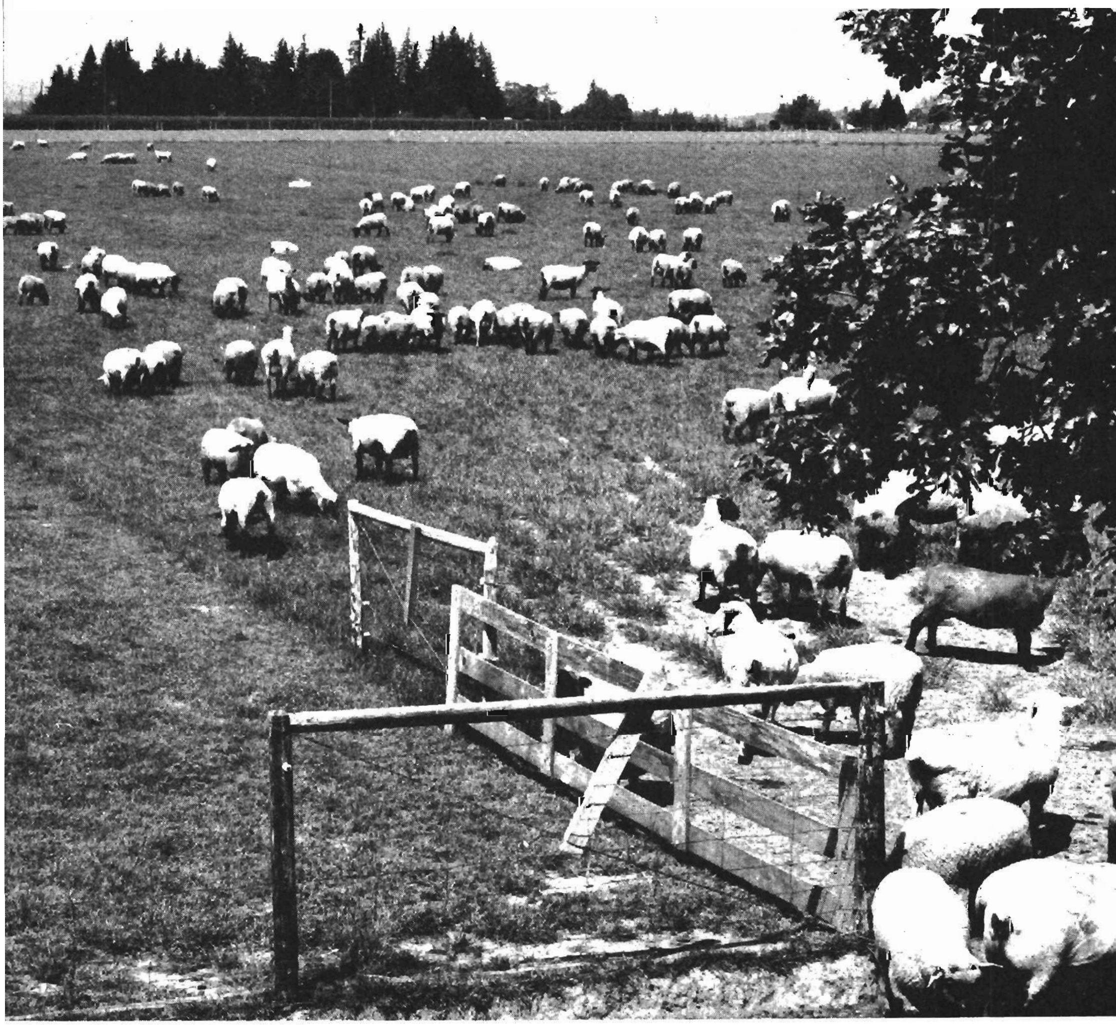
Recycling Nitrogen and Sulfur in Grass-Clover Pastures



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Recycling Nitrogen and Sulfur in Grass-Clover Pastures

M. D. Dawson and W. S. McGuire

Abstract

Improved grass-clover pastures utilized under high stocking systems epitomize conservation management at its best. Under intensive grazing and in spite of nitrogen (N) or sulfur (S) losses through leaching, volatilization, or sales of meat and wool from the farm, good management permits symbiotic fixation of nitrogen and recycling of N and S in amounts needed for top production. In the comparisons of management practices involving unimproved indigenous grasses with (1) fertilized grass-clover cut for hay and (2) fertilized grass-clover intensively grazed, this bulletin reviews certain features of soil-plant-animal interrelationships as they influence soil nitrogen and sulfur cycles.

Introduction

Many acres of western Oregon land not ideally suited to cultivation can produce much meat and wool by way of intensively grazed pastures. High stocking rates on these improved grass-clover pastures are a means by which man can economically provide good quality, high protein livestock feed. But quality forage requires considerable nitrogen, phosphorous, and sulfate in balance. Few crops have a higher demand for these nutrients than a vigorously growing grass-clover pasture.

It is of considerable economic and environmental interest to examine the cyclical changes of the comparatively mobile nutrients—nitrogen and sulfur—under variously managed pastures. Indeed, the soil-plant-animal chain is a fascinating intra-system where the nitrogen and sulfur cycles have practical significance.

The management practices compared are (1) unimproved, indigenous grasses, (2) fertilized grass-clover cut for hay, and (3) fertilized grass-clover intensively grazed. The purpose of this bulletin is to review certain features of soil-plant-animal interrelationships as they influence soil nitrogen and sulfur cycles under different management practices in grass-clover pastures.

The Nitrogen Cycle

In western Oregon, annual yields of 6,000 pounds and 12,000 pounds of dry matter per acre are common on subterranean clover and irrigated grass-white clover pastures, respectively. The 6,000 pounds of dry matter from healthy subterranean clover pasture should contain about 3 percent nitrogen. At least 180 pounds nitrogen per acre would be needed to produce this 6,000 pounds of dry matter. Twice this amount of nitrogen would be needed to produce the 12,000 pounds of dry matter on irrigated grass-white clover pasture.

The average total soil nitrogen content under normal pastures (Table 1)

Table 1. Average percentage total soil nutrients[1]

Nutrient	Percent
Total nitrogen	0.24
Total sulfur	0.02
Total organic phosphorus	0.03

[1] From 12 Oregon grass-clover pastures.

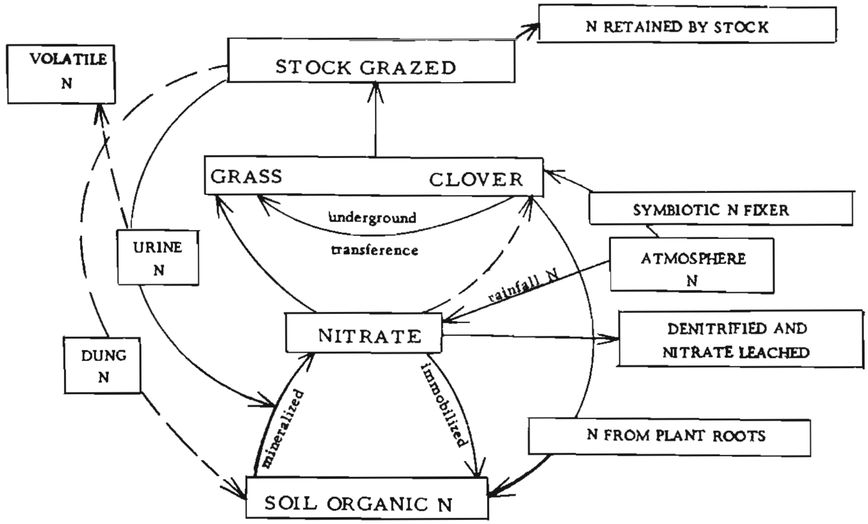

Figure 1. The nitrogen cycle on grazed grass-clover pasture. Adapted from T. W. Walker (*12*).

is low, about 0.20 percent. In an acre furrow slice of soil (2 x 10^6 lbs.) that would amount to 4,000 pounds of nitrogen, but most of this is bound in the soil in complex organic forms. Grasses and clover obtain some of this soil-bound nitrogen as nitrate or ammonium after the decay and mineralization of soil organic matter. However, there is evidence that only about 1.25 percent (*11*)[1] of the total soil nitrogen complex in grass-clover pastures is mineralized to plant-available forms annually. This would mean at best 50 pounds of nitrogen could be mineralized from 4,000 pounds in an acre furrow slice annually, or a total deficit of 130 pounds (180-50) of plant-available nitrogen per acre.

Figure 1, adapted from Walker's nitrogen cycle model (*12*), shows the nitrate mineralized from decaying soil organic matter is subject to uptake by the pasture, mainly by the grass component. Also evident is an arrow indicating symbiotic fixation of atmospheric nitrogen by the rhizobia living in nodulated roots of the clover plants. Numerous workers have tried to measure the amounts of nitrogen fixed by clovers annually. Estimated net additions vary from nil (where the hay is removed) to 10 pounds nitrogen per acre (where the legume is sparse) to 100 up to more than 400 pounds nitrogen per acre (where effective legume is plentiful). The amount depends on such factors as species of legume, a proven effective rhizobia strain, and a host of environmental conditions (*10*).

The amount of nitrogen fixed and available, either for companion grass by underground transference from clover roots or for the clover plant itself, depends on effective nodulation which is only possible with proven effective rhizobium strains (Table 2). There is evidence that "native" strains of rhizobia are in many cases only partially effective in N fixation for clovers grown in Oregon.

For subterranean clover, an average of 150 pounds nitrogen per acre is fixed symbiotically per year. That is more than enough to make up the 130-pound deficit of nitrogen previously noted, except that, firstly, much

[1] Numbers in parentheses refer to Literature Cited, page 12.

Table 2. Effect of inoculation with a proven rhizobium strain on New Zealand white clover

Inoculated		Uninoculated	
Avg. yield (dry matter)	Avg. plant N	Avg. yield (dry matter)	Avg. plant N
lbs./A	%	*lbs./A*	%
11,574	3.17	7,903	2.18

of this fixed nitrogen is not immediately available to the companion grass and, secondly, soil conditions often preclude the clover's ability to fix nitrogen efficiently. Ineffectively nodulated plants, due often to poor sowing techniques, produce clover which is low in plant nitrogen (Table 3). Data in Table 3 indicate that conventional inoculation was often ineffective. To insure effective nodulation with the applied strain, it was necessary to plant seeds with a lime-superphosphate mixture.

Once established, a legume must be supplied with adequate phosphorus, sulfur, molybdenum, and possibly other nutrients to insure optimum symbiotic nitrogen fixation. Table 4 data illustrate the effect of applied sulfur and molybdenum on clover yield and reflect the role these nutrients have upon the symbiotic nitrogen fixation efficiency. Such responses have been observed frequently in Oregon. Where grasses and clovers are growing together, grasses utilize almost all the mineral N available (*11*).

Recent research shows that soil moisture stress may be as much a limiting factor on the ability of clover to symbiotically fix atmospheric nitrogen as are deficiencies in plant nutrients. Kuo (*6*) found that nitrogen fixation by a legume is reduced as the soil dries out (Table 5). Together with leaching losses of nitrates during winter and volatile losses of nitrogen from the soil, such less-than-optimum conditions for nitrogen fixation increase the practical difficulties of obtaining sufficient nitrogen for the yield of 6,000 pounds dry matter per acre in a grass-clover pasture.

An ideal way to restore balance to the nitrogen cycle (Figure 1) is to use

Table 3. Percent effective nodulation of subclover and plant nitrogen content

Treatment	Percent effective nodulation four weeks after planting: Polk Co.	Washington Co.	Coos Co.	Average plant nitrogen
	%	%	%	%
Uninoculated	14	2	3	1.29
Inoculated	14	2	44	......
Inoculated and "lime-super mix"[1]	72	96	79	3.54

[1] Equal mixture of 20 percent superphosphate and lime.

Table 4. Mean subterranean clover yields and nitrogen content as influenced by applied sulfur and molybdenum

Treatment	Dry matter	Clover nitrogen	Total plant nitrogen
	lbs./A	%	*lbs./A*
P	3,420	2.06	70
PS	5,220	2.78	145
PSMo	5,982	3.17	190

Table 5. **Rates of nitrogen fixation in a legume as influenced by moisture stress at 50 degrees F**[1]

Soil water stress (bars)	Soil status	Nitrogen fixation (mg of N per day)
0.35	Field capacity	0.76
1.50	Moist	0.30
2.50	Moderately dry	0.23

[1] From unpublished M.S. thesis by T. Kuo (*6*).

Table 6. **Nitrogen uptake from grass and grass-plus-clover pastures**[1]

Management	Grass alone	Grass-clover pasture		
		Grass N	Clover N	Total
	lbs./A	*lbs./A*	*lbs./A*	*lbs./A*
Hay crop taken	50	188	346	534
Grazed	75	379	271	650

[1] J. Melville and P. D. Sears, (*7*).

the grazing animal. The data in Table 6 (taken from New Zealand) illustrate the role of the grazing animal in the nitrogen cycle. Where a hay crop is taken, underground transference of nitrogen from clover has provided grass in association with clover with 138 pounds more nitrogen per acre than an all-grass pasture. This was a small effect compared with the grazed grass-clover pasture, where the grass uptake of nitrogen amounted to 379 pounds per acre.

A greater proportion of the nitrogen originally fixed by clover appears in the grass where urine is returned and serves as a nitrogen fertilizer. Indeed, at a stocking rate of three or four ewes per acre, dung and urine excreta would likely return an equivalent of at least 150 pounds nitrogen per acre annually (*12*). A high stocking rate assists the nitrogen recycling, and with clover apparently supplies the total nitrogen requirement for the expected yield of 6,000 pounds of dry matter per acre in the pasture.

Recent experiments using perennial ryegrass as an indicator plant support this probability (Table 7). No yield response from applied nitrogen was apparent when ryegrass was grown in a field fertilized with superphosphate (300 lbs. of 20% superphosphate applied annually) that had been intensively grazed (4 sheep per acre) for the past 12 years. Furthermore, the yield and nitrogen content of ryegrass on this soil were significantly higher than of ryegrass grown on the same soil which had virtually no grazing during this period. The accumulated soil organic nitrogen on the intensively grazed grass-clover pasture apparently is mineralized and cycled at a rate sufficient to provide optimum nitrogen nutrition for the grass. Under such conditions, the nitrogen cycle appears balanced in such a way that moisture and sufficient solar energy alone drive the system near optimum. As has been vividly demonstrated by Petersen and others (*8*), significant benefits from excreta of grazing animals can be expected only under conditions of high stocking intensity over long periods of time.

Several workers (*14*, *15*) have recognized consistent carbon, nitrogen, sulfur, and phosphorus ratios in grassland soils, as would be expected from the rather definite proportions of these

Table 7. Yield and nitrogen content of ryegrass grown on screened subterranean clover soils[1]

Management history	Treatment	Yield (dry weight)	Percent plant nitrogen
		grams	%
Unfertilized, unutilized	Check	1.86	2.66
	PSK	2.74	1.85
	NPSK	4.85	2.01
Fertilized, hay crop	Check	3.25	2.14
	PSK	3.52	2.14
	NPSK	4.79	2.69
Fertilized, grazed 12 years (4 ewes per acre)	Check	7.74	3.03
	PSK	7.07	2.91
	NPSK	7.60	3.07

[1] Soils had 12 years of different past management. From unpublished M.S. thesis by V. Impithuksa, OSU, 1971.

Table 8. Average carbon, nitrogen, phosphorus, sulfur ratios in topsoil from selected Oregon pastures

Pasture	Carbon		Nitrogen		Phosphorus		Sulfur
Unimproved	156	:	10	:	2.5	:	0.7
Fertilized plus grazed	142	:	10	:	2.8	:	1

elements in the soil organic matter. An increase or decrease of one of these elements is accompanied by a parallel increase or decrease in the others. Recent studies on Oregon pastures revealed a carbon-nitrogen-phosphorus-sulfur relationship (Table 8). The somewhat narower C:N:P:S ratios obtained in the soils from fertilized and grazed pasture suggest less immobilization and more mineralization of nitrogen, phosphorus, and sulfur. Such a situation would enhance efficient recycling of these plant nutrients through the soil and reabsorption by the pasture plants. High correlations were noted between soil nitrogen and total phosphorus as well as between nitrogen and total soil sulfur (Figure 2). This further illustrates the interdependence of these nutrients, where the build-up of any one nutrient depends upon the supply of the others.

Summary of Nitrogen Cycle

High stocking rates on grass-clover pastures fertilized with superphosphate simultaneously provide high-quality livestock feed and a generous supply of nitrogen for recycling through the soil-plant-animal system. To produce 6,000 pounds of dry matter, subterranean clover will require at least 180 pounds of nitrogen per acre annually. While for one reason or the other, nitrogen symbiotic fixation might more nearly approach 100 pounds nitrogen per acre, animal excreta at three to four ewes per acre could well recycle another 150 pounds of nitrogen per acre. Certainly some nitrogen is lost by leaching, volatilization, and from meat or wool sales. Loss of N through removal in meat or wool probably does not exceed 15 percent of the nitrogen ingested by the animal, or about 25 pounds nitrogen per acre.

Since mineralization of soil organic matter (even in the absence of animal excreta) could be estimated to equal 40 pounds nitrogen per acre, the nitrogen economy for sustained high producing grass-clover pastures intensively grazed seems assured. Indeed,

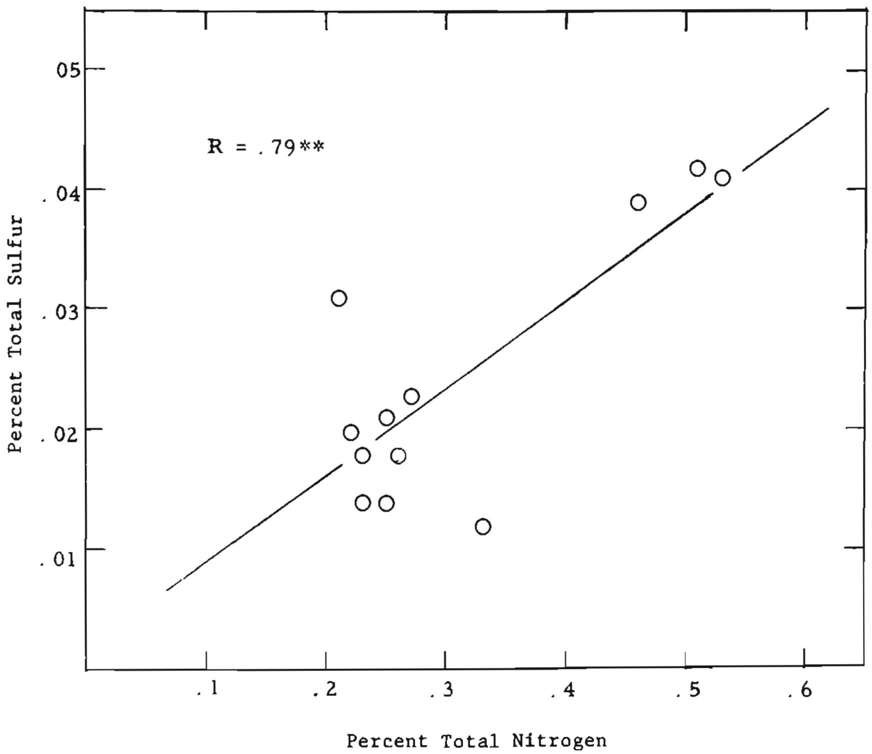

Figure 2. The relationship between soil total nitrogen and soil total sulfur.

one might term the nitrogen cycle under intensively stocked grass-clover pastures as "econology," since it preserves and conserves a quality environment with a sound economic base for providing quality livestock feed.

The Sulfur Cycle

Although sulfur is not fixed symbiotically by clover rhizobia or other soil organisms as is nitrogen, there are striking similarities between the nitrogen and sulfur cycles (Figure 3). Moreover, just as there is a close relationship between available soil nitrogen and clover nitrogen content, there is also an intimate relationship between available soil sulfur and plant nitrogen due to the essential role of sulfur in protein synthesis. Indeed, the 145 pounds of total plant N (Table 4) represents a pasture producing twice the plant protein yield that was obtained where sulfur was deficient in the soil.

In producing a 6,000-pound dry weight yield of subterranean clover containing an adequate total plant sulfur of 0.30 percent (*4, 13*), at least 18 pounds of sulfur per acre would be required. Furthermore, sulphate like nitrate is subject to leaching (Table 9). Assuming that cutting the clover pasture as hay removed 54 pounds of sulfur per acre from the 120 pounds of sulfur applied during a three-year period (Table 9), only 5½ pounds of sulfur over the amount in the check treatment was recovered in the Steiwer profile. This would amount to a loss of about 24 pounds of sulfur per acre annually.

The movement of sulfate into the lower horizon of some western Oregon subterranean clover hill soils following

Table 9. Net increase of sulphate[1] in two contrasting soil profiles

Soil depth	Soil profile	
	Steiwer	Nekia
inches	*lbs.* S/A	*lbs.* S/A
0–6	1.5	8.5
6–12	1.5	11.5
12–18	2.0	14.0
18–30	0	1.0

[1] Extracted with 0.1 N KH_2PO_4; 120 pounds of sulfur per acre were applied as gypsum over a three-year period.

winter rains will vary according to soil type (Table 9). The movement of soil SO_4-S recently has been studied in Oregon. For instance, the Steiwer soil retained little sulfate to a depth of 30 inches, while the red Nekia soil retained appreciable sulfate particularly in the subsoil layers. Sulfate leaching from surface horizons and accumulation as adsorbed SO_4 in the lower horizons has been observed by other workers (5). For a relatively shallow-rooted legume like subterranean clover, subsoil sulfate is of little value if beyond the reach of feeder roots.

Thus far we have considered aspects of the sulfur cycle (Figure 3) concerned with soil sulfur loss either by uptake and removal in hay or animals or by leaching. The combined subterranean clover sulfur uptake and soil sulfate leaching loss could approach at least 40 pounds sulfur per acre annually. Available sulfur to balance the loss can come from four sources: (1) the atmosphere, (2) weathering of rocks and minerals, (3) mineralization of soil organic matter, and (4) on-site excreta from the grazing stock. Fertilizer sulfur, of course, is another potential source.

Atmospheric returns of sulfur, either direct or via rainfall, appear low in western Oregon except for very local situations. Additions seldom exceed seven to eight pounds sulfur per acre

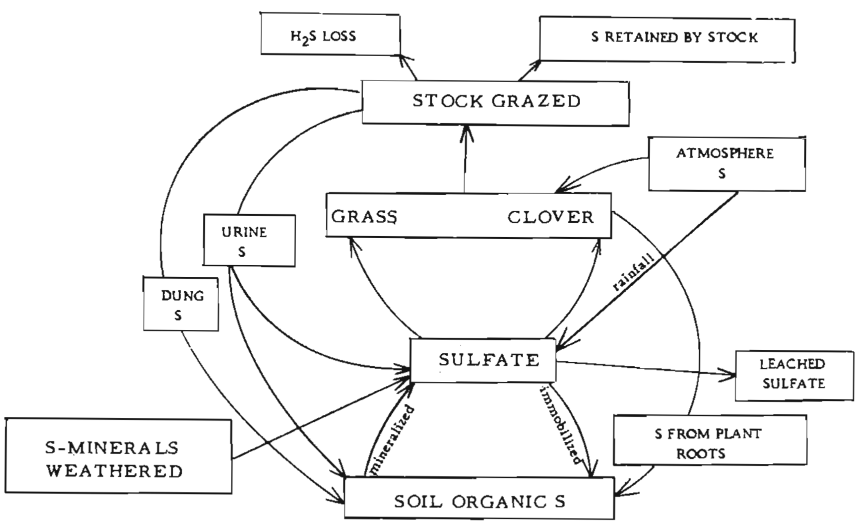

Figure 3. The sulfur cycle on grazed grass-clover pasture. Adapted from T. W. Walker (*13*).

annually, even from areas within one mile of the Pacific Ocean (3). Release of sulfates to the soil from weathering of sulfur-poor rocks also appears minimal.

Mineralization of soil organic matter appears to be a primary source of plant-available sulfur. Indeed, several workers (*13*) have suggested that in humid, temperate climates and given reasonable soil drainage, most of the sulfur in the surface soil is contained in soil organic matter. Moreover, sulfate availability to plants depends on the *rate* of soil organic matter mineralization by microorganisms (*1*, *9*). The amount of sulfate formed from soil organic matter will depend on the organic sulfur content and factors affecting the activity of microbes.

In particular, the N:S and possibly the N:P ratios of soil organic matter affect its rate of mineralization. New Zealand studies (*13*) show an N:S ratio for soil organic matter of about 10:1, indicating that for every 10 pounds of NO_3-nitrogen per acre mineralized, one pound of SO_4-sulfur per acre would be produced. For western Oregon soils, the N:S ratio of soil organic matter is higher than 10:1 except in fertilized and grazed pastures (Table 8). The high correlation between total soil N and S noted in Figure 2 further emphasizes the close relationship and constancy these nutrients have to one another.

On the basis of a 10:1 N:S soil organic matter ratio, a soil with 0.20 total nitrogen that released 40 pounds NO_3-nitrogen annually should concurrently release four pounds of sulfur per acre. A sulfur deficit of 30 pounds per acre annually would persist unless some further sulfur additions were forthcoming. This is consistent with results of numerous field experiments showing yield response from application of 20 to 40 pounds of sulfur per acre annually under hay management systems.

A familiar type of response to sulfur applied to an ungrazed grass-clover pasture may be seen in Table 10. In both years the pasture yield increased. The response to S was due to clover in the first year, yet by the third year it was due to grass. This demonstrates the influence of applied sulfur in stimulating clover to fix more N symbiotically which, in turn, stimulated grass growth to the relative suppression of clover in a two-year period. Note that this occurred under *ungrazed* conditions.

Anderson and Spencer (2) give figures for subterranean clover of 1.71 and 0.058 percent nitrogen and sulfur respectively when no sulfur was applied and 2.26 and 0.24 with sulfate applied. Walker (*13*) reported an even greater increase in clover nitrogen and sulfur content following a 200-pound application of gypsum; nitrogen increased from 2.87 to 3.45 percent and sulfur from 0.17 to 0.34 percent. That grasses compete strongly with clover when mineral nitrogen is not limiting appears obvious from these data. What is equally important is the grass competition for available soil SO_4, since

Table 10. Ryegrass-subterranean clover response to applied gypsum and resultant change in species composition

Treatment (lbs. S/A)	First year: Avg. yield dry matter per acre	First year: Percent clover	Third year: Avg. yield dry matter per acre	Third year: Percent clover
	lbs.	%	*lbs.*	%
0	3,675	30	2,813	10
10	4,590	30	3,825	50
20	5,524	70	4,583	30
40	6,976	70	6,278	30

for each 10 pounds of nitrogen incorporated in plant tissue there is a need for about one pound of sulfur. A soil sulfur deficit is first likely to be nutritionally disadvantageous to clover and contribute to a grass-dominant pasture.

Grazing and the Sulfur Cycle

The grazing animal returns sulfur to the pasture by way of dung and urine just as it returns nitrogen. Walker concluded that 70 to 85 percent of the sulfur ingested by stock is returned to the pasture in urine (*13*) along with additional small amounts in the feces. Certainly, some sulfur of this excreta is lost by volatilization, but most enters the soil organic sulfur pool or is reasonably quickly available for reabsorption by the grass-clover (Figure 3).

The nitrogen content of the urine is variable but reportedly is proportional to sulfur content at roughly a 5:1 ratio (*13*). If, as has been suggested, a urine patch contains a nitrogen concentration equivalent to about 400 pounds nitrogen per acre (*12*), it follows that such a patch also supplies 80 pounds sulfur per acre. A stocking rate of three to four ewes per acre could therefore theoretically contribute about 20 pounds sulfur per acre per annum, a significant sulfur return that is absent in a haying management program of a grass-clover pasture.

The effect of the grazing animal on the reserve supply of soil sulfur after intense stocking is reflected in data from a recent greenhouse experiment (Table 11). In each instance, the sieved soil was removed from an old subterranean clover pasture that had been annually top-dressed with superphosphate. However, in both locations one field had been intensively grazed while the other had been hayed and kept ungrazed. Ryegrass was planted into each sieved soil and appropriately fertilized. For both locations, ryegrass grown in soils from the "previously fertilized but ungrazed field" responded to applied sulfur, and yields were greater but there was no response to sulfur where the soils had presumably benefited from urine returns under grazing. The percent plant sulfur confirms the increased sulfur uptake from soils of "previously intensively grazed and previously top-dressed grass-clover pastures" compared with the "ungrazed pastures."

Summary

Intensive grazing of improved pastures under conditions such as in western Oregon, represents a system of farming where maximizing production can be synonomous with optimizing production. The high stocking rates of grass-legume pastures elegantly illustrate a soil-plant-animal interrelationship manifested through the nitrogen and sulfur cycles. Soil fertility, pasture yields, and animal production concurrently increase as improved grass-clover fields are intensively grazed. Production and conservation are seldom such good bedfellows. Improved grass-clover pastures utilized under high stocking systems epitomize conservation management at its best.

The success in producing quality pasture, especially improved hill grass-

Table 11. Yield and sulfur content of ryegrass grown in sieved surface soil (top 10 cm) from variously managed old subclover pastures[1]

Applied nutrient(s)	Location 1 Ungrazed		Location 1 Grazed		Location 2 Ungrazed		Location 2 Grazed	
	Yield	Sulfur	Yield	Sulfur	Yield	Sulfur	Yield	Sulfur
	g/pot	*%*	*g/pot*	*%*	*g/pot*	*%*	*g/pot*	*%*
N	2.61	.09	5.80	.27	3.76	.11	8.38	.23
NS	3.72	.41	5.03	.29	4.11	.32	7.59	.31

[1] From unpublished M.S. thesis by V. Impithuksa, OSU, 1971.

clover pastures, in western Oregon depends primarily upon the efficiency of the nitrogen and sulfur cycles. In producing 6,000 pounds of dry matter, about 180 pounds of nitrogen per acre and 18 pounds of sulfur per acre would be required. Under intensive grazing, and in spite of N or S losses through leaching, volatilization, or sale of meat and wool from the farm, good management permits symbiotic fixation of nitrogen and recycling of nitrogen and sulfur in amounts needed for top production.

The clover plant plays a pivotal role in this system of intensive pasture management. Furthermore, on many soils it will require at least a decade of annual applications of superphosphate fertilizer and high stocking rates to reach the point where the cycling of nitrogen and sulfur is sufficient to be virtually self-sustaining. Evidence suggests that in many western Oregon situations, sulfur (not phosphate) becomes the first limiting nutrient for clover if the nitrogen and sulfur cycle are to continue at peak efficiency.

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