Leaching and Uptake of Nitrogen Applied to Annual Grass and Clover-Grass Mixtures in Lysimeters[1]

M. B. Jones, J. E. Street, and W. A. Williams[2]

ABSTRACT

The annual grassland soils of California are nearly always N deficient. If early winter feed is desired and total production is to be increased, N must be added, either by a legume or through N fertilization. Comparison of these two N sources in terms of forage and protein production and groundwater pollution is important for efficient management of land, water, and N resources.

This study was initiated to measure the effect of N fertilization on forage yields, N-uptake by the plants, and N leached from the soil where grass grew alone or from clover-grass mixtures.

Grass (soft chess, *Bromus mollis* L.) growing alone, grass plus subclover (*Trifolium subterraneum* L.), and grass plus rose clover (*T. hirtum* All.) were grown in lysimeters on Josephine soil with and without N applied in the autumn of each of 4 years.

Nitrogen fertilization increased winter forage yields and N-uptake in all species mixtures. However, in the spring harvest, clover-grass mixtures yielded as much forage and N-uptake without N as with N applied. Apparent recovery of the applied N in the forage was 25% for the grass, −2% for the subclover-grass, and 0% for the rose clover-grass. The amount of apparent fertilizer N found in drainage water was 37% from grass, 58% from subclover-grass, and 50% under rose clover-grass. Without N fertilization the N leached was about the same from clover-grass as from grass alone. Of total N leached, 94% was in the fall, 6% in winter, and less than 1% in spring, whereas the total drainage water was divided 43% in the fall, 54% in winter, and 3% in spring. With N fertilization, NO_3-N in the water in the fall was 45 ppm from clover-grass and 38 ppm from grass. Without applied N, the NO_3-N values were 25 ppm in the fall and were 1/10 as great in winter and about 1/100 in spring. There was no rain in the summer.

***Additional index words:* *Bromus mollis* L., *Trifolium subterraneum* L., *Trifolium hirtum* All., N fertilization, Nitrate nitrogen.**

THE annual grasslands of California are usually very deficient in nitrogen. Extensive research (Martin and Berry, 1970) on fertilization of California annual grasslands has indicated that nitrogenous materials are most profitable in the rainfall zone of 30 to 75 cm. It has been hypothesized that where rainfall exceeds 75 cm much of the N is lost by leaching. Nevertheless, significant amounts of N are being applied in the wetter areas of the state because yields during winter are often doubled or tripled (Jones, 1967) and because it is easier to apply nitrogen than to establish legumes. Occasionally we also see N applied to good stands of legumes in order to increase production of winter forage.

Nitrogen fertilization has recently received attention as a source of groundwater pollution, though no study of this type has been reported for the annual grasslands of California. Since N fertilization has a large potential for increasing forage production on unirrigated grasslands, its effects on groundwater should be considered.

This study was done to measure the effect of N applied to grass and grass-clover mixtures on N leached into the drainage water, N-uptake by the crop, and forage production.

MATERIALS AND METHODS

The lysimeters consisted of galvanized cans 559 cm deep and 49.6 cm in diameter, painted inside and out with black rustoleum. Each can was fitted with a drainpipe in the center of the bottom and with an overflow pipe. The cans were filled with Josephine soil; subgroup, typic haplozerults, family, fine loamy, mixed, mesic (Soil Survey Staff, 1972). The clay mineral composition of the soil was 30% kaolinite, 50% vermiculite, and

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[2] Agronomist, University of California, Hopland Field Station, Hopland; Extension Range Technologist; and Professor of Agronomy and Range Science, University of California, Davis.

Table 1. Four-year mean forage yields and percent clover as affected by N fertilization of different species combinations.

Species	N applied annually	Clover	Jan	Feb	Mar	Apr	May	Total
			Months of growing season					
	kg/ha	%	Yield, kg/ha					
Soft chess	0	0	100a*	40a	300a	510a	2,280a	3,230a
	112	0	400d	120c	690c	530a	2,270a	4,010b
Subclover + soft chess	0	70	250b	'90bc	950e	980b	4,750e	7,020d
	112	35	330c	230d	1,180f	910b	4,090d	6,740d
Rose clover + soft chess	0	40	90a	50ab	520b	1,000b	3,440c	5,100c
	112	25	250b	120c	790d	960b	3,180b	5,300c

* Means in a given column followed by the same letter are not significantly different at the 5% level.

Table 2. Four-year mean N-uptake as affected by N fertilization.

Species	N applied annually	Jan	Feb	Mar	Apr	May
		Months of growing season				
	kg/ha	N uptake, kg/ha				
Soft chess	0	4a*	1a	8a	9a	28a
	112	13c	8c	19b	9a	29a
Subclover + soft chess	0	11bc	4b	35d	31d	99e
	112	16d	11d	42e	26c	83d
Rose clover + soft chess	0	4a	2ab	17b	23bc	65c
	112	9b	8c	24c	21b	50b

* Means in a given column followed by the same letter are not significantly different at the 5% level.

3% montmorillonite (Begg, 1968). The cation-exchange capacity was 12.0 meq/100 g, pH was 6.0, and base saturation was 66%. Various cations were present as follows: Ca, 5.9; Mg, 1.2; Na, 0.1; and K, 0.7 meq/100 g soil. The surface 15 cm had 0.14% total N, and the 15 to 45 cm depth had 0.09% N.

The soil was removed from the field in two layers, 0 to 30.5 cm and 30.5 to 61 cm, screened, placed in the lysimeter in two layers, and soaked with deionized water to promote settling before adding more soil to bring the soil level to within 2.5 cm of the top. The soil surface was 1 cm from the bottom of the overflow pipe. The same lysimeters were used in a previous experiment (Jones, Martin, and Williams, 1968).

The 12 treatments included 2 N levels (zero and 112 kg N/ha applied as urea annually in October for 4 years) on 2 clipping treatments. In one treatment, forage was clipped back every other time that the first treatment was clipped. The plant combinations were soft chess (*Bromus mollis* L. var. 'Blando brome') only, subclover (*Trifolium subterraneum* L. var. 'Dinninup') with soft chess, and rose clover (*T. hirtum* All. var. 'Hykon') with soft chess. Each treatment was replicated three times. In October of the first year subclover and rose clover seeds were pellet-inoculated (Holland, Street, and Williams, 1969) and sown at 56 kg/ha. The grass was sown at 112 kg/ha. All tanks were fertilized with treble superphosphate at 123 kg P/ha and with 56 kg elemental S/ha.

Forage was clipped with a reel type power mower except for a sample quadrat 15 cm on a side, which was hand-clipped from one replication on each sampling date to determine leaf areas of grass and clover. Final harvest was also made by hand, though at ground level. All forage samples were oven-dried at 70 C, weighed, and ground in a Wiley mill. Nitrogen in the forage was determined by Kjeldahl procedure.

Drainage water was combined to represent three periods: from the first fall rain to January 1, from January 1 to March 1, and from March 1 until the spring rains stopped. Nitrate nitrogen in the water was determined for each period (Johnson and Ulrich, 1959). Surface runoff water (also collected and analyzed) made no significant contribution in the total N balance sheet, and thus is not reported.

RESULTS

Forage Production. Forage production by soft chess without N was typical of that of many California annual grasslands, i.e., very low in winter, with a flush of growth in the spring (Table 1). Consequently, fall application of 112 kg N/ha resulted in four times as much forage in January, although by April or May there was no additional increase.

Subclover percentage of the forage leaf area when planted with soft chess was 35% in N-fertilized treatments and 70% in unfertilized. The unfertilized subclover-grass mixture produced more than double the forage produced by unfertilized grass alone throughout the season. The unfertilized subclover-soft chess produced less forage than fertilized grass alone during winter, but produced more than twice as much during spring. Nitrogen increased forage production of subclover-grass in winter but decreased production in spring.

Rose clover percentage of the forage leaf area when planted with soft chess was 25% in N-fertilized treatments and 40% in unfertilized. Without N, rose clover-grass did not produce significantly more in winter than grass alone, but produced substantially more in spring. Nitrogen more than doubled rose clover-grass yields in winter, but yields were greatest in spring with no N.

Yields differed significantly between years, but the basic response patterns for the legume-grass-N treatments remained essentially the same.

Percentage N in Forage. Respective N concentrations in December without and with added N were: 5.00 and 5.88% for soft chess, 5.54 and 6.31% for the subclover-grass mixture, and 5.07 and 5.93% for the rose clover mixture. The L.S.D. (.05) in December was 0.13. Nitrogen percentages decreased in all forages from December to May, when they were 1.28 and 1.28% for soft chess, 2.03 and 1.97% for subclover-soft chess, and 1.85 and 1.57% for rose clover-soft chess. The L.S.D. (.05) in May was 0.09.

Nitrogen Uptake. Fertilization increased N-uptake by soft chess in winter but not in spring (Table 2). The much larger amounts taken up in May than in April reflected the May clipping at ground level rather than at 2.5 cm. Applied N increased N-uptake by subclover-grass in winter but decreased it in spring. Nitrogen uptake by rose clover-grass was similar to that by grass alone in winter, but N applications decreased uptake in spring.

Nitrogen uptake differed significantly in different years but the pattern was essentially the same.

Concentration of NO_3-N in Drainage Water. In all treatments the concentrations of NO_3-N in lysimeter drainage water were highest in November-December (Table 3). The values dropped sharply in January-February and again in March-April. Neither rose nor subclover growing with grass increased NO_3-N in the water above the levels from grass alone. Applied N increased NO_3-N in the drainage water in all treatments, but the increases were substantially greater with the clover-grass treatments than with grass alone.

Nitrate nitrogen concentrations in November-December drainage water differed significantly between

Table 3. Concentration of NO_3-N in lysimeter drainage water as affected by N fertilization, sampling period, and plant species.

Species	N applied annually	Nov-Dec	Jan-Feb	Mar-Apr
		Sampling period		
	kg/ha	ppm NO_3-N		
Soft chess	0	24a*	2.3a	0.2a
	112	38b	4.5b	0.5b
Subclover + soft chess	0	25a	2.3a	0.2a
	112	46c	6.7c	0.3ab
Rose clover + soft chess	0	25a	2.5a	0.2a
	112	44c	6.2c	0.4ab

* Means in a given column followed by the same letter are not significantly different at the 5% level.

Table 4. Effect of species and N fertilization on amounts of N leached from lysimeters.

Species	N applied annually	Sampling periods		
		Nov-Dec	Jan-Feb	Mar-Apr
	kg/ha	kg N/ha leached		
Soft chess	0	60a*	3a	< 1a
	112	99b	5a	< 1a
Soft chess + subclover	0	66a	4a	< 1a
	112	124c	11c	< 1a
Soft chess + rose clover	0	65a	3a	< 1a
	112	116c	8b	< 1a

* Means in a given column followed by the same letter are not significantly different at the 5% level.

years, being lowest in the first year and about equal in the other years. In that first year values were relatively higher from clover than from grass alone and from applied N than from no N. Nitrate nitrogen values in January-February also differed between years, increasing each year in all treatments. Nitrate nitrogen levels in spring did not differ significantly between years.

Total N Leached. Of the N leached, 94% was in November and December, 6% in January and February, and less than 0.1% in the spring. Leaching was not proportional to the volume of drainage water (43, 54, and 3% of the drainage came in the three periods, respectively, with the total averaging 640 mm/year). Average annual rainfall over the four growing seasons was 838 mm, with 42, 51, and 7% in the three sampling periods.

Without applied N, the N leached was about the same from grass as from clover with grass. With N applied clover-grass lost more N, however, than grass did. For example, applications of N doubled the amount of N leached from clover-grass but only increased the amount of N leached from grass by about one-third (Table 4).

Nitrogen leaching was significantly greater in the fourth year than in the first, with the second and third years intermediate. Relative to grass, more N leached from the subclover treatment in the first year than in the fourth.

DISCUSSION AND CONCLUSIONS

Table 5 gives the 4-year average amounts of N taken up and leached. Since we estimated that rainfall contributed only 1.3 kg N/ha per year, the 50 kg/ha uptake and 63 kg/ha leached from unfertilized grass appear rather high. Steyn and Delwiche (1970) reported nonsymbiotic N fixation rates from 2 to 4 kg N/ha on unirrigated California soils. The concentration of NO_3-N in drainage water from the unfertilized grass is also high compared with unpublished NO_3-N values in a stream from a nearby watershed with some soils of similar type. Perhaps soils in lysimeters were releasing organic N at an accelerated rate for the 4-year period. Our values are similar to data from other lysimeter experiments; Chapman, Liebig, and Rayner (1949) reported gains of 45 kg N/ha per year, and Smith (1944) found 274 kg N in lysimeter studies under nonlegumes.

Table 5. Summary of mean N-uptake and N leached per year as affected by N fertilization and species.

	Soft chess		Subclover + soft chess		Rose clover + soft chess	
	kg N/ha					
N applied annually	0	112	0	112	0	112
N uptake	50a*	78b	180d	178d	111c	112c
Apparent applied N taken up†		28		- 2		1
N leached	63a	104b	70a	135d	68a	124c
Apparent applied N leached†		41		65		56

* Means in a given line are not significantly different (5% level) from each other if followed by the same letter. † Increases due to N fertilization.

Annual application of 112 kg N/ha to grass increased N-uptake 28 kg (efficiency 25%). In April and May 1% was taken up and in January, February, and March, 24%. Applying N to clover-grass did not increase total N-uptake. However, the apparent respective N efficiencies of subclover-grass and rose clover-grass were 16 and 15% for January-February-March. With applied N, N-uptake decreased in April and May because of a reduction in clover stand, giving a total seasonal effect of no significant change in N-uptake due to applied N. Leaching of applied N was apparently 37% in grass, 58% in subclover-grass, and 50% in rose clover-grass. Hence, it would be better to apply N to grass than to pastures with good clover stands to reduce N contributions to groundwater supplies.

Of applied N, 38 to 50% remained unaccounted for at the end of the study. Part was probably lost by denitrification during the wet winter, and some probably remained in the soil, fixed in undecomposed roots and organic matter. The differences involved were too small to measure by Kjeldahl procedures. The NO_3-N levels in drainage water in the spring were so low that probably very little NO_3-N remained in the soil.

Jones (1967) previously reported that N fertilization increased winter forage production even on good clover and that N decreased spring production and protein levels. The present data, however, are the first indicating that the clovers contributed virtually no N to groundwater and that substantially more applied N was leached from clover than from grass.

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