		0.046	0.082	0.078	0.087

TABLE A-69. NUTRIENT RECOVERY BY RYEGRASS - 1973

Rate	mm/week	25	50	75	100
			Harvested, kg/ha		
N		112	172	192	205
P		33	45	40	41
K		59	81	83	88
Ca		25	22	25	27
Mg		12	14	15	15
Na		50	74	79	87
Fe		0.90	0.99	0.90	1.45
Zn		0	0	0	0
Mn		0.078	0.082	0.085	0.096
Cu		0.046	0.082	0.078	0.087
			Applied, kg/ha		
N		160	320	480	640
P		60	120	180	240
K		29	58	87	116
Ca		170	340	510	680
Mg		50	100	150	200
Na		190	380	570	760
Fe		2.3	4.7	7.0	9.4
Zn		1.0	2.1	3.1	4.2
Mn		-	-	-	-
Cu		-	-	-	-
			Recovered, %		
N		70	54	40	32
P		55	38	22	17
K		205	140	95	76
Ca		15	6.5	4.9	4.0
Mg		24	14	10	7.5
Na		26	19	14	11
Fe		39	21	13	15

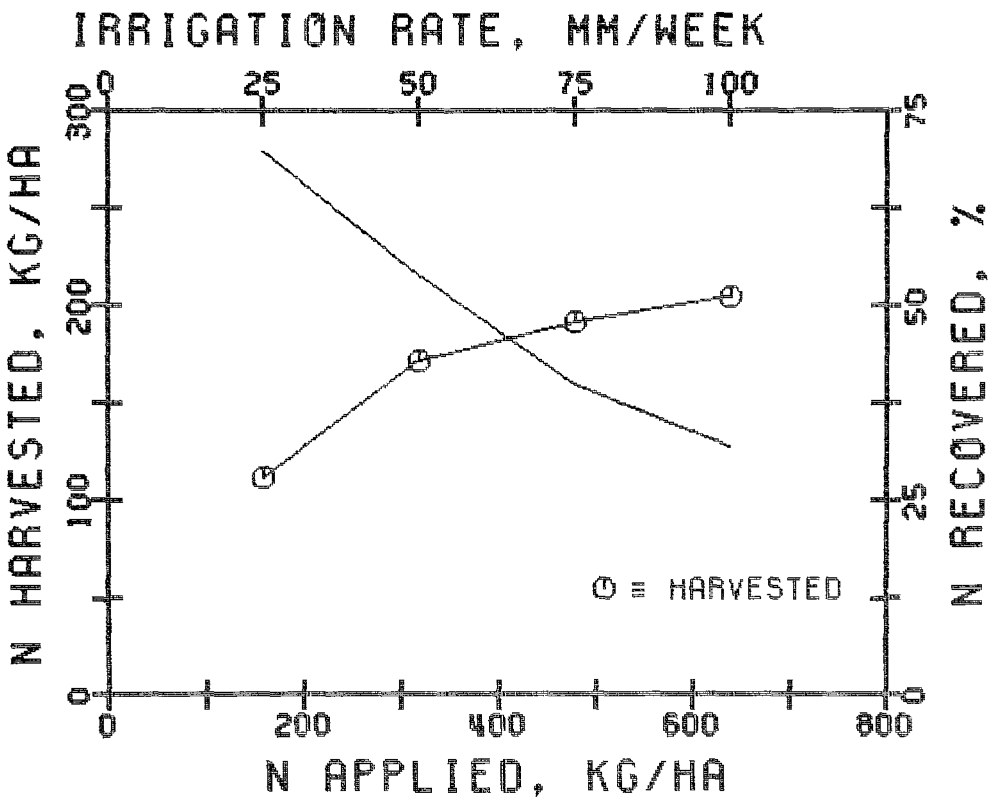

Figure A-23. Nitrogen recovery by ryegrass - 1973.

1974 SUMMER CROPS

Crops included pearl millet (Tiflate and Gahi-1), corn (Pioneer 3369 A) and coastal bermudagrass. All plots were prepared by disking, plowing, and disking again. Field operations followed the schedule of Table A-70. Pearl millet was planted at the rate of 11 kg/ha (10 lb/acre) with a cultipacker seeder. Corn was planted in 0.9-m (36-in.) rows at a density of approximately 73,000 plants/ha (29,000 plants/acre). Coastal bermudagrass was sprigged in August 1973 at the rate of 25 bales/ha (10 bales/acre). Bales of fresh green coastal bermudagrass were distributed over the plots using a manure spreader and then cut-in by light disking. Good plot coverage was obtained by June 1974. Some weeds were evident in the first cutting.

Characteristics of the effluent for the period 4/74-9/74 are given in Table 6.

Pearl Millet - Gahi 1

Three cuttings were obtained for the season. Green and dry yields as well as dry matter content, were all essentially independent of irrigation rate (Table A-71). Slight lodging was evident at the first harvest for 200 mm/week indicating that the first harvest should have been at 6 or 7 weeks after planting. A small amount of forage in this plot was not harvestable. Nitrogen content showed a small increase with rate (Table A-72). Values of N uptake (Table A-73) were slightly erratic. Efficiency of N recovery (Figure A-24) was low due to the high application rates of N. Uptake of K exceeded application for all rates, indicating a potential for K deficiency. Recovery of other elements decreased with irrigation rate (Table A-74).

TABLE A-70. FIELD SCHEDULE FOR SUMMER 1974

Crop	Planting	Harvesting
Pearl Millet		
Gahi-1	4/10/74	6/5/74 7/31/74 10/16/74
Tiflate	6/12/74	10/16/74
Corn Silage	3/27/74	7/3/74
Coastal Bermudagrass	-	6/5/74 7/3/74 7/31/74 10/16/74

TABLE A-71. YIELD AND DRY MATTER OF PEARL MILLET (GAHI-1) - 1974

Rate mm/week	100	150	200
		1st Harvest	
Green Weight, mtons/ha	38.8	36.5	41.2
Dry Matter, %	13.4	13.6	13.2
Dry Weight, mtons/ha	5.20	4.97	5.44
		2nd Harvest	
Green Weight, mtons/ha	40.5	36.7	37.6
Dry Matter, %	19.8	19.8	20.4
Dry Weight, mtons/ha	8.02	7.28	7.68
		3rd Harvest	
Green Weight, mtons/ha	9.2	10.0	86.0
Dry Matter, %	26.4	25.4	32.0
Dry Weight, mtons/ha	2.44	2.55	2.76
		Net	
Green Weight, mtons/ha	88.5	83.2	87.4
Dry Matter, %	17.7	17.8	18.2
Dry Weight, mtons/ha	15.7	14.8	15.9

TABLE A-72. NUTRIENT CONTENT OF PEARL MILLET (GAHI-1) - 1974

Rate	mm/week	100	150	200
			1st Harvest	
N		1.74	1.71	2.09
P		0.85	0.85	0.74
K		1.49	1.36	1.28
Ca		0.52	0.50	0.52
Mg	%	1.32	1.18	1.15
Na		0.052	0.032	0.172
Fe		0.016	0.021	0.018
Zn		0.0021	0.0022	0.0026
Al		0.0025	0.0025	0.0075
			2nd Harvest	
N		1.53	1.56	1.63
P		0.52	0.45	0.41
K		1.06	1.04	1.18
Ca		0.64	0.58	0.61
Mg	%	1.09	0.91	0.90
Na		0.035	0.025	0.042
Fe		0.018	0.028	0.016
Zn		0.0027	0.0012	0.0014
Al		0.0050	0.0025	0.0025
			3rd Harvest	
N		1.14	1.67	1.31
P		0.60	0.49	0.50
K		0.95	1.02	0.86
Ca		0.81	0.88	0.75
Mg	%	0.89	0.88	0.43
Na		0.025	0.042	0.023
Fe		0.017	0.015	0.010
Zn		0.0028	0.0030	0.0040
Al		0.0125	0.0125	0.0075

(continued)

TABLE A-72. (continued)

Rate	mm/week	100	150	200
			Net	
N		1.55	1.63	1.73
P		0.64	0.59	0.54
K		1.19	1.14	1.16
Ca		0.63	0.61	0.60
Mg	%	1.00	1.00	0.90
Na		0.039	0.030	0.084
Fe		0.017	0.023	0.015
Zn		0.0025	0.0019	0.0023
Al		0.0054	0.0042	0.0050

TABLE A-73. NUTRIENT UPTAKE BY PEARL MILLET (GAHI-1) - 1974

Rate	mm/week	100	150	200
			1st Harvest	
N		90	85	114
P		44	42	40
K		77	68	70
Ca		27	25	28
Mg	kg/ha	69	59	63
Na		2.7	1.6	9.4
Fe		0.83	1.04	0.98
Zn		0.11	0.11	0.14
Al		0.13	0.12	0.41
			2nd Harvest	
N		123	73	125
P		42	33	31
K		85	76	91
Ca		51	42	47
Mg	kg/ha	87	66	69
Na		2.8	1.8	3.2
Fe		1.4	2.0	1.2
Zn		0.22	0.09	0.11
Al		0.40	0.18	0.19
			3rd Harvest	
N		28	43	36
P		15	12	14
K		23	26	24
Ca		20	22	21
Mg	kg/ha	22	22	12
Na		0.61	1.07	0.63
Fe		0.41	0.38	0.28
Zn		0.068	0.077	0.110
Al		0.31	0.32	0.21

TABLE A-73. (continued)

Rate	mm/week	100	150	200
			Total	
N		241	201	275
P		101	87	85
K		185	170	185
Ca		98	89	96
Mg	kg/ha	178	147	144
Na		6.1	4.5	13.2
Fe		2.6	3.4	2.8
Zn		0.40	0.28	0.36
Al		0.84	0.62	0.81

TABLE A-74. NUTRIENT RECOVERY BY PEARL MILLET (GAHI-1) - 1974

Rate	mm/week	100	150	200
		Harvested, kg/ha		
N		241	201	275
P		101	87	85
K		185	170	185
Ca		98	89	96
Mg		178	147	144
Na		6.1	4.5	13.2
		Applied, kg/ha		
N		840	1260	1680
P		260	390	520
K		85	128	170
Ca		670	1000	1340
Mg		200	300	400
Na		770	1150	1540
		Recovered, %		
N		29	16	16
P		39	22	16
K		220	130	110
Ca		14.6	8.9	7.2
Mg		89	49	36
Na		0.79	0.39	0.86

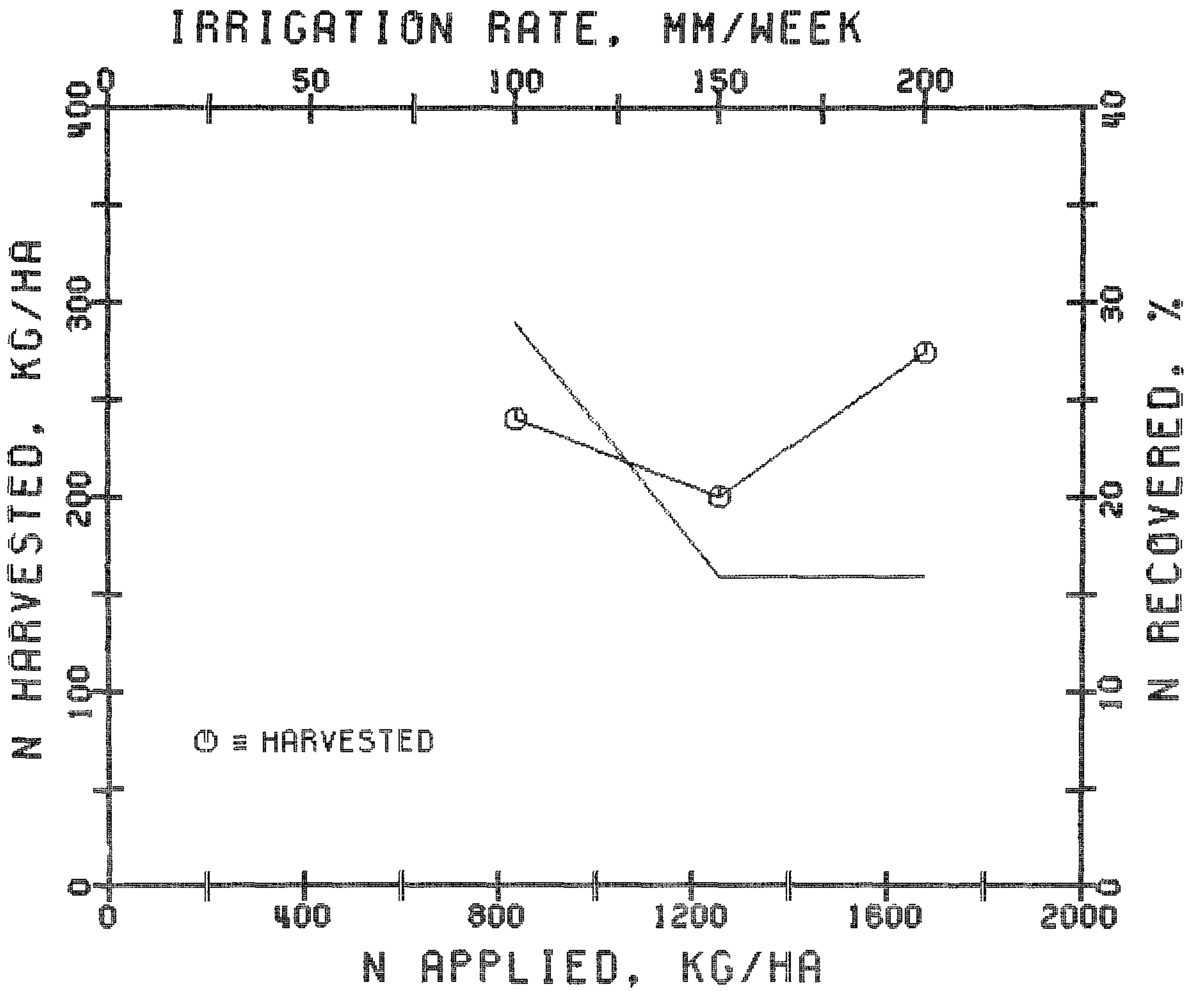

Figure A-24. Nitrogen recovery by pearl millet (Gahi-1) - 1974.

Pearl Millet - Tiflate

Only one harvest was obtained, 18 weeks after planting. Plots were irrigated for only 14 weeks. Yields of green and dry forage increased with irrigation rate (Table A-75), while dry matter content remained approximately constant. Nitrogen content showed an increase with rate. Crop uptake of N showed a strong increase with application rate (Table A-76), while recovery showed a gradual decline from 37% at 50 mm/week (Figure A-25). Again, K uptake exceeded application.

TABLE A-75. YIELD AND COMPOSITION OF PEARL MILLET (TIFLATE) - 1974

Rate	mm/week	50	100	150
Green Weight, mtons/ha		34.3	53.8	60.7
Dry Matter, %		29.4	26.8	27.2
Dry Weight, mtons/ha		10.1	14.4	16.5
N		0.94	1.10	1.25
P		0.55	0.26	0.42
K		0.60	0.72	0.71
Ca	%	0.40	0.40	0.42
Mg		0.45	0.44	0.45
Na		0.020	0.030	0.032
Fe		0.0105	0.0112	0.0162
Zn		0.0042	0.0035	0.0036
Al		0.0050	0.0075	0.0150

TABLE A-76. NUTRIENT RECOVERY BY PEARL MILLET (TIFLATE) - 1974

Rate	mm/week	50	100	150
			Harvested, kg/ha	
N		95	158	206
P		56	37	69
K		61	104	117
Ca		40	58	69
Mg		45	63	74
Na		2.0	4.3	5.3
Fe		1.1	1.6	2.7
Zn		0.42	0.50	0.59
Al		0.51	1.1	2.5
			Applied, kg/ha	
N		260	520	780
P		78	156	234
K		26	52	78
Ca		200	400	600
Mg		62	124	186
Na		235	470	705
Fe		-	-	-
Zn		-	-	-
Al		-	-	-
			Recovered, %	
N		37	30	26
P		72	24	29
K		230	200	150
Ca		20	15	12
Mg		73	50	40
Na		0.85	0.91	0.75

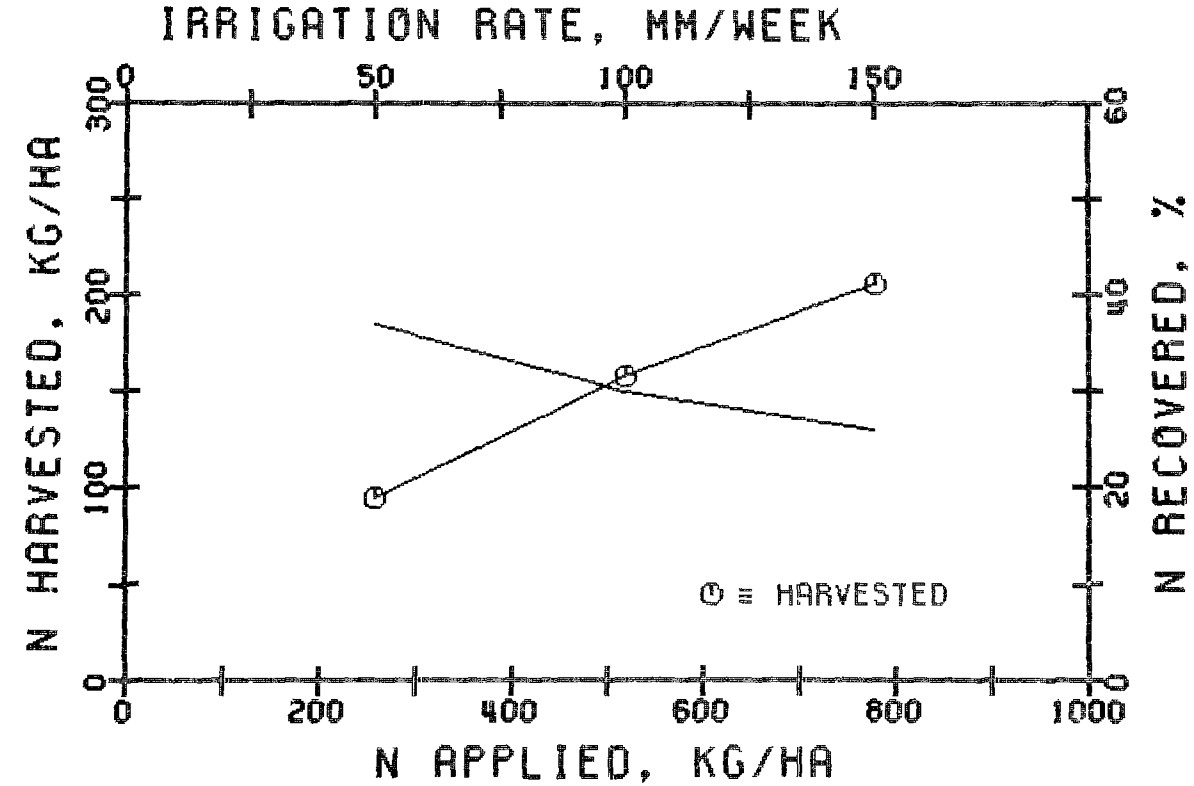

Figure A-25. Nitrogen recovery by pearl millet (Tiflate) - 1974.

Corn Silage

The corn was harvested at the hard dent stage, 14 weeks after planting. Green and dry yields showed a strong increase with irrigation rate (Table A-77), while dry matter content was approximately constant. Nitrogen content showed a slight increase with rate. A large increase in crop N with application rate was obtained (Table A-78), but recoveries of N were low (Figure A-26) due to the high application rates.

TABLE A-77. YIELD AND COMPOSITION OF CORN SILAGE - 1974

Rate	mm/week	100	150	200
Green Weight, mtons/ha		20.0	25.2	31.5
Dry Matter, %		28.0	27.2	30.0
Dry Weight, mtons/ha		5.58	6.83	9.43
N		1.18	1.29	1.26
P		0.37	0.39	0.35
K		0.27	0.26	0.26
Ca	%	0.31	0.36	0.26
Mg		0.27	0.31	0.24
Na		0.038	0.035	0.035
Fe		0.024	0.015	0.011
Zn		0.0030	0.0015	0.0010
Al		0.0050	0.0025	0.0025

TABLE A-78. NUTRIENT RECOVERY BY CORN SILAGE - 1974

Rate	mm/week	100	150	200
		Harvested, kg/ha		
N		66	88	119
P		21	27	33
K		15	18	25
Ca		17	25	25
Mg		15	21	23
Na		2.1	2.4	3.3
Fe		1.3	1.0	1.1
Zn		0.17	0.10	0.094
Al		0.28	0.17	0.24
		Applied, kg/ha		
N		510	765	1020
P		155	232	310
K		52	78	104
Ca		403	604	806
Mg		123	185	246
Na		470	705	940
Fe		-	-	-
Zn		-	-	-
Al		-	-	-
		Recovered, %		
N		13	12	12
P		14	12	11
K		29	23	24
Ca		4.2	4.1	3.1
Mg		12	11	9
Na		0.45	0.34	0.35

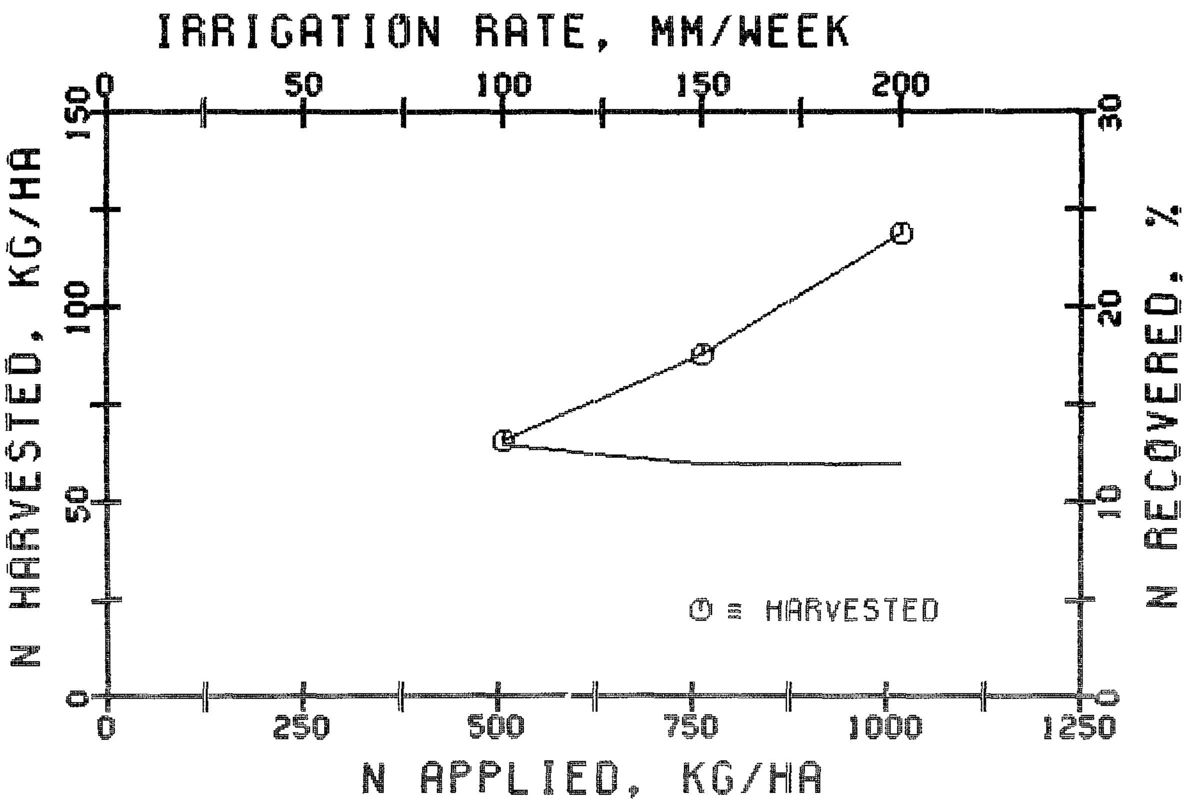

Figure A-26. Nitrogen recovery by corn silage - 1974.

Coastal Bermudagrass

This grass responded very well to irrigation with effluent. Some problem with weeds in the plots was experienced. Four cuttings were obtained (Table A-79). Yields of green and dry forage increased with irrigation rate, while dry matter content showed a slight decline. Nitrogen content showed an increase with rate (Table A-80). Nitrogen levels in the last cutting were low because of the age of the grass; viz, 11 weeks. Better forage quality would have been obtained at an earlier age, yielding 5 cuttings instead of 4. Crop uptake of N showed a general increase with application rate (Tables A-81 and A-82). Recovery efficiency exhibited the trend of diminishing returns (Figure A-27), from a value of 49% at 50 mm/week.

TABLE A-79. YIELD AND DRY MATTER OF COASTAL BERMUDAGRASS - 1974

Rate mm/week	50	100	150	200
	1st Harvest			
Green Weight, mtons/ha	10.3	16.1	13.9	13.1
Dry Matter, %	20.0	16.4	19.6	20.0
Dry Weight, mtons/ha	2.07	2.63	2.73	2.62
	2nd Harvest			
Green Weight, mtons/ha	6.3	8.8	12.1	14.4
Dry Matter, %	24.4	25.4	26.4	24.0
Dry Weight, mtons/ha	1.54	2.23	3.19	3.46
	3rd Harvest			
Green Weight, mtons/ha	7.5	8.6	9.6	12.3
Dry Matter, %	25.6	25.4	25.2	23.6
Dry Weight, mtons/ha	1.91	2.19	2.41	2.91
	4th Harvest			
Green Weight, mtons/ha	10.9	9.7	12.4	11.8
Dry Matter, %	46.0	42.0	40.6	43.6
Dry Weight, mtons/ha	5.03	4.05	5.05	5.16
	Net			
Green Weight, mtons/ha	35.0	43.2	48.0	51.6
Dry Matter, %	30.3	25.7	27.9	27.4
Dry Weight, mtons/ha	10.6	11.1	13.4	14.2

TABLE A-80. NUTRIENT CONTENT OF COASTAL BERMUDAGRASS - 1974

Rate	mm/week	50	100	150	200
			1st Harvest		
N		1.95	2.57	2.57	2.82
P		0.37	0.37	0.37	0.37
K		1.53	1.80	1.73	0.73
Ca		0.88	0.89	0.72	0.81
Mg	%	0.33	0.33	0.30	0.35
Na		0.13	0.26	0.20	0.22
Fe		0.014	0.019	0.017	0.016
Zn		0.0071	0.0040	0.0043	0.0038
Al		0.0050	0.0050	0.0050	0.0050
			2nd Harvest		
N		1.96	2.79	2.43	2.80
P		0.35	0.37	0.36	0.40
K		1.50	1.75	1.69	1.79
Ca		0.73	0.66	0.58	0.58
Mg	%	0.30	0.36	0.34	0.34
Na		0.070	0.105	0.095	0.095
Fe		0.021	0.011	0.014	0.014
Zn		0.0030	0.0018	0.0016	0.0018
Al		0.0050	0.0050	0.0050	0.0050
			3rd Harvest		
N		1.59	1.85	2.01	2.18
P		0.37	0.34	0.32	0.38
K		1.53	1.60	1.45	1.66
Ca		0.56	0.55	0.53	0.60
Mg	%	0.30	0.34	0.34	0.40
Na		0.055	0.062	0.058	0.058
Fe		0.012	0.010	0.015	0.016
Zn		0.0019	0.0010	0.0012	0.0016
Al		0.0025	0.0025	0.0100	0.0125
			4th Harvest		
N		0.49	0.56	0.70	0.90
P		0.28	0.25	0.24	0.24
K		0.78	1.09	0.89	1.02
Ca		0.45	0.54	0.45	0.50
Mg	%	0.21	0.27	0.23	0.27
Na		0.032	0.045	0.040	0.035
Fe		0.0062	0.0112	0.0062	0.0078
Zn		0.0018	0.0015	0.0009	0.0015
Al		0.0075	0.0125	0.0075	0.0100

(continued)

TABLE A-80. (continued)

Rate	mm/week	50	100	150	200
			Net		
N		1.18	1.74	1.73	1.98
P		0.32	0.32	0.31	0.33
K		1.16	1.49	1.35	1.47
Ca		0.59	0.65	0.55	0.60
Mg	%	0.26	0.32	0.29	0.41
Na		0.061	0.111	0.089	0.088
Fe		0.011	0.013	0.012	0.013
Zn		0.0030	0.0021	0.0018	0.0020
Al		0.0057	0.0072	0.0082	0.0083

TABLE A-81. NUTRIENT UPTAKE BY COASTAL BERMUDAGRASS - 1974

Rate	mm/week	50	100	150	200
			1st Harvest		
N		40	68	70	74
P		7.7	9.7	10.1	9.7
K		32	47	47	45
Ca		18	23	20	21
Mg	kg/ha	6.8	8.7	8.2	9.2
Na		2.7	6.8	5.5	5.8
Fe		0.29	0.50	0.46	0.42
Zn		0.15	0.11	0.12	0.10
Al		0.10	0.13	0.14	0.13
			2nd Harvest		
N		30	62	78	35
P		5.4	8.3	11.5	13.8
K		23	39	54	62
Ca		11	15	19	20
Mg	kg/ha	5	8	11	12
Na		1.1	2.3	3.0	3.3
Fe		0.32	0.25	0.45	0.48
Zn		0.050	0.040	0.051	0.062
Al		0.08	0.11	0.16	0.17
			3rd Harvest		
N		30	41	48	63
P		7.1	7.4	7.7	11.1
K		29	35	35	48
Ca		11	12	13	17
Mg	kg/ha	5.7	7.4	8.2	11.6
Na		1.1	1.4	1.4	1.7
Fe		0.23	0.22	0.36	0.47
Zn		0.036	0.022	0.029	0.047
Al		0.05	0.05	0.24	0.36
			4th Harvest		
N		80	23	35	46
P		14	10	12	12
K		329	44	45	53
Ca		23	22	23	26
Mg	kg/ha	11	11	12	14
Na		1.6	1.8	2.0	1.8
Fe		0.31	0.45	0.31	0.40
Zn		0.090	0.061	0.045	0.077
Al		0.38	0.51	0.38	0.52

TABLE A-82. NUTRIENT RECOVERY BY COASTAL BERMUDAGRASS - 1974

Rate	mm/week	50	100	150	200
			Harvested, kg/ha		
N		180	194	231	218
P		34	35	41	47
K		123	165	181	208
Ca		63	72	75	84
Mg		29	35	39	47
Na		6.5	12	12	13
Fe		1.2	1.4	1.6	2.0
Zn		0.33	0.23	0.24	0.28
Al		0.61	0.80	0.92	1.18
			Applied, kg/ha		
N		365	730	1095	1460
P		112	224	336	448
K		37	74	111	148
Ca		290	580	870	1160
Mg		87	174	261	348
Na		335	670	1005	1340
Fe		-	-	-	-
Zn		-	-	-	-
Al		-	-	-	-
			Recovered, %		
N		49	27	21	15
P		30	16	12	10
K		330	220	160	140
Ca		22	12	9	7
Mg		33	20	15	4
Na		1.9	1.8	1.2	1.0

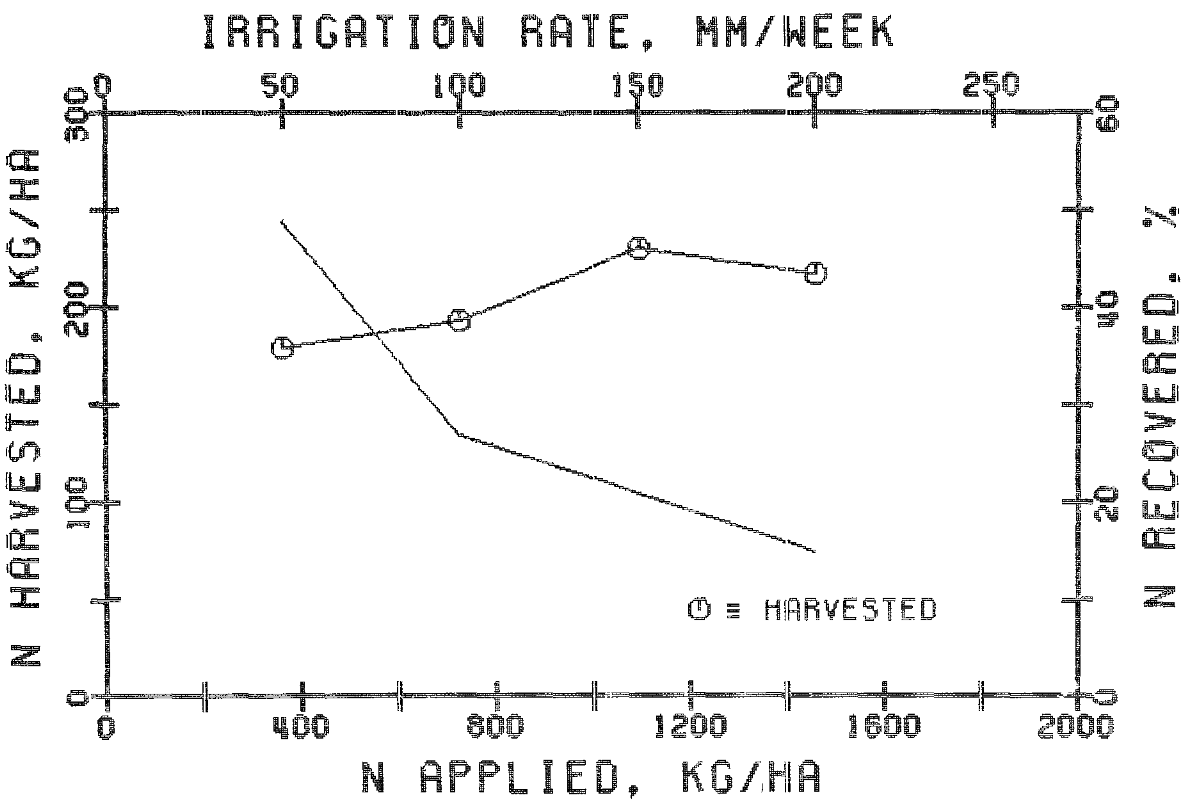

Figure A-27. Nitrogen recovery by coastal bermudagrass - 1974.

1974 WINTER CROPS

Rye and ryegrass were seeded at rates of 0.5 hl/ha (1/2 bu/acre) and 0.9 hl/ha (1 bu/acre), respectively, with a cultipacker seeder. Plots were prepared by disking, plowing and disking again before planting. Two cuttings of both crops were obtained.

Characteristics of the effluent for the period 10/74-3/75 are given in Table 6.

Rye

Green and dry yields both increased slightly with irrigation rate (Table A-83). Dry matter content was approximately constant. More than 80% of the forage harvested was collected in the second cutting; growth was more vigorous after the first harvest. Nitrogen content increased with rate (Table A-84). Nitrogen uptake also showed an increase (Table A-85). Due to the high levels of application (Table A-86), recovery of N was low. Recovery did follow the downward trend (Figure A-28) generally observed.

TABLE A-83. YIELD AND DRY MATTER OF RYE - 1974

Rate mm/week	50	75	100
		1st Harvest	
Green Weight, mtons/ha	3.00	2.78	3.99
Dry Matter, %	16.4	17.5	16.1
Dry Weight, mtons/ha	0.49	0.49	0.64
		2nd Harvest	
Green Weight, mtons/ha	13.8	15.7	14.9
Dry Matter, %	19.0	19.7	18.5
Dry Weight, mtons/ha	2.61	3.10	2.75
		Net	
Green Weight, mtons/ha	16.8	18.5	18.9
Dry Matter, %	18.5	19.4	17.9
Dry Weight, mtons/ha	3.1	3.6	3.4

TABLE A-84. NUTRIENT CONTENT OF RYE - 1974

Rate	mm/week	50	75	100
			1st Harvest	
N		3.82	3.72	4.26
P		0.70	0.70	0.67
K		1.80	1.96	1.84
Ca		0.51	0.54	0.61
Mg	%	0.27	0.26	0.27
Na		0.030	0.025	0.060
Fe		0.024	0.020	0.028
Zn		0.0065	0.0030	0.0052
Al		0.0100	0.0125	0.0275
			2nd Harvest	
N		2.57	2.62	2.89
P		0.46	0.44	0.45
K		2.00	2.05	2.14
Ca		0.41	0.42	0.49
Mg	%	0.23	0.23	0.23
Na		0.040	0.038	0.045
Fe		0.0210	0.0225	0.0188
Zn		0.0034	0.0052	0.0045
Al		0.0050	0.0075	0.0100
			Net	
N		2.76	2.77	3.15
P		0.50	0.48	0.49
K		1.96	2.04	2.09
Ca		0.42	0.63	0.51
Mg	%	0.24	0.23	0.24
Na		0.038	0.036	0.048
Fe		0.0212	0.0222	0.0205
Zn		0.0039	0.0049	0.0036
Al		0.0058	0.0082	0.0133

TABLE A-85. NUTRIENT UPTAKE BY RYE - 1974

Rate	mm/week	50	75	100
			1st Harvest	
N		19	18	27
P		3.4	3.4	4.3
K		8.8	9.6	11.8
Ca		2.5	2.6	3.9
Mg	kg/ha	1.3	1.3	1.7
Na		0.15	0.12	0.38
Fe		0.11	0.10	0.18
Zn		0.032	0.015	0.033
Al		0.049	0.061	0.176
			2nd Harvest	
N		67	81	79
P		12	14	12
K		52	64	59
Ca		11	13	13
Mg	kg/ha	6.0	7.1	6.3
Na		1.0	1.2	1.2
Fe		0.55	0.70	0.52
Zn		0.089	0.16	0.12
Al		0.13	0.23	0.28
			Total	
N		86	99	106
P		15	17	16
K		61	74	63
Ca		14	16	17
Mg	kg/ha	7.3	8.4	8.0
Na		1.2	1.3	1.6
Fe		0.66	0.80	0.70
Zn		0.12	0.18	0.15
Al		0.18	0.29	0.46

TABLE A-86. NUTRIENT RECOVERY BY RYE - 1974

Rate	mm/week	50	75	100
			Harvested, kg/ha	
N		86	99	106
P		15	17	16
K		61	74	63
Ca		14	16	17
Mg		7.3	8.4	8.0
Na		1.2	1.3	1.6
Fe		0.66	0.80	0.70
Zn		0.12	0.18	0.15
Al		0.18	0.29	0.46
			Applied, kg/ha	
N		455	682	910
P		100	150	200
K		45	68	90
Ca		320	480	640
Mg		112	168	224
Na		280	420	560
Fe		2.0	3.0	4.0
Zn		3.6	5.4	7.2
Al		-	-	-
			Recovered, %	
N		19	15	12
P		15	11	8
K		140	110	70
Ca		4.4	3.3	2.7
Mg		6.5	5.0	3.6
Na		0.43	0.31	0.29
Fe		33	27	18
Zn		3.3	3.3	2.1

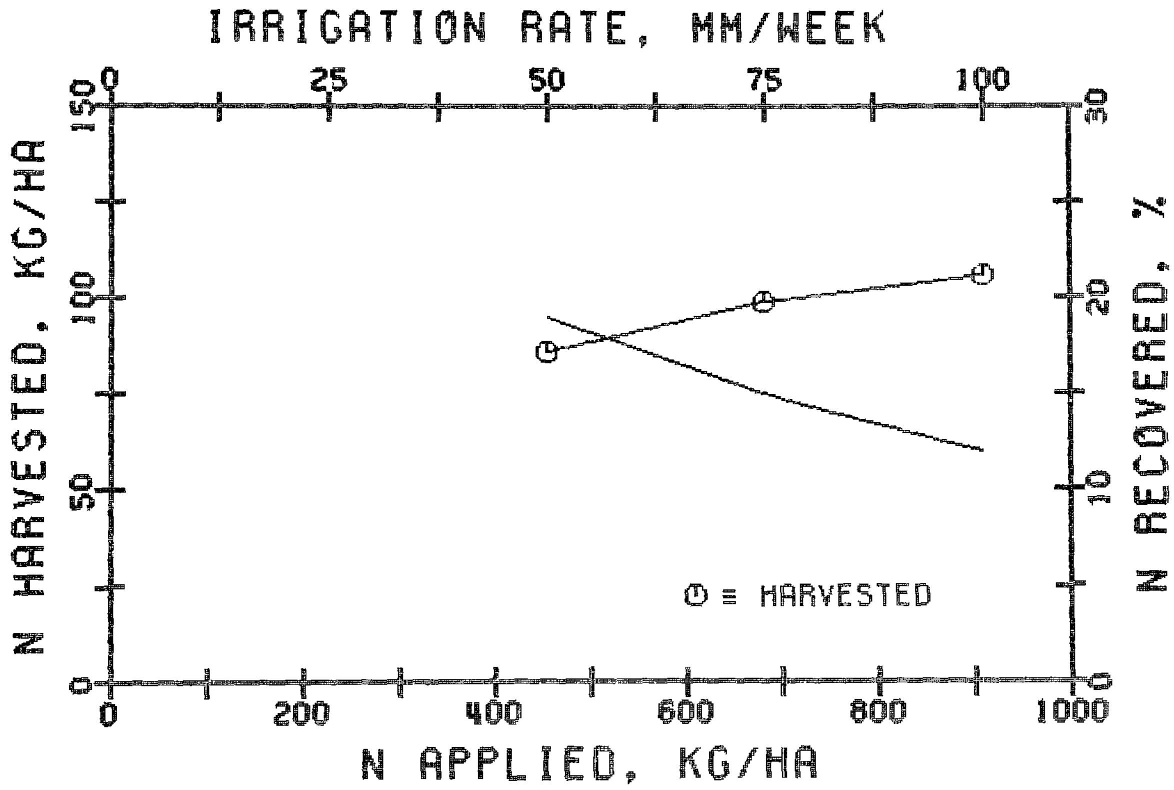

Figure A-28. Nitrogen recovery by rye - 1974.

Ryegrass

Green and dry yields were somewhat erratic (Table A-87), and showed no definite trend. Dry matter content did show an increase with rate. Nitrogen content (Table A-88) did not show a definite trend. Nitrogen uptake showed a slight upward trend with application rate (Table A-89), with a corresponding decrease in N recovery (Figure A-29). Recovery of N was low due to the high application rates of N (Table A-90).

TABLE A-87. YIELD AND DRY MATTER OF RYEGRASS - 1974

Rate mm/week	50	75	100
		1st Harvest	
Green Weight, mtons/ha	6.76	7.66	7.77
Dry Matter, %	13.6	14.4	12.0
Dry Weight, mtons/ha	0.92	1.10	0.93
		2nd Harvest	
Green Weight, mtons/ha	19.0	26.4	18.0
Dry Matter, %	12.8	13.4	15.2
Dry Weight, mtons/ha	2.43	3.53	2,73
		Net	
Green Weight, mtons/ha	25.8	34.1	25.8
Dry Matter, %	13.0	13.6	14.2
Dry Weight, mtons/ha	3.35	4.63	3.66

TABLE A-88. NUTRIENT CONTENT OF RYEGRASS - 1974

Rate	mm/week	50	75	100
			1st Harvest	
N		3.80	3.62	4.12
P		0.85	0.75	0.84
K		2.06	2.00	2.18
Ca		0.45	0.47	0.41
Mg	%	0.24	0.23	0.24
Na		1.14	1.00	1.29
Fe		0.018	0.034	0.039
Zn		0.0048	0.0055	0.0065
Al		0.0050	0.0050	0.0125
			2nd Harvest	
N		2.57	2.56	3.05
P		0.58	0.60	0.58
K		1.66	1.71	1.99
Ca		0.50	0.50	0.50
Mg	%	0.24	0.23	0.25
Na		1.25	1.31	1.10
Fe		0.035	0.071	0.026
Zn		0.0194	0.0056	0.0109
Al		0.0125	0.0075	0.0175
			Net	
N		2.89	2.80	3.32
P		0.65	0.64	0.65
K		1.76	1.78	2.03
Ca		0.48	0.49	0.48
Mg	%	0.24	0.23	0.25
Na		1.21	1.24	1.14
Fe		0.030	0.062	0.030
Zn		0.0153	0.0056	0.0098
Al		0.0103	0.0070	0.0162

TABLE A-89. NUTRIENT UPTAKE BY RYEGRASS - 1974

Rate	mm/week	50	75	100
			1st Harvest	
N		35	40	38
P		7.8	8.2	7.8
K		19	22	20
Ca		4.1	5.2	3.8
Mg	kg/ha	2.2	2.5	2.2
Na		10	11	12
Fe		0.17	0.37	0.36
Zn		0.044	0.060	0.060
Al		0.046	0.055	0.116
			2nd Harvest	
N		62	90	83
P		14	21	16
K		40	60	54
Ca		12	18	14
Mg	kg/ha	5.8	8.1	6.8
Na		30	46	30
Fe		0.85	2.51	0.71
Zn		0.47	0.20	0.30
Al		0.30	0.26	0.48
			Total	
N		97	130	121
P		22	29	24
K		59	82	74
Ca		16	23	18
Mg	kg/ha	8.0	10.6	9.0
Na		40	57	42
Fe		1.0	2.9	1.1
Zn		0.51	0.26	0.36
Al		0.35	0.32	0.60

TABLE A-90 . NUTRIENT RECOVERY BY RYEGRASS - 1974

Rate	mm/week	50	75	100
			Harvested, kg/ha	
N		97	130	121
P		22	29	24
K		59	82	74
Ca		16	23	18
Mg		8.0	10.6	9.0
Na		40	57	42
Fe		1.0	2.9	1.1
Zn		0.51	0.26	0.36
Al		0.35	0.32	0.60
			Applied, kg/ha	
N		455	682	910
P		100	150	200
K		45	68	90
Ca		320	480	640
Mg		112	168	224
Na		280	420	560
Fe		2.0	3.0	4.0
Zn		3.6	5.4	7.2
Al		-	-	-
			Recovered, %	
N		21	19	13
P		22	19	12
K		130	120	82
Ca		5.0	4.8	2.8
Mg		7.1	6.3	4.0
Na		14	14	8
Fe		50	97	28
Zn		14.2	14.8	5.0

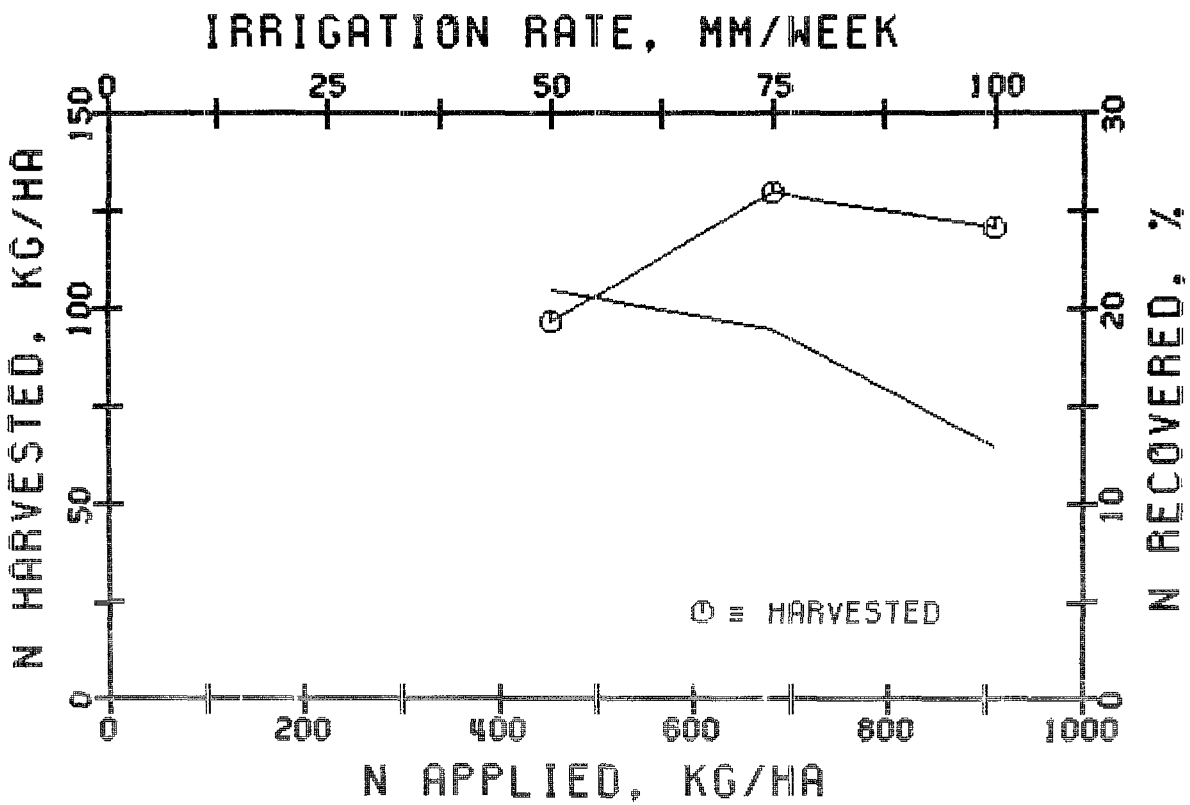

Figure A-29. Nitrogen recovery by ryegrass - 1974.

1975 SUMMER CROP

For this period only coastal bermudagrass was studied. In the summer of 1973 a 1.35 ha (3.34 acres) strip of coastal bermudagrass was sprigged at the same time and in the manner as the plots. The strip was irrigated with water from 4 large guns at an average intensity of 28 mm/hr (1.1 in./hr) for 4 hours for an irrigation rate of 112 mm/week (4.4 in./week). This area had not been irrigated previously and thus had less weed infestation than the plots.

All plots and the strip were clipped on April 2, 1975, to remove any early weeds. Some weeds were evident in the 50 mm/week plot at the first and second harvests, so these plots were simply clipped without weighing the material. Plots and strip were harvested by the schedule shown in Table A-91.

Effluent characteristics for the period 4/75-9/75 are given in Table 6.

TABLE A-91. HARVEST SCHEDULE FOR SUMMER 1975

Harvest	Coastal Bermudagrass Plots	Coastal Bermudagrass Strip
1	4/30/75	4/30/75
2	6/5/75	6/5/75
3	6/25/75	6/25/75
4	8/6/75	8/6/75
5	9/10/75	9/10/75
6	-	10/21/75
Total Time, weeks	23	29

Coastal Bermudagrass Plots

The plots were harvested 5 times during the season. Due to light weed infestation, vegetation from the 50 mm/week was not saved for the first and second harvests. Thus, values for this rate are somewhat low. With this in mind, it may be seen that dry yields increased only slightly with irrigation rate (Table A-92), as did dry matter content. Nitrogen content appeared somewhat uniform with rate (Table A-93). Nitrogen uptake showed only modest increase with application rates from 100 to 200 mm/week (Table A-94). The value of nutrient uptake at 50 mm/week was adjusted by assuming that 40% of total uptake occurred in the first two cuttings (based on results for the other irrigation rates). Adjusted values are given in Table A-95. Based on these values N recovery declined downward from 44% at 50 mm/week (Figure A-30). At this rate K uptake exceeded application, indicating potential deficiency in long term operation.

TABLE A-92. YIELD AND DRY MATTER OF COASTAL BERMUDAGRASS (PLOTS) - 1975

Rate mm/week	50	100	150	200
		1st Harvest		
Green Weight, mtons/ha	-	2.97	1.43	1.95
Dry Matter, %	-	20.0	28.8	26.4
Dry Weight, mtons/ha	-	0.60	0.40	0.52
		2nd Harvest		
Green Weight, mtons/ha	-	9.77	10.7	11.2
Dry Matter, %	-	24.6	30.8	31.2
Dry Weight, mtons/ha	-	2.40	3.29	3.49
		3rd Harvest		
Green Weight, mtons/ha	6.99	6.88	5.64	6.27
Dry Matter, %	24.0	25.0	33.5	30.7
Dry Weight, mtons/ha	1.68	1.72	1.88	1.93
		4th Harvest		
Green Weight, mtons/ha	5.24	7.10	5.44	4.84
Dry Matter, %	27.6	26.0	33.4	29.0
Dry Weight, mtons/ha	1.46	1.84	1.81	1.41
		5th Harvest		
Green Weight, mtons/ha	3.70	4.61	3.38	4.84
Dry Matter, %	26.5	23.8	40.4	30.8
Dry Weight, mtons/ha	0.99	1.10	1.37	1.48
		Net		
Green Weight, mtons/ha	15.9	31.3	26.6	29.1
Dry Matter, %	26.0	24.5	32.9	30.3
Dry Weight, mtons/ha	4.13	7.66	8.75	8.83

TABLE A-93. NUTRIENT CONTENT OF COASTAL BERMUDAGRASS (PLOTS) - 1975

Rate	mm/week	50	100	150	200
			1st Harvest		
N		-	3.05	3.04	3.29
P		-	0.41	0.31	0.34
K		-	1.76	1.50	1.58
Ca	%	-	1.22	0.72	0.72
Mg		-	0.34	0.27	0.26
Na		-	0.258	0.092	0.068
Fe		-	0.0230	0.0155	0.0100
Zn		-	0.0048	0.0033	0.0029
			2nd Harvest		
N		-	2.45	2.27	2.50
P		-	0.31	0.33	0.34
K		-	1.45	1.95	1.68
Ca	%	-	1.04	1.02	1.16
Mg		-	0.30	0.23	0.26
Na		-	0.118	0.075	0.052
Fe		-	0.0100	0.0128	0.0122
Zn		-	0.0033	0.0031	0.0027
			3rd Harvest		
N		2.49	2.09	2.53	2.83
P		0.35	0.40	0.29	0.27
K		1.51	1.65	1.62	1.60
Ca	%	0.78	0.88	0.54	0.56
Mg		0.31	0.28	0.26	0.25
Na		0.092	0.108	0.052	0.050
Fe		0.0215	0.0130	0.0108	0.0108
Zn		0.0042	0.0041	0.0026	0.0023
			4th Harvest		
N		1.90	2.42	2.25	1.86
P		0.40	0.34	0.29	0.29
K		1.32	1.41	1.48	1.58
Ca	%	0.55	0.59	0.54	0.65
Mg		0.27	0.30	0.26	0.27
Na		0.032	0.070	0.030	0.062
Fe		0.0420	0.0125	0.0232	0.0205
Zn		0.0075	0.0029	0.0054	0.0060

(continued)

TABLE A-93. (continued)

Rate	mm/week	50	100	150	200
			5th Harvest		
N		2.39	3.11	3.00	3.50
P		0.42	0.31	0.25	0.30
K		1.26	1.32	1.10	1.41
Ca	%	0.75	0.84	0.50	0.81
Mg		0.32	0.32	0.27	0.31
Na		0.050	0.105	0.045	0.052
Fe		0.0235	0.0218	0.0180	0.0280
Zn		0.0037	0.0024	0.0017	0.0033
			Net		
N		2.28	2.49	2.48	2.68
P		0.38	0.56	0.31	0.32
K		1.39	2.24	1.61	1.60
Ca	%	0.71	0.89	0.73	0.86
Mg		0.30	0.29	0.26	0.27
Na		0.060	0.112	0.056	0.055
Fe		0.0300	0.0132	0.0153	0.0165
Zn		0.0054	0.0034	0.0033	0.0033

TABLE A-94. NUTRIENT UPTAKE BY COASTAL BERMUDAGRASS (PLOTS) - 1975

Rate	mm/week	50	100	150	200
			1st Harvest		
N		-	18	12	17
P		-	2.5	1.2	1.8
K		-	11	6.0	8.2
Ca	kg/ha	-	7.3	2.9	3.7
Mg		-	2.0	1.1	1.4
Na		-	1.55	0.37	0.35
Fe		-	0.14	0.062	0.052
Zn		-	0.029	0.013	0.015
			2nd Harvest		
N		-	59	33	35
P		-	7.4	10.9	11.9
K		-	35	64	59
Ca	kg/ha	-	25	34	40
Mg		-	7.2	7.6	9.1
Na		-	2.8	2.5	1.8
Fe		-	0.24	0.42	0.43
Zn		-	0.079	0.102	0.094
			3rd Harvest		
N		42	36	48	55
P		5.9	6.9	5.5	5.2
K		25	28	30	31
Ca	kg/ha	13	15	10	11
Mg		5.2	4.8	4.9	4.8
Na		1.5	1.9	1.0	1.0
Fe		0.36	0.22	0.20	0.21
Zn		0.071	0.071	0.049	0.044
			4th Harvest		
N		28	45	41	26
P		5.8	6.3	5.2	4.1
K		19	26	27	22
Ca	kg/ha	8.0	10.9	9.8	9.2
Mg		3.9	5.5	4.7	3.8
Na		0.47	1.29	0.54	0.87
Fe		0.61	0.23	0.42	0.29
Zn		0.11	0.05	0.10	0.08

(continued)

TABLE A-94. (continued)

Rate	mm/week	50	100	150	200
			5th Harvest		
N		24	34	41	52
P		4.2	3.4	3.4	4.4
K		12	15	15	21
Ca	kg/ha	7.4	9.2	6.9	12.0
Mg		3.2	3.5	3.7	4.6
Na		0.50	1.16	0.61	0.77
Fe		0.23	0.24	0.25	0.41
Zn		0.037	0.026	0.023	0.049
			Total		
N		94	192	175	185
P		16	27	26	27
K		56	115	142	141
Ca	kg/ha	28	67	64	76
Mg		12	23	22	24
Na		2.5	11.3	5.0	4.8
Fe		1.2	2.3	1.4	1.4
Zn		0.22	0.18	0.28	0.28

TABLE A-95. NUTRIENT RECOVERY BY COASTAL BERMUDAGRASS (PLOTS) - 1975

Rate	mm/week	50	100	150	200
			Harvested, kg/ha*		
N		155	192	175	185
P		26	27	26	27
K		95	115	142	141
Ca		48	67	64	76
Mg		20	23	22	24
Na		4.1	11.3	5.0	4.8
Fe		2.0	2.3	1.4	1.4
Zn		0.37	0.18	0.28	0.28
			Applied, kg/ha		
N		350	700	1050	1400
P		105	210	315	420
K		67	134	201	268
Ca		320	640	960	1280
Mg		110	220	330	440
Na		380	760	1140	1520
Fe		4.5	9.0	13.5	18.0
Zn		2.1	4.2	6.3	8.4
			Recovered, %		
N		44	27	17	13
P		25	13	8.3	6.4
K		140	86	71	53
Ca		15	10	6.7	5.9
Mg		18	10	6.7	5.5
Na		1.1	1.5	0.4	0.3
Fe		44	26	10	8
Zn		18	4.3	4.4	3.3

*Value at 50 mm adjusted for 1st two harvests.

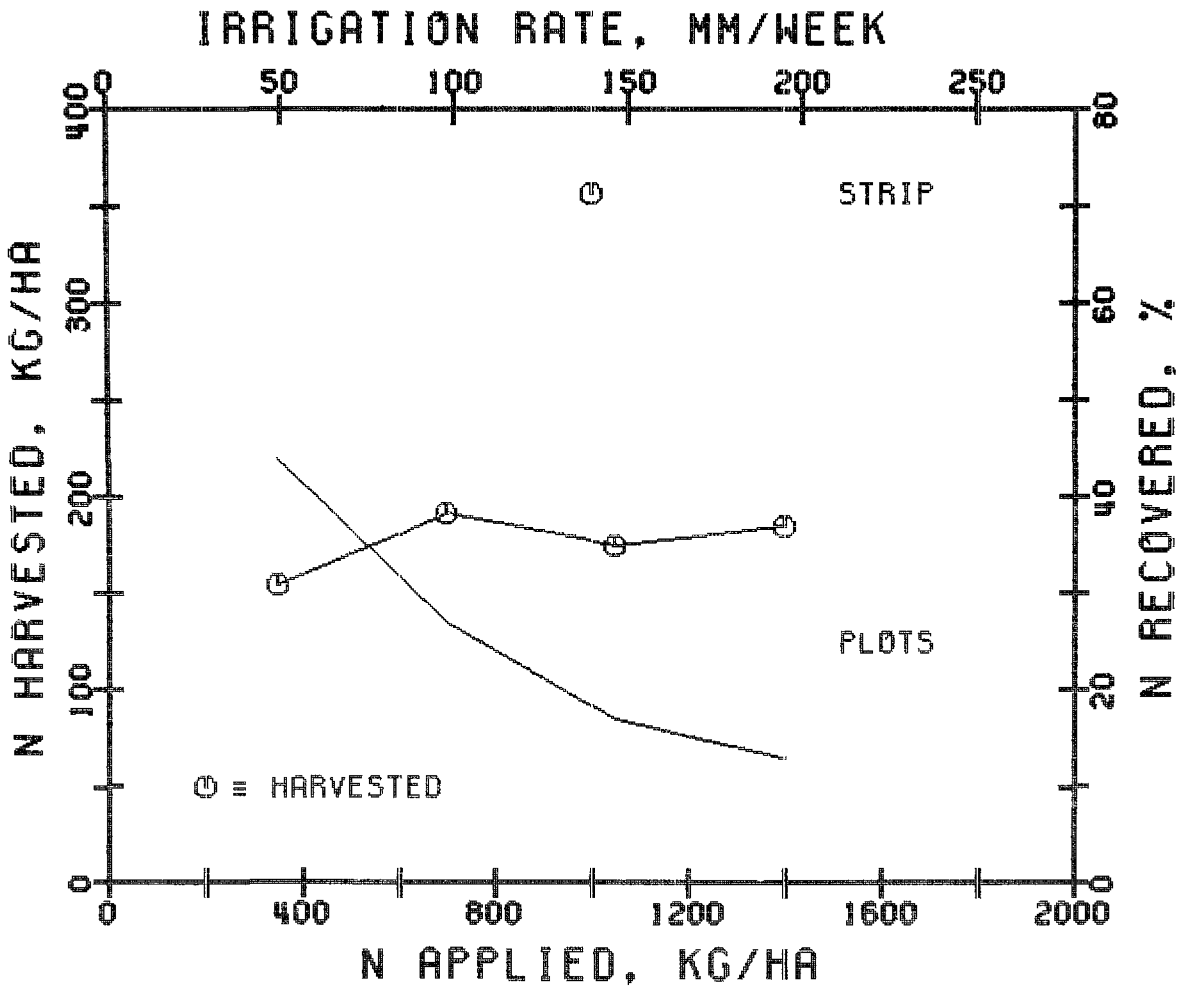

Figure A-30. Nitrogen recovery by coastal bermudagrass - 1975.

Coastal Bermuda Strip

Six cuttings were obtained. Yield of oven dried forage was 15.2 mton/ha, with an average dry matter content in the field of 28.4% (Table A-96). Nitrogen content averaged 2.36%. Nutrient uptake values for the various cuttings are given in Table A-97. Recovery efficiencies for all elements are given in Table A-98. The value for N was low due to the high application rate of 1000 kg/ha (890 lb/acre). Even at this high irrigation rate, K uptake slightly exceeded application. Other elements appeared quite adequate.

TABLE A-96. YIELD AND COMPOSITION OF COASTAL BERMUDAGRASS (STRIP) - 1975

Harvest		1	2	3	4	5	6	Net
Green Weight, mtons/ha		2.2	13.4	8.8	13.0	10.0	6.3	53.7
Dry Matter, %		28.8	27.9	27.4	28.5	27.5	31.7	28.4
Dry Weight, mtons/ha		0.63	3.71	2.42	3.72	2.76	1.99	15.2
N	%	2.49	2.49	2.58	1.83	2.80	2.12	2.36
P	%	0.32	0.35	0.33	0.30	0.30	0.31	0.32
K	%	1.54	1.56	1.53	1.24	1.27	1.31	1.39
Ca	%	0.57	0.59	0.62	0.48	0.51	0.55	0.55
Mg	%	0.25	0.28	0.30	0.28	0.29	0.30	0.29
Na	%	0.062	0.089	0.079	0.040	0.062	0.050	0.065
Fe	%	0.0190	0.0035	0.0198	0.0097	0.0149	0.0206	0.0263
Zn	%	0.0046	0.0054	0.0058	0.0046	0.0031	0.0025	0.0044

TABLE A-97. NUTRIENT UPTAKE BY COASTAL BERMUDAGRASS (STRIP) - 1975

Harvest	1	2	3	4	5	6	Total
				Harvested, kg/ha			
N	16	93	62	67	77	43	357
P	2.0	12.9	8.1	11.2	8.4	6.2	49
K	10	58	37	46	35	26	212
Ca	3.6	22	15	18	14	11	84
Mg	1.6	10.5	7.3	10.3	8.0	6.0	44
Na	0.39	3.3	1.9	1.5	1.7	1.0	9.9
Fe	0.12	2.21	0.48	0.36	0.41	0.41	4.0
Zn	0.029	0.20	0.14	0.17	0.085	0.050	0.67

TABLE A-98. NUTRIENT RECOVERY BY COASTAL BERMUDAGRASS (STRIP) - 1975

Element	Harvested kg/ha	Applied kg/ha	Recovered %
N	357	1000	35
P	49	300	16
K	212	190	110
Ca	84	910	9.2
Mg	44	310	14
Na	9.9	1090	0.91
Fe	4.0	12.5	32
Zn	0.67	5.9	11

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-79-151	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE WASTEWATER IRRIGATION AT TALLAHASSEE, FLORIDA		5. REPORT DATE August 1979 issuing date 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Allen R. Overman		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of Florida Agricultural Engineering Department Gainesville, Florida 32611		10. PROGRAM ELEMENT NO. 1BC822 11. CONTRACT/GRANT NO. S800829
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15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Municipal wastewater from the City of Tallahassee, Florida, which has received secondary treatment was used to demonstrate the effectiveness of wastewater renovation without pollution of groundwater or surface water through land application to forage crops by sprinkler irrigation. Five summer and two winter forage crops were grown with applied wastewater at rates up to 200 and 100 mm per week, respectively. Vegetation was harvested at appropriate stages of growth and evaluated for yield response, forage quality, and nutrient removal. Groundwater chemical characteristics were measured in wells located in the irrigated fields and compared with off-site control wells and the applied wastewater. Soil samples were collected from several plots at various depths through time to characterize the change in soil properties in relation to chemical processes and crop production.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Land use/water quality Sewage treatment/winter reclamation Groundwater/soil water Environmental engineering/waste disposal	Land treatment/sewage effluents Land pollution abatement Land management/crop management Wastewater spray irrigation	68D 68C 48B 48G 48E 91A

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