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A Four-Year Field Trial With Animal Manures

I. Nitrogen Balances and Yields

II. Mineralization of Nitrogen

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ABSTRACT

Data are presented for a 4-year field experiment with various rates of both dry and liquid manures, and two levels of irrigation. Yields of sudangrass and barley forages were increased at moderate rates of manures, but higher rates decreased yields. Effects of the rate of irrigation water on yields were not significant. Leaching of NO_3^- was correlated with rates of manures applied. Increased drainage volumes decreased NO_3^- concentrations of leachate only at the high rates of manures, but increased mass emissions of NO_3^- for all manure treatments. A N balance in which the sum of accumulation in the organic matter, in crop removal, and in leaching losses was subtracted from the total N input in manures and irrigation water to obtain unmeasured losses, indicated that volatilization losses were small unless large excesses of manure were applied.

The measured mineralization of the N added in dry dairy manure and in liquid feedlot manure agreed well with mineralization calculated from decay series. The relationships between forage yields and amounts of N leached as NO_3^-, and between yields and calculated rates of N mineralization, were studied. The N in the dry dairy manure, which averaged 1.6% N on a dry weight basis, was about 45% available the first year after application, whereas the N in the liquid feedlot manure, which averaged 4.5% N on a dry weight basis, was about 75% available. The problems of conducting experiments with animal manures as N sources, and the implications of calculated mineralization rates, are discussed.

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A Four-Year Field Trial With Animal Manures[1]

I. Nitrogen Balances and Yields

INTRODUCTION

LEACHING OF NO_3^- from soils that have been treated with manure has been demonstrated in a number of experiments (Bartlett and Marriott, 1971; Mathers and Stewart, 1971). In southern California, Adiano *et al.* (1971*a*, 1971*b*) found that the unsaturated zone and the top of the saturated zone contained NO_3^- as a result of the use of excessive amounts of dairy manures on croplands. Azevedo and Stout (1974) discussed the need to apply manures at rates not exceeding soil and crop capacities for removing soluble nutrients. Thus, it is well established that NO_3^- will leach from croplands that have received animal wastes. The present need is to determine the leaching losses for various rates of manure for specific cropping sequences, water managements, soils, and climates. The experiment reported here was designed to respond to this need for one cropping sequence in one climate and one soil.

Concerns for the contributions of manures to the NO_3^- and other ions in groundwaters led to the initiation of a 4-year experiment with both liquid and dry manures. The objective was to measure forage yields, leaching of NO_3^- and soluble salts, accumulation of NO_3^- in forages, removal of N and other elements in crops, and accumulation of N and other elements in soils, in relation to the rates of dry and liquid manures and the rates of water applied in a climate where double cropping is common. The accumulation of NO_3^- in barley and sudangrass forages has been reported by Pratt *et al.* (1976). The present paper deals with yields, leaching of NO_3^- below the root zone, and N balances.

The rates of manures used in the experiment reported here were dictated largely by the dairy industry in the Chino-Corona Basin, centered about 30 miles east of downtown Los Angeles. This basin has about 175,000 dairy cows in an area containing about 5,100 ha of irrigated cropland. The population of density of cows in most areas of the basin is thus likely to be 25 to 35 per ha. The lowest rate of application of dry dairy mànure was equivalent to the amount produced by about 25 cows per ha. Approximately 60% of the 4 million dry tons of manure produced annually in California is from dairies (Garrett, 1973), which provides justification for concentrating field research on dairy manure.

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METHODS AND MATERIALS

The soil on which the experiment was conducted is a Hanford sandy loam derived from granitic alluvium. The profile has a uniform sandy loam texture to a depth well below the root zone, and has good internal drainage.

The experiment consisted of six treatments with manures (Table 1), two irrigation levels, and three replications. The cropping sequence, barley (*Hordeum vulgare* 'Numar') in the winter and sudangrass (*Sorghum sudanese* 'Trudan V.') in the summer, went through four complete cycles starting in the fall of 1970.

The manures were added in two applications per year, once before the barley was planted, and again before the sudangrass was planted. The dry manure was from dairy corrals, whereas the liquid manure came from a feedlot which collects both urine and feces under slatted floors and hauls it to the field each day. Both materials were applied by equipment mounted on hauling trucks. The total weight of material for each treatment at each application date was the same. But because the water contents of materials varied among application dates, the dry weights of materials added varied from year to year.

The dry dairy manure (average 31% water) was air dried in the greenhouse before being analyzed. Assuming that this manure, as defecated by the animals, contained 3.5% total N on a dry weight basis (Loehr, 1968), at least 55% of the original N had volatilized as NH_3 during the process of accumulation in the corral. Because this manure as delivered to the plots was relatively stable, air drying was considered to have caused very little additional loss of NH_3.

The liquid manure was analyzed without drying. Samples of the material as it was delivered to the field were digested for total N determinations. The land was disced within 48 hr after applications to incorporate the liquid manure into the soil. Laboratory studies indicated that about 10% of the N could have been lost between application and incorporation.

The barley was cut for forage one or two times per crop year, and the sudangrass was cut two or three times per crop year. The sudangrass was cut when the flower heads were beginning to emerge, and the barley was harvested soon after the heads had emerged. The experimental plots were 15 by 15 m, with guard areas of the same size.

The two rates of irrigation were 1) an arbitrarily selected amount that, by experience, was considered ade-

TABLE 1

RATES OF APPLICATION OF MANURES AND N, AND DRY MATTER AND N CONTENTS OF DRY AND LIQUID MANURES

Treatment: Type of manure	Treatment: Rate* tons/ha per yr	N added* kg/ha per yr	Composition of manures*: Dry matter %	Composition of manures*: N %
Check	0	0	–	–
Dry	40	646	69.0	1.63
Dry	79	1291	69.0	1.63
Dry	158	2582	69.0	1.63
Liquid	21	963	11.1	4.52
Liquid	42	1921	11.1	4.52

* Average of 4 years. The N percent and application rates are expressed on an air-dry weight basis.

quate for optimum production, *i.e.*, a level that would meet the evapotranspiration (ET) demand; and 2) this selected level plus 33%. Amounts of water added averaged 114 and 142 cm per year for the low and high irrigation treatments, respectively. Water was added by a sprinkler system in response to tensiometer readings.

The forage sample for each harvest for each plot was a composite of six samples of the total plant cut at 5 cm above the soil surface. Data for yields and N removal in harvested crops represent the sum of those for crop plants plus weeds. The samples were dried at 65 C and ground to pass a 20-mesh screen. Total N was determined by a microkjeldahl procedure.

At the end of the 4-year treatment period, soil samples were taken from 10 locations per plot to a depth of 4.5 m. Samples were collected at 0.3-m (1-ft) intervals, and all samples from each depth were composited to provide a sample for each 0.30-m depth interval for each plot, giving a total of 15 samples per plot. This sampling procedure was estimated to give a plot mean for the NO_3^- concentration of the unsaturated zone within 20% of the true mean, as estimated from a statistical analysis of data from 10 holes from one plot, in which each sample from each hole was analyzed separately.

In addition to the samples described in the previous paragraph, samples were taken from the plow layer (0–25 cm) for analysis of total N and organic matter. In this case, 40 subsamples were composited to provide a sample for analysis. Total N in soil samples were determined by a microkjeldahl procedure, and organic matter was determined by a modified Walkeley-Black procedure (Chapman and Pratt, 1961). Bulk densities of the plowed layer were determined so that amounts of total N could be calculated.

The soil depth to 1.5 m was considered the root zone, and the 1.5- to 4.5-m depth was taken as the below-rooting depth. Soil samples collected to the 4.5-m depth were weighed, air dried, and weighed again, and the water lost was taken as an estimate of the field water content. The air-dried samples were then analyzed for soluble constituents by the saturated paste extraction technique (U.S. Salinity Laboratory Staff, 1954).

Chloride and NO_3^--N concentrations in saturation extracts were converted back to concentrations in the water in the soil at the time the samples were taken. However, in the 0- to 1.5-m depth, data for saturated extract concentrations are presented. Conversion to the field water content was considered undesirable bacause of the large variations in field water contents within the root zone. Drainage volumes were calculated by multiplying irrigation water intake times the leaching fraction, which was calculated as the ratio of Cl^-concentration in the irrigation water to the average Cl^-concentration in the water of the unsaturated zone at the 1.5- to 4.5-m depth. This ratio was assumed to be equal to the volume of the drainage water divided by the volume of the intake water. The Cl^-concentration in the irrigation water was adjusted for the Cl^-in the manures, and also for the Cl^-removed in harvested forages.

RESULTS

Total yields of dry matter for the 4 years of the experiment are presented in Table 2. For sudangrass, there was a consistent yield increase from manure applications as compared to the check, except at the highest rate of

TABLE 2

DRY MATTER YIELDS OF FORAGES ON PLOTS TREATED WITH DRY AND LIQUID MANURES AND TWO RATES OF IRRIGATION WATER. YIELDS ARE SUMS OF 4 YEARS. ALL DATA ARE METRIC TONS PER HA.

	Sudangrass				Barley			
	Dry manure		Liquid manure		Dry manure		Liquid manure	
Manure treatment	Low irrigation	High irrigation	Low irrigation	High irrigation	Low irrigation	High irrigation	Low irrigation	High irrigation
Check	30.6a*	25.3a	30.6a	25.3a	19.1a	16.8a	19.1a	16.8a
Dry 40 ton/ha	43.8b	43.3b			25.0ab	27.6b		
Dry 79 ton/ha	47.2b	46.4b			29.0b	26.6b		
Dry 158 ton/ha	31.3a	36.4a			25.6ab	23.7b		
Liquid 21 ton/ha			49.9b	48.7b			25.8a	23.3b
Liquid 42 ton/ha			43.6b	46.2b			22.2a	21.4b

* Within each column, mean yields that do not have common subscript letters differ statistically at the 0.05 probability level.

dry manure, where the yields were not statistically different. The total salt load was probably the cause of this yield decrease as compared to the two lower rates of application. Irrigation rate had no significant effect, but there was a tendency toward increased yields with the high irrigation at the highest rates of application of both manures. For barley, yield responses to the manures were not consistent, and irrigation treatments had no effect. Because barley was grown during the rainy season, which extends roughly from November to April inclusive, very little irrigation water was needed for this crop; thus, no large effect was expected.

The proportion of weeds in the total yield recorded increased with increases in rates of manures and with increases in time, so that during the fourth year, plots in treatment 4 (158 tons dry manure per ha/yr) had greater than 50% weeds. Unfortunately, no weights of weeds versus forages were taken, and thus no quantitative data for this effect can be reported.

The relationships between yields and the estimated total available N in the soil during the 4 years of the experiment, for dry and liquid manures, are presented graphically in Fig. 1. For each manure, the relationship fits a parabolic function, with a higher yield from liquid than from dry manure at given levels of available N. The decreases in yield at the highest N levels were probably the effects of salts in the soil. The greater yield decrease with dry manure is consistent with the fact that much greater amounts of dry solids were added with this material per unit of available N. The liquid manure had about 50% more salts than did the dry manure when both salt contents were expressed on a dry weight basis, but the salt added per unit of available N was

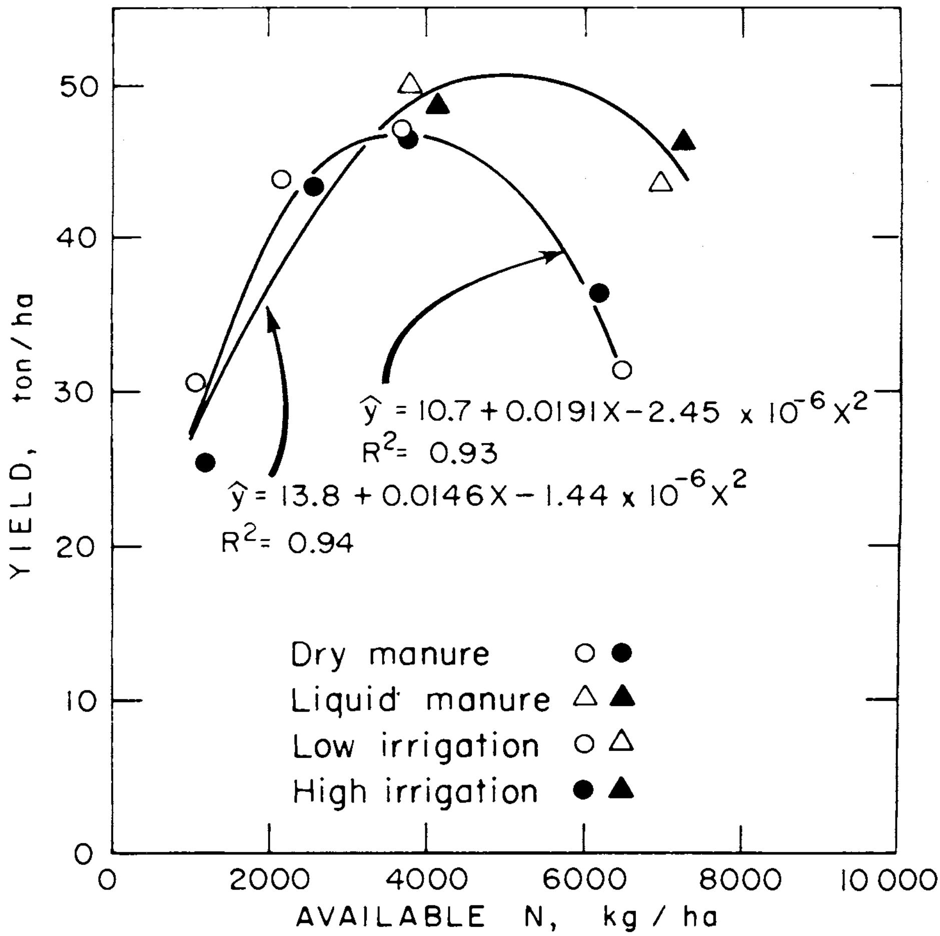

Fig. 1. Relationships between dry weight yields of sudangrass (metric tons) and estimated total available N in the soil for a 4-year period.

about 80% higher with dry manure.

The data for volumes of irrigation and drainage waters, leaching fraction, adjusted Cl^- concentration in the irrigation water, and the measured Cl^- concentration in the drainage water, are presented in Table 3. The effective Cl^- concentration of the irrigation water is taken as the total input minus crop removal divided by total volume of irrigation water. The Cl^- concentration in the drainage water is the average measured in the water of the 1.5- to 4.5-m depth.

The drainage volumes were fairly uniform for each irrigation treatment, except for the treatment with dry manure at 158 tons/ha in the high irrigation level. No explanation is offered for this low value. The Cl^- concentration in the drainage water in this treatment appears to be out of line with other data, but repeats of the analyses gave values nearly the same as the original data.

Relationships between NO_3^- concentrations and depth for the dry manure treatments are presented in Fig. 2, and

TABLE 3

VOLUME OF IRRIGATION WATER, Cl^- ADDED IN WATER AND MANURES AND REMOVED IN HARVESTED CROPS, ADJUSTED Cl^- CONCENTRATION IN THE IRRIGATION WATER, Cl^- CONCENTRATION IN THE DRAINAGE WATER, AND CALCULATED LEACHING FRACTION AND DRAINAGE VOLUME

Manure Treatment	Irrigation water used	Chloride					Leaching fraction	Drainage volume†
		Irrigation water	Manure	Crop	Irrigation water*	Drainage water		
	Surface cm		kg/ha		meq/liter			Surface cm
				Low irrigation				
Check	456	8036	0	773	4.49	16.3	0.28	128
Dry 40 ton/ha	456	8036	2433	1512	5.54	23.6	0.23	105
Dry 79 ton/ha	456	8036	4866	1633	6.97	32.6	0.21	96
Dry 158 ton/ha	456	8036	9732	1270	10.21	42.3	0.24	109
Liquid 21 ton/ha	456	8036	2122	1513	5.35	22.5	0.24	109
Liquid 42 ton/ha	456	8036	4244	1465	6.69	26.7	0.25	114
				High irrigation				
Check	568	10000	0	646	4.65	12.6	0.37	210
Dry 40 ton/ha	568	10000	2433	1378	5.49	15.8	0.35	199
Dry 79 ton/ha	568	10000	4866	1397	6.54	18.4	0.36	204
Dry 158 ton/ha	568	10000	9732	1178	9.21	38.0	0.24	136
Liquid 21 ton/ha	568	10000	2122	1464	5.29	14.6	0.36	204
Liquid 42 ton/ha	568	10000	4244	1344	6.41	18.2	0.35	199

* Total Cl^- input minus Cl^- romoved in crop divided by the volume of irrigation water used.
† Leaching fraction times volume of irrigation water used.

for the liquid manure treatments in Fig. 3. Average NO_3^- concentrations for the 1.5- to 4.5-m depths are indicated in Table 4. The manure treatments induced significant increases, but the effects of the higher irrigation level statistically decreased NO_3^- concentrations only at the highest rates.

The NO_3^--N concentrations in the unsaturated zones of the check plots were high, considering the small N inputs, which came only from the NO_3^- in the irrigation water. The NO_3^- in the soil system at the start of the experiment, and mineralization from the organic matter in the soil, must have both contributed sufficient NO_3^- for this leached N.

The relationships between the average NO_3^- concentrations in the unsaturated zones and the estimated total available N in the soil systems, are presented in Fig. 4. The relationships were highly linear; but, with so few points on each line, statistical correlation coefficients were not calculated. In these relationships, the effects of the two manures and the two water treatments are obvious. The highest drainage volume effectively diluted the NO_3^- from both manures. The higher concentrations from the dry manure at given levels of available N in the soil are not readily explainable, but they could be related to time sequences of availability of N from the two manures. The N from the liquid manure was largely available as NH_4^+ at the time of incorporation into the soil, whereas the N from the dry material would be dependent on microbiological processes which mineralize the organic N.

Data for N balances during the 4-year treatment period are presented in Table 5. The N added was the sum of that in the manure and in the irrigation water. The N accumulated in the organic matter was the total N in the 0- to 25-cm depth (the plowed layer) of soil in the treated plots minus the total N in the same depth

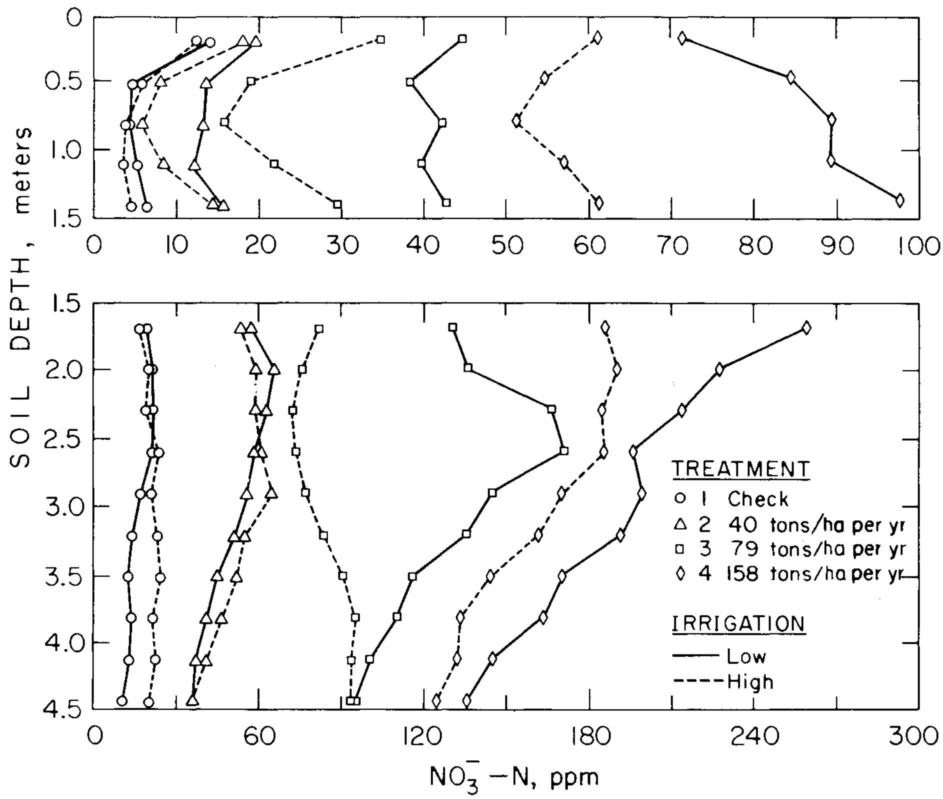

Fig. 2. Relationship between NO_3^--N concentration and depth for dry manure treatments. The concentration for the 0- to 1.5-m depth is ppm in the saturation extract, and for the 1.5- to 4.5-m depth it is ppm in the water in the field sample.

of soil in the check plots. Measured bulk densities were used in calculating the total N in the plowed layer. The main cause of differences in organic N in treated and untreated soil was assumed to be the application of manures. Effects of nonsymbiotic N fixation, and other possible factors, were considered too small to be important. Also, corrections for the amounts of NO_3^- and NH_4^+ in the soil made practically no differences in the N balance data. Data for leached N were calculated as the product of the drainage volume and the NO_3^--N concentration of the water in the 1.5- to 4.5-m depth.

The sums of removal in harvested crops plus leaching in drainage water for the check plots (no manure) were 1057 and 1142 kg N/ha, respectively, for the low and high irrigation treatments. These quantities of N are assumed to be the sums of NO_3^- added in the irrigation water, mineral N in the soil at the beginning of the treatments, and the N mineralized from soil organic matter during the experimental period. These quantities of N, plus those available from manures, are assumed to have been available in the soil in all treatments, and were added to the N mineralized from manures to obtain an estimate of the total mineral N in the soils of each treatment. These estimates were used to obtain the corrected values for losses in the last

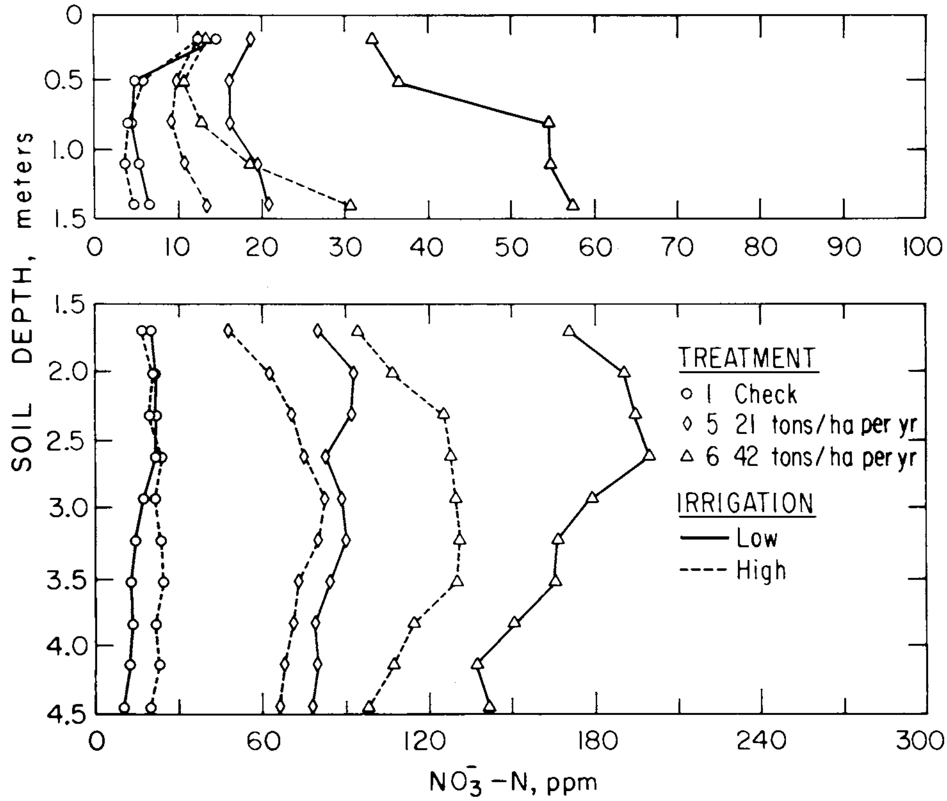

Fig. 3. Relationship between NO_3^--N concentration and depth for liquid manure treatments. The concentration in the 0- to 1.5-m depth is ppm in the saturation extract, and in the 1.5- to 4.5-m depth it is ppm in the water in the field sample.

TABLE 4

MEAN NO_3^- CONCENTRATION IN THE WATER OF THE 1.5- TO 4.5-m DEPTH

Manure treatment	Average NO_3^--N concentration: Low irrigation		High irrigation	
	mg/liter			
Check	16a*	16a	21a	21a
Dry 40 ton/ha	51b		52a	
Dry 79 ton/ha	131c		83b	
Dry 158 ton/ha	190d		161c	
Liquid 21 ton/ha		85b		70b
Liquid 42 ton/ha		170c		116c

* Within each column, mean concentrations that do not have common subscript letters differ statistically at the 0.05 probability level.

column of Table 5, and were also used in Figs. 1 and 4. These estimates also assume that the check plots lost no N by denitrification or by volatilization of NH_3.

Figure 5 presents the relationships among N removed in the harvested crops, N removed by leaching, unmeasured N losses, and estimated total available N during the 4-year experi-

TABLE 5

DATA FOR N ADDITIONS, ACCUMULATIONS, REMOVALS, AND UNMEASURED INPUTS OR LOSSES

Manure treatment	Nitrogen, kg/ha					
	Added	Accumulated in Organic matter	Removed in forage	Leached	Balance* Actual	Balance* Corrected
			Low irrigation			
Check	339	0	847	210	−718	0
Dry 40 ton/ha	2791	1336	1515	538	−598	120
Dry 79 ton/ha	5425	2459	1840	1255	−129	589
Dry 158 ton/ha	10507	4759	1400	2075	2273	2991
Liquid 21 ton/ha	4026	1012	1871	924	219	937
Liquid 42 ton/ha	7713	1483	1859	1932	2439	3157
			High irrigation			
Check	428	0	699	443	−714	0
Dry 40 ton/ha	2970	1152	1449	1041	−672	42
Dry 79 ton/ha	5512	2458	1678	1699	−323	391
Dry 158 ton/ha	10596	5184	1267	2191	1954	2668
Liquid 21 ton/ha	4115	709	1656	1418	332	1046
Liquid 42 ton/ha	7802	1281	1622	2312	2587	3301

* Nitrogen added minus the sum of accumulation in organic matter, removal in crops, and leached.

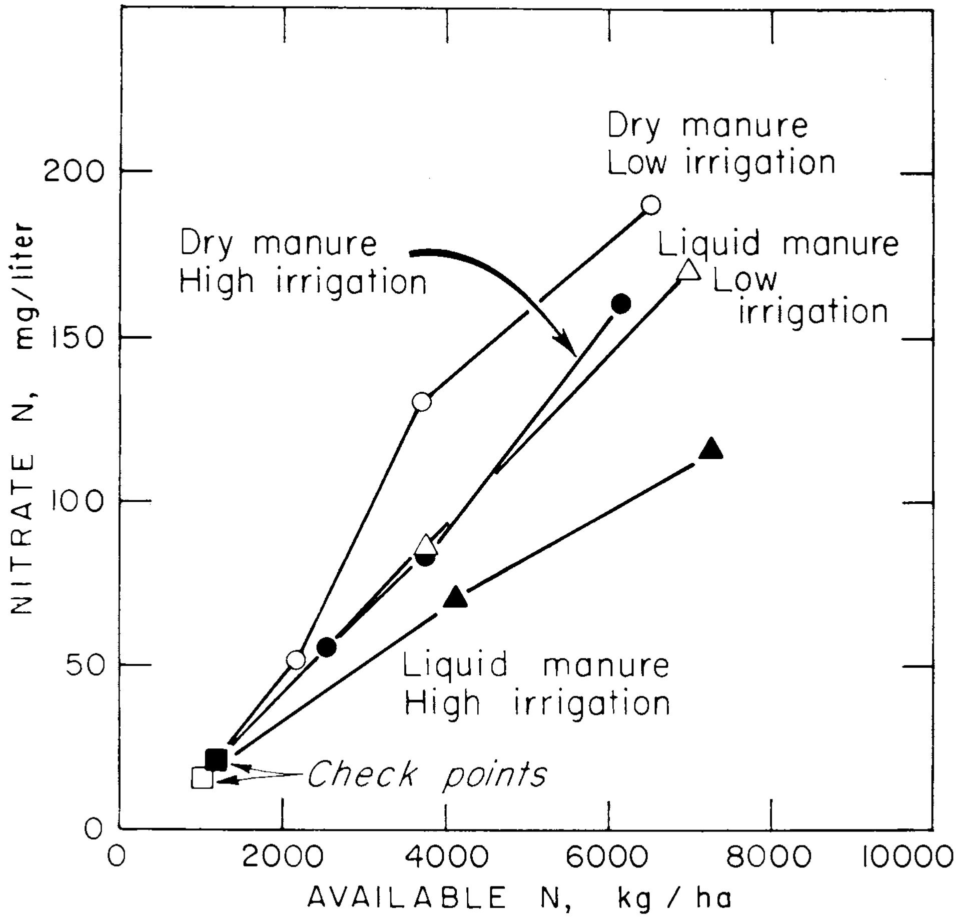

Fig. 4. Relationships between the average NO_3^--N concentration of the drainage water and the estimated available N in the soil for a 4-year period.

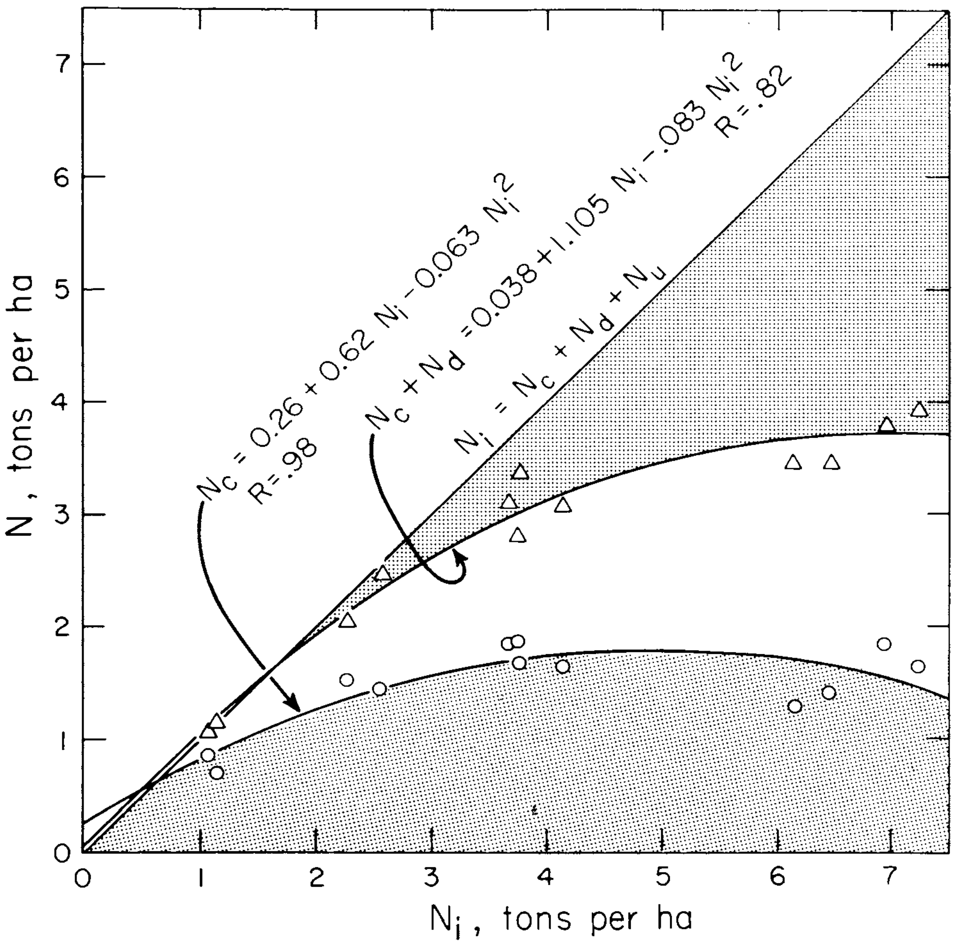

Fig. 5. Relationships of crop removal, N_c, leaching, N_d, and unmeasured losses, N_u, and the estimated total available N, N_i, in the soil system. The lower shaded area represents N removed by harvested crops, and the upper shaded area represents unmeasured N losses. The area in between represents the N removed by leaching.

mental period. The assumption that there were no losses due to denitrification or NH_3 volatilization in the check plots is involved in these relationships. This assumption is realistic considering the pressure that was placed on the available N by crops that were moderately N deficient, and the excellent drainage characteristics of the soil.

DISCUSSION

The NO_3^- and Cl^- concentrations in the drainage water, which are the concentrations of these ions in the water in the 1.5- to 4.5-m depth, seem to be related to the treatments imposed. However, one might question whether the water and salt in this depth at the beginning of the experiment were completely replaced by drainage water which left the root zone during the experiment, or whether salts and drainage from the experimental period had drained beyond the depth of sampling. To check these questions, the simple relationship $T = S\Theta/D$, in which T is transit time in years, S is soil depth in cm, Θ is the volumetric water content in the soil, and D is the drainage volume in surface cm per yr, was used (Pratt *et al.,* 1972). The average water content of the unsaturated zone in this soil was 10% of the dry weight of the soil, and was fairly uniform across the field. Assuming a bulk density of 1.8, Θ is 0.18. Using this value, and a drainage volume of 100 cm to represent the low irrigation level, transit time to the 4.5-m depth is 3.2 yr. For the higher irrigation level, transit time for 200 cm of drainage water is 1.6 yr. The lowest drainage value measured gives a calculated transit time of 3.4 yr. Thus, for the lower irrigation level, all of the residual salt was probably leached below the 4.5-m depth; and in the higher water treatment, the 1.5- to 4.5-m depth contained the drainage water from the last 2 yr of the experiment. Even allowing for some variability in transit time, the experiment probably was conducted sufficiently long to avoid complications due to the time factor. But, for a highly rigorous comparison of the two irrigation treatments, the plots of the lower irrigation should have been sampled to 4.5 m and those of the higher irrigation to a depth of 9 m, to correspond to transit times of about 3.2 yr in both cases.

The average NO_3^--N concentration in the 3- to 6-m depth in the Chino-Corona dairy area was about 70 mg/liter in the drainage water (Adriano *et al.,* 1971*a*). In the experiment reported here, such a concentration would correspond to 45 to 50 metric tons of dry manure per ha per yr, or the equivalent of about 25 to 28 cows per ha. The estimated cow-to-disposal-area ratio in the Chino-Corona basin is 25 to 30 cows/ha, a fairly close agreement. Also, the estimate of drainage volume used by Adriano *et al.* (1971*a*) to approximate the amount of leached NO_3^--N was 37.5 surface cm per year, or 150 surface cm in 4 yr, which is in good agreement with the average drainage volume reported here. However, Adriano *et al.* (1971*a*) estimated that manure at a rate of 13.5 tons per ha/yr or less, would result in drainage water having less than 10 mg NO_3^--N per liter, assuming relatively high production of crops. In contrast, extrapolation of our data to this rate would result in the water having about 30 ppm NO_3^--N.

The sources of the average of 716 kg/ha unmeasured inputs of available N into the check plots of this experiment are subject to speculation. The steady rates of removal of N by crops and by leaching throughout the 4 yr of the experiment indicate that most of this N came from inputs that were reasonably constant, such as mineralization of the organic matter. If we assume a 4% mineralization per yr from the soil, the total mineralized in this case would be about 416 kg/ha in 4 yr. The surface 25 cm has about 2600 kg organic N per ha. Perhaps 100 to 200 kg N/ha could have mineralized from organic N in the lower horizons. Some mineral N could have been available at the start of the experiment; and the possibility exists that some available N could have come from the atmosphere via absorption of NH_3 through the leaves, or from rainfall. We have no recent data for rainfall contributions, but an earlier report by Pratt and Chapman (1961) indicated that only 1 or 2 kg N per ha/yr were contributed by rainfall, leaving some doubt as to rainfall being an important source of unmeasured inputs. In view of recent evidence by Porter *et al.* (1972) and Hutchinson *et al.* (1972) that plants can and do absorb NH_3 from the atmosphere, one is tempted to speculate that some of the unmeasured N came from this source. But we have no evidence to support this speculation other than the facts that the experimental field is located about 25 miles from an area with an extremely high concentration of dairy cattle, and that the atmosphere near the dairies is relatively high in NH_3 (Luebs *et al.*, 1973).

In interpreting the data in this report, one must consider that the soil is open and porous, with no restricting layers or textural discontinuities. This explains the lack of significant denitrification losses (unmeasured losses) until large excesses of NO_3^- and organic matter were present. The data indicate that the high organic loading was more important than water management in creating the oxygen deficient conditions conducive to denitrification. This is particularly illustrated by the small effect of irrigation level on unmeasured N losses.

The drainage waters from each of the various treatments in this field trial had relatively uniform NO_3^- concentrations. That is, the NO_3^- concentration as a function of depth below the 1.5-m level, which is analogous to time, was relatively uniform. There were no high concentrations followed by low concentrations, indicating a major leaching event that would flush out most of the NO_3^- in a leaching front, followed by increments of drainage water of decreasing concentrations. Thus, the drainage must have taken place in a number of small events, each following a rain or irrigation, so that each event accumulated about the same NO_3^- concentration as previous and following events. This may indicate that drainage frequently followed the irrigations during the April to November irrigation seasons.

An alternate explanation for the lack of variation in the NO_3^- concentration with depth is that peaks and lows in concentration were at different depths in different areas of the plots. Thus, compositing 10 soil samples from each depth to obtain the sample that was analyzed masked the natural variability with depth. However, samples from 10 holes in each plot for which samples were analyzed separately for each depth in each hole had the same uniformity in NO_3^- concentrations as did the composited samples. Thus, this explanation does not seem valid.

The NO_3^- concentration in the unsaturated zone and the amount of NO_3^- leached, were linearly related to available N in the soil and also to the amounts of dry or liquid manure added. This means that leaching did not proportionately increase as crop removal, expressed as a fraction of the total available N, decreased at the highest rates of application of manures. The unmeasured N losses increased proportionately as the proportionate removal by crops decreased. Thus, the high organic loading favoring denitrification adds a buffering factor on leaching of NO_3^- from high rates of application of organic materials. But, in this soil, and perhaps in most well-aerated, uniformly sandy loam soils, this buffering is not sufficient to prevent large leaching losses and high concentrations of NO_3^- in drainage waters from excess applications of manures.

The concentrations of NO_3^- in drainage waters were nearly the same with both irrigation treatments for the plots that received no manures and also for the plots treated with dry manure at 40 tons per ha/yr. Within the range of 16 to 52 mg NO_3^- per liter, the NO_3^- concentration was independent of drainage volume, even though this volume for the high irrigation treatment was about double that for the low treatment. In other words, the concentration of NO_3^- did not decrease in proportion to increases in the drainage volume.

The range of concentrations of NO_3^- in which the concentrations were independent of drainage volume, is typical of concentrations in the dairy area of the Chino-Corona basin (Adriano *et al.*, 1971*a*) where dairy manures are used on croplands and pastures. This range of concentrations is probably also typical of NO_3^- concentrations in most drainage waters from irrigated lands that have received N fertilizers (Pratt and Adriano, 1973).

If this strong tendency for the NO_3^- concentration in drainage waters to be constant, as found in this experiment, is a general phenomenon for any given cropping system and rate of N in manures, fertilizers, or both, the savings in available N in the soil is proportional to the reduction in leaching. The converse statement is that leaching losses are directly proportional to the drainage volumes. Perhaps these two suggested generalities should be restricted to sources of N that become available slowly during the year, and not to immediately available forms such as nitrate salts, for which the N would all be available for leaching soon after it enters the soil system.

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