THE IMPROVEMENT AND UTILIZATION OF TUSSOCK GRASSLANDS: A SCIENTIST'S VIEWPOINT

Cycling Nitrogen for Production

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Introduction

THE ROLE OF THE SCIENTIST

THERE has been a large increase in the volume of facts about tussock grassland improvement in the last few years. Although facts are important to the scientist, he is not merely a facts-gatherer. He also makes general statements. In the tradition of Anglo-Saxon logic formulated by John Stuart Mill, the scientist derives these general statements from the facts by the process called induction. Nobel Prizewinner for Medicine, Dr P. B. Medawar, questions this traditional assumption. He claims that "truth takes shape in the mind of the observer: it is his imaginative grasp of what might be true that provides the incentive for finding out, so far as he can what ***is*** true." If this imaginative idea of truth still fits the facts after rigorous testing, then it is a good idea and the facts themselves can be conveniently forgotten. Paradoxically, therefore, the factual burden of a science grows less as a science matures. As a science advances, "particular facts are comprehended within and therefore in a sense annihilated by general statements of steadily increasing explanatory power and compass".

PROGRESS IN GRASSLAND SCIENCE

The degree of maturity of the science of tussock grassland improvement and utilization may therefore be judged by the ability of the scientist to make valid and true general statements. In the recent progress of grassland science in New Zealand, some general statements of great value have been advanced concerning the relationship of the nitrogen cycle to production. Sears (1953, 1956, 1959) has summarized the role of the grazing animal and has outlined the phases of grassland improvement from low fertility and productivity to high fertility and productivity. More recently, Sears *et* al. (1965) have demonstrated quantitatively the rate of nitrogen fixation and increase in soil nitrogen accumulation with finely ground herbage clippings returned to ryegrass and white clover grown on the subsoil of Kairanga silt loam. Walker (1956, 1962) has developed quantitative concepts concerning the nitrogen cycle in soils under grassland. He also outlined (1960, 1965) the pattern of natural soil conditions in which the amount and form of soil phosphorus affect the character of the organic cycle. In another area of grassland science, considerable advances have been made by the work of Mitchell (1956) and Brougham (1960) on plant growth in relation to light energy available in particular conditions.

THE NEED FOR A NEW GENERAL STATEMENT

None of the general statements already proposed could be expected to have validity and explanatory power in the whole range of conditions of tussock grassland management. Furthermore, the increasing volume of facts about tussock grassland development serves to confuse rather than inform if these facts are not interpreted in the context of general statements. It is therefore desirable to put forward a new general statement that has both explanatory power and validity in the wide compass of grasslands, developed and undeveloped.

The following general statement is proposed:

> The total mass of life in and on the soil exists at an energy level whose potential or ceiling is determined by the inherent capabilities of available plants and animals and by the energy sources, the light and heat of each particular site. *Within this ceiling, the energy level actually achieved in conversion of light to chemical energy and subsequent transformations is governed by the mass flow of cyclic nitrogen through soil, plants and animals.* The mass flow of cyclic nitrogen is the product of the total nitrogen content of the system and the effective rate of nitrogen transfers throughout the system. The total nitrogen content is subject to varying losses and gains, The nitrogen transfers

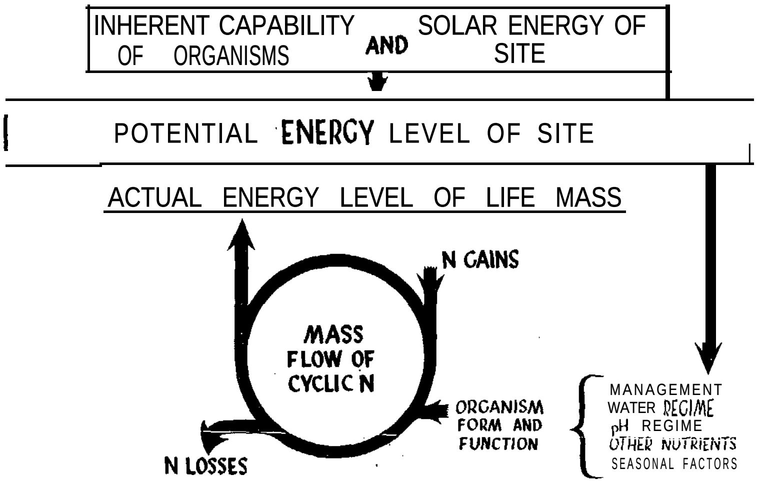


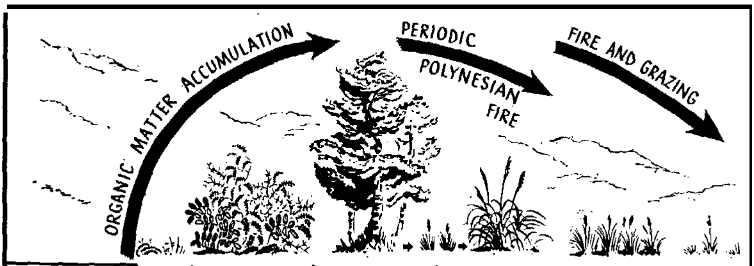
FIG. 1: ***Relationships between energy levels, cyclic nitrogen and other factors in life systems.***

within the system are themselves affected by the organisms present and by the enviromental influences on their form and function including such factors as management, the water regime, the availability of other nutrients, the concentration of hydrogen ions, the actual seasonal regimes of light and heat.

There is nothing really new in these ideas taken individually. However, the relationships between them are often forgotten or misunderstood. They are illustrated schematically in Fig. 1.

Application of General Statement to Unimproved Tussock Grassland

How well does this general statement fit the observable facts about unimproved tussock grasslands? To interpret these grasslands as they are now, one must consider what they have been. Over the span of years, nature has not remained constant. Soils mature and grow old as Walker has exemplified (1965) in his sequence studies. There are also changes in the systems of life. In Fig. 2 is illustrated the succession of life systems that has probably taken place on the moraine of Lake Pukaki area since the re-



VEGETATION	HERBS	SHRUBS	FOREST	TALL GRASS	SHORT GRASS	DEPLETED GRASS
N BALANCE	=NITROGEN GAINING⇒		STABLE	==NITROGEN LOSING==⇒		STABL
CYCLIC N VOLUME	VERY LOW	MEDIUM	HIGH	MEDIUM HIGH	MEDIUM LOW	
CYCLIC N RATE	—FAST ?—		SLOW—	—SLOW—	—VERY SLOW	

FIG. 2: *An interpretation of probable vegetation and nitrogen conditions in successive phases of life systems up to the present on Tekapo soil, Lake Pukaki.*

cession of the giant Pukaki glacier. The first three stages represent seral succession to forest with accumulation of organic matter and maturation of the soil. The fourth stage was probably achieved 1,300 to 700 years ago in Polynesian culture (Molloy, *et al.*, 1963), the forest being destroyed by fire, and, as Connor (1964) has outlined, a short tussock grassland evolved which was itself soon invaded by tall tussocks, probably red tussock. As shown by Mark (1965) in Otago and O'Connor and Powell (1963) in South Canterbury, periodic burning without grazing does not destroy tall tussock grassland although it may reduce its vigour. Burning followed by the heavy stocking of the last century resulted in short grasslands, further depleted by the plague of rabbits (Connor, 1964). Although the several stages shown in Fig. 2 do not universally apply throughout tussock grasslands, the same basic processes of soil genesis, maturation and wasting and of vegetation colonization, development and depletion are evident in the conditions reported from many localities (Molloy, 1964; Connor, 1965).

The likely nitrogen conditions of such stages and processes are shown in Fig. 2. In line with studies on glaciated areas on the West Coast (Stevens, 1963), nitrogen accumulation is interpreted over the first three stages.

Subsequent phases may be nitrogen-losing but this is not yet clearly proven in New Zealand. Similar sequences in Southern Chile (O'Connor *et al.*, 1965) and an unpublished survey of several North American grassland sequences by the same persons show greater numbers of nitrifying bacteria and a greater proportion of nitrate in mineral soil nitrogen with each stage of vegetation degradation. Moore (1965) reported from south-eastern Australia a pattern of increasing autumn nitrate with the grazing-induced transition from tall warm-season perennial grasses through short cool-season perennial grasses and dwarf cool-season perennial grasses to cool-season annuals. With increasing formation of nitrate, as shown in these degradation sequences, there is increasing risk of loss by leaching.

Following persistent nitrogen losses with no compensating gains, one would expect a relatively stable, low energy situation to be reached, such as Robinson and MacDonald (1964) have shown for the Craigieburn soil in Canterbury. Gains and losses are then negligible and low mineralization results in a very slow rate of cyclic nitrogen. As Walker and Adams (1959) have shown for many tussock grassland areas, there are relatively large quantities of nitrogen in soils, sitting rather than cycling.

A fair judgment of the proposed general statement in the light of the published facts about unimproved tussock grasslands might include three points: first, the proposed general statement is not contraverted by any known evidence; second, it serves to enlighten understanding of the genesis of these grasslands and of their behaviour in past cultures; third, it is not yet adequately tested in all of its aspects nor have its corollaries been fully demonstrated in tussock grasslands.

Application of General Statement to Tussock Grassland Development

Under the influence of man's work on land, a natural life system (an ecosystem) is modified to become a cultural life system (an agrobiosystem) (Montserrat, 1965). The life system mechanisms are essentially the same, although the components and their activity may be greatly changed. Economic production is only a small fraction of the total lifework (energy conversion) accomplished. To increase production, the fundamentals of the old and new life systems must be known more **thoroughly** in order that they may be manipulated, One must also know the features that differentiate and the features that integrate the several tussock grasslands in their response to cultural treatments. Climate, slope, parent material and past history have differently affected the soil and present vegetation of different sites. These differentiations are reflected in the different responses to legume oversowing and topdressing revealed in studies of several sites by Ludecke (1960, 1962) and O'Connor (1962). The integration of these sites in their response to such culture is likely to be found in the same unifying pattern that Walker (1965) has demonstrated for soil phosphorus in pedogenesis. Thus Ludecke (1962) has demonstrated that responses of introduced legumes to phosphate in the presence of sulphur in the different soils of a precipitation sequence' follow the same basic pattern. With increasing precipitation, the inorganic phosphorus soluble in N H_2SO_4 declines and the response to added phosphate increases.

Although the introduction of legumes into tussock grasslands is the chief method in current practice for increasing nitrogen gains, it has been emphasized in the general statement already proposed that the mechanism governing the energy level of the life mass is not how much nitrogen is added but how much is cycled and how fast. Accordingly, it is important to recognize the features of tussock grasslands which differentiate the several grasslands and the features which integrate them, not just in their fertilizer needs for legumes but also in their cyclic nitrogen behaviour under the impact of many different aspects of cultural improvement. A simple version of the nitrogen cycle is outlined in Fig. 3, indicating possible pathways of nitrogen but not showing the volume or rate components of mass flow of cyclic nitrogen. These components vary greatly from one life system to another. Different kinds of tussock grasslands therefore warrant different emphases on different phases of the nitrogen cycle. In contrasting situations, the same cultural effort has unequal effect on particular phases of the nitrogen cycle. This principle is illustrated in subsequent discussion.

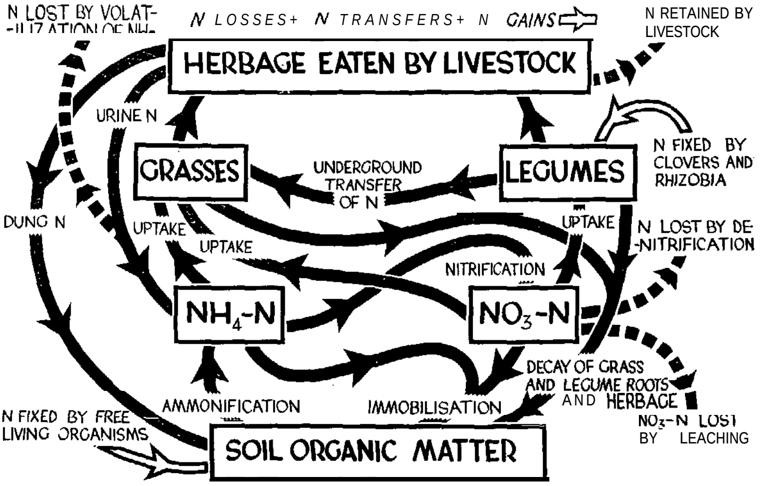


FIG. 3: *A four-tier representation of the nitrogen cycle in a grazed legume-grass association. The tiers from top to bottom are animal nitrogen, herbage nitrogen, soil mineral nitrogen and soil organic nitrogen.*

NITROGEN UPTAKE, ASSIMILATION AND UTILIZATION

The first phase of the nitrogen cycle for consideration is the promotion of greater nitrogen uptake and assimilation by grasses. If grasses of high inherent capability are introduced into depleted sites of fairly high native fertility, such plants may establish under suitable moisture regimes, take up nitrogen that might otherwise be lost, with resulting increase in herbage production. This is exhibited in successful cocksfoot oversowing at Molesworth (Chisholm, 1960), Tara Hills (Campbell and Calder, 1964), Mid Dome (Sly, 1960) and in different parts of Central Otago (Cockayne, 1922). If, however, such grasses are sown into low fertility sites without fertilizer, there may be poor establishment and little improvement in nitrogen uptake or herbage production. Ryegrass and cocksfoot introduction with little or no fertilizer into the Craigieburn soil (O'Connor, 1966a) or into the Te Anau soil (Cullen, 1966) illustrates this condition. If nitrogen alone is added to sites of low fertility, there may be little benefit because the ability of grasses to assimilate and utilize added nitrogen is limited by the deficiency of other nutrients such as phosphorus or sulphur (O'Connor, 1961c, Vartha, 1963).

MINERALIZATION OF SOIL NITROGEN AND NITRIFICATION

Intimately related to nitrogen uptake by grasses are the mineralization of soil nitrogen and nitrification. If mineralization of organic nitrogen by soil organisms is slow and inadequate in acid soils, as has been shown for the Cragieburn soil by O'Connor *et al.* (1962), responses in sown grasses may be obtained from liming (O'Connor, 1963; Cullen, 1966). Liming may result in increased mineralization of soil organic matter with consequent increase in nitrogen available as ammonium ions. The benefit from liming, however, has been shown to accrue to establishing ryegrass and cocksfoot even in the presence of large dressings of urea (O'Connor, 1963) and it is possible that some at least of the value of lime to grasses may be derived from its added stimulation to nitrification in Craigieburn soil (Robinson, 1963). Nitrate nitrogen, being more mobile, may be more effective in dry periods than the less mobile ammonium nitrogen resulting from simple hydrolysis of urea. Mineralization and nitrification have not been as intensively studied in tussock grasslands soils of higher natural fertility but it appears unlikely from the reports available (White, 1959; Ross, 1958, 1960) that these processes of the nitrogen cycle are as retarded in higher fertility tussock grassland soils as they appear to be in the unimproved Craigieburn soil. Benefit to grasses from liming is therefore not likely to be universal in tussock grasslands but much more research is needed into the mechanisms of its value.

NITROGEN GAINS FROM LEGUME GROWTH

The introduction of legumes and the symbiotic fixation of nitrogen are major factors affecting the volume of nitrogen available for cycling in a life system (Sears, 1953; Sears *et* al., 1965). Levels of nitrogen harvested in clover- herbage at the Broken River experimental area in a favourable season were in excess of 150 lb nitrogen per acre (O'Connor, 1961a, 1361b). Reference has already been made to the work of Ludecke (1960, 1962), O'Connor (1962) and Walker (1960, 1965) in establishing the soil pattern of the fertilizer requirements for legume establishment. The following observations are noteworthy in that they are derived from a series of experiments where

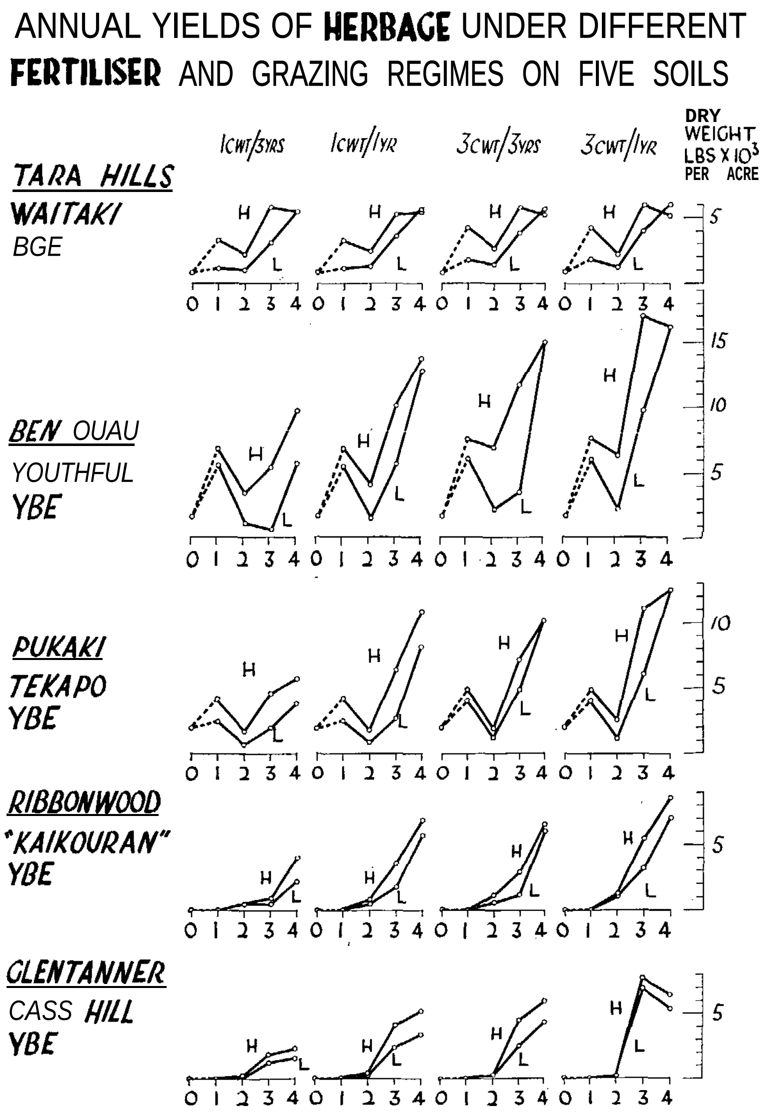


FIG. 4: *Herbage harvested during four years on five oversown tussock grasslands in the Upper Waitaki catchment under four rates of sulphur superphosphate. The year 0 represents estimated annual yield before treatments began. H signifies periodic hard grazing. L signifies periodic lax grazing. The lax grazing treatments were suspended for the fourth year at Tara Hills, Ben Ohau and Pukaki only and all plots there treated with periodic hard grazing.*

each plot has been individually grazed in proportion to herbage yield over a period of four years. O'Connor and Clifford (1966) have outlined the design and practice of these experiments and salient results in herbage yield under different fertilizer and grazing regimes are presented in Fig. 4.

If, into a high fertility site where sulphur and nitrogen are the only deficiencies, legumes and appropriate rhizobia are introduced and the sulphur deficiency corrected, nitrogen gain by fixation and increased herbage yield should result. At such sites as Tara Hills in Fig. 4, no appreciable gain may ensue from more frequent or heavier applications of sulphur-superphosphate fertilizer to the cocksfoot-dominant association. In extreme contrast to the results from Tara Hills, those from the low fertility Cass Hill soil at Glentanner, also summarized in Fig. 4, indicate that more fertilizer and longer time are needed before there is appreciable increase in herbage yield. On moderately fertile sites, such as the moraine at Pukaki and the youthful "Dobson" soil at Ben Ohau, 3 cwt per acre of sulphur-superphosphate applied every three years was insufficient to maintain herbage yields into the third year, especially under lax grazing. Sulphur-deficiency symptoms in clover foliage of these treatments were clearly evident in the third season. Under such conditions of inadequate fertilizer, legumes may suffer in competition with grasses for sulphur and the nitrogen gains eventually decline (Walker and Adams, 1958). The striking effect of cycling all herbage nitrogen through the grazing animal to compensate for the decline in legume vigour and in nitrogen gains is discussed more fully later in this paper.

Nitrogen Transfer from Legume Residues

If climatically-adapted legumes are introduced to sites with low available nitrogen, and, at the same time, high availability ensured of sulphur, phosphorus, potassium, molybdenum, boron and whatever other nutrients may be required, then legume dominance may be expected (Sears *et al.*, 1965). This legume dominance can be promoted by allowing long intervals between effective grazings. In such conditions, established grasses may not be clearly benefited by nitrogen from the legumes but may be suppressed. Such suppression of grasses by white clover shading has been demonstrated for ryegrasses in cultivated pastures at Broken River (O'Connor 1961b), oversown cocksfoot, fescue tussock, browntop, Yorkshire fog, and sweet vernal in uncultivated grasslands (O'Connor, 1961~). If herbage is allowed to decompose instead of being utilized with grazing animals, the cyclic nitrogen flow is likely to slow down. Decomposition of plant residues with a wide C:N ratio is usually slower than that of residues such as legume herbage with a narrow C :N ratio and readily available carbon. However, research at Broken River on limed and topdressed cultivated pastures on Craigieburn soil has revealed that nitrogen from even finely-ground lucerne meal is much more slowly available for plant uptake than equivalent nitrogen applied as urea (K. F. O'Connor, unpubl. results). The use of regular grazing can therefore bypass the slow decomposition pathway in the nitrogen cycle. Even in grazed pastures where the growth of legumes is favoured by regular topdressing, mor-type mats can develop on low-calcium soils (Stockdill, 1959). As Stockdill has shown, fostering of earthworms may result in the breakdown of the mat, and in higher herbage production. How widely these practices of promoting plant residue decomposition apply in tussock grasslands is unknown. Evidence so far is confined to upland and high country yellow-brown earths. It is possible that the occurrence of slow residue decomposition will be found to parallel the occurrence of slow mineralization of soil organic matter referred to earlier. However, the added importance of soil fauna to plant residue decomposition may imply much wider significance for this latter problem.

NITROGEN CYCLING THROUGH GRAZING ANIMALS

If effective grazing is practised on grasslands with vigorous legume growth, clover dominance should cease, generally resulting in a higher production level with a greater proportion of grass herbage. Two important factors are involved in such treatment, defoliation frequency and return of nutrients through the grazing animal. Sears (1953, 1956) has indicated the importance of defoliation in maintaining an appropriate supply of light to clovers in a sward tending to grass dominance. In a sward at Broken River with low nitrogen availability

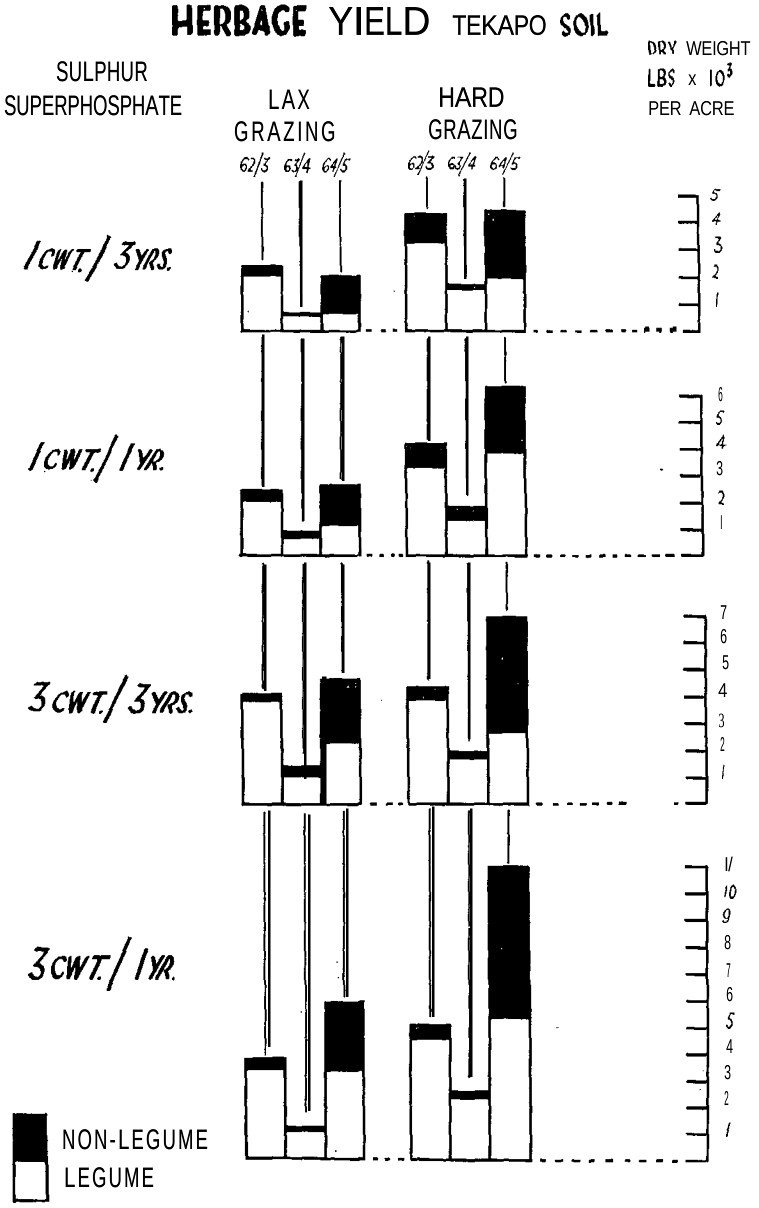


FIG. 5: *Annual harvests of clover and grass under eight different fertilizer-grazing regimes on clover-oversown tussock grassland at Lake Pukaki during 1962 to 1965.*

and therefore tending to clover dominance, O'Connor (1966a) found that fairly frequent mowing was necessary to maintain the grass component. In the same review of experiments, it has been pointed out that failure to defoliate when a substantial bulk of herbage had been reached led to less total herbage production. This was attributed to decomposition of herbage counterbalancing the photosynthesis in the upper part of the canopy. The levels of herbage that can accumulate before decomposition occurs may be fairly high in the high light regimes of the inter-mountain basins, Herbage yields from frequent mowings were consistently lower than from infrequent mowings during two seasons at Broken River over a wide range of nitrogen conditions. From these results, it might be inferred that higher herbage production could be ensured by allowing fairly long intervals between defoliations to permit tillers already present to make maximum growth, fully utilizing in photosynthesis the nitrogen already taken up. At the same time, if all herbage were eaten by the grazing animal *in situ,* the greatest increase in nitrogen availability from urine returned to the sward would be assured and a greater proportion of grass obtained in yield. Striking benefits from such a practice have been demonstrated in the comparison of lax and hard grazings at different fertilizer levels in the five experiments of O'Connor and Clifford (1966). Results for herbage yield and composition from one experiment, that on Tekapo soil at Lake Pukaki, are presented in Fig. 5. There has been a general improvement in grass yield by the third year under all fertilizer regimes even with periodic lax grazings. This improvement has been greater under the high initial fertilizer regimes, following greater first year legume production. Grass yield has been dramatically increased in the third year under periodic hard grazing. It may also be noted that this benefit from more effective cycling of nitrogen by hard grazing has more than compensated for the decline in legume production experienced in the third year under the 1 cwt/3 yr and 3 cwt/3 yr fertilizer regimes because of sulphur deficiency.

The general superiority of total herbage production under periodic hard grazing to that under periodic lax grazing is indicated in Fig. 4 for four fertilizer regimes at the five experimental sites. The current benefit from hard grazing was relatively small under two kinds of conditions :

(1) Where there was very little legume production as at Ribbonwood and Glentanner on low fertility soils during the first two years, and as at Tara Hills in the second and subsequent years when the clover was suffering competition from cocksfoot for available moisture.

(2) Where clover dominance was currently at a maximum, such as at Ben Ohau and Pukaki under high fertilizer during the first year and at Glentanner in the third and fourth years under heavy annual fertilizer.

The maximum value of periodic hard grazing in accelerating the mass flow of cyclic nitrogen is therefore clearly dependent on the appropriate stage of culture of the grassland. This stage is reached more quickly on soils of high natural fertility than on soils of lower fertility.

Little benefit can be expected from periodic hard grazing of tussock grasslands which have not been culturally improved. With no addition of nitrogen to the system, there may be difficulty in mobilizing the nitrogen reserves in the soil. If the volume of added nitrogen is small, or if control over animal movements is poor, then poor distribution of animal excretions may result. As Suckling (1959) has shown at Te Awa, the herbage production of stock camps may be built up at a much greater rate than that of hillside grazing areas. Under conditions of ammonium concentration from urine at stock camps, increased nitrogen losses can occur through volatilization of ammonia (Doak, 1952) or through nitrification and subsequent leaching of nitrate (Thompson and Coup, 1940, 1943). It will be appreciated that the within-plot distribution of animal return of nutrients obtained in the experiments of O'Connor and Clifford (1966) under conditions of mob-stocking with several hundred sheep per acre for a few days was more uniform than is likely in a large paddock with varied topography and lower stocking rates. Nutrient transfer may be a major phenomenon even under conditions of random return. Jackman (1960) calculated that at 10 sheep per acre with a total of 20 urinations per day, 60% of the area would not receive any return of urine in one year's grazing.

Conclusion

IMPLICATIONS FOR GRASSLAND MANAGEMENT

The changes in culture outlined and their effects on the cyclic mass flow of nitrogen are not without continuing influences on the grasslands themselves or on the animals which graze them. Periodic hard grazings on clover-oversown grasslands tend to promote grasses that can tolerate such conditions. They are highly productive and generally acceptable to livestock, whether they be browntop, sweet vernal, Yorkshire fog, Kentucky bluegrass, Chewings fescue, or similar species. Only at Tara Hills, where successful cocksfoot oversowing had been carried out some years before the experiment was begun, was any appreciable contribution to the high levels of production shown in Fig. 4 made by bred grasses. Under periodic hard grazing at high fertility one can expect fescue tussock eventually to disappear. Figure 6 shows the effects of the fertilizer-grazing treatment combinations at Pukaki on the number per acre and relative size and flowering of fescue tussock in the fourth season. The results indicate a general improvement except in the plots of high herbage production under periodic hard grazing, especially with annual fertilizer. If it is desired to retain the tussock in some situations, it can be saved by reducing grazing pressure, but at the expense of the cyclic nitrogen flow and total energy level.

This paper demonstrates that improvement and utilization are as intimately interwoven in a scientific understanding of grassland as farmers know they need to be in business. The animal production potential of developed tussock grasslands in the Mackenzie country has been calculated elsewhere (O'Connor, 1966b, 1966c). This potential will not be achieved with a simple permanent grassland system of farming because of the needs of animals for winter feed. If, in the grasslands, mass flow of cyclic nitrogen is increased, better cycling of sulphur and phosphorus and also of bases such as potassium and calcium could be expected. Eventually, a new organic matter equilibrium appropriate to the climate and soil should

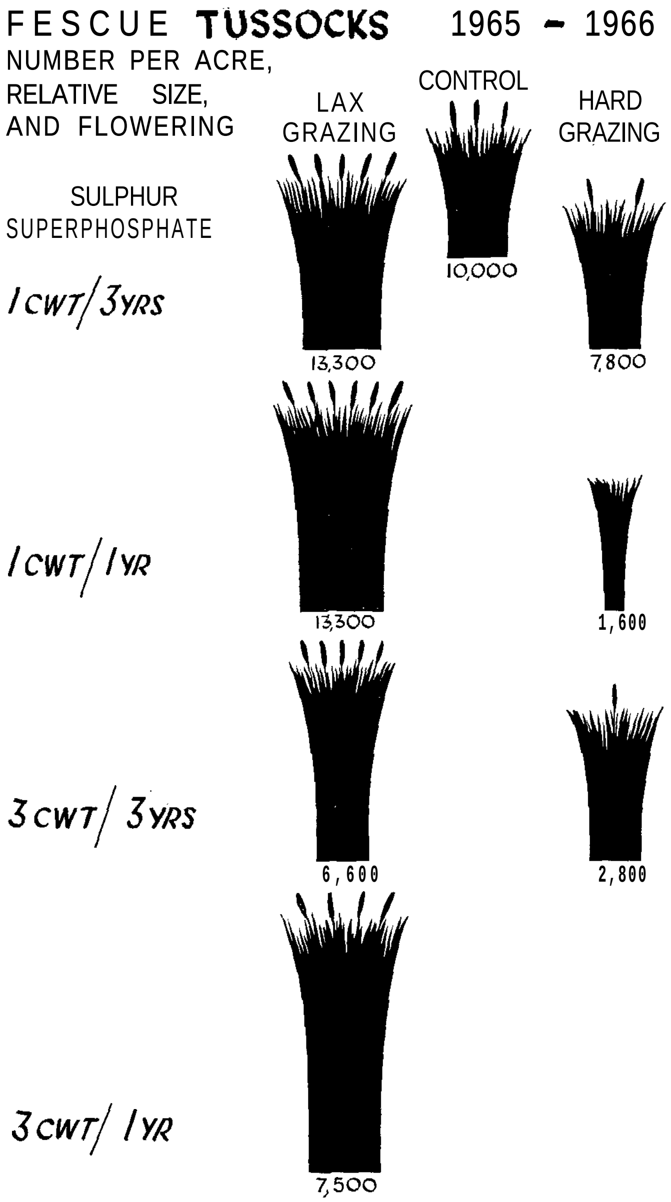


FIG. 6: *Physiognomy and density of* fescue *tussock plants* after *Three years Of different grazing-fertilizer regimes at Lake Pukaki.*

result (Jackman, 1964). Only as that stage is approached will fertilizer applications be at a truly maintenance level. At a high level of developed fertility, a cheap and easy solution may be found to the problems of winter feeding stock in sufficient numbers to carry on an integrated improvement-utilization programme. Whether this solution be by growing grain crops, root crops, greenfeed crops, or special purpose pastures of ryegrasses or other species, or by saving a seasonal surplus of herbage as hay, silage, summer-saved pasture, or autumn-saved pasture in milder districts, moderately high fertility appears to be an essential prerequisite (Clifford and Vartha, 1966; O'Connor, 1966a). Clearly there is no need for cultivation as part of grassland culture until such fertility is built up.

Full utilization of clover-oversown tussock grasslands by animals is demanded for three practical purposes :

(1) To get maximum improvement by making the nitrogen cycle work as quickly as possible.

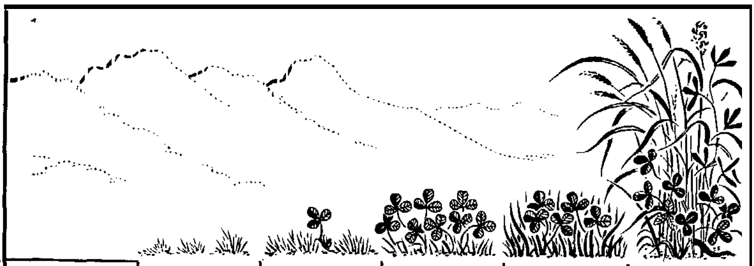
(2) To build fertility for winter feed production.

(3) To make tussock grassland improvement pay its way and pay it quickly.

IMPLICATIONS FOR FUTURE RESEARCH

The emphasis throughout this paper on the governing role of the mass flow of cyclic nitrogen may give the impression that it is the only factor considered important. In fact, mass Row of cyclic nitrogen is not regarded as a limiting factor in the traditional sense. This concept of limitations belongs to static analysis. The concept of mass flow of cyclic nitrogen as a "governor" is offered as appropriate to dynamic analysis, where one is attempting to understand a continuing system constantly subject to change. Of its nature, the governor is geared to other actions and subject to feed-back mechanism control.

The proposition on the governing role of cyclic nitrogen has been applied in order to interpret better the tussock grasslands, in their unity and in their variety. It has been applied to tussock grassland improvement as known in experiment and farm practice during the last decade. In that area of knowledge, too, the successes and the



VEGETATION	DEPLETED GRASS	INTRODUCED LEGUME	CLOVER DOMINANCE	CLOVER-GRASS SWARD	? TALL SWARD
N BALANCE	.STABLE	⟹ NITROGEN GAINING = ? ⟹			? STABLE
CYCLIC N VOLUME	MEDIUM-LOW	⟹ MEDIUM HIGH = ? = ? ⟹			
CYCLIC N RATE	VERY SLOW	= SLOW = ? ⟹ FAST = ? ⟹			

FIG. 7: *Possible vegetation and nitrogen conditions of future life systems in Mackenzie Basin* grasslands.

failures, the wastes and the deficiencies can thereby be better understood, for good land and poor land, for dry land and wet land. The general statement proposed need not yet be rejected as unfitted to known facts. Finally, it can be applied to the future to suggest the directions of culture that might be followed in such tussock grassland areas as the Mackenzie Basin. The apparently favourable high light environments of the tussock grasslands may soon demand the development of tall swards to obtain better utilization of light and perhaps to promote better use of water and of nitrogen. Possible future life systems and their nitrogen characteristics are summarized in Fig. 7. The abundant signs of doubt indicate a need for more scientists in tussock grasslands, fully supported and equipped for discovery. Perhaps the prospect of some twenty to fifty million ewe equivalents in the tussock grasslands region will warrant from the nation the full attention it deserves. There seems little prospect of curing the present degraded and eroding life systems of the tussock country without both the scientists and the animals. These two together will have rapid beneficial impact on the life systems of the tussock country only by serving and being served by technicians and farmers.

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