NITROGEN RELATIONSHIPS IN GRAZED AND CUT GRASS-CLOVER SYSTEMS

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SECTION I

GENERAL INTRODUCTION

Pursuit of an improved understanding of nitrogen relationships in New Zealand grass-clover pastures is the central theme of the results presented in this report. Unless indicated otherwise, reference throughout will be to well managed semi-permanent swards, developed to a high level of production, adequately drained and fertilised, but with little or no fertiliser nitrogen applied.

1. Productivity of New Zealand Pastures

Understanding of pasture production in New Zealand has been reviewed (Sears 1956, 1960, 1962; McMeekan 1960; Walker 1962, 1968; Levy 1970; Jackman 1971a, b; Brougham 1973, 1977). Levy (1970) concluded: 'Of all factors affecting (potential) plant growth, climate has the greatest influence, and climatically New Zealand is one of the most favoured countries in the world'.

The farmed area totals some 13.5 million ha, of which about 95% is occupied by grassland. About two-thirds of that comprises sown grassland (Levy 1970; Brougham 1973). Some 4.5 million ha of flat and downland occupied by pastoral agriculture support about two-thirds of the country's livestock (Brougham 1977). Intensive grassland farming is confined to areas where climate allows a long seasonal spread of growth, and where soils are either highly fertile or made so by appropriate fertiliser and lime practices (Levy 1970). Under these conditions, sward composition is relatively simple. Perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) are the predominant species in productive, permanent pastures (*loc. cit.*), with cocksfoot (*Dactylis glomerata* L.), poa (*Poa* spp.), Yorkshire fog (*Holcus lanatus* L.), paspalum (*Paspalum dilatatum* Noir.), Kikuyu grass (*Pennisetum clandestinum* Hochst. ex Chiov.) and red clover (*T. pratense* L.) also making significant contributions to yield in appropriate

situations.

Predominantly ryegrass-white clover pastures on lowland occupy the focal position in this review. Soils are generally ploughable, are slightly to moderately acid and relatively fertile. Average stocking rate is 16 stock units (ewe equivalents), with an annual dry herbage (DM) intake of 8.5 t, per hectare (Brougham 1977). The annual yield of well managed, permanent pastures averages between 11 and 18 t DM/ha (Levy 1970), indicating a considerable discrepancy between average pasture yield and utilisation.

Very large quantities of nitrogen are involved in the growth of productive grassland. Outside New Zealand, DM yield from temperate grass swards has been reported to be roughly proportional to the input of fertiliser nitrogen up to yearly rates of 350 to 500 kg N/ha (Whitehead 1970). In New Zealand, on the other hand, intensive livestock production systems have been developed on swards comprising clovers grown in association with temperate grass species. The substantial annual turnover of herbage nitrogen in grazed pastures, and the reliance placed on symbiotic nitrogen fixation to develop and sustain pasture production, are well recognised (Melville & Sears 1953; Sears & Evans 1953; Sears 1953c, 1956, 1960, 1962; Walker 1956a, b, 1962, 1968; Sears *et al*. 1965a; Levy 1970; Hoglund *et al*. 1979).

Very little fertiliser nitrogen has been used.

Grasses and white clover are normally grown together in mixed swards to capitalise on the better cool season activity of temperate grasses (Mitchell 1956), the yield advantage of grass-clover associations over a pure clover sward (Sears *et al*. 1965a; Harris & Thomas 1973), and the better seasonal spread of yield obtained from a mixture than from the component species in pure swards (Sears 1962). The attributes of white clover as a pasture legume have been reviewed elsewhere (Brougham & Jackman 1974), as have the ecology and management of white clover-based pastures (Brougham *et*

al. 1978).

The equitable climate in New Zealand allows almost all pasture herbage to be utilised *in situ* by grazing animals. To attain as close a match as possible between the seasonal pattern of pasture production and animal feed requirements, mating is timed so that lambs and calves arrive over late winter-early spring. The consequent increase in feed requirements is then met by more rapid pasture growth as the season progresses. Surplus pasture growth may be conserved as ensilage and/or hay, which is fed out during periods of deficit in pasture production. Use of feedstuffs other than pasture and its conservation products is of only minor importance.

2. Concepts of Nitrogen Relationships Based on Research in New Zealand

Grassland research, as opposed to ecological observation, was initiated shortly after manufactured fertilisers became freely available. New Zealand research has contributed a great deal to present understanding of nitrogen relationships in pastoral agriculture. Important concepts are listed below (with key references).

(a) The importance of vigorous clover growth to sward production, and of symbiotic nitrogen fixation to the performance of grass associates, was established (Sears 1953a, c; Sears *et al.* 1953, 1965a).

(b) Redistribution of the bulk of ingested plant nutrients in animal excrement was recognised as an important component of the 'fertility cycle'. At least 80% of ingested nitrogen was excreted, mainly in urine. This was considered the major pathway for transfer of fixed nitrogen from clovers to grasses (Sears *et al.* 1948, 1953, 1965a; Sears & Goodall 1951; Metson & Hurst 1953; Sears 1953c, 1956; Sears & Thurston 1953; Davies *et al.* 1962; Hutton *et al.* 1967; Weeda 1967, 1977; During 1972; MacDiarmid & Watkin 1971, 1972a, b).

(c) A pronounced aggregation of nitrogen in urine patches and dung pats was recognised. Small nitrogen losses through volatilisation of ammonia were observed, and leaching of nitrate was suspected, as a consequence of this aggregation (Thompson & Coup 1940, 1943; Doak 1952; Dale 1961; During & McNaught 1961; MacDiarmid & Watkin 1972a; Butler & Hopewell, G.W. Butler pers. comm.).

(d) Mineral nutrition was recognised as very important to clover performance. Within limits imposed by nitrogen availability, clovers were recognised as weaker competitors than grass associates for phosphate, sulphur and potassium (Sears et al. 1953; Walker & Adams 1958; Mouat & Walker 1959; Jackman 1960b; During 1972; Jackman & Mouat 1970).

(e) Climatic limitations to clover growth and nitrogen fixation were recognised. Parallel plot studies established that while a potential for annual fixation of about 620 kg N/ha existed in Manawatu, only half that figure was attained in cool-temperate Southland and even less in the dry Canterbury environment (Sears et al. 1953).

(f) Below-ground transfer of nitrogen from clovers to grasses was found to be important, with white clover capable of providing over 100 kg N/ha this way in a year, to soil and associated grasses. The extent of death and decomposition of clover root and nodule tissues was influenced by shading and defoliation, and differed between clover species (Butler & Bathurst 1956; Butler 1957; Sears et al. 1965a; Chu & Robertson 1974).

(g) A glasshouse study involving labelled ammonium and nitrate salts established that when white clover and ryegrass were grown together, clover derived little of its nitrogen by uptake of mineral nitrogen. The results were interpreted as indicating that changes in clover yield reflected corresponding changes in symbiotic nitrogen fixation (Walker et al. 1956; Walker 1956a).

(h) Grazing management was established as an important determinant of pasture performance. Providing nutrients other than nitrogen were adequate, contrasting ecological situations were recognised. With grass growth limited by severe nitrogen stress, as in early pasture development, grazing management had to be directed towards preventing 'shading out' of the weaker grass component, especially over summer-autumn; in more developed, grass-dominant swards the emphasis changed to prevention of shading out of the more prostrate clover component by taller grasses, especially over winter-spring. Systems of grazing management that involved frequent defoliation in spring, followed by less frequent grazing as drier weather occurred, encouraged strong growth of white clover (Sears 1956, 1962; Brougham 1966, 1973; Brougham & Jackman 1974; Brougham et al. 1975, 1978).

(i) Organic matter studies established that well managed, grass-clover pastures were fertility-building. Different ecological situations were recognised. Where resident organic matter was of the mor-type (Barratt 1966), characteristic of soils under scrub or regressed grassland in wetter areas, good pasture husbandry resulted in narrowing of soil carbon/nitrogen ratio and progressive conversion to mull over a period of 20 to 30 years. Where soil organic matter content had been reduced by cultivation of fertile soils, reinstatement of well managed pasture resulted in accumulation of mull organic matter over the ensuing decade or so. In both situations, soil nitrogen accumulated at maximum annual rates of about 110 to 120 kg N/ha, following a classical asymptotic pattern towards 'steady-state' organic matter levels. Little change was recorded below 15 cm, and allophane-like colloids were considered to enhance organic matter accumulation. Yearly accumulation of 190 kg N/ha was recorded in an impoverished soil below cut swards, but 310 kg N/ha when herbage was dried, ground and returned to plots (Baumgart & Browning, cited by Dixon & Jackman 1954;

Walker et al. 1959; Jackman 1960a, 1964a, b; Sears et al. 1965a).

(j) Fertiliser nitrogen studies gave no support to its use. Application of nitrogen at rates from 40 to 150 kg N/ha, generally in the late winter-early spring period, increased grass yields, but a subsequent 'slumping' in clover performance over the warm season resulted in an overall DM response which was small, or even negative, from cut swards (Hudson & McPherson 1933; Hudson 1934; Sears 1953b; Walker et al. 1953; Scott 1963). Those results were somewhat at divergence with recommendations drawn from the very large number of field trials conducted by staff of the Department of Agriculture. It was generally concluded that relatively small, tactical dressings of nitrogen had a place on heavily stocked farms, to offset feed shortages over the late autumn-winter-early spring period. Following prescribed use of nitrogen, appropriate pasture management could prevent any serious slumping in subsequent pasture performance (Hudson & Woodcock 1931; Lynch 1953; Lammerink 1959; During & Weeda 1968; Elliott 1969; Cumberland et al. 1970; During 1972; O'Connor & Cumberland 1973; O'Connor 1979).

3. Recent Developments in Farming and Research

(a) Farming patterns

Over the past 15 years, a swing away from supplementary forage cropping to 'all grass' management systems has been apparent (Stephen & McDonald 1978). An important practical consequence is that soils and pastures are generally at a more advanced stage of development than was the case when much of our pioneering research was being carried out 15 to 20 years ago. Soil organic matter levels are at or approaching a steady-state, and pastures are markedly grass dominant.

A better understanding of nitrogen relationships in developed pastures is needed. While appropriate for the time, most of our earlier research concentrated on developing swards.

(b) Fertiliser nitrogen

Nitrogen use on pastures varies according to prevailing cost-price relationships. Throughout the 1970's, use on grassland has totalled some 10 000 to 20 000 t N each year. Most of that is used tactically, as relatively small dressings to alleviate anticipated feed shortages on heavily stocked farms, under climatic conditions allowing a nitrogen response (Field & Ball 1978). While most dairyfarmers involved in year-round fresh milk production use some nitrogen to stimulate cool-season pasture growth, it would be common practice on only about 10 to 15% of factory-supply dairyfarms. However, a recent survey of top producers in the latter group revealed that over 80% use fertiliser nitrogen, some regularly and some only occasionally (Hutton 1977). Use of fertiliser nitrogen on sheep or mixed sheep and beef farms appears to be the exception rather than the rule. The writer knows of no farming situation in New Zealand where grazed pastures regularly receive more than 50 kg N/ha over a year, few where regular inputs would average more than 25 kg N/ha each year over the entire farmed area, and many where none is used at all. A significant part of the nitrogen used on grassland is associated with small seed production.

(c) Research findings and concepts

Important developments have taken place in related research. Adopting a mass balance approach, Allison (1955, 1965, 1966) has contributed a great deal to understanding of nitrogen relationships in many agricultural systems. Conservation of matter dictates that nitrogen inputs and outgoings must balance, after allowance for any change in nitrogen retention within an ecosystem. Even under intensive pastoral farming, nitrogen retention and outgoing in livestock growth and product removal is small; some 15 to 30 kg N/ha each year with sheep or beef farming, and 45 to 75 kg N/ha annually with dairyfarming (Whitehead 1970; Henzell & Ross 1973). Little if any soil nitrogen is accumulating in fertile grassland soils, so only a

relatively small annual input of nitrogen would be required to meet known retention and outgoings.

Henzell (1970) has seriously questioned the large estimates obtained for symbiotic fixation by pasture legumes, from studies involving any form of 'cutting and removal' management, and using a nitrogen balance on the soil-plant complex. Estimates for annual inputs of 500 to 700 kg N/ha, now incorporated into our grassland literature, were obtained in this way (Sears & Melville 1953; Sears & Evans 1953; Sears *et al*. 1953, 1965a). Inability to measure symbiotic fixation in grazed pastures has been cited as a serious impediment to better understanding of nitrogen relationships in pastoral ecosystems (Henzell 1970). However, recent development of two quite different techniques has allowed progress in this respect. By labelling the soil mineral nitrogen pool at frequent intervals with a minute quantity of stable isotope, the proportion of legume nitrogen obtained from the soil can be estimated (Vallis *et al*. 1967, 1977). The acetylene reduction assay of nitrogen fixation ($N_2(C_2H_2)$ fixation; Hardy *et al*. 1968) has also been developed for field use in New Zealand (Sinclair 1973, 1975; Sinclair *et al*. 1976; Hoglund & Brock 1978). Doubtless these techniques will be refined with time. Meanwhile, their application to studies in grass-clover associations in this country (Edmeades & Goh 1978; Hoglund *et al*. 1979) has provided estimates for fixation by white clover which are only a half or less of those derived from earlier mowing studies.

Understanding of nitrogen relationships would be more simple if clovers did meet almost all their nitrogen requirements by symbiotic fixation,

as has been contended. Citing many exceptions, Vallis (1978) questioned the premise that pasture legumes invariably obtain little of their nitrogen by uptake of mineral nitrogen. White clover in clover-dominant swards obtained more than 40% of its nitrogen from the soil, in a Queensland study (Vallis *et al*. 1977). Edmeades & Goh (1978) found that white clover obtained between 12 and 18% of total nitrogen from soil, throughout a year in Canterbury. Distinct seasonal contrast in 'fixation efficiency' (Hoglund *et al*. 1979) has also been observed, with efficiency much higher for clover growth over winter than during summer or autumn.

Recent studies in Manawatu, involving application of a mass balance approach to areas of developed pasture influenced by urine, have exposed an avenue for substantial nitrogen losses from the soil-plant complex in grazed ecosystems. Urine was applied to plots at rates considered likely to represent *in vivo* sheep and cattle urine patches (300 and 600 kg N/ha; Ball *et al*. 1979b, and unpublished data). Ammonia volatilisation, herbage nitrogen yield, $N_2(C_2H_2)$ fixation and mineral nitrogen transformations throughout the soil profile were then monitored, during separate runs under contrasting climatic conditions. Depending on urine rate and weather conditions, between 5 and 80% of urinary nitrogen volatilised as ammonia. Soil total nitrogen did not increase below the urine-treated swards. Comparison with values obtained from a control sward indicated that only some 20 to 40% of urinary nitrogen could be accounted for, either removed in cut herbage or present as nitrate at depth below the treated swards, three to five months after urine deposition (*loc. cit.*).

Ten years ago, the writer discussed the changing pattern of nitrogen relationships in developing pastures (Ball 1969) and pointed out that nitrogen inputs by symbiotic fixation must decline as pasture development proceeds. Not only does the annual yield of clover decline, but white clover would also obtain a greater proportion of its nitrogen from the soil, it was reasoned (*loc. cit.*). There is now an additional concept to superimpose on that developed earlier. The progressive increase in stocking rate normally associated with pasture development results in formation of an increasing quantity of urinary nitrogen within the ecosystem. As substantial losses of nitrogen have been associated with aggregation of nitrogen into urine patches, it follows that this avenue for nitrogen outgoings from the ecosystem becomes quantitatively more important as livestock density increases. Nitrogen removal in animal products and any transfer of animal excrement to unproductive parts of the ecosystem would add to those outgoings. Within the conceptual framework of a mass balance for nitrogen, it is contended that the plateau to production from grass-clover pastures (Sears 1960) is finally imposed by nitrogen relationships. As development proceeds, the increasingly vigorous growth of taller grasses suppresses white clover performance, so nitrogen inputs by symbiotic fixation decline. Superimposed is an increasing outflow of nitrogen from the ecosystem, as livestock density increases. It appears axiomatic that within limits imposed by climate, species and management, chronic nitrogen stress on grass growth must impose an upper limit to total forage

production from grazed grass-clover pastures.

It was reasoned previously that, with existing species, any increase in pasture production beyond this plateau would require recourse to fertiliser nitrogen (Ball 1969). In the decade since that view was formulated a number of detailed studies have recorded herbage yield responses to fertiliser nitrogen, in a variety of farming situations throughout the country: dairyfarming (Ball 1970; During 1972; Holmes & Wheeler 1973; Cumberland et al. 1970; O'Connor & Cumberland 1973); sheepfarming (Harris et al. 1973; Scott 1973; Steele 1976; Ball et al. 1978); beef (Sherlock & O'Connor 1973), and moist hill country (Ball et al. 1976; Luscombe 1979). Considered collectively, these results support the view that an upper limit to total forage production from well managed, grass-clover pastures is imposed by chronic nitrogen stress on grass growth.

4. Experimental Objectives

This study was undertaken to gain additional information on nitrogen relationships in a relatively mature, highly productive ryegrass-white clover association. Because of a dichotomy of views regarding application of results from cut swards to grazed ecosystems, sward performance and soil nitrogen were monitored under both grazing and mechanical defoliation. At the same time, a range of nitrogen treatments was included to test the hypothesis that soil nitrogen availability imposes an upper limit to total herbage production from grass-clover associations. The range of measurements made was to allow nitrogen balances to be assembled for the grazed and cut systems.

SECTION II

DRY HERBAGE YIELDS AND SWARD CHARACTERISTICS

A INTRODUCTION

Much of our earlier research was carried out in mown swards (Walker et al. 1953; Sears et al. 1965a). Alternatively, pasture performance was monitored by repeatedly mowing a central strip in grazed plots (Sears 1953a, c; Sears et al. 1953). This was valid for the experimental objectives and reflected the state of knowledge at that time. However, in view of subsequent reports of qualitative differences in sward performance under grazing and mechanical defoliation (Watkin 1954; Brockman et al. 1970; Sherlock & O'Connor 1973; Ball et al. 1976), or combinations of these (Watkin 1962), the application of some of those results to grazed pastures is open to question. It is indeed surprising that in a country where almost all forage is harvested directly by grazing animals, so much agricultural research has been conducted under cutting management. New Zealand scientists have directed little effort towards assessing the equivalence of pasture performance under grazing and cutting.

Relative to mechanical harvesting, grazing animals exert a variety of influences on pastures, both beneficial and deleterious. These effects have been the subject of a recent review (Watkin & Clements 1978). Most of the minerals and nitrogen contained in good quality forage consumed by ruminants are returned to the soil-plant complex in animal excreta. The influence of return of animal excreta has been widely studied and the benefits to pasture production are generally recognised (Sears 1953c; Watkin 1954; Jackman 1960a; Levy 1970; Whitehead 1970; Brockman et al. 1971). Because of pronounced partitioning of nutrients likely to limit pasture growth (nitrogen, phosphorus, potassium, sulphur and magnesium) between urine and dung, the effects of these two avenues of nutrient return have been subjected to separate scrutiny in some studies (Sears 1953a, c; Watkin 1954; Wolton 1955). The deleterious effect of

treading damage by grazing animals, on pasture production has been quantified (Edmond 1970) and discussed (Watkin & Clements 1978). While damage is possible whenever pastures are grazed, this effect may dominate only at critical times, with soils near saturation.

The influence of grazing animals as defoliators has also been widely studied. In grass-clover associations the effects are complex, with importance to light interception by swards, regrowth rates, competitive ability of various sward constituents, yield and botanical composition of pastures (Brougham 1960; Harris 1978; Watkin & Clements 1978), soil moisture relationships (Brougham 1959) and, because of the aptitude of sheep in particular for selective grazing, the grass-clover balance in mixed swards (Brougham 1966; Lancashire & Keogh 1968). These inter-related effects have been considered within the context of New Zealand farming conditions in formulating principles of grazing management for developing (Sears 1953c; O'Connor 1966; Levy 1970; Suckling 1975) and developed (Brougham 1970; Harris 1978) grass-clover pastures.

There are few reported comparisons of pasture performance under either grazing or mechanical defoliation, with management otherwise common to both treatments. Whitehead (1970) has reviewed relevant studies carried out in the United Kingdom. In many instances, such grazing vs cutting comparisons have been confined to pure grass swards, which provide a simpler situation for interpretation than do grass-clover mixtures (Whitehead 1970; Richards 1976, 1977). While in the United Kingdom, Watkin (1954) measured the performance of grass-clover swards, including responses to fertiliser nitrogen, under both sheep grazing and gangmowing. Over the first year, pasture production was very similar under both mowing and normal animal grazing, although mowing showed an advantage during autumn. In the second year differences became apparent, with gangmown pastures exhibiting the superior yield with no or a low rate of fertiliser nitrogen input, but superseded by grazed

pastures at the heavier rates of nitrogen application. In an extension to that line of investigation under New Zealand conditions, that author (Watkin 1962) measured higher dry herbage yields from gangmown pastures in all three years of a study in Canterbury. Yield superiority over grazed pastures was largely confined to the summer period, and resulted almost entirely from increased clover growth. It was considered that the greater clover yields in the mown pastures reflected both improved light relationships for clover growth, through removal of any tall grass hamper, and selective removal of clover tissues by the grazing animals. Following a study of the separate effects of cutting and grazing on nitrogen responses by grass-clover swards, also in the United Kingdom (Shaw *et al.* 1966), it was reported that grazed swards had a lower clover content than their mown counterparts, at all levels of applied nitrogen. This depression of clovers by grazing was considered to result partly from stimulation of grass competition by animal returns of nitrogen. As that effect did not entirely explain those results, treading damage and selective grazing by animals were also considered likely to have contributed (*loc. cit.*).

An inflated clover content would appear to be characteristic of mown swards. Over the three years of Watkin's (1962) New Zealand study, the average clover content of the grazed and mown pastures was 17 and 31% respectively, with clover contents falling as the study progressed. Similarly, the contribution by clovers to total herbage yield from control swards was 35% under grazing and 45% under cutting, in the two-year experiment conducted by Shaw *et al.* (1966). However, such an effect was not recorded in an earlier study by Sears and coworkers (Sears 1953a, c) at Palmerston North. They studied the response of mixed pastures to return of animal excreta, under both grazing and mowing, for four years. While no averaged effect of defoliation method on the proportion of clovers in the swards was apparent, some contrasts were noted within individual sub-treatments (Sears 1953a):

in the 'no return' series, the contribution of red clover was much greater under mowing than grazing, where the single-crowned plants were damaged 'by both treading and nibbling'; and where no complication arose from the presence of red clover, the proportion of ground cover by white clover was greater under mowing, interpreted as the result of less intense defoliation by the mower than sheep (loc. cit.).

Besides measurement under mowing, another feature of previous New Zealand studies into nitrogen relationships in pastures has been the emphasis placed on research in developing swards. On average, clovers contributed over half the total herbage yield from mixed swards in two such studies; the first conducted over a four-year experimental period (Sears 1953a) and the other, six years (Sears et al. 1965). Such a high clover/grass ratio reflected the poor soil nitrogen status of the two sites, as also indicated by the very low average annual yields of dry herbage (c 2 t/ha) from pure grass swards receiving no nitrogen as excreta or fertiliser. This emphasis on developing swards was pertinent to the then state of our pastoral industry. But the relevance of those results, particularly the very high levels of nitrogen fixation recorded, to the situation in well developed pastures on soils of high nitrogen status, has been questioned (Ball 1969; Ball et al. 1979a).

The study reported herein was undertaken to gain additional information on nitrogen relationships in highly productive, grass-clover associations. Aspects of the performance of a relatively well developed ryegrass-white clover sward were monitored under both grazing and mechanical defoliation. At the same time, a range of nitrogen treatments was included to test the view that nitrogen availability imposes an upper limit to total herbage production from a well managed grass-clover association, and to gain information on the nitrogen status of the experimental site. In this section, treatment effects on dry herbage yields and sward characteristics are reported. Effects on herbage

nitrogen, and mineral characteristics of herbage and soil, are considered in Section III. Treatment effects on soil nitrogen, and nitrogen balances in the grazed and cut associations, are considered in Section IV.

B MATERIALS AND METHODS

1 Site and Climate

This study was carried out at Grasslands Division, Palmerston North, during the period autumn 1972 to winter 1975 inclusive. A detailed account of the experimental site, its history and preparation for this study has been given (Ball *et al*. 1978). Details of cultural modifications to soil at the site are considered in Section IV, A. The recent alluvial soil (Manawatu fine sandy loam; Cowie 1972) was freely drained and inclined to drought. When measurements began, the area supported a vigorous 'Grasslands Ariki' ryegrass (*Lolium* [(*multiflorum* x *perenne*) x *perenne*)] - 'Grasslands Huia' white clover sward, which had been grazed by sheep for the two years from sowing.

Basal fertilisers were applied twice each year throughout the experiment, with the aim of precluding nutrient deficiencies other than nitrogen. Chemical analyses carried out on replicated soil samples before the study commenced, indicated a relatively fertile, uniform site, exhibiting marginal phosphorus deficiency (Ball *et al*. 1978). Accordingly, potassic superphosphate was applied each autumn (22.5 kg P/ha, 120 kg K/ha and 27.5 kg S/ha) and superphosphate each spring (45 kg P/ha and 55 kg S/ha).

To preclude sward failure through atypically dry conditions, supplemental irrigation was used. Water was applied to equate the monthly water receipt with its long term average rainfall if, and only if, that month's rainfall was less than two-thirds of its average, soil moisture was less than two-thirds of estimated field capacity and there was no immediate prospect of heavy rain. Following these criteria, water was applied on

the following dates at the nominal rates indicated:

Year I; Nov.-Dec., 51 mm; Feb., 32 mm; Mar., 57 mm.

Year II; Feb., 51 mm; Mar., 51 mm.

Year III; Nov.-Dec., 25 mm; Feb., 51 mm; Mar., 45 mm.

Owing to failure of the irrigation system, the stated policy was not adhered to in Year II.

Temperature and water relations over the experimental period are presented in Table 1. The outstanding climatic feature during the study was the very dry conditions encountered during the latter half of Year II. An estimated water deficit of 170 mm over mid spring-mid summer was followed by a further estimated deficit of 102 mm over mid summer-mid autumn. Average topsoil moisture level fell to half estimated field capacity over the mid spring-mid summer period and at one sampling (28 January 1974) had fallen to 7%. Considerable plant death occurred.

General views of the experimental area are presented in Fig. 1. The upper photograph was taken during early development of the experimental sward. The lower photograph, taken during summer of year I, clearly illustrates a benefit from the supplemental irrigation policy adopted. Both views incorporate little more than half the entire experimental site.

2 Treatments

(a) Method of defoliation: the performance of swards was compared when subjected to grazing by sheep, or continual mechanical defoliation.

Under grazing, large plots (0.025 ha) were periodically mob-stocked with dry sheep. Pasture yields were recorded under three, 2 m^2 cages located at random within each plot immediately before grazing. Sampling was, as nearly as possible, at the mid point of each grazing and normally took two days. Samples were harvested with an electric shearing handpiece, below which an adjustable skid was attached, to leave stubble

TABLE 1 - Climatic data (from Grasslands Division's recording station) and soil moisture levels over the experimental period

		Temperatures (°C)†					Water relations (mm)				Soil moisture (g water/100 g dry soil) §	
		Screen		Grass		Soil					Depth (cm)	
		Min.	Max.	Mean	Min.	0.1 m	Rainfall	Total water receipt	Potential evapotranspiration ‡	Deficit	0-15	15-30
Years												
I	18.4.72-17.4.73	17.3	8.8	13.1	5.9	12.3	740	880	688	-		
II	18.4.73-8.4.74	18.0	9.7	13.8	6.6	12.6	727	829	770	-		
III	9.4.74-15.4.75	18.3	10.1	14.2	7.4	13.1	1096	1217	876	-		
Autumn-winter												
I	18.4.72-1.8.72	13.6	5.1	9.4	1.9	7.8	277	277	83	-	25.2 ± 0.4	25.4 ± 0.4
II	18.4.73-31.7.73	14.2	6.7	10.4	3.7	8.1	271	271	82	-	25.0 ± 3.2	23.7 ± 2.3
III	9.4.74-14.8.74	14.3	7.1	10.7	4.6	9.2	526	526	126	-	26.6 ± 3.1	24.2 ± 2.5
IV	16.4.75-12.8.75	13.9	6.0	9.9	3.7	8.3	406	406	117	-	28.1 ± 1.8	25.8 ± 0.9
Winter-spring												
I	2.8.72-25.10.72	14.7	6.9	10.8	3.9	9.2	195	195	98	-	21.4 ± 4.6	21.4 ± 4.4
II	1.8.73-16.11.73	16.1	8.4	12.2	5.4	11.1	297	297	153	-	25.0 ± 5.5	24.3 ± 4.7
III	15.8.74-19.11.74	16.3	8.4	12.3	5.6	11.3	353	353	187	-	26.5 ± 3.0	24.2 ± 1.8
Spring-summer												
I	26.10.72-10.1.73	20.3	11.4	15.8	9.0	16.5	90	141	226	85	19.4 ± 2.9	20.5 ± 2.4
II	17.11.73-16.1.74	21.4	12.3	16.9	8.8	17.1	72	72	242	170	14.4 ± 4.9	15.8 ± 3.3
III	20.11.74-21.1.75	23.8	13.8	18.8	10.7	18.4	99	124	285	161	16.1 ± 6.0	15.9 ± 4.1
Summer-autumn												
I	11.1.73-17.4.73	21.3	12.5	16.9	9.6	16.6	178	267	280	13	16.1 ± 4.6	17.1 ± 4.4
II	17.1.74-8.4.74	22.9	13.1	18.0	10.2	17.0	88	190	292	102	15.4 ± 4.6	16.7 ± 4.4
III	22.1.75-15.4.75	22.4	13.7	18.1	11.1	16.9	118	214	278	64	16.4 ± 4.4	15.9 ± 3.5

† weighted means. ‡ raised pan evaporation X 0.8

§ arithmetic means (± standard deviations) from regular samplings.

FIGURE 1 - General views across the experimental area

During development; winter 1970

Experiment in progress; summer 1973

approximately equal to that left by the sheep. Samples from cages within plots were bulked and weighed, and sub-samples were taken for dry matter (DM) determinations and botanical analyses.

For continual mechanical defoliation (cutting), 3.72 m^2 small plots were maintained within the framework of the experiment. They were protected from grazing, and herbage was harvested at the same time and in the same manner as was that from the grazed plots. A petrol-driven vacuum cleaner, of the type used to pick up leaves and litter in public areas, was used to gather up cut herbage in all treatments.

(b) Nitrogen treatments: 7 were imposed.

1 (NO) = grass-clover, control sward;

2 (N56) = grass-clover sward receiving a total of 56 kg N/ha, in split dressings over the period late autumn to early summer (c 9 months);

3 (N112) = grass-clover sward receiving a total of 112 kg N/ha, in split dressings as above;

4 (N224) = grass-clover sward receiving a total of 224 kg N/ha, in split dressings as above;

5 (N448) = grass-clover sward receiving a total of 448 kg N/ha, in split dressings as above;

6 (N45 x 10) = grass clover sward receiving a total of 448 kg N/ha in equal splits throughout the whole year;

7 (Grass) = a sward maintained free of clovers, and receiving no fertiliser nitrogen.

All were measured under grazing, but only treatments 1, 3, 5 and 7 under cutting.

Treatments 1 to 5 were designed to cover nitrogen responses over the periods of the year when such responses had been shown to be most likely in this locality (Ball 1970a, b, 1973; Ball & Field in press). Treatment 6 was included to assess the extent of any response over the dry mid summer-mid autumn period. The purpose of treatment 7 was primarily to obtain information relevant to the nitrogen relationships considered in Section IV.

Nitrogen was applied as lime-ammonium nitrate

(23% N) throughout, to minimise soil pH shifts among treatments. In treatments 2 to 5 (N56 to N448) the annual nitrogen input was split in the following manner: 20% after a close defoliation in late autumn, 10% following defoliation near mid winter, 20% at the start of regrowth over late winter, then the remaining 50% as split dressings after each of the 4 or 5 defoliations over the spring-early summer period. In treatment 6 (N45 x 10) nitrogen was applied throughout the year, in equal splits after each defoliation. Clovers were removed from the original sward to create treatment 7 (Grass), by spraying with 'Tordon 75T' (a commercial formulation of 20% a.i. 2, 4,5-T (2,4,5-trichlorophenoxy-acetic acid) as the amine salt, with 7.5% a.i. picloram (4-amino-3,5,6-trichloropicolinic acid)). This was applied at 2.1 l/ha diluted to 340 l/ha in water, using a tractor-mounted boom spray, at the start of the study. Subsequently, volunteer clover plants were hand-weeded or spot-sprayed as necessary.

In the final year of the experiment a subsidiary study was undertaken to check for possible effects from the herbicide used, on sward performance. A pair of small plots (each 1.86 m^2) was randomly located within each replicate of the control pasture. The grass-clover swards had been grazed up to that point, when clovers were removed by either application of herbicide, as practised in the main experiment, or hand-weeding. Plots were protected from grazing and sward performance was monitored under cutting for 12 months.

3 Experimental Procedure

The interval between defoliations varied with seasonal changes in pasture growth rate, following guidelines for grazing management in this environment (Brougham 1970). A long spell of about 10 weeks was given over the late autumn-early winter period; 3-4 weeks over spring-early summer; and as little as two weeks during the mid autumn 'clean up'. Over the first year there were 12 defoliations. This was reduced to 10

in the subsequent two years, because of dry summer-early autumn conditions. The nitrogen application rate in treatment 6 (N45 X 10) was adjusted accordingly.

For the grazed swards, stocking rates were calculated in relation to expected yields, with all plots grazed at the same time over 3-5 days. Towards the end of each grazing, sheep numbers were adjusted in an attempt to leave a uniform stubble of 1-2 cm on all plots. Sheep were pre-fed on pasture of the relevant treatments for 24-36 h immediately before each grazing, and were managed to ensure that they entered and left the plots in a relatively empty state, to minimise fertility transfer.

The area was fenced so that plots were either neighbouring, or surrounded by an enclosed race. Additional sheep were held on these races to avoid any camping tendency among sheep occupying peripheral plots. Water was available to stock at all times.

Cut swards were protected during grazing by large cage exclosures. These were positioned just before each grazing, and removed immediately afterwards. A protective wire was fitted 25 cm out from the cage walls to prevent sheep from loafing and excreting near the plot edges.

To record any change in plant populations, sward 'plugs' (Mitchell & Glenday 1958) were taken from 4 treatments (NO, N112, N448 and Grass) for dissection in late autumn each year. Up to 50 plugs were taken from each grazed area, and 32 from each of the smaller cut plots. To minimise plot damage, the latter were replaced with plugs drawn from the protected area abounding the plots. Sampling took place some 4 to 6 weeks after reinstatement of a positive soil water balance in autumn. An additional set of samples was taken at the height of the growing season, but only from the grazed swards. It was considered that twice-yearly sampling would create undue disturbance in the cut swards, which were much smaller in area.

The severely dry conditions over the latter half of year II (Table 1) caused substantial sward damage. All

swards were under-drilled with 'G. Ariki' ryegrass at 28 kg/ha, on 1 April 1974, using a disc-coulter drill followed by light chain harrows. Surface soil disturbance was minimal. Both grass establishment and clover regeneration were excellent, resulting in reinstatement of a productive ryegrass-white clover sward within three months.

4 Design, Statistical Procedure and Format of Results

Treatments were randomly assigned to plots within each of 4 replicates. The small plots of the 'cutting' treatments were located, using randomised co-ordinates, within the corresponding grazed areas.

For 7 months prior to the imposition of treatments, data were collected on species' yields from individual plots. Tiller populations were also recorded immediately before the experiment commenced. This information was used for adjustment, by covariance analyses, of relevant data derived over the experimental period.

Analyses of variance were carried out using a statistical procedure which would accommodate the unbalanced design. This allowed tests of significance for main treatment (defoliation and nitrogen treatments) effects, but would not allow for interactions to be tested. Because of treatment differences in variance, neither standard errors nor least significant differences were calculated. To give an indication of error variance, co-efficients of variation (CV) have been tabulated.

Throughout this report adjusted means have been tabulated for herbage yields and sward characteristics. In some few instances this statistical procedure generated implausible values (e.g. a negative clover yield for the clover-free treatment). In deference to commonsense, such values have been expurgated from the tabulated data and replaced with an appropriate word (e.g. 'nil' or 'trace') in sympathy with the raw data.

Three or four significant figures were included in

the raw data for statistical analyses. Because of the volume of data collected, means have been severely rounded in some cases to facilitate tabulation. For the same reason, the format used in presenting results has been simplified. The comparison of principal interest among the nitrogen treatments is that between the grass-clover control (NO) and each of the other 6 treatments. Summaries of tests for significance are presented in full, only for those comparisons. Conventional symbolism is used throughout (ns = not significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$). Only data essential to development of concepts in this series of papers have been presented. A copy of the full range of all treatment comparisons, for all parameters recorded at each measurement, is held by the author.

To gain information on the extent of any interactions, annual data from the nitrogen treatments common to both methods of defoliation were subjected to separate analyses. Annual totals for dry herbage yield, and its components, were extracted for treatments NO, N112 and N448, and were subjected to analyses of variance as 2 X 3 X 4 factorials. The 'Grass' treatment data were also included in separate analyses as 2 X 4 X 4 factorials. In both cases, tests of significance were conducted on the defoliation X nitrogen treatment interactions.

C RESULTS AND DISCUSSION

1 Total and Species' Herbage DM Yields

Herbage dissections were carried out at each harvest, to apportion total yield among clover, ryegrass, other grasses, other species and dead herbage. For reporting, total yields have been aggregated among clover, grass and dead herbage components. The 'grass' component comprises all live, non-leguminous material (ryegrass, other grasses and weeds). Sown species made up the bulk of measured herbage. Clover was almost entirely white

(T. repens), with an occasional trace of red (T. pratense) and suckling (T. dubium) clovers. Ryegrass provided over 90% of the non-leguminous herbage measured over the first year, 82% in the second, and 88% in the final year. The remainder comprised other grasses (principal contributors being Poa spp., browntop (Agrostis tenuis) and goose grass (Bromus mollis)) and weed species (principal contributors being docks (Rumex spp.), dandelion (Taraxacum officinale) and common daisy (Bellis perennis)), in roughly equal proportions. There was no indication of a consistent relationship between the input of fertiliser nitrogen and the yield of either weed species or grasses other than ryegrass. Differences did develop, however, in the third year between defoliation treatments. Mean annual yield of grasses other than ryegrass from the grazed swards was higher than that from the cut swards (627 vs 441 kg DM/ha; result *). The reverse was the case with weed species' yields (787 vs 1090 kg DM/ha; result *).

Herbage yields are presented in Tables 2 and 3, together with summaries of statistical analyses. 'Seasonal' yields represent the aggregated yields from individual harvests as follows: (i) autumn-winter: incorporates yields following the 20% split dressing of nitrogen in autumn and a subsequent 10% dressing in early winter; (ii) winter-spring: incorporates yields following the 20% split dressing of nitrogen ahead of regrowth in late winter, and two subsequent 10% splits over early spring; (iii) spring-summer: incorporates yields over the remainder of the growing season, while split applications of nitrogen were continued; (iv) summer-autumn: nitrogen application was discontinued to all but treatment 6 (N45 X 10) over this seasonally dry period of the year.

(a) Method of defoliation (Grazing vs Cutting)

Grass yield over the year was higher under grazing in all three years, this difference becoming more pronounced as the experiment progressed (Table 2). Annual dead herbage yields under grazing were about

TABLE 2 - Annual and seasonal dry herbage yields (t DM/ha); adjusted means for defoliation treatments

	ANNUAL YIELDS		SEASONAL YIELDS							
			AUT.-WINT.		WINT.-SPR.		SPR.-SUM.		SUM.-AUT.	
	Grazed	Cut	Grazed	Cut	Grazed	Cut	Grazed	Cut	Grazed	Cut
YEAR I	(18.4.72 - 17.4.73)		(18.4.72 - 1.8.72)		(2.8.72 - 25.10.72)		(26.10.72 - 10.1.73)		(11.1.73 - 17.4.73)	
Total	19.01	16.79 ***	2.42	2.58 ns	4.58	4.44 ns	6.55	5.15 ***	5.48	4.65 ***
Clover	5.13	4.93 ns	0.33	0.35 ns	0.93	0.72 *	1.82	1.43 *	2.04	2.42 *
Grass	12.72	11.42 *	2.00	2.13 ns	3.58	3.67 ns	4.48	3.61 **	2.68	2.00 ***
Dead	1.14	0.54 ***	0.09	0.07 ns	0.06	0.06 ns	0.28	0.14 ***	0.74	0.26 ***
YEAR II	(18.4.73 - 8.4.74)		(18.4.73 - 31.7.73)		(1.8.73 - 16.11.73)		(17.11.73 - 16.1.74)		(17.1.74 - 8.4.74)	
Total	16.54	13.56 ***	2.70	1.85 ***	6.96	5.82 ***	3.71	2.85 **	3.17	3.03 ns
Clover	3.35	3.79 ns	0.37	0.45 ns	0.82	0.92 ns	0.32	0.50 **	1.83	1.92 ns
Grass	11.95	9.25 ***	2.25	1.36 ***	5.86	4.75 ***	2.72	2.14 *	1.12	0.99 ns
Dead	1.24	0.59 ***	0.07	0.04 **	0.29	0.16 ***	0.66	0.24 ***	0.22	0.16 **
YEAR III	(9.4.74 - 15.4.75)		(9.4.74 - 14.8.74)		(15.8.74 - 19.11.74)		(20.11.74 - 21.1.75)		(22.1.75 - 15.4.75)	
Total	18.69	15.07 ***	3.72	2.91 ***	7.30	5.92 ***	3.94	2.94 ***	3.73	3.31 *
Clover	2.82	3.55 *	0.65	0.79 ns	0.73	0.73 ns	0.45	0.52 ns	1.00	1.50 ***
Grass	14.21	10.74 ***	2.95	2.02 ***	6.28	5.05 ***	2.70	2.02 ***	2.28	1.65 ***
Dead	1.68	0.82 ***	0.13	0.10 ***	0.31	0.13 ***	0.78	0.40 ***	0.45	0.18 ***
YEAR IV	(AUT.-WINT. only)		(16.4.75 - 12.8.75)							
Total			3.23	2.82 **						
Clover			0.35	0.82 ***						
Grass			2.77	1.89 ***						
Dead			0.11	0.10 ns						

TABLE 3 - Annual and seasonal dry herbage yields (t DM/ha); adjusted means for nitrogen treatments

(a) ANNUAL YIELDS

	Nitrogen treatment†							CV
	0	56	112	224	448	45X10	Grass	(%)
YEAR I (18.4.72 - 17.4.73)								
Total	17.13	18.68	18.66	18.59	21.16	19.96	11.13	
		ns	*	ns	***	**	***	7
Clover	7.06	6.52	6.09	5.23	5.20	5.01	0.07	
		ns	ns	**	***	**	***	20
Grass	9.23	11.58	11.54	12.84	15.46	13.91	9.91	
		*	**	**	***	***	ns	14
Dead	0.80	0.74	0.82	0.73	0.97	0.92	0.88	
		ns	ns	ns	ns	ns	ns	18
YEAR II (18.4.73 - 8.4.74)								
Total	13.64	15.92	15.59	15.85	17.41	17.25	9.67	
		*	**	*	***	***	***	9
Clover	4.53	4.08	4.94	3.93	3.82	3.66	0.01	
		ns	ns	ns	ns	ns	***	29
Grass	8.16	11.11	9.69	11.30	12.90	12.50	8.53	
		**	ns	**	***	***	ns	16
Dead	0.87	0.87	0.85	0.94	1.03	0.97	0.88	
		ns	ns	ns	ns	ns	ns	19
YEAR III (9.4.74 - 15.4.75)								
Total	16.10	16.94	17.16	18.48	19.73	19.45	10.30	
		ns	ns	**	***	***	***	7
Clover	5.00	3.77	4.06	3.63	2.64	3.21	trace	
		*	*	*	***	**	***	27
Grass	9.92	12.01	11.86	13.83	15.92	14.87	8.95	
		*	**	***	***	***	ns	10
Dead	1.08	1.38	1.21	1.34	1.42	1.24	1.07	
		*	ns	*	***	ns	ns	14

† Statistical comparisons are between NO (control) and other nitrogen treatments.

TABLE 3 (Contd)

(b) SEASONAL YIELDS

	Nitrogen treatment†							CV
	0	56	112	224	448	45X10	Grass	(%)
Autumn-winter I (18.4.72 - 1.8.72)								
Total	2.21	2.44	2.43	2.65	2.99	2.86	1.83	
		ns	ns	**	***	***	**	9
Clover	0.40	0.44	0.41	0.38	0.40	0.33	0.02	
		ns	ns	ns	ns	ns	***	21
Grass	1.72	1.93	1.92	2.20	2.53	2.45	1.70	
		ns	ns	**	***	***	ns	11
Dead	0.09	0.07	0.08	0.06	0.07	0.08	0.11	
		ns	ns	ns	*	ns	ns	31
Autumn-winter II (18.4.73 - 31.7.73)								
Total	2.09	2.01	2.31	2.21	2.54	2.77	2.02	
		ns	ns	ns	**	***	ns	13
Clover	0.51	0.50	0.47	0.41	0.52	0.46	0.01	
		ns	ns	ns	ns	ns	***	36
Grass	1.54	1.46	1.80	1.73	1.96	2.26	1.89	
		ns	ns	ns	*	**	*	18
Dead	0.06	0.03	0.04	0.04	0.05	0.05	0.13	
		ns	ns	ns	ns	ns	***	47
Autumn-winter III (9.4.74 - 14.8.74)								
Total	3.17	3.29	3.27	3.44	3.70	3.72	2.60	
		ns	ns	ns	*	*	*	13
Clover	0.89	0.75	1.07	0.96	0.65	0.73	trace	
		ns	ns	ns	ns	ns	***	36
Grass	2.15	2.48	2.10	2.44	2.95	2.87	2.39	
		ns	ns	ns	**	*	ns	19
Dead	0.11	0.09	0.11	0.10	0.13	0.09	0.16	
		ns	ns	ns	ns	ns	**	24
Autumn-winter IV (16.4.75 - 12.8.75)								
Total	2.81	2.95	3.17	3.50	3.47	3.37	1.90	
		ns	ns	**	**	*	***	12
Clover	0.96	0.81	0.71	0.55	0.53	0.53	trace	
		ns	ns	*	**	*	***	43
Grass	1.78	2.04	2.41	2.78	2.76	2.73	1.82	
		ns	**	***	***	***	ns	17
Dead	0.08	0.08	0.09	0.12	0.11	0.12	0.12	
		ns	ns	ns	ns	ns	ns	39

TABLE 3 (Contd)

	Nitrogen treatment†							CV
	0	56	112	224	448	45X10	Grass	(%)
Winter-spring I (2.8.72 - 25.10.72)								
Total	4.10	4.58	4.70	4.71	5.55	5.10	2.82	
		ns	*	ns	***	**	***	10
Clover	1.33	1.07	0.94	0.99	0.76	0.71	trace	
		ns	**	*	***	***	***	26
Grass	2.69	3.50	3.69	3.71	4.78	4.29	2.72	
		*	**	*	***	***	ns	16
Dead	0.05	0.05	0.06	0.06	0.06	0.08	0.05	
		ns	ns	ns	ns	ns	ns	25
Winter-spring II (1.8.73 - 16.11.73)								
Total	5.73	6.53	6.91	6.86	8.05	7.59	3.07	
		*	***	**	***	***	***	9
Clover	1.32	0.96	1.44	0.77	0.83	0.76	trace	
		ns	ns	*	*	*	***	43
Grass	4.19	5.39	5.24	5.96	7.01	6.55	2.79	
		**	**	***	***	***	***	12
Dead	0.20	0.20	0.23	0.17	0.23	0.27	0.23	
		ns	ns	ns	ns	ns	ns	30
Winter-spring III (15.8.74 - 19.11.74)								
Total	6.24	6.37	6.80	7.36	8.17	7.72	3.58	
		ns	**	***	***	***	***	6
Clover	1.42	0.81	0.95	0.82	0.44	0.66	trace	
		**	**	**	***	***	***	44
Grass	4.57	5.44	5.61	6.41	7.57	6.81	3.24	
		*	***	***	***	***	***	9
Dead	0.22	0.22	0.21	0.21	0.24	0.21	0.23	
		ns	ns	ns	ns	ns	ns	25

TABLE 3 (Contd)

	Nitrogen treatment†						CV
	0	56	112	224	448	45X10	Grass	(%)
Spring-summer I (26.10.72 - 10.1.73)								
Total	5.71	5.98	6.03	6.22	7.29	6.49	3.20	
		ns	ns	ns	***	*	***	8
Clover	2.45	2.04	2.06	1.43	1.52	1.88	trace	
		ns	ns	**	***	ns	***	31
Grass	3.05	3.84	3.74	4.73	5.67	4.38	2.89	
		ns	ns	**	***	**	ns	18
Dead	0.17	0.17	0.19	0.18	0.24	0.20	0.21	
		ns	ns	ns	ns	ns	ns	25
Spring-summer II (17.11.73 - 16.1.74)								
Total	2.76	3.96	3.15	3.55	3.84	3.67	2.04	
		*	ns	ns	**	*	*	21
Clover	0.59	0.46	0.66	0.34	0.42	0.42	trace	
		ns	ns	*	ns	ns	***	42
Grass	1.70	3.13	2.05	2.77	2.99	2.73	1.63	
		**	ns	*	***	*	ns	27
Dead	0.45	0.40	0.40	0.55	0.56	0.48	0.33	
		ns	ns	ns	ns	ns	ns	26
Spring-summer III (20.11.74 - 21.1.75)								
Total	2.92	3.71	3.63	3.88	4.02	4.20	1.70	
		**	**	***	***	***	***	11
Clover	0.90	0.64	0.51	0.46	0.40	0.49	0.01	
		ns	**	**	***	**	***	46
Grass	1.57	2.37	2.51	2.76	3.00	3.01	1.32	
		**	***	***	***	***	ns	16
Dead	0.45	0.73	0.58	0.69	0.68	0.68	0.34	
		**	ns	**	**	*	ns	23

TABLE 3 (Contd)

	Nitrogen treatment†							CV
	0	56	112	224	448	45X10	Grass	(%)
Summer-autumn I (11.1.73-17.4.73)								
Total	5.10	5.68	5.48	5.01	5.35	5.50	3.31	
		ns	ns	ns	ns	ns	***	11
Clover	2.88	2.97	2.68	2.43	2.52	2.09	0.05	
		ns	ns	ns	ns	*	***	21
Grass	1.77	2.30	2.18	2.20	2.48	2.78	2.65	
		ns	ns	ns	**	***	***	18
Dead	0.48	0.45	0.48	0.42	0.60	0.56	0.51	
		ns	ns	ns	ns	ns	ns	25
Summer-autumn II (17.1.74-8.4.74)								
Total	3.06	3.42	3.22	3.25	2.98	3.22	2.55	
		ns	ns	ns	ns	ns	ns	15
Clover	2.12	2.17	2.38	2.41	2.05	2.02	trace	
		ns	ns	ns	ns	ns	***	31
Grass	0.74	1.12	0.59	0.84	0.93	0.96	2.21	
		ns	ns	ns	ns	ns	***	43
Dead	0.16	0.23	0.18	0.18	0.19	0.17	0.18	
		ns	ns	ns	ns	ns	ns	31
Summer-autumn III (22.1.75-15.4.75)								
Total	3.75	3.58	3.46	3.80	3.83	3.80	2.41	
		ns	ns	ns	ns	ns	***	13
Clover	1.80	1.56	1.53	1.40	1.14	1.34	trace	
		ns	ns	ns	**	ns	***	31
Grass	1.62	1.73	1.63	2.21	2.39	2.18	1.99	
		ns	ns	ns	**	ns	ns	24
Dead	0.29	0.35	0.30	0.33	0.37	0.25	0.34	
		ns	ns	ns	ns	ns	ns	24

† Statistical comparisons are between NO (control) and other nitrogen treatments.

double those recorded under cutting, in each of the three years. From near-equivalence in year I, relative clover yield from the cut swards increased as the experiment proceeded. In the final year, cut swards produced more clover than those under grazing. However, inspection of the annual yield data in Table 2 indicates that this result reflected a progressive decline in clover yield from the grazed swards rather than inflation of clover yield by cutting.

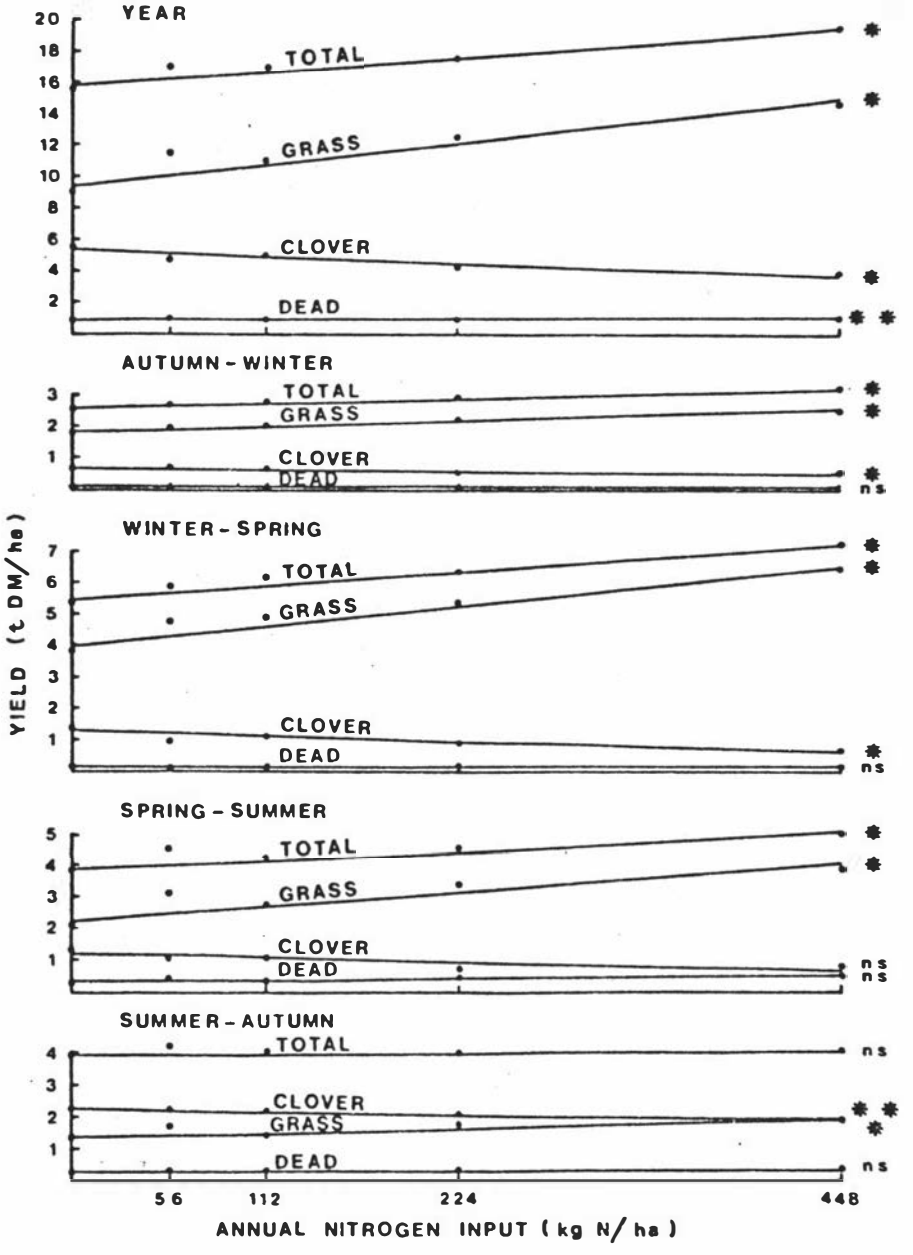
Under the experimental conditions, grazed swards clearly outyielded their cut counterparts. The yield superiority of the grazing treatment, in terms of both grass and dead herbage, was evident following mid spring-mid summer growth in year I, and then persisted over all seasonal periods throughout the experiment (Table 2). The reduction in clover yield associated with grazing in the second and third years did not fully offset the gains from other yield constituents. The increase in annual total dry herbage yield attributable to grazing (13 to 24%) became more pronounced as the experiment progressed.

(b) Responses to fertiliser nitrogen

Responsiveness of these grass-clover swards to fertiliser nitrogen is clearly established (Table 3), although there was some variability between years. To provide a general description of this response, the adjusted dry herbage means have been averaged over years (Table 3a) and individual seasons (Table 3b) for the NO, N56, N112, N224 and N448 treatments, and are presented in Fig. 2.

Examination of these data was frustrated by unaccountable variation among treatment means. Treatment N56, in particular, exhibited what appear to be some aberrant results: its total yield was similar to that recorded from N112 and N224 over years I and II (Table 3a); and it exhibited the highest yield among all treatments over the very dry spring-summer period of year II (Table 3b). Inspection of the experimental site revealed that three of the four replications of N56 occupied localised areas of deeper topsoil. This was confirmed

FIGURE 2 - Herbage DM responses to fertiliser nitrogen by grass-clover swards; averages of annual and seasonal yields (significance indicated for slope of regression lines)



from aerial photographs taken soon after the pronounced dry spell in year II. The relatively good performance of N56 under seasonally dry conditions is apparent from visual inspection of the seasonal data in Fig. 2, and is reflected in the average annual yields from that treatment. Unfortunately, this variation was not identified during the period of uniformity measurements, as the site was not then subject to severe moisture stress.

Linear regression analyses were carried out using these average annual and seasonal means to test for significant effects of fertiliser nitrogen rate on dry herbage yields. Separate regression analyses were conducted, first using all treatment means, then exclusive of data from the N56 treatment. The latter approach resulted in little change in the pattern of relationships recorded from the annual and autumn-winter data. However, it did result in significant slopes being recorded for the regressions of clover yield in winter-spring, total yield in spring-summer and grass yield in summer-autumn, all on annual nitrogen input. (These were not significant with N56 data included). In view of the author's circumspection about results from the N56 treatment, those data have been excluded from the linear regressions presented in Fig. 2.

Significant positive slopes were recorded in the regression lines for grass and total herbage yields over all three seasons when these swards were receiving fertiliser nitrogen. This relationship was reflected in average annual yields, with grass and total herbage increasing as the rate of nitrogen input increased. These averaged effects are largely supported by results recorded in individual years (Table 3a). Relative to control, N448 increased total yield in all three years, N224 and N112 in two of the three years, and N56 only in the second year. With one exception, annual yields of grass herbage were increased with nitrogen use, irrespective of application rate, in all three years.

Significant negative slopes were recorded in the regression lines for clover yield in two of the three

seasons when nitrogen was being applied to these swards. That clover yield fell as nitrogen rate increased was also evident in the average annual yields of clover herbage. Again, these averaged effects are largely in accord with the pattern of results recorded over individual years (Table 3a). In year I, when clover yields were generally substantial, reductions relative to control were recorded in swards receiving N112 and N448. In the second year, which was much drier (Table 1) and when clover yields were almost a third less on average, no significant reduction in clover yield was recorded. In the final year, clover yields were significantly reduced in all swards receiving nitrogen, irrespective of rate.

Over the mid summer-mid autumn period, when nitrogen applications were discontinued to all these treatments, residual responses were apparent in the averaged results (Fig. 2). Grass yields increased and clover yields decreased as the annual rate of nitrogen input increased. These two effects were complementary, as total herbage yield was virtually unaffected by nitrogen rate. That the slope of the regression lines for the grass and clover components was significant over this period would appear to reflect a smoothing of the data by averaging over the three years. Within individual years (Table 3b), the only residual effects recorded over the summer-autumn period were from the N448 swards; a significant increase in grass yield in the first and final years and a significant reduction in clover yield in the final year. However, results from the individual years confirm that total herbage yield was unaffected by nitrogen treatment over this seasonally dry period.

Average seasonal yields of dead herbage were unaffected by nitrogen treatment. However, the significant positive slope for the regression of average annual dead herbage yield on annual nitrogen rate (Fig. 2) indicates a minor effect. Within years (Table 3a), such an effect was recorded only over the final year, when dead herbage yield from the N448 swards was a modest 340 kg DM/ha greater than that from the control swards.

The performance of swards in treatment N45 X 10, to which split dressings of nitrogen were continued under seasonally dry conditions, was similar in almost all respects to that of N448, over this mid summer-mid autumn period. Both treatments received the same total input of nitrogen each year, but none was applied to N448 swards over this period. Yet, neither total herbage yield nor any of its components differed between these two treatments, over any of the three mid summer-mid autumn seasonal periods (statistical summaries not presented). Nor did either of these two treatments differ in total herbage yield from control over that period (Table 3b). Botanical composition was affected, however, with significant reductions, relative to NO, in clover yields and/or increases in grass yields recorded in the first and final years.

(c) Efficiency of nitrogen responses

To give an indication of the efficiency of herbage responses (kg additional DM/kg N applied) recorded from these grass-clover swards, total yield increments have been averaged over each of the three relevant seasonal periods, and years, for treatments N56, N112, N224 and N448. The averaged data are presented in Table 4. Bearing in mind the author's reservations over data from treatment N56, some trends are indicated.

Relatively low response efficiencies were recorded under the cool, moist conditions of mid autumn-mid winter. Under the better conditions for pasture growth over mid winter-mid spring-mid summer, greater response efficiencies are indicated. Values were at least double those recorded over mid autumn-mid winter, but they may have included some carry-over effects from nitrogen dressings in the preceding season (Sherlock & O'Connor 1973; Luscombe 1979).

The average annual efficiency values of the two lower rates of application are comparable to values of 12 to 20 attainable from relatively small, tactical dressings of nitrogen (Ball 1970a, b; During 1972). Average efficiencies at the two higher rates are similar to those

TABLE 4 - Average total dry herbage increments by grass-clover swards, and efficiencies of response, for seasons and year

	Nitrogen treatment			
	56	112	224	448
Autumn-winter				
Yield increment (kg DM/ha)	113	225	380	605
Nitrogen applied (kg N/ha)	16.8	33.6	67.2	134.4
Efficiency (kg DM/kg N)	6.7	6.7	5.7	4.5
Winter-spring				
Yield increment (kg DM/ha)	470	780	953	1747
Nitrogen applied (kg N/ha)	22.4	44.8	89.6	179.2
Efficiency (kg DM/kg N)	21.0	17.4	10.6	9.7
Spring-summer				
Yield increment (kg DM/ha)	757	473	753	1247
Nitrogen applied (kg N/ha)	16.8	33.6	67.2	134.4
Efficiency (kg DM/kg N)	45.1	14.1	11.2	9.3
Year				
Yield increment (kg DM/ha)	1557	1513	2017	3810
Nitrogen applied (kg N/ha)	56	112	224	448
Efficiency (kg DM/kg N)	27.8	13.5	9.0	8.5

reported by Holmes & Wheeler (1973), following heavy use of urea on dairy pastures in this locality. In his review of results from the United Kingdom, Whitehead (1970) concluded that nitrogen responses from grass-clover associations are generally smaller and much less reliable than those from pure grass swards, giving efficiency values in the vicinity of 12. These results would concur with that view, both quantitatively and in terms of the variability encountered in results.

(d) Performance of pure grass swards

The pure grass swards yielded less total herbage than the control grass-clover mixture (Tables 3a & 3b). No significant differences developed in grass or dead herbage annual yields, between the pure grass and control swards over the three year period (Table 3a). Some significant differences did emerge on a seasonal basis (Table 3b). Grass yields were either the same as or larger than those from the control swards over the mid autumn-mid winter and mid summer-mid autumn periods, when clover growth was active. A complementary relationship was observed over mid winter-mid spring, when white clover was relatively inactive. Then, grass yield from the cloverless swards was either the same as or less than that from grass-clover control. Viewed collectively, these results appear to indicate a seasonal competitive effect of white clover against grasses in the mixed swards. No significant difference in grass yields between these two treatments was recorded over the peak of the growing season, mid spring-mid summer. More dead herbage was measured in the pure grass swards only over the mid autumn-mid winter periods of years II and III.

Results from the associated study, to test for any effects on yield from the herbicide used to remove clovers, gave no indication of significant treatment effects on total annual dry herbage yield (weeded = 8.31 t DM/ha; sprayed = 8.55 t DM/ha; result ns) nor on any of the yield components (ryegrass, other grasses, weed species and dead herbage). Seasonal data indicated a small advantage to the sprayed swards initially, which

disappeared as the year progressed. This could be taken to indicate a temporary acceleration in rate of nitrogen release following spraying and death of clover tissues. However, the more likely explanation is that plant damage, caused by hand-weeding, temporarily impaired the performance of the weeded swards.

(e) Defoliation method X nitrogen treatment interactions

Of the 24 analyses of variance carried out on data from the nitrogen treatments common to both grazing and cutting, significant treatment interactions were indicated in three (summaries not presented): the grass component, whether or not data from the pure grass swards were included, and total dry herbage yield only when data from the pure grass swards were included; all in year I. Over the first year, the annual total yield of grass was higher under grazing in the pure grass and control treatments, but higher under cutting with N448. These effects were reflected in superior annual total herbage yields from the grazed pure grass and control swards, but a compensatory reduction (not significant) in clover yield from the cut N448 swards resulted in there being no difference between defoliation treatments in annual total herbage yield at this level of nitrogen input. In the annual dry herbage yields over the following two years, no treatment interaction was indicated for either of these yield components. Grass and total herbage yields were then invariably higher under grazing, irrespective of nitrogen treatment. Nor was any treatment interaction significant in the annual yields of the clover and dead herbage components, for any of the three years. In view of this relative absence of significant treatment interactions among the dry herbage yield components over the three-year experimental period, attention is focussed on main treatment effects throughout this report.

Greater error variance was associated with measurement of the minor yield components (clover and dead herbage; Tables 3a & 3b), than was the case for grass or total yields. This is reflected in the higher

CV values tabulated for the former and, doubtless, accounts for the failure of many recorded differences in clover and dead herbage yields to attain statistical significance.

2 Plant Populations and Sward Structure

Plant populations are reported in Table 5, together with summaries of analyses of variance for main treatment effects. As with dry herbage, much higher error variance was associated with measurement of the minor sward constituents (poa (*Poa* spp.), other grasses and weeds) than with ryegrass and white clover.

As a measure of clover populations, data were collected for both rooted clover nodes and total clover growing points (all nodes and terminal buds). As both forms of population assessment exhibited essentially the same response to treatments, only the results for rooted clover nodes have been presented.

Sward structure is reported in Table 6. To provide some indication of treatment effects on the extent of bare ground in particular, the proportion of plugs devoid of plants, bearing no grass tillers or no clover growing points, was calculated for all samplings. Presence of moss was not taken into account in the assessment of bare ground.

(a) Method of defoliation

Compared with grazing, continual cutting resulted in swards with a lower frequency of ryegrass tillers and higher frequency of rooted clover nodes, although the latter effect was significant in the autumn of years II and III only. Grasses other than ryegrass constituted 12 to 15% of the total grass tiller populations in autumn. While none of the results attained statistical significance at any sampling, the frequency of poa tillers was higher in the grazed swards, while remaining grasses were more abundant in the cut swards. Weed species, which constituted a very minor part of total plant populations, were more abundant in the cut swards in autumn of years I and III.

TABLE 5 - Plant populations in swards (growing points/dm^2); adjusted means for main treatment effects

(a) Autumn measurements in grazed and cut swards

	Defoliation		Nitrogen treatment†				CV
	Grazed	Cut	0	112	448	Grass	(%)
May 1973							
Ryegrass	77.0	49.6	39.8	49.5	51.3	112.7	
	***			ns	ns	***	26
Clover	50.4	59.0	79.7	75.6	64.7	trace	
	ns			ns	ns	***	29
Poa	9.5	8.9	5.3	9.2	3.9	18.4	
	ns			ns	ns	***	71
Other grasses	1.6	3.0	0.6	5.0	1.2	2.4	
	ns			ns	ns	ns	152
Weeds	1.1	1.9	2.2	1.5	1.4	0.7	
	*			ns	ns	ns	69
May 1974							
Ryegrass	76.3	46.5	48.9	40.1	42.1	114.5	
	**			ns	ns	***	40
Clover	35.2	46.4	55.6	60.0	46.3	1.2	
	**			ns	ns	***	24
Poa	6.8	2.3	3.1	1.3	7.2	6.7	
	ns			ns	ns	ns	155
Other grasses	2.4	7.2	0.6	6.6	1.4	10.6	
	ns			ns	ns	**	142
Weeds	1.8	2.5	3.7	2.4	1.5	1.0	
	ns			ns	*	**	71
April 1975							
Ryegrass	56.5	35.9	32.9	38.4	44.2	69.1	
	***			ns	ns	***	23
Clover	20.5	36.0	45.2	38.8	28.7	0.4	
	***			ns	**	***	33
Poa	3.1	1.9	1.2	1.2	1.0	6.5	
	ns			ns	ns	***	105
Other grasses	2.9	4.4	0.5	3.6	1.6	9.0	
	ns			ns	ns	**	134
Weeds	0.2	1.3	1.1	0.7	0.8	0.4	
	**			ns	ns	ns	141

TABLE 5 (Contd)

(b) Spring-summer measurements in grazed swards only (also March 1974)

	November 1972					November 1973				
	Nitrogen treatment†				CV	Nitrogen treatment†				CV
	0	112	448	Grass	(%)	0	112	448	Grass	(%)
Ryegrass	50.1	65.8	57.8	101.9		61.8	81.2	80.4	72.9	
		ns	ns	***	15		ns	ns	ns	14
Clover	58.2	49.4	34.1	trace		17.7	16.9	10.0	trace	
		ns	**	***	27		ns	*	***	41
Poa	13.1	11.8	10.5	20.3		28.4	19.5	10.1	32.9	
		ns	ns	ns	55		ns	ns	ns	56
Other grasses	2.3	0.3	trace	1.5		trace	0.3	0.3	1.8	
		ns	ns	ns	127		ns	ns	ns	188
Weeds	1.1	0.6	0.3	0.4		1.1	0.3	0.6	0.7	
		ns	ns	ns	86		ns	ns	ns	87

	December 1974					(March 1974)				
	Nitrogen treatment†				CV	Nitrogen treatment†				CV
	0	112	448	Grass	(%)	0	112	448	Grass	(%)
Ryegrass	70.4	90.0	80.7	97.4		13.5	23.4	4.2	81.1	
		ns	ns	ns	17		ns	ns	*	68
Clover	31.5	20.2	12.5	2.6		16.8	23.7	16.0	1.0	
		*	**	***	39		ns	ns	**	33
Poa	13.2	13.6	17.0	25.7		0.8	0.8	0.1	2.6	
		ns	ns	ns	49		ns	ns	**	63
Other grasses	3.9	1.3	0.8	3.8		0.2	2.5	2.4	3.2	
		ns	ns	ns	162		ns	ns	ns	110
Weeds	1.5	0.7	0.4	trace		1.2	0.7	0.9	trace	
		ns	**	**	72		ns	ns	**	64

† See footnote to Table 3.

TABLE 6 - Structure of swards; adjusted means for main treatment effects

(a) Autumn measurements in grazed and cut swards

	Defoliation		Nitrogen treatment†				CV
	Grazed	Cut	0	112	448	Grass	(%)
May 1973							
Without grass (%)	24.3	20.6	32.8	25.8	29.1	1.9	
		ns		ns	ns	***	40
Without clover (%)	26.8	20.4	nil	1.4	4.3	89.9	
		ns		ns	ns	***	76
Bare (%)	0.6	1.1	nil	nil	0.5	3.1	
		ns		ns	ns	**	195
May 1974							
Without grass (%)	21.7	27.1	23.6	34.2	36.5	3.2	
		ns		*	*	**	42
Without clover (%)	45.2	33.3	21.2	10.8	27.5	97.3	
		**		*	ns	***	23
Bare (%)	4.6	3.8	3.4	3.5	4.6	5.3	
		ns		ns	ns	ns	105
April 1975							
Without grass (%)	27.5	31.8	38.4	34.2	41.0	5.0	
		ns		ns	ns	***	31
Without clover (%)	52.4	33.8	18.3	19.0	36.9	98.2	
		***		ns	***	***	21
Bare (%)	6.6	2.9	3.2	3.6	8.9	3.2	
		*		ns	*	ns	94

TABLE 6 (Contd)

(b) Spring-summer measurements in grazed swards only (also March 1974)

	November 1972					November 1973				
	Nitrogen treatment†				CV	Nitrogen treatment†				CV
	0	112	448	Grass	(%)	0	112	448	Grass	(%)
Without grass (%)	19.5	18.1	23.3	14.1		21.5	20.1	26.3	5.1	
		ns	ns	ns	49		ns	ns	*	38
Without clover (%)	5.9	9.7	9.8	all		16.5	19.8	43.2	all	
		ns	ns	***	10		ns	**	***	21
Bare (%)	2.0	2.5	2.7	10.9		2.2	5.0	8.0	2.9	
		ns	ns	**	72		ns	ns	ns	76

	December 1974					(March 1974)				
	Nitrogen treatment†				CV	Nitrogen treatment†				CV
	0	112	448	Grass	(%)	0	112	448	Grass	(%)
Without grass (%)	14.3	23.8	34.6	nil		68.8	71.6	81.9	15.2	
		ns	*	ns	56		ns	ns	***	12
Without clover (%)	23.7	33.9	58.2	all		35.5	40.5	51.5	all	
		ns	**	***	20		ns	ns	***	16
Bare (%)	0.9	4.4	13.9	0.5		29.8	26.7	40.2	15.8	
		ns	**	ns	92		ns	ns	*	29

† See footnote to Table 3.

Bare ground was greater in the grazed swards in the final year, but no difference was apparent between defoliation treatments in either preceding autumn (Table 6). Compared with grazing, cutting resulted in a higher proportion of the area supporting rooted clover nodes in years II and III. The absence of treatment differences at all three autumn samplings, in the proportion of plugs devoid of grass tillers, indicated a similar pattern for dispersal of grasses throughout the grazed and cut swards.

(b) Fertiliser nitrogen treatments

Averaged over both defoliation methods, treatments N112 and N448 had only a minor influence on autumn plant populations. No consistent effect was recorded on the frequency of ryegrass, poa or other grass tillers. The heaviest rate of nitrogen application lowered the occurrence of rooted clover nodes, relative to control, in the final autumn. Weed frequency was lower in the N448 swards in autumn of year II.

Treatment effects recorded at the height of the growing season, when only the grazed pastures were sampled, were similar to those in autumn (Tables 5b and 6b). No consistent effect of nitrogen fertiliser was recorded on tiller frequencies of ryegrass, poa or other grasses. The sward of treatment N448 exhibited a lower frequency of rooted clover nodes at all three samplings, as did that of N112 in year III. The frequency of weeds declined in association with nitrogen use at the heaviest rate, in the final year.

Use of the heaviest rate of nitrogen increased the extent of bare ground, but only in the final year (both spring and autumn samplings). A higher proportion of area supporting no grass plants was associated with the N448 treatment, relative to NO, at the autumn sampling of year II and spring sampling of year III. The proportion of area devoid of clover growing points was higher in the N448 swards at the spring sampling of year II, and at both samplings in year III. Relative to control, no consistent treatment effects were exhibited by the N112 swards, whether in terms of bare ground or the proportion

of area devoid of grass or clover growing points. No explanation is offered for the significant increase, relative to NO, in the proportion of area supporting clover growing points in the N112 swards, at the autumn sampling of year II.

(c) Pure grass swards

The frequency of ryegrass, poa and other grass tillers was generally higher in the grass swards than in the grass-clover control, but differences did not always attain statistical significance. The occurrence of clovers and weeds was seldom more than one or two percent of that in control swards.

Compared with the grass-clover control, in autumn the pure grass swards exhibited a higher proportion of area bearing grass tillers. However, in spring this difference was apparent only in year II. The greater proportion of bare ground recorded in the first year was no longer apparent in the second and third years, as grasses spread to fill spaces caused by the removal of clovers from these swards.

(d) Sward characteristics at March 1974

Results from measurements made in the grazed swards, during March 1974, are included in Tables 5 and 6. Sampling took place as swards were recovering from a pronounced drought (Table 1), and followed supplemental irrigation with a nominal 51 mm water in both early February and March. The extremely low plant populations recorded, particularly for grasses (Table 5b), and the substantial extent of bare ground (Table 6b) were considered to vindicate the decision to undersow all swards that autumn.

A visual comparison of the contrast between grazed and cut swards under the drought conditions of summer 1974 can be gained from Fig. 3. The repeatedly cut, small plot is clearly visible within the grazed sward in the upper photograph. Below are depicted areas within both grazed and cut control swards. Selective grazing had greatly reduced the clover population, impairing clover performance under the dry conditions.

FIGURE 3 - Comparison of grazed and cut swards under drought conditions; mid summer 1974

Cut sward stands out in grazed pasture

Grazed sward

Cut sward

D GENERAL DISCUSSION

Average annual total herbage yields from previous, relevant studies at Palmerston North (Sears 1953a; Sears et al. 1965a) are presented, with the contributions by clovers to total yield, in Table 7. Averages have been extracted for appropriate grass-clover treatments from the two experiments. In the first (Sears 1953a), responses by swards to return of dung and urine were measured under both grazing and mowing, over a period of four years. In the second (Sears et al. 1965a), all treatments were measured under mowing for 6 years. Recycling of nutrients by animals was simulated by returning 80% of the cut herbage to appropriate plots, after it had been dried and ground, in the latter experiment.

The benefit of nutrient returns is obvious, lifting total yield by 22% on average over both studies. Attention has already been drawn to the very high clover content of these swards, a consequence of the poor soil nitrogen status at the two sites. Return of nutrients, whether as dung and urine or ground herbage, reduced the contribution of clovers to total yield. In the first experiment, mean total dry herbage yield was considerably higher under mowing than grazing. As discussed by the author (Sears 1953a), that result reflected, in part, a failure to measure pasture growth during periodic mob grazings, and possibly included an effect from selective grazing of early regrowth in the strips mown for pasture measurements in the grazed plots. No difference is apparent between grazing and mowing in the mean contribution by clovers to total yield, in that experiment.

Annual total herbage yields recorded from grass-clover pastures in the present study ranged from 13.6 to 21.2 t DM/ha (Table 3a) and are considered satisfactory in relation to other published yields from this locality. Lower annual yields in year II reflect the very dry conditions over the latter half of that year (Table 1). Yearly average total dry herbage yield of the control swards was 15.6 t/ha, to which the average contribution by clovers was 35% over the course of the study. Such a

TABLE 7 - Average annual dry herbage yields and clover contents of grazed and mown swards, with and without animal returns, in previous studies at Palmerston North

	No return		Full return		Mean	
	Yield (t DM/ha)	Clover (%)	Yield (t DM/ha)	Clover (%)	Yield (t DM/ha)	Clover (%)
Grazed †	9.5	58	11.2	43	10.4	51
Mown †	12.1	65	15.3	38	13.7	52
Mown ‡	11.5	59	13.6	47	12.5	53
Mean	11.0	61	13.4	43		

† Average of four years' data, from Sears 1953a.

‡ Average of six years' data, from Sears *et al*. 1965.

grass-clover balance is considered characteristic of pastures at an intermediate stage of development in this environment (Sears 1960; Ball 1976). On average over the experimental period, clovers contributed 21% of total herbage yield from the grazed swards (Table 2) and 27% from the cut swards (25 and 31%, respectively, if data from the Grass treatment is omitted).

1 Method of Defoliation

Over recent years there has been increasing use by staff within Grasslands Division of electric shearing handpieces, powered by portable generators, to harvest pasture samples. This method of mechanical defoliation is considered to allow the operator to simulate sheep grazing more closely than was possible with previous methods. It facilitates the harvesting of low-growing species, including white clover, from among the more tufted grass plants and allows minor irregularities in soil surface contour to be followed more closely than is possible with a reel or sickle bar mower, or scythe. However, the method is also subject to operator error or bias.

Frame & Hunt (1971) have discussed problems associated with achieving equivalence between cutting and grazing treatments. Agreement between cutting and grazing systems was better at their more intense levels of pasture utilisation. Fairly complete utilisation was the aim for all defoliations in the present study. During the early stages of this experiment, herbage measurements to ground level were carried out on stubbles immediately after defoliation. The results confirmed that quantitatively similar stubble yields remained after both grazing and cutting in the control, N112 and N448 swards.

More complete harvesting of clovers, including stolon tissue, may account for the failure to reproduce so dramatic a contrast in clover yields as that previously reported by Watkin (1954, 1962), when comparing grazed and gangmown pastures. Otherwise, the results are in reasonable accord with those reported by other workers. No explanation is offered for the lack of agreement

between these and Sears' (1953a) results recorded in the same locality (Table 7). Use of a reel mower in that study would have been expected to inflate clover content in their mown swards rather more than use of a shearing handpiece. A further point of divergence from results of previous studies (Sears 1953c; Watkin 1962) is that these results (Table 5) fail to support a previous conclusion that grazing animals are needed on pasture to restrict invasion of poa species.

The design of this experiment does not allow for the total yield superiority of the grazed swards to be attributed to any specific aspect of animal grazing. The grazing treatment embodied an interplay among the many influences, both beneficial and detrimental, which might be exerted on pastures by periodic mob grazings with sheep. By contrast, the cutting treatment represented a much simpler system, with herbage harvested to simulate sheep grazing and completely removed from the soil-plant complex. Walker (1956a) has likened the effect of grazing a grass-clover pasture to the use of fertiliser nitrogen on such pastures, either leading to an increased yield of grasses and lower production from clovers. This partial suppression of clovers he considered may be due mainly to the stimulation of grasses by excreted nitrogen.

On average, the amount of nitrogen recycled by animals in the grazed swards during each year of this study was considerably greater than that applied in the N448 treatment (525 to 710 kg N/ha; Sections III & IV). Doubtless, this played some part in producing higher yields from the grazed swards. However, the total dry herbage yield advantage to grazing (13%; Table 2) was minor in relation to that attributable to N448 (25%; Table 3a), over the first year of the experiment. This first-year superiority of grazing over cutting was almost identical to the result reported by Frame & Hunt (1971), working with perennial ryegrass dominant swards in Scotland. The total herbage yield superiority of the grazing treatment became more pronounced as this experiment progressed, reaching 24% in the final year

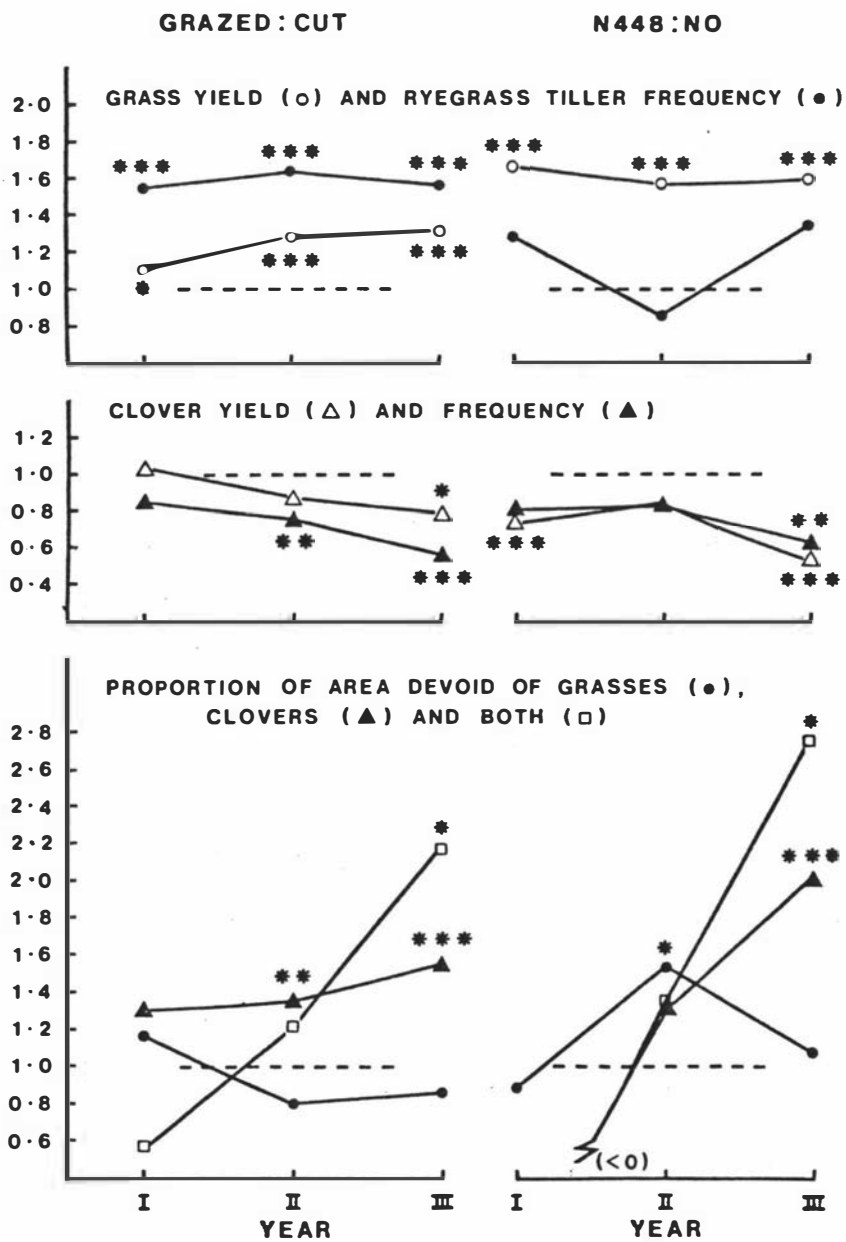
(Table 2). To the contrary, the total herbage yield advantage attributable to treatment N448 was a consistent 20 to 25% of the yield at NO, in each of the three years (Table 3a).

To facilitate comparison between the effects of defoliation treatments and effects from the heaviest rate of fertiliser nitrogen input, relevant data for the principal components of dry herbage yield (Tables 2 & 3) and sward characteristics in autumn (Tables 5 & 6) have been assembled in Fig. 4. These have been expressed as ratios (grazed:cut and N448:NO), with equivalence and significant treatment differences indicated.

Both grazing relative to cutting and N448 relative to NO reduced the annual yield of clover, the frequency of clover growing points and the proportion of area supporting rooted clover nodes, in the final year. There was divergence in the two preceding years: fertiliser nitrogen reduced clover yield in year I, while grazing did not; and grazing reduced the frequency of clover growing points and the proportion of area supporting rooted clover nodes in year II, while nitrogen did not. The extent of bare ground was increased by both the grazing and nitrogen treatments, in the final year.

Performance of the grass component of the swards provides a major contrast between these two treatment comparisons (Fig. 4). Grazing relative to cutting increased the annual herbage yield of the grass component, this effect becoming more pronounced as the experiment proceeded. However, N448 relative to control had a much more dramatic effect on annual herbage yield of grasses, a continuing feature of results over the three years. The relative advantage attributable to N448 was six-fold that attributable to grazing in year I. An opposing contrast is apparent in the tiller frequency data for ryegrass. Relative to cutting, grazing resulted in much higher tiller frequencies in all three years. This difference was marked at the first autumn sampling, and remained unchanged in subsequent samplings. Relative to control, N448 had no consistent effect on the frequency of

FIGURE 4 - Annual mean clover and grass DM yields and sward characteristics recorded in autumn, expressed as the ratios Grazed:Cut and N448:NO, throughout the experiment (significant treatment differences indicated; broken lines indicate equivalence)



ryegrass tillers, but it did increase the proportion of area bearing no grass tillers in year II. Considered together, these results show a marked increase in dry weight per ryegrass tiller in response to fertiliser nitrogen; an effect not apparent from grazing. Results for poa and other grass species' populations have not been incorporated into Fig. 4, as no significant treatment effects were indicated (Table 5).

To some extent, particularly in the performance of clover, comparison of these treatment differences supports the contention (Walker 1956a) that the effect of grazing can be viewed as a straightforward response to nitrogen. However, differences between the grazing and nitrogen treatments in their relative effects on important characteristics of the grass component in the swards, coupled with differences in the pattern of effects on total herbage yield, are taken to indicate that sheep-grazing exerted some additional influence on sward performance, which was quite separate from that associated with the recycling of nitrogen. It is concluded that selective defoliation of clovers contributed to the declining clover yield from the grazed swards. Drier summer-autumn conditions in the latter two years may have accentuated this effect (Brougham & Jackman 1974). The role of animals as selective defoliators may have been underemphasised in the past (Brougham *et al*. 1978).

Viewed as a whole, the results show a pattern of progressive development in differences between defoliation treatments over the study period (Table 2 & Fig. 4). The superiority in total dry herbage yield attributable to grazing in the first year was minor, but became more pronounced in subsequent years. While very similar in the first year, lower clover yields and a reduced clover content became a feature of grazed swards as the experiment progressed. A slow opening up of the grazed swards was indicated by a small increase in bare ground in the final year.

Dead herbage yields from grazed swards were double those from cut swards. This effect was fairly

consistent throughout the study, the average difference being 700 kg DM/ha each year (Table 2). The author does not place too great an emphasis on this result. With cutting, measurements were made repeatedly at the same sites, whereas with grazing cage exclosures were randomly relocated on fresh sites before each measurement. Any consistent refusal of dead herbage by the sheep would have inflated dead herbage yields measured from the latter treatment.

Results obtained under these experimental conditions would indicate that the technique of mechanical defoliation described in this paper could yield information applicable to pastures periodically mob-stocked with sheep, for measurement periods of up to a year, without marked errors. However, the major differences that developed between defoliation treatments in the first year became apparent over the main period of clover growth and water stress, mid spring-summer-mid autumn (Table 2). Had the study been initiated in mid spring, effects recorded over the first full year may have been equally apparent by autumn. Brockman et al. (1970), using a rather different cutting technique, concluded that while cutting management may be used for short-term experiments, its use in long-term experiments gives different results from grazing. These results concur with their view.

2. Fertiliser Nitrogen Responses

In the three seasons when swards were receiving fertiliser nitrogen, and in the annual totals, a classical response to nitrogen was exhibited (Fig. 2 & Table 3): total dry herbage yield increased; the response came from the grass (non-legume) component of the sward; and clover yields were depressed (Walker 1956b; Donald 1963; Crofts 1965; Whitehead 1970; Richards 1976; Ball & Field, in press). There was an indication of greater dead herbage accumulation at the heavier rates of nitrogen input, but this effect was minor.

A number of researchers (Watkin 1954; Walker 1956a; Linehan & Lowe 1960; Richards 1976) have reported that use of light dressings of nitrogen on mixed swards, while increasing grass yield, have resulted in a compensatory reduction in clover yield such that there is little change in total herbage production, unless heavier rates of nitrogen are used. In the present study, some reduction in clover yields did occur as the rate of nitrogen input increased, but this depression in clover yield did not fully offset the associated gains in grass production (Fig. 2 & Table 3). If anything, these results indicate a declining efficiency of response at the higher rates of nitrogen tested (Table 4), although the form of the averaged responses (Fig. 2) indicates that the rates of nitrogen tested did not cover the full range of the response curve. Further gains in grass and total herbage production, both annually and during relevant seasonal periods, might have been expected to an annual input of nitrogen in excess of 448 kg N/ha.

The effects of season and weather on fertiliser nitrogen responses by grass-clover pastures have been considered in detail elsewhere (Ball & Field, in press). Following classical studies into the responsiveness of mixed pastures to applied nitrogen, Blackman (1936) reported that grasses did not grow below a soil temperature (0.1 m depth, 0900 h) of 5.6°C; that between 5.6 and 8.3°C growth was limited by the rate at which soil micro-organisms mobilised soil nitrogen, and responses could therefore be expected; and that above 8.3°C the rate of release of mineral nitrogen from soil organic matter was sufficiently rapid to negate fertiliser nitrogen responses. In the absence of relevant information, Blackman's results have been applied to New Zealand conditions (Ball 1970a).

Climatic conditions at this site were not sufficiently extreme to preclude pasture growth over winter through cold temperatures. Mean soil temperatures over mid autumn-mid winter spanned a low of 7.8°C in year I to a high of 9.2°C in year III (Table 1). Responses

were recorded under these cool, moist conditions (Fig. 2 & Table 3b) but the response efficiencies were low compared with those recorded later in the season (Table 4). There was no clear indication that differences encountered between years in climatic conditions over mid autumn-mid winter affected the form of nitrogen responses recorded then (Table 3b). Views developed subsequently on responses to autumn-applied nitrogen (Ball & Field, in press) would indicate that larger responses would have occurred had the 20% split dressing been applied closer to the reinstatement of a positive soil moisture balance in autumn. In years I and II it was considerably delayed because of an associated soil sampling programme, and in the third autumn, because of under-drilling.

Responses were most clear-cut over the mid winter-mid spring period (Fig. 2). With few exceptions, nitrogen-treated pastures exhibited significant total dry herbage yield superiorities over control, irrespective of rate (Table 3b). While it may be concluded from the known temperature and moisture optima for soil nitrogen mineralisation (Harmsen & Kolenbrander 1965) that nitrogen mobilisation would have been increasing as the season progressed (Table 1), it is also apparent that the rate was insufficient to meet the nitrogen demand for potential growth by these swards. These results confirm the view that nitrogen responses by ryegrass-white clover pastures are generally large and reliable over the late winter and early spring, in this environment (During 1972; Ball 1973; Ball & Field, in press).

The first year was a little colder and the final year a little warmer than the average for the study period (Table 1). Colder temperatures in year I were particularly obvious in the autumn-winter and winter-spring periods, with mean screen, grass minimum and 0.1 m soil temperatures all 1 to 2^{o}C lower than those for corresponding periods in the other two full years. While allowing for small differences between years in the length of 'seasons' (Table 1), this contrast in temperatures

between years appears to have been reflected in the total yields measured over mid winter-mid spring (Table 3b). Total yields during years II and III were considerably higher than those recorded during the winter-spring period of year I, with yields in the final year a little larger than those in year II. Total yield response to the heaviest rate of nitrogen (1.5 t DM/ha) was smaller under the colder winter-spring conditions of year I than were those recorded in the following two years (2.3 and 1.9 t DM/ha respectively). However, responses in all three years reflected a similar proportional increase of 30 to 40% over the control yield for the winter-spring period.

Estimated water deficits occurred in spring-summer of all three years, and were reflected in the reduced gravimetric soil moisture levels recorded (Table 1). Against this background of progressive drying of the soil and rising temperatures, nitrogen responses were recorded (Fig. 2 & Table 3b). Obviously, these occurred at very much higher soil temperatures than the upper limit suggested by Blackman (1936). Mid spring-mid summer soil temperature averaged 17.3^{o}C (Table 1). In reviewing research results from the United Kingdom, Whitehead (1970) has suggested that Blackman's finding was unusual, and may have been influenced by a very high soil organic nitrogen content and relatively short regrowth periods. Ball & Field (in press) have also considered an interaction between soil moisture and mineral nitrogen availability, whereby soil nitrogen becomes progressively unavailable to pasture plants as the surface soil dries out, generally over late spring-early summer in this district. Providing that fertiliser nitrogen is applied while there is still sufficient moisture to ensure its incorporation into the surface soil, this practice can delay the retardation of grass growth associated with the onset of dry conditions (Mitchell 1957). Such an interaction is embodied in results from this study, with responses most clearly apparent in the grass component of the swards.

In this locality moisture stress generally restricts pasture growth, often quite severely, over mid summer-mid autumn (Brougham 1969). Notwithstanding the

supplementary irrigation practised, such was clearly the case during this study. Swards of one treatment (N45 X 10) received split applications of nitrogen over this period. No total yield superiority over control resulted at that time, in any of the three years, although some changes in botanical composition were recorded (Table 3b). This result confirms the conclusion reached earlier from small plot studies (Ball 1970a, b, 1973; Ball & Field 1978) that there is little to be gained from nitrogen use on mixed pastures, under seasonally dry conditions in this locality.

When the seasonal data were averaged (Fig. 2), a general pattern to residual responses by the nitrogen-treated swards was apparent over the dry mid summer-mid autumn period. As the annual rate of nitrogen input increased, grass yields increased and clover yields exhibited a complementary decrease, such that total dry herbage yields were unaffected by fertiliser nitrogen rate. Results from individual seasons (Table 3b) confirmed that total herbage yield was relatively insensitive to annual fertiliser nitrogen rate, over this period.

That no residual effect, relative to control, was recorded in total dry herbage yield from the nitrogen-treated swards over this dry period diverges from some previously published views. Following studies in the United Kingdom and New Zealand, Walker (1956b) cautioned against the risk of reductions in total yield following moderate applications of nitrogen to mixed pastures. His explanation was that as a result of an initial nitrogen response by grasses in spring, associated clover suppression would be expressed in reduced clover and total herbage yields over the following summer. The extent of clover suppression, he pointed out, would depend on species mixtures, defoliation management, and nutrient and moisture supply. However, the experimental conditions under which Walker and coworkers (Walker *et al*. 1953) measured such a result in Canterbury were extreme. In the relevant 'hay stage' treatment, swards were spelled for 71 and 103 days over spring-summer, under ideal

conditions for pasture growth. Such long spells would be expected to accentuate any clover suppression caused by an initial response to nitrogen. Clovers constituted almost 40% of measured yield from control swards, falling to 32% in their nitrogen-treated swards. While clover contents were similar in the present study, defoliation intervals were very much shorter over the main growing season. Watkin (1954) studied nitrogen responses in mixed swards, defoliated frequently to approximate sheep grazing. He found that pastures receiving a relatively small input of nitrogen (c 50 kg N/ha/an) showed a total yield response in spring and autumn, but associated clover suppression was pronounced relative to control swards with their strong clover growth over summer. In the second year of that study, when moister summer conditions were encountered, this 'slumping' in clover performance over summer was so pronounced that it caused a nett reduction in total herbage production for the year to be associated with nitrogen use at the lowest rate under test. Subsequent research (Wolton 1955) indicated that potassium deficiency may have substantially influenced results obtained at that site. Richards (1976) put forward the view that fertiliser could be combined with clover, as mixed sources of nitrogen for pasture growth, more successfully on soils of high potassium status. In the present study, basal fertilisers were applied at rates which were considered adequate to preclude deficiency of any nutrient other than nitrogen, and this may account for the absence of any relative failure by the nitrogen-treated swards over mid summer-mid autumn.

Sward failure following ammonium sulphate use, in the early studies at Marton (Hudson & McPherson 1933; Hudson 1934), can clearly be attributed to potassium deficiency. Plots were cut, and clippings discarded, for up to three years. Soil at the site is now recognised as one of the most potassium deficient in the country (Marton silt loam; Metson 1968). Following a subsequent field experiment in that area, During (1972) reported a

marked potassium response by white clover in sheep-grazed pastures. In deference to Hudson and coworkers, it is pointed out that they were researching in a 'pioneer' situation. A basal dressing of potassium was applied to their swards, but the writer estimates it to have been meagre in view of the defoliation management adopted. With hindsight, it may be viewed as a most unfortunate combination of site and experimental technique. Unfortunate, because the results led Hudson (1934) to conclude: 'These trials indicate that sulphate of ammonia cannot be used regularly and intensively without undesirable consequences'. In the writer's view, that set of experiments caused an almost complete disinterest in fertiliser nitrogen research on New Zealand pastures, over the ensuing 25 or 30 years. They are also considered the basis for almost automatic association of the terms 'nitrogen fertiliser', 'clover suppression' and 'slumping in pasture yield' in much of our grassland literature since.

Contrary to the observation of Watkin (1954), Lynch (1953) reported from New Zealand research experience that a slump in pasture production over summer, following spring responses to small nitrogen dressings, was likely to be more severe in dry than moist summers. To the extent that the influences of fertiliser nitrogen treatments on annual and seasonal clover yields (Tables 3a & 3b) was more pronounced in the first and last years, which were wetter than the intermediate year (Table 1), these results are more in sympathy with the view expressed by Watkin (1954).

3 Pure Grass Swards

The superiority of the grass-clover control swards over the pure grass swards illustrates the well-documented advantage to be gained from inclusion of an active legume component in pastures, both in terms of total yield (Sears 1953c; Sears *et al*. 1965a; Harris & Thomas 1973) and seasonal spread of yield (Sears 1962; Brougham & Jackman 1974; Brougham *et al*. 1978). Under

the conditions of this experiment, however, no advantage to the non-legume component of these swards was apparent as a consequence of the presence of clover. No significant differences developed in annual yields of grass or dead herbage, between the pure grass and control grass-clover treatments.

That the site was relatively fertile is indicated by the annual dry herbage yields of these clover-free swards, in the vicinity of 10 t/ha. Previous studies in New Zealand (Sears 1953a; Sears et al. 1965a) have been conducted on much less fertile sites, with clover-free swards exhibiting about one-fifth the total herbage yields recorded here. As reasonable steps were taken in all these experiments to preclude nutrient deficiencies other than nitrogen, the better performance of the pure grass swards in the present study must largely reflect a higher soil nitrogen status. While the situation could not have persisted indefinitely, it is surprising that no serious decline in annual non-legume yields was apparent over the three-year period. In the absence of any legume, these swards would have been almost entirely dependent on mobilisation of soil nitrogen to sustain their nitrogen requirements (Walker 1956a; Allison 1965; Sears et al. 1965a).

E CONCLUSIONS

1. Under the conditions of this experiment, grazed swards outyielded cut swards; grass yields and ryegrass populations were higher under grazing, while continual cutting eventually resulted in more clovery swards with greater populations of clover growing points.

2. Changes in sward performance and sward characteristics were gradual. Using the technique described, it would appear that results from studies involving repeated cutting of swards for up to a year can be applied to pastures periodically mob-stocked by sheep, without marked errors. The divergence in sward performance between cutting and grazing is likely to be

substantial thereafter.

3. Under the conditions of this experiment, availability of nitrogen from all sources in the grass-clover control swards was clearly not sufficient to meet requirements for potential growth. Responses to fertiliser nitrogen were recorded in growth over mid autumn-mid winter-mid spring-mid summer. No total yield responses were recorded over the seasonally dry mid summer-mid autumn period. Response efficiency values recorded over the main growing season were twice those recorded from responses under the cool, moist conditions of mid autumn-mid winter.

4. While showing some variability, nitrogen responses displayed a general pattern: increased total dry herbage yields; the response came from the non-legume component, principally ryegrass; and clover yields were depressed. There was no evidence that nitrogen use impaired subsequent sward performance, over the seasonally dry mid summer-mid autumn period. Annual dry herbage yields (14 to 17 t/ha) were increased 20 to 25% by use of the highest rate of nitrogen (448 kg N/ha/an) on these swards. The pattern of responses in relation to rate of nitrogen input indicates that further total yield increases would have resulted from even heavier rates of application.

5. The site was relatively fertile, sustaining annual dry herbage yields of about 10 t/ha from clover-free swards receiving no fertiliser nitrogen.

SECTION III

HERBAGE NITROGEN, AND MINERAL CHARACTERISTICS OF HERBAGE AND SOIL

A INTRODUCTION

Characteristics of the New Zealand pastoral industry were considered briefly in Section I. Almost all forage is harvested *in situ* by sheep and cattle.

Grazing animals exert a variety of influences on pastures, both detrimental and beneficial. When reviewing New Zealand research on this subject, Sears (1956) stated: "In practice, the separate effects of treading, grazing and manuring act together, but their relative importance depends on local conditions .... the animal factors can all be of major importance, and considerable mental effort is needed to use them in combination to the best advantage of the pasture, from sowing to final ploughing". These effects have been the subject of a recent review (Watkin & Clements 1978).

Attention has been drawn to the necessity for incorporation of the effects of grazing animals on pastures during field experimentation (Lynch 1947; Sears 1951). Yet few studies have been carried out in this country to compare pasture performance under either grazing or mechanical defoliation, with management otherwise common to both treatments. Relative to mechanical harvesting, a major advantage ascribed to the grazing of pastures is that 80 to 100% of ingested plant nutrients are returned to the soil-plant complex (Sears 1956). The manurial benefits of excreta from grazing animals are widely recognised (Sears 1953c, 1960; Watkin 1954; Wolton 1955; Jackman 1960a; Walker 1962; Brockman *et al*. 1970).

Another feature of New Zealand's pastoral agriculture is almost complete reliance on symbiotic nitrogen fixation by legumes, principally white clover,

for the inputs of nitrogen required to sustain pasture production. Little use has been made of fertiliser nitrogen. While early research in this country (reviewed in Section I) contributed a great deal to present understanding of nitrogen relationships in grazed, grass-clover pastures, emphasis then was on development of productive pastures on low fertility sites, either scrubland or deteriorated grassland. Development sequences have been described for lowland (Sears 1960; Walker 1962; Levy 1970), hill country (Suckling 1959, 1975; Levy 1970) and high country (O'Connor 1966).

In essence, pasture development requires that nutrient deficiencies other than nitrogen are alleviated (generally by heavy dressings of superphosphate) and that any impediment to successful establishment of the legume-rhizobial symbiosis is removed (by liming acid soils and/or application of molybdenum). Improved pasture species, especially white clover, must be established. There follows a period of clover dominance, aided by continuing heavy inputs of basal fertilisers (generally superphosphate only) and grazing management directed towards utilising the forage produced as fully as is compatible with stock and pasture thrift. Over a period of years, nitrogen availability in soils gradually increases, promoting more vigorous grass growth, and clover dominance gives way to grass dominance and higher annual yields. With the full development of soil fertility, fertiliser inputs decline to maintenance rates and a plateau in annual yield is reached with the bulk of annual production coming from the grass component of developed swards. This development sequence seems to have wide generality to temperate grasslands (Donald 1963; Lowe 1966; Wolfe 1972; Brougham *et al*. 1978).

Grazing animals play an important biological role in such development sequences. (Fencing and water supplies must be adequate to allow stock control.) As defoliators, animals are managed to prevent ingress of weeds and to minimise the dominance of clovers over

grasses during early development, or dominance of grasses over clovers during the later, grass-dominant phases (Sears 1962; Brougham et al. 1978). The 'shower of fertility' (Sears 1956; Levy 1970) in animal excreta is considered to be of vital importance in effecting the transfer of symbiotically-fixed nitrogen from clovers to associated grasses (Walker 1956a, b; Sears 1956, 1960; O'Connor 1966; Levy 1970; Jackman 1971a, b).

As long as attention is paid to lime requirements and adequate provision of all non-nitrogenous plant nutrients, soil nitrogen availability occupies a focal position in determining ecological changes during pasture development (Sears 1962; Levy 1970; Brougham et al. 1978) and is considered to set an upper limit to pasture production from mixed swards, within limits imposed by climate, soils, species and grazing management (O'Connor 1966, 1974; Ball 1969, 1976; Jackman 1971a, b; Harris & Thomas 1973). Working in Australia, Wolfe (1972) found that the transitional period between clover and grass dominance could be substantially shortened if judicious use were made of combined nitrogen in the fertiliser programme during pasture development.

When considering the management of grass-clover associations in New Zealand, Walker (1956b, 1962) stated that the aim is to produce the highest possible yield of grasses consistent with maximum nitrogen fixation by clovers. In developed pastures, the defoliation management required for those two aims is substantially in opposition. As stated by Jackman (1971b): '.... an inherent contradiction in the grass-clover pasture. Management for high nitrogen fixation implies management for clover dominance, but this will prevent the greater production inherent in grasses. Conversely the maintenance of an adequate leaf area index for grasses (to maximise growth rate) must mean shading of clover and reduced nitrogen fixation. The conditions for high nitrogen fixation and high production must conflict'. The writer (Ball 1969) reasoned that the established

plateau in total herbage production (Sears 1960) was imposed by chronic nitrogen deficiency, and that further yield increases from developed, mixed pastures would not be possible without recourse to fertiliser nitrogen.

Following grazing trials on New Zealand dairyfarms, Hudson & Woodcock (1931) reported that prescribed use of ammonium sulphate gave responses approaching one kg milkfat, plus some additional feeding for dry stock, from each kg nitrogen applied. Those authors recommended the practice, which was considered profitable with the cost-price relationships prevailing then, and viewed strategic use of nitrogen as 'well worth while' in the town milk industry with its higher return for milkfat. Their views were not supported by results from subsequent plot studies (Hudson & McPherson 1933; Hudson 1934), where serious clover suppression and a 'slumping' in total pasture growth were recorded in response to nitrogen use, even though attention was paid to adequate lime and superphosphate inputs. The failure of those early experiments has been ascribed to severe potassium deficiency at the trial site (Section II, D). Sears (1953b) applied 50 to 100 kg N/ha/an as ammonium sulphate or sodium nitrate to mixed swards receiving 'full return' of dung and urine. These mid-late winter nitrogen dressings resulted in only small visible responses for about 6 weeks after application, and had only negligible effects on annual dry herbage yields. All treatments retained a botanical composition of 60 grass:40 clover over the two and a half year study, with no marked 'slumping' of pasture growth or depression of clover recorded over the warm season. Uniform distribution of urine with a watering can, which was carried out to plots of the 'return' series (Sears 1953a), would have elevated nitrogen availability to all treatments in that study.

Following experience in both the United Kingdom and New Zealand, Walker (1956b) made a valuable contribution to our understanding of the course of events when fertiliser nitrogen is applied to mixed swards. The following sequence of events was considered likely.

Taller-growing grasses take up by far the major part of any applied nitrogen, and the resulting stimulation to growth enhances their ability to compete for light, nutrients and water. Suppression of associated clovers results, the extent depending on species' mix, nutrient and moisture supplies, and defoliation management. If any nutrient other than nitrogen is seriously limiting, clover suppression is intensified, as grasses compete more successfully than clovers for nutrients commonly limiting pasture growth (phosphorus, potassium and sulphur). Under conditions of moisture and nutrient adequacy, the length of time for which pasture is spelled following nitrogen application was considered the major determinant of clover suppression (loc. cit.). Clover persistence is better with more frequent defoliation to reduce shading, although this probably also produces lower dry herbage yields richer in nitrogen in response to the initial dressing of nitrogen, Walker reasoned.

Following a study in Canterbury, in which a ryegrass-white clover pasture was cut for conservation as dried grass, silage and hay stages of regrowth, (Walker et al. 1953) it was reported that applications of up to 80 kg N/ha gave negligible increases in total dry herbage yields; increased grass yields being almost offset by a compensatory fall in clover yields. Sulphate of ammonia suppressed clovers more than did lime-ammonium nitrate or urea. His experience led Walker (1956a) to express the view that while the insignificant part played by fertiliser nitrogen in New Zealand's pastoral industry was partly due to its high cost, with the very high production possible because of high nitrogen fixation by clovers it was doubtful whether fertiliser nitrogen would normally be beneficial, even if it were cheaper.

Some support for this view came from overseas studies on mixed swards about that time. Working in the United Kingdom, Watkin (1954) reported a depression in total dry herbage yield following annual application to a mixed sward, of some 50 kg N/ha as lime-ammonium nitrate.

This result was recorded only in the second year of the study, when weather conditions particularly suited clover growth over summer. Then, clover suppression lowered total production from the nitrogen-treated sward, relative to grass-clover control, which exhibited strong clover growth under the prevailing conditions. Over the same year, annual crude protein yield in mixed herbage was little better from the sward receiving the highest rate of nitrogen input (350 kg N/ha/an) in the absence of animal 'returns', than from the control sward. In part, the latter result reflected the reduced contribution of protein-rich clover herbage to total yield, associated with use of nitrogen. In Northern Ireland, Linehan & Lowe (1960) applied a range of nitrogen rates (0 to 400 kg N/ha/an) to cut grass-clover swards, and measured dry herbage and crude protein yields over a five-year period. Clovers contributed 36% to the yearly average 5.5 t DM/ha measured from control. While dry herbage yield increased with successive increments of nitrogen, the contribution by clovers fell, reaching 1% in association with an annual input of 235 kg N/ha. This progressive displacement of clovers from the swards resulted in there being no increase in crude protein yield, over control, unless nitrogen rates in excess of 140 kg N/ha/an were applied. Similar results were reported from Holland by Dilz (1965), who studied the response of cut ryegrass-red clover mixtures to a range of nitrogen rates (0 to 225 kg N/ha/an). On a soil of low pH, clover growth was poor, so a near-linear response to nitrogen was measured in total yield. At near-neutral pH clover growth was excellent, and the response by ryegrass to nitrogen was substantially offset by reduced clover yields.

A recent paper (Richards 1976) considers the complexity of responses by grass-clover swards to applied nitrogen. Following numerous field trials in the United Kingdom, two distinctly different relationships are described. The more common relationship is that in which an increase in grass nitrogen yield, through

fertiliser application, gives little increase in total herbage nitrogen yield until the sward becomes distinctly grass dominant. Under these conditions, clover nitrogen and fertiliser nitrogen were considered incompatible, the one largely substituting for the other in determining crude protein yields, at least over the lower range of nitrogen inputs. An alternative, less common relationship was also identified, where clover and fertiliser nitrogen could be combined more successfully: clover suppression associated with increasing nitrogen input and greater grass nitrogen yield was much less severe, so total crude protein response was near linear. While the causes of variability in these relationships were not considered to be clear, that author commented that relationships of the latter type arose from studies on soils which tended to have higher available potassium status (loc. cit.).

The study reported herein was undertaken to gain additional information on nitrogen relationships in highly productive, grass-clover associations. Aspects of the performance of a relatively well developed ryegrass-white clover sward were monitored under both grazing and mechanical defoliation. At the same time, a range of nitrogen treatments was included to test the view that nitrogen availability imposes an upper limit to total herbage production from a well managed grass-clover association, and to gain information on the nitrogen status of the experimental site. Treatment effects on dry herbage yields and sward characteristics are reported in Section II. Effects on herbage nitrogen, and mineral characteristics of herbage and soil, are considered in this section. Treatment effects on soil nitrogen, and nitrogen balances in the grazed and cut associations are reported in Section IV.

B MATERIALS AND METHODS

1 Site and Climate

This study was carried out at Grasslands Division,

Palmerston North, over the period autumn 1972 to winter 1975, inclusive. A detailed description of the site, and climatic conditions throughout the three-year experimental period, has been given (Section II, B, 1). The outstanding feature of the climate over this three-year period was the very dry conditions encountered over the mid spring-mid autumn period of the second year (Section II, Table 1).

Chemical analyses of representative soil samples, carried out before the study commenced, indicated a relatively uniform, fertile site exhibiting marginal phosphate deficiency (Ball et al. 1978). Topsoil C/N ratio was 9.5 (organic C, 1.74%; total N, 0.183%) and pH 6.1 (CEC, 11.4 me %; base saturation, 97%). A small plot study, carried out at the site before this experiment was initiated (R. Ball, unpublished data) confirmed marginal phosphorus deficiency, but only during late autumn-early winter regrowth. No responsiveness to potassium or sulphur was indicated, even though neither of these elements had been applied to the test area over the preceding three years. Responses to fertiliser nitrogen were recorded in that preliminary study.

A basal fertiliser policy was adopted with a view to precluding any likelihood of nutrient deficiencies, other than nitrogen. Potassic superphosphate (22.5 kg P/ha, 120 kg K/ha and 27.5 kg S/ha) was applied each autumn and straight superphosphate (45 kg P/ha and 55 kg S/ha) each spring. The whole area received a dressing of dolomite (15 kg Mg/ha) shortly before treatments were imposed.

2 Treatments

A detailed account of treatments has been given (Section II, B, 2).

(a) Method of defoliation: the performance of swards was compared when subjected to periodic mob-stocking with dry sheep (grazing) or repeated mechanical defoliation with a shearing handpiece (cutting). All

material harvested from the cut swards was removed from the area. Otherwise, management was common to the two defoliation treatments, with herbage harvested at the same time and in the same manner at each measurement.

(b) Nitrogen treatments: 7 were imposed.

1 (NO) = grass-clover, control sward;
2 (N56) = grass-clover sward receiving a total of 56 kg N/ha, in split dressings over the period late autumn to early summer (c 9 months);
3 (N112) = grass-clover sward receiving a total of 112 kg N/ha, in split dressings as above;
4 (N224) = grass-clover sward receiving a total of 224 kg N/ha, in split dressings as above;
5 (N448) = grass-clover sward receiving a total of 448 kg N/ha, in split dressings as above;
6 (N45 X 10) = grass-clover sward receiving a total of 448 kg N/ha in equal splits throughout the whole year; and
7 (Grass) = a sward maintained free of clovers and receiving no fertiliser nitrogen.

All were measured under grazing, but only treatments 1, 3, 5 and 7 under cutting.

3 Experimental Procedure

A detailed account of sward management and methods of measurement has been given (Section II, B, 2 & 3). There were 12 defoliations in the first year, but this was reduced to 10 in each of the subsequent two years, because of dry summer-early autumn conditions. The nitrogen application rate to treatment 6 (N45 X 10) was adjusted accordingly.

Nitrogen treatments were maintained within individual, small paddocks to preclude the possibilities of selective defoliation or transfer of nitrogen, between treatments, by the grazing animals. Sheep were pre-fed for 24 to 36 h on pasture receiving the relevant treatments, before entering the experimental swards, and were managed to minimise fertility transfer. 'Sheep-

days' were recorded for all treatments at each grazing. Cut swards were adequately protected from any influence of grazing animals.

Herbage samples from the three cages within grazed plots were bulked. All samples were weighed fresh, and after careful mixing sub-samples were drawn for dry matter determinations, botanical and chemical analyses.

For chemical analyses, individual clover and 'grass' samples (mostly ryegrass, but including all live, non-leguminous herbage) were separated by hand from the fresh herbage, dried overnight at 80°C in a forced-air oven, then ground and stored. When dead herbage comprised a significant part of total yield it was similarly separated for total nitrogen analyses. To keep within realizable working limits, individual analyses were only carried out on bulked samples representing four 'seasonal' periods, corresponding to those reported in Section II. They were: (i) mid autumn-mid winter: incorporating regrowth following a 20% split dressing of nitrogen in autumn and a subsequent 10% dressing in early winter; (ii) mid winter-mid spring: including yields following a 20% split dressing of nitrogen ahead of regrowth in late winter, and two subsequent 10% splits over early spring; (iii) mid spring-mid summer: incorporating herbage regrowth over the remainder of the growing season, while split applications of nitrogen were continuing; and (iv) mid summer-mid autumn: including yields from regrowth over this seasonally dry period, when fertiliser nitrogen application was discontinued to all but treatment 6 (N45 X 10). Subsamples of dried material from individual harvests within each period were bulked, according to relative yields, to give representative herbage samples for each of the 13 seasonal periods in the study.

Chemical analyses of herbage followed standard practices within Grasslands Division's analytical laboratory. For potassium, magnesium and calcium contents of herbage, 0.2 g subsamples were ashed at 520°C for 3.5 h, and were then taken up in 2M HCl and made up

as 0.4M HCl solutions. Potassium and calcium were determined by flame photometry, using a Technicon AutoAnalyser, while magnesium was determined by atomic absorption, using a Techtron spectrophotometer. For total herbage phosphorus and nitrogen, 0.14 g subsamples were digested by the Kjeldahl method, with modification to include nitrate by addition of salicylic acid (Bremner 1965), following which both elements were determined colourimetrically in the same diluted digests, on a Technicon AutoAnalyser. For phosphorus, the method used was a modified molybdate-vanadate complex (Kitson & Mellon 1944) and for nitrogen, the hypochlorite-phenol reaction with ammonium (Williams & Twine 1967). Herbage nitrate levels were determined colourimetrically on water extracts (0.2 g plant material in 200 ml), following hydrazine reduction to nitrite, by the sulphanilamide-naphthyl ethylene diamine method (Henzell et al. 1968) on a Technicon AutoAnalyser. Standard checks on quality control were used routinely throughout the chemical analyses. These comprised inclusion of a 'reference' sample of known composition with every analytical run and duplicate analyses on 10% of 'unknowns'. Analyses were repeated in the few instances when serious discrepancies emerged. Elemental contents and nitrogen yields are reported on an oven-dry (105°C) herbage basis.

Grazing records and field observations during the earlier stages of this study suggested that apparent dry herbage intakes by sheep may have been greater from swards receiving the higher rates of nitrogen input. Experience over the first two years suggested that differences were most apparent over the mid spring-summer period. Accordingly, samples were taken from the grazed swards of representative nitrogen treatments, for in vitro digestibility estimates, over the appropriate seasonal period in the final year. These comprised representative samples of the mixed herbage, taken at grazing stage, dried overnight at 80°C in a forced-air oven, ground, and stored until analysed. Duplicate analyses were carried out on material from individual

harvests, without bulking. A two stage, rumen liquor-pepsin technique for forage crops (Tilley & Terry 1963) was used.

'Quicktest' analyses were carried out on sub-samples of soil samples collected for total nitrogen determinations (details in Section IV, B, 3). Only the topsoil (0-7.6 cm) from two treatments, control (N0) and the heaviest rate of nitrogen (N448), was analysed, incorporating samples from below both the grazed and cut swards at the start and finish of the experiment. Analyses were carried out at Ruakura Agricultural Research Centre, Hamilton, using their standard analytical methods (Anon. 1979), including the recently introduced bicarbonate test for soil phosphate. Samples were dried in a forced-air oven (<20°C), subsamples were ground (<2 mm) and then stored pending analysis. All samples were processed together, after completion of the experiment.

4 Design, Statistical Procedure and Format of Results

Details have been given (Section II, B, 4). Nitrogen treatments were randomly assigned to plots within each of 4 replicates. Small plots for the cutting treatment were located, using randomised co-ordinates, within the corresponding grazed areas.

In the main framework of the experiment, there were 7 nitrogen treatments measured under grazing, but only 4 representative treatments under cutting. Analyses of variance on the nitrogen and mineral characteristics of herbage were carried out using a statistical procedure which would accommodate the unbalanced design. This allowed tests of significance for main treatment (defoliation and nitrogen treatments) effects, but would not allow for interactions to be tested. For chemical composition of herbage, adjusted means are reported throughout with coefficients of variation (CV) to give an indication of error variance. To reduce the volume of tabulated data, means have been severely rounded and summaries of analyses of variance for differences among nitrogen treatments have not been presented in full.

Only results for the comparison of principal interest, between control (NO) and each of the other 6 treatments, are tabulated. A copy of the full array of all treatments comparisons at all measurements, for all parameters measured, is held by the author.

To gain information on the extent of any treatment interactions in determining herbage nitrogen yields, annual data from the nitrogen treatments common to both methods of defoliation were subjected to separate analyses. Annual totals for herbage nitrogen yield, and its components, were extracted for treatments NO, N112 and N448, and were subjected to analyses of variance as 2 x 3 x 4 factorials. Data from the 'Grass' treatment were also included in separate analyses as 2 x 4 x 4 factorials. In both cases tests for significance of the defoliation method X nitrogen treatment interactions were carried out.

Where the available data constituted a balanced factorial design, conventional analyses of variance were carried out, including tests for treatment interactions, as indicated in the text.

C RESULTS

1 Herbage Total and Nitrate Nitrogen Contents

Adjusted means for main treatment effects on total and nitrate nitrogen contents are presented in Tables 8 and 9, respectively, together with summaries of statistical analyses. The very high CV (%) values tabulated with the nitrate data, relative to those for the other elements under study, are indicative of the substantial error variance associated with measurement of this parameter in field studies.

Relative to cut swards, grazed herbage frequently exhibited higher total and nitrate nitrogen levels. For total nitrogen this effect was more apparent in the grass component, which was higher (4 to 16%) under grazing in two or more years over every seasonal period. By contrast, total nitrogen in clover herbage was higher (2

TABLE 8 - Herbage nitrogen contents (g N/100 g dry herbage); adjusted means for main treatment effects

	Defoliation		Nitrogen treatment†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
Autumn-winter										
Year I										
Clover	4.40	4.26	4.48	4.30	4.24	4.38	4.29	4.27	-	
	ns			ns	ns	ns	ns	ns	-	4
Grass	3.78	3.65	3.68	3.73	3.72	3.79	3.90	3.71	3.48	
	*			ns	ns	ns	**	ns	*	4
Year II										
Clover	4.44	4.45	4.36	4.44	4.42	4.52	4.54	4.40	-	
	ns			ns	ns	ns	ns	ns	-	3
Grass	4.01	3.87	3.83	3.81	4.01	4.15	4.28	4.18	3.29	
	*			ns	*	**	***	**	***	4
Year III										
Clover	4.33	4.34	4.25	4.21	4.32	4.34	4.48	4.39	-	
	ns			ns	ns	ns	ns	ns	-	3
Grass	3.37	3.29	3.30	3.20	3.30	3.40	3.64	3.58	2.86	
	ns			ns	ns	ns	***	*	***	5
Year IV										
Clover	4.36	4.23	4.18	4.21	4.33	4.26	4.50	4.26	-	
	ns			ns	ns	ns	***	ns	-	4
Grass	3.63	3.42	3.52	3.40	3.46	3.59	3.87	3.72	3.10	
	***			ns	ns	ns	***	ns	***	4
Winter-spring										
Year I										
Clover	5.03	4.91	4.89	4.90	4.91	4.99	5.11	4.98	-	
	**			ns	ns	ns	***	ns	-	2
Grass	4.20	3.63	3.72	3.82	3.81	4.08	4.67	4.18	3.13	
	***			ns	ns	***	***	***	***	2
Year II										
Clover	4.51	4.47	4.53	4.38	4.43	4.56	4.62	4.43	-	
	ns			*	ns	ns	ns	ns	-	2
Grass	3.34	3.07	2.96	2.95	3.13	3.32	3.85	3.63	2.59	
	***			ns	***	***	***	***	***	3
Year III										
Clover	4.64	4.73	4.73	4.59	4.59	4.74	4.76	4.69	-	
	ns			ns	ns	ns	ns	ns	-	3
Grass	3.16	2.86	2.80	2.75	2.84	3.26	3.68	3.49	2.24	
	***			ns	ns	***	***	***	***	5

TABLE 8 (Contd)

	Defoliation		Nitrogen treatment †							CV
	Grazed	cut	0	56	112	224	448	45x10	Grass	(%)
				Spring-summer						
Year I										
Clover	4.85	4.61	4.73	4.62	4.61	4.79	4.87	4.87	-	
	**			ns	ns	ns	ns	ns	-	4
Grass	3.55	3.07	3.25	3.31	3.22	3.39	3.82	3.70	2.50	
	***			ns	ns	ns	***	***	***	5
Year II										
Clover	3.92	3.96	3.77	3.89	3.87	3.98	4.04	4.09	-	
	ns			ns	ns	*	***	**	-	4
Grass	3.04	2.98	2.72	2.79	2.92	3.15	3.43	3.32	2.77	
	ns			ns	**	***	***	***	ns	5
Year III										
Clover	4.32	4.10	4.24	3.99	4.16	4.32	4.35	4.22	-	
	*			ns	ns	ns	ns	ns	-	6
Grass	2.91	3.03	2.69	2.54	2.80	3.17	3.61	3.26	2.69	
	ns			ns	ns	**	***	***	ns	7
				Summer-autumn						
Year I										
Clover	4.49	4.39	4.36	4.49	4.41	4.46	4.37	4.57	-	
	*			ns	ns	ns	ns	ns	-	3
Grass	3.82	3.57	3.69	3.75	3.68	3.60	3.73	3.97	3.46	
	***			ns	ns	ns	ns	***	***	3
Year II										
Clover	3.99	4.04	4.00	3.92	3.90	3.92	4.15	4.21	-	
	ns			ns	ns	ns	ns	ns	-	4
Grass	3.78	3.51	3.59	3.53	3.77	3.47	3.93	3.80	3.43	
	***			ns	ns	ns	**	ns	ns	5
Year III										
Clover	4.63	4.58	4.60	4.49	4.60	4.60	4.64	4.70	-	
	ns			ns	ns	ns	ns	ns	-	2
Grass	3.69	3.32	3.34	3.16	3.41	3.54	3.95	4.11	3.04	
	***			ns	ns	ns	***	***	***	5

† Statistical comparisons are between N0 (control) and other nitrogen treatments

TABLE 9 - Herbage nitrate levels (ppm NO_3-N); adjusted means for main treatment effects

	Defoliation		Nitrogen treatment†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
Autumn-winter										
Year I										
Clover	154	147	91	105	93	167	276	174	-	
	ns			ns	ns	ns	***	ns	-	47
Grass	527	346	308	353	326	466	850	565	188	
	***			ns	ns	ns	***	**	ns	31
Year II										
Clover	409	300	245	193	473	533	386	300	-	
	ns			ns	ns	ns	ns	ns	-	61
Grass	2411	1663	1215	1122	1912	2829	3455	3334	391	
	***			ns	***	***	***	***	***	16
Year III										
Clover	321	205	140	119	159	163	470	527	-	
	*			ns	ns	ns	***	***	-	39
Grass	843	600	328	450	485	676	1597	1332	186	
	*			ns	ns	ns	***	***	ns	43
Year IV										
Clover	323	222	151	132	174	344	523	312	-	
	*			ns	ns	*	***	*	-	40
Grass	1033	692	561	513	499	1222	1784	1268	185	
	**			ns	ns	**	***	**	*	37
Winter-spring										
Year I										
Clover	786	454	177	220	300	537	1630	854	-	
	***			ns	ns	**	***	***	-	27
Grass	2647	1482	810	1396	1206	2302	5262	3150	329	
	***			ns	ns	***	***	***	ns	28
Year II										
Clover	559	344	81	56	175	207	1201	989	-	
	**			ns	ns	ns	***	***	-	38
Grass	1466	880	334	241	539	880	3632	2504	78	
	***			ns	ns	ns	***	***	ns	36
Year III										
Clover	449	210	79	21	122	296	917	544	-	
	**			ns	ns	*	***	***	-	49
Grass	1489	691	296	219	447	1298	3196	2082	87	
	***			ns	ns	**	***	***	ns	46

TABLE 9 (Contd)

	Defoliation		Nitrogen treatment†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
				Spring-summer						
Year I										
Clover	1537	351	427	271	513	892	2366	1196	-	
	***			ns	ns	ns	***	*	-	60
Grass	2453	935	1063	987	1104	1892	3882	2781	147	
	***			ns	ns	ns	***	***	*	43
Year II										
Clover	1046	396	229	193	380	683	1586	1251	-	
	***			ns	ns	*	***	***	-	36
Grass	1446	989	410	485	777	1428	3074	2136	212	
	**			ns	ns	***	***	***	ns	33
Year III										
Clover	604	167	92	trace	110	390	1156	717	-	
	**			ns	ns	ns	***	**	-	82
Grass	1232	894	299	117	434	1377	3188	1835	189	
	*			ns	ns	***	***	***	ns	42
				Summer-autumn						
Year I										
Clover	951	457	566	485	630	701	723	1119	-	
	***			ns	ns	ns	ns	**	-	39
Grass	2451	1515	1863	1908	1788	1918	2394	3425	582	
	***			ns	ns	ns	*	***	***	25
Year II										
Clover	2055	1032	893	873	1182	1422	2484	2405	-	
	***			ns	ns	*	***	***	-	22
Grass	3118	2433	2251	2319	2548	2458	4259	4682	912	
	*			ns	ns	ns	***	***	***	26
Year III										
Clover	772	175	230	trace	301	350	755	1234	-	
	***			ns	ns	ns	**	***	-	64
Grass	1948	938	791	346	1017	1323	2699	3648	277	
	***			ns	ns	ns	***	***	ns	40

† See footnote to Table 8

to 5%) in association with grazing, in only 4 of the 13 periods under consideration. Nitrate levels were invariably higher in herbage from the grazed swards, both clover and grass, with treatment differences recorded at all measurements except for the clover component over autumn-winter in years I and II. This contrast between defoliation treatments was more pronounced under warm, dry seasonal conditions. Both clover and grass herbage from grazed swards occasionally exhibited nitrate levels several-fold those measured in their cut counterparts, over the spring-summer and summer-autumn periods.

An elevated total nitrogen content was frequently a feature of grass herbage from swards receiving the higher levels of fertiliser nitrogen input. Relative to control, N448 increased total nitrogen levels in grass (6 to 33%) over all except two measurement periods, while smaller increases were recorded in clover (5 to 8%) at only three of the 13 measurements. Herbage from swards receiving the heavier rates of fertiliser nitrogen frequently exhibited higher nitrate levels than herbage from control swards. Nitrate levels in grass herbage from N448 were invariably higher than those from NO, exceeding ten-fold over three measurement periods. Relative to control, clover herbage from N448 also contained substantially more nitrate over all but two of the 13 measurement periods.

Total nitrogen and nitrate levels in herbage from the N45 X 10 treatment followed a similar, general pattern to that exhibited by N448 swards. While each received the same annual input of nitrogen, N448 received the heavier input over autumn-winter, winter-spring and spring-summer. This resulted in higher total and nitrate nitrogen levels in the herbage from N448 swards over winter-spring, for grass in all three years but clover only in two. While there was no consistent difference between these two treatments in total nitrogen content over autumn-winter or spring-summer, both grass and clover herbage from N448 exhibited higher nitrate

levels over each of these seasonal periods in two or more years. During the summer-autumn period, when split dressings of nitrogen were continued only to treatment N45 X 10, there was little difference between these two treatments in herbage total nitrogen content; the grass component exhibited a higher level, only in year I, in treatment N45 X 10. Herbage nitrate levels were higher in both clover and grass, relative to those from swards of treatment N448, in the first and final years over this seasonally dry period.

Herbage from the pure grass swards invariably contained less total nitrogen than did the grass component of control swards over the seasonally cool, moist periods of the year (Table 8). This difference was less consistent under seasonally warm, drier conditions, with lower total nitrogen recorded only in year I over spring-summer, and in years I and III over summer-autumn. Relative to grass herbage from control, herbage from the pure grass swards invariably exhibited lower nitrate levels (Table 9), the difference reaching significance on 5 occasions. No significant difference was recorded over winter-spring in any year.

2 Herbage Nitrogen Yields

Dry herbage yields from this experiment have been reported previously (Section II, Tables 2 & 3). In association with corresponding herbage total nitrogen contents (Table 8), those data were used to calculate herbage nitrogen yields for the clover and grass components of total yield. Dead herbage nitrogen yields were calculated using nitrogen contents only from periodic chemical analyses of dead herbage. For measurement periods when values were not available, nitrogen contents were extrapolated from the most appropriate of the available data. Herbage nitrogen yields are reported in Tables 10 and 11, together with summaries of statistical analyses. Annual totals are presented in Table 10, with a breakdown into seasonal herbage nitrogen yields in Table 11.

TABLE 10 - Annual herbage nitrogen yields (kg N/ha); adjusted means for main treatment effects

	Defoliation		Nitrogen treatments†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
Year I										
Total	754	639	670	730	714	733	872	817	340	
	***			*	*	*	***	***	***	6
Clover	241	223	324	300	277	244	241	235	3	
	ns			ns	ns	*	**	**	***	20
Grass	490	408	330	421	415	483	629	556	311	
	***			*	**	***	***	***	ns	13
Dead	22	12	16	14	16	16	20	21	16	
	***			ns	ns	ns	**	**	ns	16
Year II										
Total	576	475	463	520	541	559	664	649	281	
	***			ns	**	**	***	***	***	8
Clover	139	158	188	167	203	160	165	154	trace	
	ns			ns	ns	ns	ns	ns	***	30
Grass	413	307	256	343	319	391	488	470	257	
	***			*	*	***	***	***	ns	16
Dead	23	12	15	16	16	19	22	22	16	
	***			ns	ns	ns	***	*	ns	19
Year III										
Total	629	516	547	526	561	646	731	723	274	
	***			ns	ns	**	***	***	***	8
Clover	127	159	225	165	179	164	121	147	trace	
	*			*	*	*	***	**	***	26
Grass	469	341	296	344	355	465	587	541	242	
	***			ns	*	***	***	***	*	11
Dead	34	18	21	26	24	29	32	30	20	
	***			ns	ns	**	***	**	ns	16

† See footnote to Table 8

TABLE 11 - Seasonal herbage nitrogen yields (kg N/ha); adjusted means for main treatment effects

	Defoliation		Nitrogen treatments†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
Autumn-winter I										
Total	91	94	83	89	91	101	117	108	63	
	ns			ns	ns	**	***	***	***	11
Clover	15	15	18	19	17	17	17	14	1	
	ns			ns	ns	ns	ns	ns	***	20
Grass	75	78	63	69	72	83	99	92	59	
	ns			ns	ns	**	***	***	ns	14
Dead	2	2	2	1	2	1	2	2	2	
	ns			ns	ns	ns	ns	ns	ns	32
Autumn-winter II										
Total	108	74	81	78	93	93	108	117	66	
	***			ns	ns	ns	***	***	*	13
Clover	17	20	22	22	21	18	24	20	trace	
	ns			ns	ns	ns	ns	ns	***	37
Grass	89	53	59	55	72	72	83	96	64	
	***			ns	ns	ns	**	***	ns	19
Dead	2	1	1	1	1	1	1	1	3	
	**			ns	ns	ns	ns	ns	***	48
Autumn-winter III										
Total	130	105	115	118	115	126	139	141	74	
	***			ns	ns	ns	*	*	***	14
Clover	28	34	39	31	45	41	29	32	trace	
	ns			ns	ns	ns	ns	ns	***	33
Grass	100	68	71	80	69	85	108	105	70	
	***			ns	ns	ns	***	**	ns	21
Dead	3	2	2	2	2	2	3	3	3	
	*			ns	ns	ns	ns	ns	ns	35
Autumn-winter IV										
Total	119	103	103	106	114	129	137	129	58	
	**			ns	ns	*	***	*	***	14
Clover	15	34	39	34	30	23	24	23	trace	
	***			ns	ns	*	**	*	***	41
Grass	102	66	63	69	84	101	108	104	58	
	***			ns	*	***	***	***	ns	19
Dead	2	2	1	1	2	2	2	3	2	
	ns			ns	ns	*	**	*	*	37

TABLE 11 (Contd)

	Defoliation		Nitrogen treatments†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
Winter-spring I										
Total	200	176	167	187	188	203	259	222	90	
	***			ns	*	**	***	***	***	9
Clover	47	35	65	53	46	49	39	35	trace	
	**			ns	**	*	***	***	***	27
Grass	151	140	100	136	140	155	222	184	86	
	ns			*	**	***	***	***	ns	15
Dead	1	1	1	1	1	1	1	2	1	
	ns			ns	ns	ns	*	***	ns	25
Winter-spring II										
Total	242	198	188	206	233	240	313	285	79	
	***			ns	***	***	***	***	***	8
Clover	37	41	60	42	64	35	38	34	trace	
	ns			ns	ns	*	*	*	***	43
Grass	199	155	124	161	165	203	270	245	73	
	***			**	***	***	***	***	***	11
Dead	6	3	4	4	5	4	5	6	4	
	***			ns	ns	ns	ns	ns	ns	31
Winter-spring III										
Total	243	193	202	189	207	255	304	284	84	
	***			ns	ns	***	***	***	***	8
Clover	34	35	67	37	44	39	21	31	trace	
	ns			**	**	**	***	***	***	44
Grass	204	156	129	151	159	216	280	245	75	
	***			*	**	***	***	***	***	9
Dead	6	3	4	4	4	5	5	5	4	
	***			ns	ns	ns	ns	ns	ns	26

TABLE 11 (Contd)

	Defoliation		Nitrogen treatments†						CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
Spring-summer I										
Total	253	186	221	225	222	234	291	265	81	
	***			ns	ns	ns	***	***	***	8
Clover	88	66	115	95	95	69	75	91	trace	
	*			ns	ns	**	**	ns	***	33
Grass	160	118	100	130	122	166	215	168	73	
	***			ns	ns	***	***	***	*	16
Dead	5	3	3	3	4	4	5	5	4	
	***			ns	ns	ns	***	*	ns	21
Spring-summer II										
Total	108	89	77	111	94	108	126	121	52	
	*			*	ns	*	***	**	*	21
Clover	13	20	22	18	25	13	17	17	trace	
	**			ns	ns	ns	ns	ns	***	41
Grass	83	66	46	88	60	88	101	93	44	
	*			**	ns	**	***	***	ns	27
Dead	12	5	7	7	7	10	11	10	5	
	***			ns	ns	ns	**	ns	ns	28
Spring-summer III										
Total	115	92	88	97	104	120	137	136	43	
	***			ns	*	**	***	***	***	14
Clover	19	22	38	26	21	20	17	21	trace	
	ns			ns	**	**	***	**	***	44
Grass	80	61	42	58	70	86	106	98	35	
	***			*	***	***	***	***	ns	17
Dead	16	9	9	13	12	15	16	16	6	
	***			*	ns	**	***	**	ns	25

TABLE 11 (Contd)

	Defoliation		Nitrogen treatments†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
Summer-autumn I										
Total	210	183	200	228	213	195	205	223	107	
	***			*	ns	ns	ns	ns	***	10
Clover	92	106	126	135	118	109	110	95	2	
	*			ns	ns	ns	ns	*	***	20
Grass	102	72	65	86	81	79	93	112	92	
	***			*	*	ns	**	***	**	17
Dead	14	6	10	9	9	9	12	13	10	
	***			ns	ns	ns	ns	*	ns	22
Summer-autumn II										
Total	118	112	117	123	121	119	117	126	85	
	ns			ns	ns	ns	ns	ns	**	16
Clover	72	77	85	84	93	93	86	83	trace	
	ns			ns	ns	ns	ns	ns	***	33
Grass	41	33	26	39	23	28	35	36	76	
	ns			ns	ns	ns	ns	ns	***	44
Dead	4	3	3	5	4	4	4	4	4	
	*			ns	ns	ns	ns	ns	ns	30
Summer-autumn III										
Total	140	131	152	130	132	147	151	166	72	
	ns			ns	*	ns	ns	ns	***	15
Clover	46	69	83	71	70	64	53	63	trace	
	**			ns	ns	ns	**	ns	***	30
Grass	85	55	54	53	56	78	93	94	63	
	***			ns	ns	*	***	**	ns	25
Dead	9	4	6	7	6	7	8	6	7	
	***			ns	ns	ns	ns	ns	ns	25

† See footnote to Table 8

(a) Defoliation method X nitrogen treatment interactions

Of the 24 analyses of variance carried out on data from the nitrogen treatments common to both grazing and cutting, significant treatment interactions were indicated in two (summaries not presented): grass herbage nitrogen yield over the first year, whether or not data from the pure grass swards were included. In both these instances nitrogen yields in grass herbage were almost identical at N448, but lower under cutting than grazing in the NO, N112 and Grass treatments. Thereafter, no treatment interaction was indicated for this yield component, nor was any detected in clover, dead or total herbage nitrogen yields over the three years of the experiment. In view of the relative absence of significant treatment interactions, attention is focussed on main treatment effects on herbage nitrogen yields throughout this report.

(b) Method of defoliation (Grazing vs Cutting)

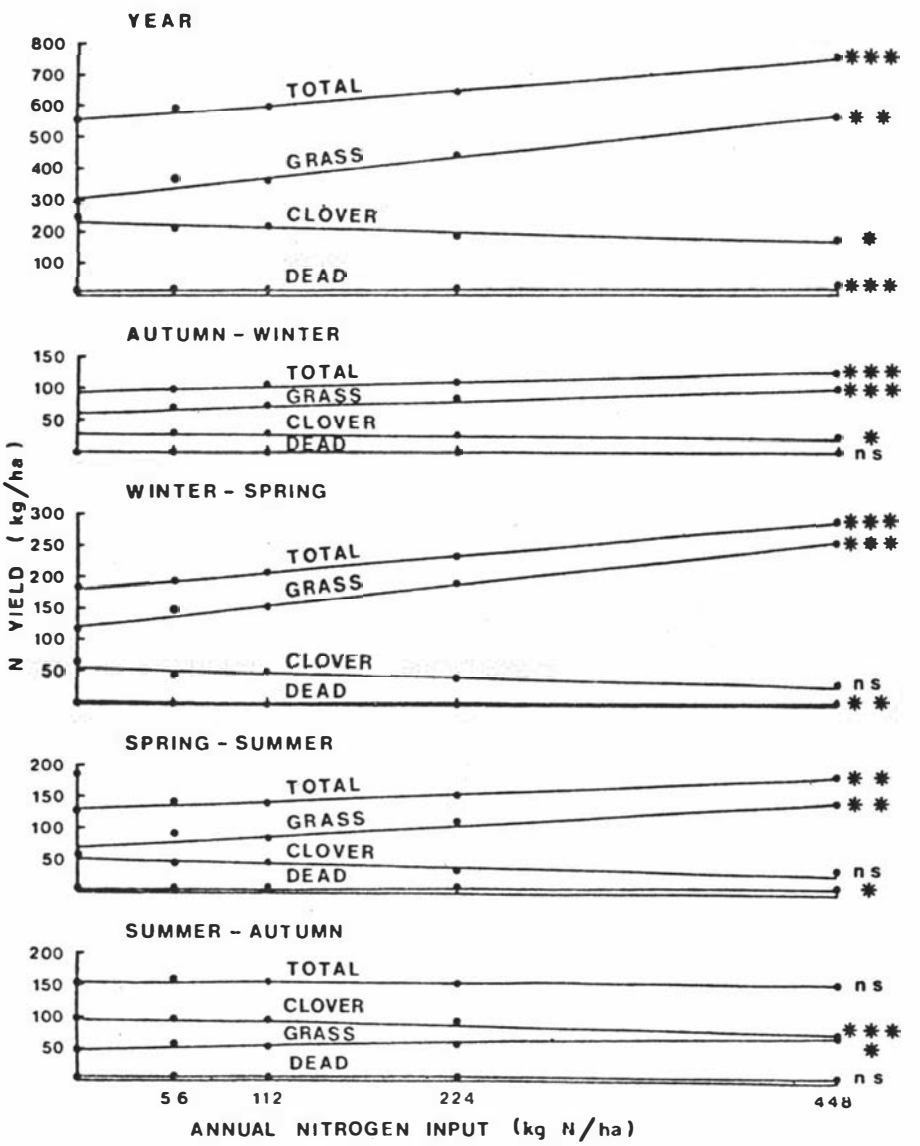
With the exception of the initial measurement period, grass, dead herbage and total nitrogen yields were invariably higher in the grazed swards than where herbage was continually cut and removed. With few exceptions, these differences were significant (Table 11) and were reflected in the corresponding annual totals for each of the three full years of the experiment (Table 10). Total herbage nitrogen yield was consistently some 20% higher under grazing each year, with the treatment differences in grass nitrogen yields making the major quantitative contribution to this result. While herbage nitrogen yields from the clover component of the swards were similar between defoliation treatments over years I and II (Table 10), a reduced clover nitrogen yield was recorded from the grazed swards in the final year. Following the initial measurement period, clover nitrogen yields were higher under grazing until summer-autumn of the first year, when this effect was reversed (Table 11). Thereafter, clover nitrogen yields were either the same for both defoliation treatments, or greater under cutting.

(c) Responses to fertiliser nitrogen

In terms of herbage nitrogen yield, responsiveness by these grass-clover swards is clearly established (Tables 10 & 11), although there was variability among years particularly in the response by the clover component of the swards. To provide a general description of these responses, the adjusted herbage nitrogen yields have been averaged over years (from Table 10) and seasons (from Table 11), for the NO, N56, N112, N224 and N448 treatments, and the averaged data are presented in Fig. 5. Linear regression analyses were carried out on these to test for significant effects of fertiliser nitrogen rate on herbage nitrogen yields. Because of the author's reservations about dry herbage yield recorded from treatment N56 (discussed in Section II, C, 1, b), separate regression analyses were conducted; first incorporating all treatment means, then exclusive of data from N56. Unlike the situation with dry herbage yields, in this instance there was no consistent change in results for tests of significance for the slope of regression lines, whether or not data from the N56 treatment were included. Accordingly, the linear regressions presented in Fig. 5 incorporate data from all treatments.

Average annual herbage nitrogen yield reflected the effects recorded over individual seasons (Fig. 5). Yearly grass nitrogen yield increased as the rate of fertiliser input increased, while yearly clover nitrogen yield decreased. However, the latter effect was less than compensatory, so average annual total nitrogen yield also rose as the annual rate of nitrogen application became heavier. The slope of the regression line for dead herbage was significant, although this component was a minor contributor to total nitrogen yield. Inspection of results from individual years (Table 10) largely confirms these averaged results. Relative to control, N112, N224 and N448 raised grass nitrogen yields in all three years; N224 and N448 raised total nitrogen yield every year (N112, only in years I and II);

FIGURE 5 - Herbage nitrogen yield responses to fertiliser nitrogen by grass-clover swards; averages for annual and seasonal yields (significance indicated for slope of regression line)



while N224 and N448 reduced clover nitrogen yield in years I and III. Over year II, when very dry climatic conditions resulted in lower yields of clover dry herbage from control swards (Section II, Table 3a), clover nitrogen yield for the year was unaffected by fertiliser nitrogen treatment. Compared with NO, N448 increased dead herbage nitrogen yield over all three years, as did N224 in the final year.

Significant positive slopes were recorded in the regression lines for grass and total herbage nitrogen yields over all three seasons when the swards were receiving fertiliser nitrogen (Fig. 5). These averaged results are in close accord with those from individual seasons (Table 11). Relative to control, N448 invariably increased grass and total herbage nitrogen yields over autumn-winter, winter-spring and spring-summer, as did N224 over 7 of those 10 measurement periods.

Inspection of the clover nitrogen yields from individual measurement periods (Table 11) indicates that these averaged effects for clover were only loosely related to results recorded within individual seasons. Over autumn-winter, clover nitrogen yield was lower at N224 and N448 than at NO, in all but one year, but significantly so only in the final year. Relative to control, N224 and N448 depressed clover nitrogen yield over winter-spring in all three years. However, the low average clover nitrogen yield recorded in treatment N56 precluded significance in the test of slope for the regression line. (In this instance, a negative relationship between clover nitrogen yield and fertiliser nitrogen rate was apparent in the averaged winter-spring data, if treatment N56 were excluded). Similarly, over spring-summer N224 and N448 reduced clover nitrogen yield, relative to control, in years I and III. However, the slope of the fitted regression line was not significant owing to relatively low average values for treatments N56 and N224.

The averaged values indicated an increasing contribution by dead herbage to total nitrogen yield as

the rate of nitrogen input increased, with significant slopes recorded in the regression lines for winter-spring and spring-summer.

Over the summer-autumn period, when nitrogen application was discontinued to all these treatments, residual responses were apparent in the averaged values for the grass and clover components (Fig. 5). While total herbage nitrogen yield was virtually unaffected by the rate of nitrogen input, clover nitrogen yield decreased and grass nitrogen yield increased in a compensatory manner, as annual nitrogen rate increased. Results from individual measurement periods (Table 11) confirm that total herbage nitrogen yield was consistently unaffected by fertiliser nitrogen rate over summer-autumn. Relative to control, N448 increased grass nitrogen yield in years I and III, but decreased clover nitrogen yield only in year III. Smoothing of data by averaging over years may have contributed to the significant slope of the regression line recorded for the clover component over summer-autumn.

Nitrogen yields from swards in treatment N45 X 10, to which split dressings of nitrogen were continued over the seasonally dry summer-autumn period, were similar in virtually all respects to those from swards receiving treatment N448 (Tables 10 & 11). Both these treatments received the same input of nitrogen each year, but none was applied to N448 swards over summer-autumn. Yet neither total herbage nitrogen yield, nor any of its components, differed between these two treatments over any of the three summer-autumn measurement periods.

(d) Pure grass swards

Annual total herbage nitrogen yields (Table 10) from swards of the Grass treatment were considerably lower than those from the grass-clover control, little more than a half on average over the three years. Most of this difference arose from the substantial contribution by the clover component to total nitrogen yield in the control swards. Yearly grass nitrogen yield did not differ between treatments NO and Grass over years I and

II. Over the final year, nitrogen yield from the grass component of the pure grass swards was some 20% lower than that from the grass-clover control. On a seasonal basis (Table 11), total nitrogen yield from the clover-free swards was lower than that from control over all periods. However, seasonal influences were apparent on grass nitrogen yield. Over autumn-winter, it did not differ between treatments. During winter-spring, nitrogen yield was always higher from the grass component of the control swards; significantly so in years II and III. This result was repeated over spring-summer of the first year, but thereafter there was no treatment difference over that seasonal period. In contrast, nitrogen yield was invariably higher in the grass component from the pure grass swards over the seasonally dry, summer-autumn period; significantly so in years I and II.

An associated study was carried out during the final year to test for any effects on dry herbage and herbage nitrogen yields, from the herbicide used to remove clovers from the pure grass swards (details in Section II, B, 2, b). Statistical analyses of results (not presented) gave no indication of a significant treatment difference in annual herbage nitrogen yield (weeded = 213 kg N/ha vs sprayed = 228 kg N/ha; result ns).

3 Mineral Composition of Herbage

(a) Herbage phosphorus content

Adjusted means, with results for main treatment effects, are presented in Table 12. There were significant differences in the phosphorus levels of herbage from the grazed and cut swards, for most seasonal periods throughout the experiment. With one exception, the phosphorus content of clover was always higher (3 to 14%) in herbage from the grazed swards. Excluding the first year, the same applied to the grass component of the swards over autumn-winter. However, the reverse was true over winter-spring and spring-summer of years I and II, and summer-autumn of year III.

TABLE 12 - Herbage phosphorus contents (g P/100 g dry herbage); adjusted means for main treatment effects

	Defoliation		Nitrogen treatment†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
Autumn-winter										
Year I										
Clover	0.42	0.42	0.42	0.41	0.41	0.42	0.42	0.42	-	
	ns			ns	ns	ns	ns	ns	-	4
Grass	0.43	0.42	0.45	0.43	0.43	0.41	0.43	0.42	0.42	
	ns			*	*	***	**	**	***	3
Year II										
Clover	0.44	0.39	0.41	0.42	0.42	0.42	0.42	0.42	-	
	***			ns	ns	ns	ns	ns	-	4
Grass	0.47	0.42	0.45	0.45	0.43	0.45	0.45	0.43	0.48	
	***			ns	ns	ns	ns	ns	**	4
Year III										
Clover	0.40	0.38	0.38	0.38	0.39	0.38	0.40	0.39	-	
	**			ns	ns	ns	ns	ns	-	5
Grass	0.43	0.40	0.43	0.41	0.42	0.42	0.40	0.42	0.41	
	***			ns	ns	ns	ns	ns	ns	4
Year IV										
Clover	0.42	0.37	0.38	0.37	0.40	0.40	0.41	0.40	-	
	***			ns	ns	ns	***	ns	-	3
Grass	0.42	0.39	0.41	0.39	0.40	0.41	0.39	0.41	0.43	
	***			ns	ns	ns	ns	ns	*	5
Winter-spring										
Year I										
Clover	0.45	0.43	0.43	0.43	0.43	0.44	0.46	0.45	-	
	*			ns	ns	ns	***	*	-	3
Grass	0.48	0.52	0.55	0.50	0.50	0.49	0.46	0.49	0.52	
	*			*	**	*	***	*	*	6
Year II										
Clover	0.40	0.37	0.36	0.37	0.38	0.39	0.43	0.38	-	
	***			ns	ns	**	***	*	-	5
Grass	0.41	0.46	0.47	0.43	0.43	0.42	0.37	0.41	0.50	
	**			ns	ns	ns	***	*	*	7
Year III										
Clover	0.44	0.41	0.40	0.40	0.41	0.43	0.45	0.45	-	
	**			ns	ns	*	***	***	-	5
Grass	0.45	0.45	0.48	0.46	0.44	0.45	0.42	0.46	0.46	
	ns			ns	**	ns	***	ns	ns	5

TABLE 12 (Contd)

	Defoliation		Nitrogen treatment†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
Spring-summer										
Year I										
Clover	0.39	0.37	0.38	0.38	0.38	0.38	0.38	0.38	-	
	***			ns	ns	ns	ns	ns	-	3
Grass	0.40	0.44	0.44	0.43	0.42	0.40	0.37	0.41	0.47	
	***			ns	ns	ns	***	ns	ns	8
Year II										
Clover	0.25	0.24	0.25	0.25	0.25	0.25	0.24	0.25	-	
	ns			ns	ns	ns	ns	ns	-	5
Grass	0.27	0.30	0.30	0.28	0.26	0.27	0.24	0.27	0.38	
	***			ns	**	*	***	*	***	8
Year III										
Clover	0.33	0.29	0.33	0.29	0.31	0.31	0.31	0.30	-	
	***			ns	ns	ns	ns	ns	-	6
Grass	0.36	0.37	0.41	0.37	0.37	0.34	0.31	0.34	0.40	
	ns			*	**	***	***	***	ns	7
Summer-autumn										
Year I										
Clover	0.34	0.33	0.33	0.34	0.33	0.33	0.34	0.33	-	
	**			ns	ns	ns	ns	ns	-	3
Grass	0.36	0.38	0.37	0.38	0.37	0.36	0.35	0.35	0.42	
	*			ns	ns	ns	*	ns	***	6
Year II										
Clover	0.32	0.30	0.33	0.33	0.32	0.30	0.30	0.32	-	
	ns			ns	ns	ns	ns	ns	-	7
Grass	0.33	0.33	0.35	0.33	0.34	0.31	0.30	0.32	0.36	
	ns			ns	ns	**	***	*	ns	7
Year III										
Clover	0.35	0.32	0.35	0.34	0.35	0.34	0.34	0.34	-	
	*			ns	ns	ns	ns	ns	-	6
Grass	0.35	0.36	0.38	0.35	0.35	0.34	0.33	0.32	0.42	
	ns			ns	ns	ns	*	*	*	10

† See footnote to Table 8

An effect of nitrogen fertiliser treatments on phosphorus level in clover herbage was apparent in all three years, but only during winter-spring. Elevated phosphorus contents (8 to 18%) were associated with nitrogen use at the higher rates of input, with a similar effect recorded from the N448 treatment over autumn-winter, but only in the final year. The reverse was the case in the grass component. Relative to control, grass herbage from swards receiving the higher rates of nitrogen under test almost invariably exhibited lower phosphorus levels. This effect was least pronounced in autumn-winter, during which period significant treatment effects were recorded only in the first year, but grass herbage from the N448 swards contained less phosphorus (6 to 21%) than that from NO over the other three seasonal periods, in all three years.

While differences in phosphorus levels in grass were recorded between control and the pure grass swards, they did not follow a consistent pattern.

(b) Herbage potassium content

As shown in Table 13, there was a clear-cut effect of defoliation method on herbage potassium levels after autumn-winter of the first year. Under grazing, both clover and grass invariably contained significantly more potassium (12 to 77% and 7 to 39% respectively) than where herbage was repeatedly cut and discarded.

The influence of fertiliser nitrogen treatments, by comparison with defoliation method, was minor. Over winter-spring, higher potassium levels in both clover and grass components (7 to 13% for both) were associated with the higher rates of nitrogen input in all years. Relative to control, the same was the case over autumn-winter of the final two years, but significant differences were generally confined to the clover component of the swards.

Compared with herbage from the grass component of control swards, herbage from the pure grass swards almost invariably exhibited a reduced potassium content. This difference was significant in one or more years over

TABLE 13 - Herbage potassium contents (g K/100 g dry herbage); adjusted means for main treatment effects

	Defoliation		Nitrogen treatment†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
				Autumn-winter						
Year I										
Clover	2.68	2.62	2.70	2.60	2.64	2.64	2.73	2.61	-	
	ns			ns	ns	ns	ns	ns	-	8
Grass	3.03	2.99	2.99	3.11	2.96	3.09	3.06	2.92	2.94	
	ns			ns	ns	ns	ns	ns	ns	6
Year II										
Clover	2.94	2.55	2.70	2.67	2.82	2.74	2.79	2.78	-	
	***			ns	ns	ns	ns	ns	-	8
Grass	3.79	3.18	3.46	3.39	3.53	3.61	3.66	3.53	3.21	
	***			ns	ns	ns	ns	ns	*	7
Year III										
Clover	3.06	2.47	2.71	2.61	2.77	2.71	3.02	2.82	-	
	***			ns	ns	ns	**	ns	-	7
Grass	3.53	2.98	3.19	3.21	3.29	3.21	3.37	3.56	2.97	
	***			ns	ns	ns	ns	**	*	6
Year IV										
Clover	2.91	2.47	2.52	2.55	2.66	2.82	2.79	2.77	-	
	***			ns	ns	**	**	*	-	6
Grass	3.56	2.97	3.23	3.18	3.24	3.41	3.37	3.39	3.02	
	***			ns	ns	ns	ns	ns	*	5
				Winter-spring						
Year I										
Clover	3.28	3.21	3.14	3.23	3.15	3.21	3.39	3.34	-	
	ns			ns	ns	ns	**	*	-	5
Grass	3.91	3.66	3.71	3.78	3.80	3.66	4.18	3.81	3.55	
	*			ns	ns	ns	**	ns	ns	7
Year II										
Clover	3.80	3.25	3.30	3.50	3.53	3.45	3.72	3.62	-	
	***			ns	*	ns	***	*	-	6
Grass	4.21	3.77	3.92	3.99	4.14	4.07	4.22	4.25	3.35	
	***			ns	*	ns	**	**	***	5
Year III										
Clover	3.47	2.72	2.99	3.02	2.95	3.05	3.28	3.27	-	
	***			ns	ns	ns	**	*	-	6
Grass	4.04	3.46	3.66	3.65	3.75	3.90	4.06	4.16	3.07	
	***			ns	ns	*	***	***	***	4

TABLE 13 (Contd)

	Defoliation		Nitrogen treatment†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
				Spring-summer						
Year I										
Clover	3.62	3.00	3.21	3.31	3.32	3.26	3.52	3.26	-	
	***			ns	ns	ns	ns	ns	-	6
Grass	3.73	3.12	3.48	3.46	3.44	3.34	3.64	3.61	3.02	
	***			ns	ns	ns	ns	ns	***	5
Year II										
Clover	2.90	2.16	2.37	2.66	2.52	2.52	2.52	2.59	-	
	***			ns	ns	ns	ns	ns	-	11
Grass	3.29	2.65	2.82	2.88	2.97	2.98	3.02	3.09	2.99	
	***			ns	ns	ns	ns	ns	ns	7
Year III										
Clover	3.21	2.04	2.65	2.58	2.52	2.54	2.80	2.66	-	
	***			ns	ns	ns	ns	ns	-	10
Grass	3.19	2.73	2.91	2.86	2.88	3.08	3.11	3.18	2.71	
	***			ns	ns	ns	ns	ns	ns	7
				Summer-autumn						
Year I										
Clover	2.94	2.60	2.73	2.88	2.81	2.68	2.67	2.85	-	
	***			ns	ns	ns	ns	ns	-	7
Grass	3.59	3.09	3.41	3.56	3.43	3.20	3.19	3.50	3.07	
	***			ns	ns	ns	*	ns	***	5
Year II										
Clover	2.75	2.12	2.47	2.50	2.44	2.36	2.43	2.45	-	
	***			ns	ns	ns	ns	ns	-	13
Grass	3.34	2.78	3.17	3.01	3.07	2.85	3.13	3.20	2.98	
	***			ns	ns	ns	ns	ns	ns	11
Year III										
Clover	3.44	1.96	2.70	2.56	2.80	2.75	2.66	2.71	-	
	***			ns	ns	ns	ns	ns	-	12
Grass	3.98	2.86	3.47	3.35	3.43	3.36	3.51	3.65	3.19	
	***			ns	ns	ns	ns	ns	ns	9

† See footnote to Table 8

each of the four seasonal periods.

(c) Herbage magnesium and calcium contents

Magnesium and calcium levels in herbage are reported in Tables 14 and 15, and show significant differences between defoliation treatments in both the clover and grass components of the swards. A similar pattern of response was exhibited in both elements, with levels invariably lower in herbage from the grazed swards. For magnesium, this effect was expressed more consistently in the grass component of the swards, with reduced levels (3 to 15%) associated with grazing in one or more years over every seasonal period. Lower levels of magnesium (4 to 16%) in clover herbage from grazed swards were recorded only over winter-spring of the first two years, and over spring-summer and summer-autumn of the final year. For calcium, the influence of defoliation treatments was more consistent. Herbage from the grass component of the grazed swards exhibited lower calcium contents (6 to 25%) in two or more years over every seasonal period, while a similar reduction (4 to 14%) was recorded in the clover component in one or more years over every seasonal period.

The influence of fertiliser nitrogen treatments on herbage magnesium and calcium levels was not pronounced under cool, moist seasonal conditions. Over autumn-winter, a small increase in the magnesium content of grass herbage from N448 was recorded in year II, while a small reduction in clover magnesium levels was recorded from the same treatment in the final year. No significant influence of nitrogen treatments on herbage magnesium levels was recorded over winter-spring in any year. The highest rate of nitrogen input resulted in an increased calcium content of grass herbage over autumn-winter, but only in year II. Relative to control, N448 raised the calcium content of grass herbage (7 to 9%) over winter-spring, in all three years, and clover herbage only in the first year.

Under warm, dry climatic conditions, influences from the nitrogen fertiliser treatments were more pronounced.

TABLE 14 - Herbage magnesium contents (g Mg/100 g dry herbage); adjusted means for main treatment effects

	Defoliation		Nitrogen treatment†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
					Autumn-winter					
Year I										
Clover	0.27	0.27	0.26	0.27	0.28	0.27	0.27	0.27	-	
	ns			ns	ns	ns	ns	ns	-	7
Grass	0.22	0.22	0.22	0.21	0.23	0.22	0.21	0.22	0.21	
	ns			ns	ns	ns	ns	ns	ns	7
Year II										
Clover	0.30	0.29	0.29	0.28	0.30	0.31	0.29	0.29	-	
	ns			ns	ns	ns	ns	ns	-	6
Grass	0.25	0.26	0.25	0.25	0.25	0.26	0.27	0.26	0.24	
	**			ns	ns	ns	*	ns	ns	6
Year III										
Clover	0.27	0.28	0.28	0.27	0.27	0.28	0.27	0.28	-	
	ns			ns	ns	ns	ns	ns	-	5
Grass	0.21	0.23	0.22	0.22	0.22	0.23	0.22	0.23	0.21	
	*			ns	ns	ns	ns	ns	ns	7
Year IV										
Clover	0.29	0.29	0.30	0.30	0.29	0.29	0.26	0.29	-	
	ns			ns	ns	ns	***	ns	-	4
Grass	0.21	0.23	0.22	0.23	0.22	0.22	0.21	0.21	0.22	
	***			ns	ns	ns	ns	ns	ns	8
					Winter-spring					
Year I										
Clover	0.28	0.29	0.28	0.28	0.29	0.28	0.28	0.29	-	
	*			ns	ns	ns	ns	ns	-	4
Grass	0.23	0.23	0.23	0.23	0.23	0.21	0.23	0.23	0.24	
	ns			ns	ns	ns	ns	ns	ns	8
Year II										
Clover	0.27	0.30	0.30	0.28	0.28	0.27	0.28	0.28	-	
	**			ns	ns	ns	ns	ns	-	4
Grass	0.22	0.24	0.23	0.22	0.23	0.23	0.24	0.23	0.23	
	*			ns	ns	ns	ns	ns	ns	7
Year III										
Clover	0.27	0.28	0.29	0.27	0.29	0.29	0.26	0.26	-	
	ns			ns	ns	ns	ns	ns	-	9
Grass	0.21	0.23	0.21	0.20	0.20	0.20	0.24	0.23	0.24	
	ns			ns	ns	ns	ns	ns	ns	13

TABLE 14 (Contd)

	Defoliation		Nitrogen treatment†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
				Spring-summer						
Year I										
Clover	0.33	0.33	0.33	0.31	0.34	0.31	0.34	0.33	-	
	ns			ns	ns	ns	ns	ns	-	4
Grass	0.26	0.26	0.26	0.25	0.26	0.26	0.28	0.28	0.24	
	ns			ns	ns	ns	*	ns	ns	8
Year II										
Clover	0.37	0.40	0.40	0.38	0.37	0.39	0.40	0.38	-	
	ns			ns	ns	ns	ns	ns	-	11
Grass	0.31	0.32	0.32	0.30	0.32	0.32	0.32	0.31	0.31	
	ns			ns	ns	ns	ns	ns	ns	10
Year III										
Clover	0.34	0.40	0.37	0.36	0.40	0.36	0.36	0.35	-	
	**			ns	ns	ns	ns	ns	-	13
Grass	0.24	0.28	0.27	0.26	0.25	0.26	0.27	0.25	0.27	
	***			ns	ns	ns	ns	ns	ns	12
				Summer-autumn						
Year I										
Clover	0.35	0.36	0.36	0.35	0.36	0.35	0.36	0.36	-	
	ns			ns	ns	ns	ns	ns	-	4
Grass	0.36	0.37	0.36	0.35	0.37	0.37	0.38	0.37	0.35	
	*			ns	ns	ns	*	ns	ns	4
Year II										
Clover	0.32	0.34	0.30	0.32	0.33	0.36	0.32	0.32	-	
	ns			ns	ns	ns	ns	ns	-	9
Grass	0.42	0.45	0.40	0.43	0.44	0.49	0.50	0.51	0.31	
	ns			ns	ns	ns	**	*	**	14
Year III										
Clover	0.28	0.32	0.29	0.30	0.29	0.30	0.31	0.31	-	
	***			ns	ns	ns	ns	ns	-	7
Grass	0.31	0.36	0.33	0.35	0.35	0.31	0.36	0.34	0.30	
	***			ns	ns	ns	**	ns	*	8

† See footnote to Table 8

TABLE 15 - Herbage calcium contents (g Ca/100 g dry herbage); adjusted means for main treatment effects

	Defoliation		Nitrogen treatment†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
Autumn-winter										
Year I										
Clover	1.27	1.21	1.25	1.26	1.24	1.26	1.20	1.23	-	
	ns			ns	ns	ns	ns	ns	-	7
Grass	0.60	0.58	0.60	0.58	0.58	0.67	0.56	0.57	0.58	
	ns			ns	ns	ns	ns	ns	ns	9
Year II										
Clover	1.20	1.29	1.23	1.16	1.23	1.26	1.29	1.29	-	
	*			ns	ns	ns	ns	ns	-	7
Grass	0.59	0.70	0.62	0.62	0.61	0.65	0.72	0.68	0.58	
	***			ns	ns	ns	**	*	ns	8
Year III										
Clover	1.23	1.27	1.25	1.20	1.23	1.26	1.25	1.31	-	
	ns			ns	ns	ns	ns	ns	-	6
Grass	0.54	0.58	0.55	0.54	0.57	0.59	0.58	0.59	0.49	
	**			ns	ns	ns	ns	ns	**	8
Year IV										
Clover	1.18	1.27	1.17	1.23	1.21	1.23	1.24	1.27	-	
	**			ns	ns	ns	ns	ns	-	6
Grass	0.49	0.56	0.54	0.54	0.52	0.52	0.53	0.54	0.49	
	***			ns	ns	ns	ns	ns	ns	7
Winter-spring										
Year I										
Clover	1.37	1.44	1.37	1.39	1.34	1.41	1.46	1.46	-	
	**			ns	ns	ns	**	*	-	3
Grass	0.64	0.63	0.64	0.63	0.60	0.64	0.70	0.66	0.62	
	ns			ns	*	ns	*	ns	ns	7
Year II										
Clover	1.25	1.36	1.30	1.28	1.24	1.27	1.36	1.39	-	
	***			ns	*	ns	ns	ns	-	5
Grass	0.60	0.64	0.61	0.57	0.56	0.63	0.66	0.65	0.61	
	*			ns	ns	ns	*	ns	ns	8
Year III										
Clover	1.29	1.43	1.33	1.34	1.32	1.34	1.44	1.37	-	
	***			ns	ns	ns	ns	ns	-	6
Grass	0.58	0.64	0.61	0.60	0.59	0.62	0.66	0.64	0.55	
	***			ns	ns	ns	*	ns	***	6

TABLE 15 (Contd)

	Defoliation		Nitrogen treatment†							CV
	Grazed	Cut	0	56	112	224	448	45x10	Grass	(%)
				Spring-summer						
Year I										
Clover	1.47	1.49	1.44	1.43	1.45	1.49	1.57	1.49	-	
	ns			ns	ns	ns	***	ns	-	5
Grass	0.71	0.71	0.71	0.69	0.67	0.72	0.77	0.81	0.63	
	ns			ns	ns	ns	ns	**	**	7
Year II										
Clover	1.70	1.90	1.64	1.68	1.78	1.83	1.97	1.91	-	
	***			ns	*	*	***	**	-	7
Grass	0.67	0.79	0.74	0.68	0.70	0.72	0.80	0.77	0.70	
	***			ns	ns	ns	ns	ns	ns	9
Year III										
Clover	1.55	1.79	1.56	1.58	1.68	1.70	1.76	1.73	-	
	***			ns	ns	ns	ns	ns	-	8
Grass	0.60	0.76	0.74	0.66	0.62	0.71	0.75	0.66	0.61	
	***			ns	**	ns	ns	ns	***	10
				Summer-autumn						
Year I										
Clover	1.46	1.52	1.49	1.47	1.45	1.45	1.49	1.58	-	
	*			ns	ns	ns	ns	ns	-	5
Grass	0.78	0.83	0.81	0.79	0.79	0.81	0.82	0.87	0.67	
	**			ns	ns	ns	ns	*	**	6
Year II										
Clover	1.41	1.49	1.40	1.38	1.43	1.42	1.52	1.54	-	
	***			ns	ns	ns	***	***	-	4
Grass	1.05	1.13	1.08	1.02	1.07	1.17	1.28	1.29	0.71	
	*			ns	ns	ns	**	**	***	10
Year III										
Clover	1.39	1.61	1.39	1.48	1.41	1.45	1.63	1.61	-	
	***			ns	ns	ns	***	*	-	9
Grass	0.66	0.88	0.73	0.83	0.79	0.77	0.81	0.85	0.64	
	***			*	ns	ns	ns	*	*	9

† See footnote to Table 8

Relative to control, grass herbage from the N448 swards contained more magnesium (6 to 24%) over summer-autumn in all years, with a small increase recorded over spring-summer only in year I. No significant influence on clover magnesium levels was recorded over these periods. By contrast, the highest level of nitrogen input increased the calcium content of clover herbage (9 to 20%) in two of the three years, over both spring-summer and summer-autumn, but resulted in a small increase in grass herbage in summer-autumn of year II only.

A lower magnesium content was recorded in herbage from the pure grass swards, relative to the grass component of control, over summer-autumn in years II and III. With the exception of one measurement period, herbage from the pure grass swards exhibited lower calcium levels than did grass from NO, with this difference significant only in year III over autumn-winter and winter-spring, but quite marked over the remaining seasonal periods.

4 Soil 'Quick test' Measurements

Soil phosphate, potassium, magnesium and calcium levels, and soil pH, are presented in Table 16.

Over the duration of the experiment, available phosphate increased under grazing but remained unchanged (NO) or declined (N448) where herbage was continually cut and removed. Similarly, soil potassium status either increased (NO) or remained unchanged (N448) under grazing, while falling dramatically under cutting. Test values for magnesium fell between the start and finish of the study, in all but the grazed control treatment. Soil calcium levels were relatively unaffected by treatments, exhibiting a small decline over the course of the experiment. Soil pH was the one parameter on which nitrogen fertiliser treatments exerted a marked effect. Use of nitrogen at the heaviest rate lowered soil pH by 0.5 units, while it remained unchanged (grazed) or fell only 0.17 units (cut) in the control treatment, over the course of the experiment.

TABLE 16- Soil 'Quicktest' values; means from treatments NO and N448, sampled on commencement and completion of the experiment

Main effects		Table of means			
		Grazed		Cut	
		NO	N448	NO	N448
(a) Phosphate					
Grazed vs Cut					
***					
NO vs N448	Start	18.50	22.75	20.75	23.75
ns	Finish	29.75	32.00	19.25	16.50
Start vs Finish	d			4.54	
*	0.05				
(b) Potassium					
Grazed vs Cut					
***					
NO vs N448	Start	13.25	12.75	10.25	13.75
ns	Finish	15.50	13.50	6.50	6.25
Start vs Finish	d			2.02	
***	0.05				
(c) Magnesium					
Grazed vs Cut					
ns					
NO vs N448	Start	34.25	34.75	35.50	38.25
ns	Finish	33.00	28.00	29.50	26.00
Start vs Finish	d			4.77	
***	0.05				
(d) Calcium					
Grazed vs Cut					
ns					
NO vs N448	Start	13.50	14.25	14.00	13.25
ns	Finish	12.50	13.00	13.50	13.00
Start vs Finish	d			1.06	
**	0.05				
(e) pH (10 soil:25 water)					
Grazed vs Cut					
ns					
NO vs N448	Start	6.25	6.33	6.30	6.33
***	Finish	6.28	5.83	6.13	5.80
Start vs Finish	d			0.14	
***	0.05				

5 Apparent DM Intake and Digestibility of Herbage

Treatment means for apparent dry herbage intakes over each full year of the experiment, and for DM digestibility estimates at each of the 5 measurements, are reported in Table 17.

Differences among nitrogen treatments in apparent dry herbage intakes were recorded only in the final year. Relative to control, apparent daily intakes were higher for sheep grazing the N448 swards, and lower for those on the pure grass swards. No difference in DM digestibility estimates was recorded for the mixed herbage from the grazed NO, N112 and N448 swards, at any of the 5 samplings.

D DISCUSSION

1 Nitrogen Yields, Total and Nitrate Nitrogen Levels in Herbage

Large yields of herbage nitrogen were a feature of this study, with annual totals averaging 655 and 545 kg N/ha from the grazed and cut swards respectively (755 and 560 kg N/ha from treatments N448 and NO respectively; Table 10). These values are high in relation to those reported from comparable studies, and are considered to testify to the high soil fertility status and equitable climate at the site.

Similarly high values were recorded by Sears and co-workers in previous studies at Palmerston North (Sears 1953a; Sears et al. 1965a). They reported three-year averages for herbage total nitrogen yield from mixed swards receiving basal fertilisers, of 590 and 640 kg N/ ha/an, where 'no return' and 'full return' of dung and urine were practised respectively (Melville & Sears 1953). However, those swards were at an early stage of development, with protein-rich clover herbage contributing over 70% of total herbage nitrogen yield from the 'no return' sward and almost 50% under 'full

TABLE 17 - Apparent dry herbage intakes (kg DM/sheep-day) over the three years of the experiment, and dry matter digestibility (%) estimates for mixed herbage at 5 harvests over mid spring-summer in the final year

(a) Apparent dry herbage intakes

	Nitrogen treatment†							d	
	0	56	112	224	448	45x10	Grass	0.05	0.001
Year I	1.53	1.50	1.52	1.53	1.59	1.55	1.48		
		ns	ns	ns	ns	ns	ns	-	-
Year II	1.46	1.61	1.52	1.54	1.59	1.53	1.43		
		ns	ns	ns	ns	ns	ns	-	-
Year III	1.91	1.90	1.84	1.99	2.08	2.02	1.51		
		ns	ns	ns	*	ns	***	0.15	0.28

(b) DM digestibility estimates

	Nitrogen treatment†		
	0	112	448
22 Oct.	72.3	71.9	71.4
		ns	ns
19 Nov.	77.0	75.9	75.0
		ns	ns
14 Dec.	73.5	71.9	73.4
		ns	ns
21 Jan.	58.2	55.1	56.3
		ns	ns
3 Mar.	65.7	63.0	63.7
		ns	ns

† See footnote to Table 8

return'. In the present experiment, clovers contributed 44% of total herbage nitrogen yield, on average, from the control swards. Over the final three years of a later study in this locality (Sears et al. 1965a), total herbage nitrogen yield averaged 510 kg N/ha/an from a repeatedly cut, mixed sward receiving basal fertilisers. Again, clovers made the major contribution to total nitrogen yield.

In reviewing nitrogen balances for pastures, under conditions prevailing in southern England, Whitehead (1970) estimated an annual yield of 200 kg N/ha in mixed herbage from a repeatedly cut, grass-clover sward receiving no fertiliser nitrogen. His corresponding estimate for dietary intake of nitrogen by dairy cows grazing such a mixed pasture was 245 kg N/ha/an. Watkin (1954) reported nitrogen yields in mixed herbage following his study in the United Kingdom. Nitrogen yields were generally higher in the second year, when the maximum recorded was 355 kg N/ha, from a treatment receiving dung and urine return plus almost 350 kg N/ha as lime-ammonium nitrate. The corresponding figure for repeatedly cut grass-clover control, receiving no 'return' and no fertiliser nitrogen, was 160 kg N/ha/an (loc. cit.). In a subsequent study into production from mixed pastures in Canterbury, Watkin (1962) reported higher total herbage nitrogen yields from a gangmown sward (300 to 400 kg N/ha/an) than from its grazed counterpart (230 to 295 kg N/ha/an). In a recent study of nitrogen relationships in developed pastures throughout New Zealand (Hoglund et al.1979), the annual turnover of nitrogen in measured herbage averaged 430 kg N/ha (range 250 to 690, among 8 climatically diverse sites) in grazed, grass-clover pastures receiving no fertiliser nitrogen. The average figure recorded at the Palmerston North site during that study was 470 kg N/ha/an (Brock & Hoglund 1979).

It is concluded that relatively high nitrogen yields were measured in the mixed herbage from control swards in the present study. However, responses to fertiliser nitrogen in terms of both dry herbage

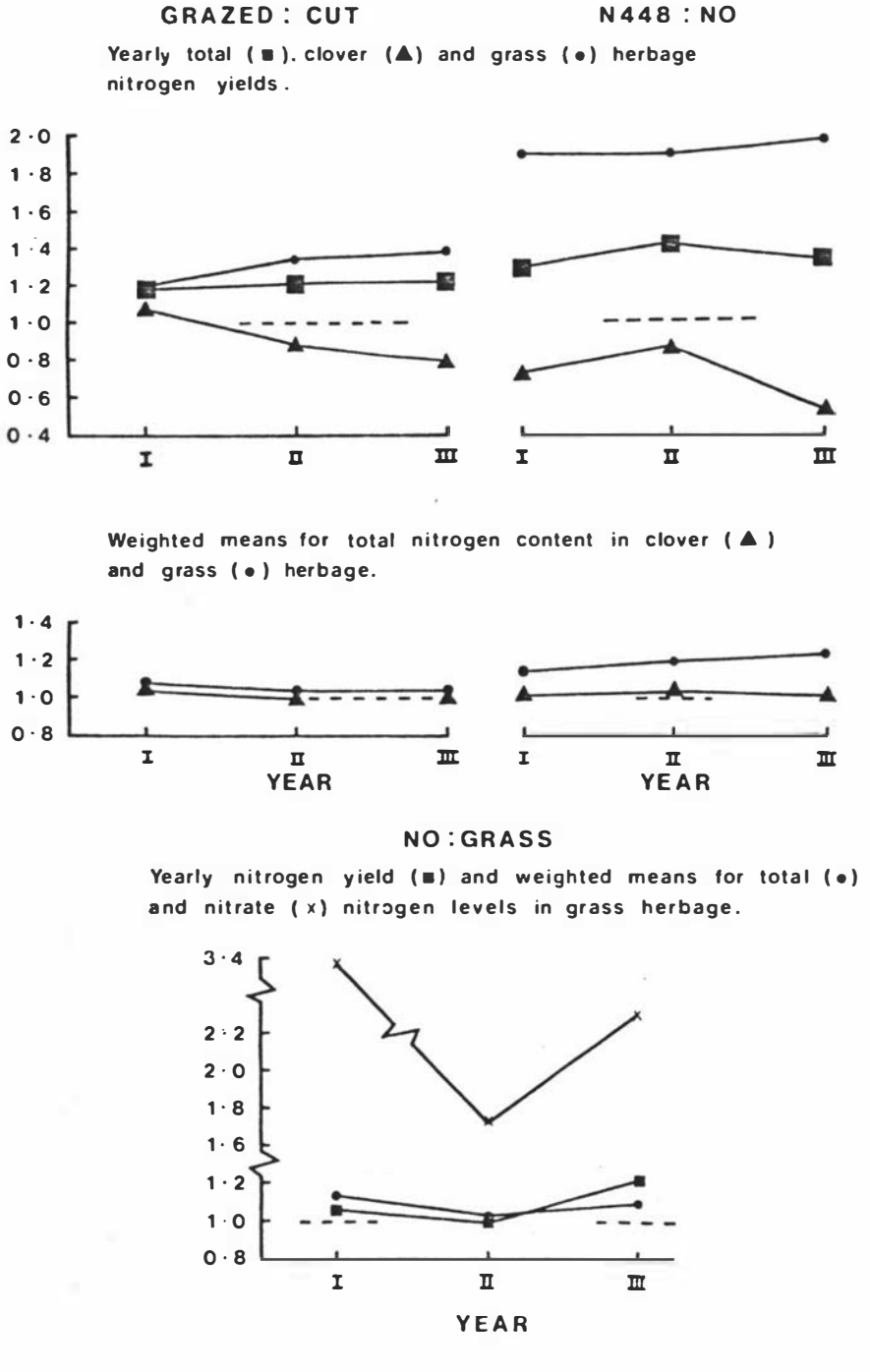
(Section II, Table 3) and crude protein yields (Tables 10 & 11) show that this grass-clover association was still suffering nitrogen stress. On average, total and grass herbage nitrogen yields increased with increasing rate of nitrogen input during all three seasons when lime-ammonium nitrate was used (Fig. 5). Application of 448 kg N/ha/an increased annual total herbage nitrogen yield by almost 200 kg N/ha, or 35% over control, on average over the three-year study period (Table 10). To facilitate discussion of main treatment effects on the yield and content of herbage nitrogen, including developments over the course of the experiment, treatment means have been brought together in Fig. 6. Values are expressed in the ratio Grazed:Cut and N448:NO (or NO:Grass), with values above equivalence indicating superiority of the Grazed, N448 (or NO) treatment. Dead herbage made only a minor contribution to total nitrogen yield (2 to 5% from grass-clover swards on an annual basis; Table 10). As it was considered that dead herbage yields measured under grazing may have been inflated as an artifact of the herbage measurement technique (Sections II, B, 3 & II, D, 1) those data are not included in Fig. 6, nor in the following figure.

(a) Defoliation treatments

It was expected that nitrogen relationships would have been substantially different between grazed and cut swards. With dry sheep as defoliators, nitrogen removal in animal products from the grazed swards would have been negligible; perhaps 20 kg N/ha/an (Whitehead 1970; Henzell & Ross 1973). By contrast, some 540 kg N/ha was removed on average each year, in material harvested from the cut swards.

Total herbage nitrogen yield measured in the grazed swards was 18 to 22% greater than that recorded from the cut swards (Fig. 6). This treatment difference was significant in each of the three years (Table 10), and was fairly consistent throughout the study. Relative to cut swards, clover nitrogen yield from the grazed swards decreased while grass nitrogen yield increased,

FIGURE 6 - Annual mean herbage nitrogen yields and weighted herbage nitrogen contents, expressed as the ratios Grazed:Cut and N448:NO (or NO:Grass), throughout the experiment (broken line indicates equivalence)



over the course of the experiment (Fig. 6). From near equivalence between defoliation treatments in year I, clover nitrogen yield declined relatively in the grazed swards. Inspection of the yield data (Table 10) reveals that a progressive decline, in absolute terms, took place in yearly clover nitrogen yield from grazed swards rather than an increase from the cut swards. This treatment difference was significant in year III. The superiority of grazed grass over cut grass in herbage nitrogen yield (Fig. 6) became more pronounced over time, increasing from 20% in year I to 38% in the final year. Inspection of the treatment means (Table 10) reveals that while this treatment difference was significant each year, declining nitrogen yield in cut grass contributed to the relative difference, especially in year II.

Weighted means for the total nitrogen content in herbage from the clover and grass components of the swards are included in Fig. 6. Treatment influences within individual seasons are reported in Table 8, but no statistical analyses were carried out on the weighted means. Grazing led to a minor increase (4%) in the nitrogen content of clover herbage, but only in the first year. Grass from the grazed swards exhibited a higher nitrogen content than that from cut swards; up 8% over year I and 4% over the second and third years. These results show that a significant part of the elevated total nitrogen yield, which resulted from grazing in the first year, arose from a higher nitrogen content in the sward constituents, particularly the grass component. In subsequent years, however, the higher grass and total nitrogen yields more directly reflected the superior dry herbage yields measured under grazing (Section II, Table 2).

Cycling of ingested nutrients is a widely acclaimed benefit attributed to animals grazing pasture, and is considered important in effecting the transfer of symbiotically-fixed nitrogen from clovers to associated grasses, as discussed previously in this report (Sections

I, 2; II, A, & III, A). Walker (1956a, b) conjectured that the influence of grazing animals on sward composition and performance could be viewed as a straightforward response to nitrogen. Consequently, the relatively minor influence of grazing on grass and total herbage nitrogen yields encountered in this study was somewhat surprising. Over the first year, the comparison between defoliation methods was not complicated by treatment differences in clover yield. Yet total herbage nitrogen yield increased only 18% under grazing that year, and a significant part of that increase arose from the higher nitrogen content of grazed grass. Obviously, apparent recovery of some 730 kg N/ha cycled by animals was poor in the short term. On average over the three years, grazing increased nitrogen turnover in measured grass herbage by only 105 kg N/ha/an, and in total herbage by 110 kg N/ha/an. Herbage measurements would indicate that the wethers ingested an average 655 kg N/ha/an. Allowing 20 kg N/ha/an for removal by growth of the sheep, it is equally obvious that nitrogen recovery in herbage was poor over the longer term. Even if substantial allowance were made for non-utilisation of measured herbage during grazing, indications are that apparent recovery in herbage of nitrogen recycled in animal excrement was no better than 20%, and possibly lower, over the three-year study period. Nitrogen relationships are considered in more detail in the following section (IV) of this report.

(b) Fertiliser nitrogen

There is little indication from the form of the averaged responses to increasing inputs of fertiliser nitrogen (Fig. 5) that these relationships were curvilinear. Rather, annual averages and those from the three seasons when swards were receiving applied nitrogen, would indicate a directly proportional response in all sward components, with the possible exception of clover herbage nitrogen yield. Clearly, larger total and grass herbage nitrogen yields could have been expected from heavier annual rates than 448 kg N/ha,

under the conditions of this experiment.

To provide further general description of the fertiliser nitrogen responses recorded in these grass-clover swards, results from the two treatment extremes are also compared in Fig. 6. Relative to control, total herbage nitrogen yield from treatment N448 was greater by 30 to 43% yearly. Inspection of annual treatment means (Table 10) shows that the absolute increase was highly significant, and a fairly consistent 200 kg N/ha, each year. The peak proportional increase, 43% in year II, reflected the very dry conditions and generally low dry herbage yields that prevailed (Section II, Tables 1 & 3). Treatment N448 exerted a pronounced effect on clover herbage nitrogen yields in the first and final years. Relative to treatment NO these were depressed, achieving little more than half the control yield in the final year. Inspection of the treatment means (Table 10) reveals that the absolute reduction over years I and III was not greatly dissimilar, 83 and 104 kg N/ha respectively, and highly significant. Its influence on proportional reduction in the first year was considerably masked by the high yields of clover herbage nitrogen recorded that year. The drop in relative clover herbage nitrogen yield attributable to N448 in the intermediate year was not significant, and small in absolute terms, again reflecting the very dry weather. There was a marked difference between treatments in nitrogen yield from grass herbage. Relative to control, it was almost doubled from swards receiving treatment N448, over all three years (Fig. 6). In the treatment means (Table 10) it can be seen that, while all these responses were highly significant, the absolute increase under the drier conditions prevailing in year II was somewhat less than in the other two years.

Weighted means for total nitrogen content of clover herbage (Fig. 6) indicate that nitrogen treatments had only a minor effect. Values near equivalence were recorded in the first and final years, while the increase over control effected by treatment N448 in year II was

only 4%. In contrast, total nitrogen content of grass herbage was always increased substantially by treatment N448. Relative to control, the increase was 14% over year I rising progressively to 24% in the final year. Treatment means for individual seasons (Table 11) show that this difference was significant at all but one of the 13 separate measurement periods.

Treatment influences on total nitrogen content of herbage show that the relative effect of treatment N448 on clover herbage nitrogen yields was expressed almost entirely through influences on dry herbage yield. However, treatment differences in total nitrogen content of grass herbage would have contributed to the higher grass nitrogen yields recorded from N448, hence to differences in total herbage nitrogen yield, with this influence becoming more pronounced year by year. While treatment N448 increased annual total dry herbage yield by 20 to 25% over control (Section II, Table 3a & Fig. 4) the corresponding increases in herbage nitrogen yields were 30 to 43%.

The increase in total herbage nitrogen yield averaged 195 kg N/ha/an, from an input of 448 kg N/ha/an. Apparent recovery in herbage of fertiliser nitrogen by this grass-clover association averaged 44%. This is a relatively low figure. Walker and associates (Walker *et al*. 1953, 1954) argued for 67% recovery in grass herbage of fertiliser nitrogen applied to mixed swards, throughout the linear portion of the nitrogen response curve. However, Steele (1976) observed apparent recoveries of only 33 and 56% from urea applied at 100 kg N/ha to ryegrass-white clover pastures at two sites in Northland. As considered in the following section (IV) substitution for symbiotic fixation by soil nitrogen uptake, in meeting the nitrogen requirements for clover growth, accounts in part for the low apparent recovery of fertiliser nitrogen recorded in this study.

(c) Pure grass swards

Included in Fig. 6 is a comparison between treatments NO and Grass, incorporating herbage nitrogen yields from the grass component of both treatments and

weighted means for total nitrogen content and nitrate level in herbage. Relative to the cloverless treatment, the total nitrogen content of grass herbage from grass-clover control was 14% greater in year I, 4% in year II and 10% over the final year (Fig. 6). These differences reflect treatment effects recorded in individual seasons (Table 8); significant in all four seasons over year I, only two in the intermediate year, and in three seasons over the final year. Herbage nitrate levels were invariably higher in grass from control swards than in herbage from the cloverless swards, significantly so in 5 of the 9 measurement periods exclusive of winter-spring (Table 9). This treatment difference is reflected in the weighted means (Fig. 6). Relative to herbage from the pure grass swards, grass from the mixed swards exhibited levels which were threefold in year I, and about two-fold in the following years. Herbage nitrogen yield from the grass component of the mixed swards was 6% higher than that from the cloverless swards in year I, equal in year II and 22% higher in the final year (Fig. 6). Only the last of these differences was significant (Table 10), a result effected by the greater nitrogen content in grass herbage from treatment NO, as dry herbage yields did not differ significantly between these two treatments in any of the three years (Section II, Table 3a).

It is surprising that significant treatment differences in annual nitrogen yield from the grass component of these swards did not develop until the final year. No simple explanation is apparent. Herbage total and nitrate nitrogen contents were generally higher in grass from the mixed sward, indicating both greater soil nitrogen availability and less pronounced nitrogen stress on grass growth in the control treatment. As this difference was not expressed in annual totals for dry herbage yield nor herbage nitrogen yield over the initial two years, the conclusion appears inescapable that white clover restricted the yield of associated grasses in some way.

The most likely explanation is provided by treatment differences in sward characteristics. Compared with control the cloverless swards exhibited much denser grass populations, both ryegrass and other grasses (Section II, Table 5); a difference which may have arisen through better light relationships at the base of the cloverless swards. In the absence of clover plants, the greater population of grasses would have been better able to exploit soil nitrogen, and moisture under dry conditions.

It is obvious that the transfer of symbiotically-fixed nitrogen from clovers to associated grasses, at least in developed pastures, is not so simple a process as previously thought (Sears 1953c; Sears & Melville 1953; Sears *et al*. 1953). These results give little support to the concept of 'direct transference' from clovers to grasses, as promoted by the Lincoln group (Walker 1956a; Scott 1973; Edmeades & Goh 1978), and lend no support to the view that clover and grass nitrogen yields from a mixed sward are causally related over the same production period (Walker *et al*. 1954). In comparisons of production from grass-clover and cloverless swards, failure of grass associates to benefit from the presence of clovers has been reported by several workers. Sears *et al*. (1953) reported such a result from their Canterbury site, following a field trial of more than two years' duration. In a South Island high country study, O'Connor (1961) found that grass nitrogen yield was negatively correlated with clover nitrogen yield; a result considered contrary to widely-held views. Where swards were adequately fertilised (exclusive of nitrogen), grasses were suppressed by vigorous clover growth in that one-year study (*loc. cit.*). Following a three-year field study in Australia, Simpson (1976) reported that white clover did not increase the nitrogen yield of associated grasses until the second year, but reduced it through competitive influences in the final year. In field studies throughout Otago, Sinclair *et al*. (1977) found

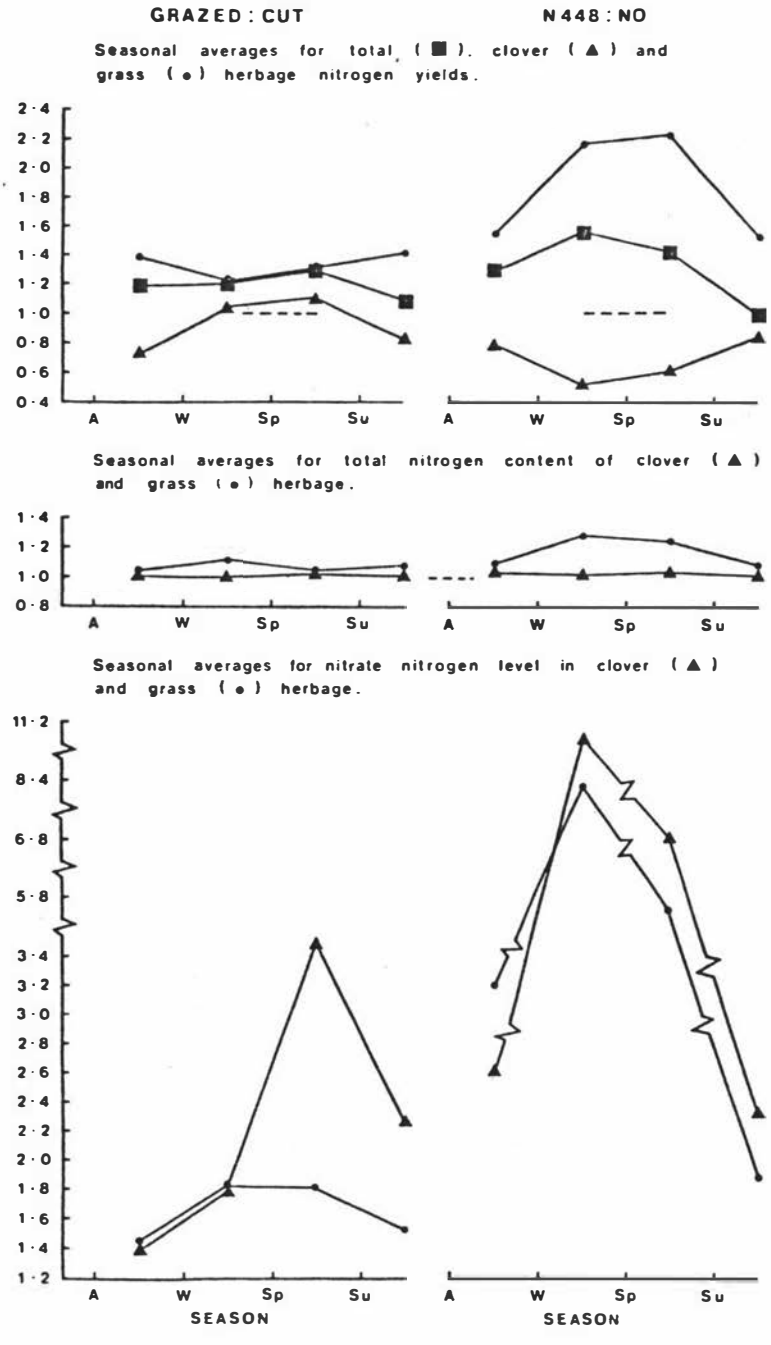
little advantage to ryegrass grown in separate associations with a variety of clover species. Initially, clovers suppressed ryegrass nitrogen yield. During the third year, there was marginal evidence that ryegrass benefited from its association with clovers at two of the three sites (loc. cit.).

(d) Seasonal influences

To provide a general description of seasonal influences on main treatment effects, means have been averaged within seasonal periods over years, for herbage nitrogen yields (Table 11), total nitrogen contents (Table 8) and nitrate levels (Table 9). Again, results are expressed as the ratios Grazed:Cut and N448:NO, and are presented in Fig. 7. It should be appreciated that averaging in this way has masked large between-years differences within seasons. No statistical analyses were carried out on these seasonal averages.

Both grazing relative to cutting and N448 relative to NO exerted their major positive influence on total herbage nitrogen yield over the winter-spring and spring-summer periods (Fig. 7), but their relative influences on the major contributors to total yield displayed a mirror-image relationship. On average, the benefit attributable to grazing over those periods, especially during spring-summer, arose through stimulation of clover yield, while the response attributable to N448 arose from a doubling of grass nitrogen yield. These differences in reaction by the principal sward components, to grazing and a heavy rate of nitrogen input, again indicate that the influence of grazing animals on sward performance cannot be viewed as a straightforward response to nitrogen, as suggested by Walker (1956a). Clover suppression under grazing over the summer-autumn and autumn-winter periods (Fig. 7) most probably reflects selective defoliation of clovers under seasonally dry conditions, with a follow-on effect into early winter (Brougham & Jackman 1974). The marked stimulation of grasses in the nitrogen-treated swards during winter-spring and spring-summer, and

FIGURE 7 - Seasonal averages for herbage nitrogen yields and herbage nitrogen contents, expressed as the ratios Grazed:Cut and N448:NO (broken line indicates equivalence)



consequent shading of clover (Donald 1963), almost certainly accounts for the pronounced suppression of clover yield by N448 over those periods (Fig. 7).

The relative influence of grazing and N448 on seasonal averages for total nitrogen content of clover herbage was minor (Fig. 7). Grazing exerted a small positive influence on grass nitrogen content over winter-spring and summer-autumn. Relative to control, treatment N448 exerted a substantial positive influence on nitrogen content of grass herbage over both winter-spring and spring-summer.

Relative nitrate levels in clover herbage were higher in grazed than cut swards, and peaked over spring-summer (Fig. 7). However, they exhibited a more pronounced peak in swards receiving treatment N448, over winter-spring and spring-summer. Then, levels were, respectively, 11 and 7 times those recorded in clover herbage from control swards. Absolute values for herbage nitrate levels were much higher in grass than clover (Table 9). Nitrate levels in grazed grass were higher than those in grass from cut swards, but displayed no distinct seasonal peak. Treatment N448 exerted a major positive influence on average grass herbage nitrate levels recorded over winter-spring and spring-summer. Respective levels were 8 and 6 times those measured in grass herbage from control swards over those two seasonal periods.

Viewed collectively, these results point to relative adequacy of soil nitrogen over the main growing season for grasses, in swards subjected to treatment N448. Not only were both total and nitrate nitrogen contents of grass herbage increased over the mid winter-spring-mid summer period, but nitrogen yield in grass herbage from the nitrogen-treated swards was also doubled. On the other hand, grass nitrogen yield from grazed swards appears to have been restricted by nitrogen stress, evidenced by the relatively minor influence of grazing on total and nitrate nitrogen levels in grass herbage, in spite of the very large amounts of nitrogen redistributed

in animal urine and dung.

(e) Total nitrogen levels in herbage

A feature of results was the relative insensitivity of total nitrogen content in clover herbage to substantial changes in external nitrogen supply. Whether this was effected through defoliation treatment or fertiliser nitrogen (Table 8 & Fig. 7), any increase was small and inconsistent. Inspection of treatment means for total and nitrate nitrogen levels in clover herbage (Tables 8 & 9) reveals that in those instances where treatment differences occurred in total nitrogen content, much or all of the difference could be accounted for by corresponding treatment effects on nitrate nitrogen levels.

The 'critical level' proposed for total nitrogen in white clover by McNaught (1970) is 5% N (range 4.5 to 5.5). Inspection of the data in Table 8 shows that the mean critical level was only attained in two individual measurements. In most cases values did not even reach the lower value of the range, suggesting that the diagnostic values are too high for field-grown white clover. However, against this view must be weighed other published values. For white clover herbage sampled over the main growing season, Walker et al. (1953) reported weighted means of 4.1 to 4.5% N, with no apparent influence of fertiliser nitrogen on values measured. Melville & Sears (1953) reported weighted annual means for total nitrogen in clover herbage from mixed swards receiving fertilisers, of 4.8 to 5.0% N. Similarly high values (4.9 to 5.4% N) were reported for clovers in a mixed sward in Canterbury (Watkin 1962). However, direct comparison with present results is not possible, as in both those cases the herbage comprised a mixture of red and white clovers. From the United Kingdom, Brockman et al. (1970) reported weighted annual means of 4.4 to 4.8% N for S.100 white clover growing in mixed swards subjected to a range of phosphate and potassium treatments. In clover herbage sampled from grazed pastures at 5 sites in the lower North Island,

Metson & Saunders (1978b) measured values above 5% N over all seasons except summer. However, pasture management may have influenced clover type (Williams & Cornege 1979). The total nitrogen content of herbage from small-leaved, 'Kentish' types is higher than that of 'G. Huia' white clover (R.H. Jackman, pers. comm.).

The proposed critical level for ryegrass herbage (McNaught 1970) is 4.3% N (range 4.0 to 4.5). This value was exceeded at only one measurement (Table 8), in the grass component from N448 swards in winter-spring of year I. Unlike that in clover, total nitrogen content in grass herbage did respond quite considerably to changes in external nitrogen supply (Table 8 & Fig. 6). Yet the bulk of measured values fell below the lower figure of the range, again suggesting that the diagnostic values are too high. Mean values for mixed grasses reported by Walker *et al.* (1953) ranged between 2.3 and 3.1% N; by Melville & Sears (1953), between 3.4 and 4.1; and by Watkin (1962), between 3.5 and 4.2% N, while total nitrogen reached 5% N over late winter, in mixed grasses sampled from grazed pastures (Metson & Saunders 1978b).

No explanation is apparent for the relatively low total nitrogen levels encountered in herbage during this study. Clean samples were separated by hand from bulk herbage for analyses. Analytical method was continually checked against reference samples analysed in other laboratories. These values are considered valid.

2 Mineral Characteristics of Herbage and Soil

During the first year of this study colleagues from Soil Bureau, DSIR, monitored several chemical characteristics of herbage, additional to those reported here. Mixed herbage was sampled at grazing stage from the grazed swards of treatments N0, N112 and N448, and analyses were carried out following each of the 12 regrowth periods that year. The influences of season and nitrogen treatments on herbage nitrogen and non-structural carbohydrate fractions (Ross *et al.* 1978), and on foliar

levels of higher fatty acids, magnesium, calcium, potassium and phosphorus (Molloy et al. 1978) have been reported. Those two publications consider in some detail the possible implications of nitrogen treatment effects to animal health, especially the hypomagnesaemic tetany syndrome. That aspect will not be considered further in this presentation.

(a) Phosphorus, potassium, magnesium and calcium levels in herbage

The main objective in measuring herbage levels of these elements was to monitor for possible plant nutrient deficiencies other than nitrogen; in particular, the possibility of exhaustion of some major nutrient through the continual removal of herbage associated with the cutting treatment. Besides main treatment differences, some interesting contrasts between seasonal effects and behaviour of the grass and clover components of the swards are indicated among the data collected (Tables 12, 13, 14 & 15). These will not be considered in detail, as the design of this experiment was not suited to allowing separation of the many possible influences which may have been involved in determining mineral composition. These include species, maturity of herbage, season, temperature, soil moisture availability (Whitehead 1966), and their many possible interactive effects. Seasonal variation in chemical composition of the grass and clover components of New Zealand pastures was the subject of an extensive survey, published recently (Metson & Saunders 1978a, b).

McNaught (1970) published critical levels, or 'minimum concentrations of nutrients in plant tissues for maximum yields', for both white clover and ryegrass. The mean nutrient levels given (with ranges) were for live herbage from actively growing plants at grazing height, and based on studies in this country. Those values (McNaught 1970) have been used as the basis for comparisons in the following discussion.

The proposed mean critical levels for phosphorus (clover = 0.35; ryegrass = 0.32% P) were approximated

or exceeded at all measurements over autumn-winter and winter-spring, irrespective of treatment, in the present study (Table 12). With the exception of spring-summer in the second year, phosphorus levels recorded in the grass component of these swards over spring-summer and summer-autumn approximated the mean critical level for ryegrass and always exceeded the lower value of that range (0.28 to 0.36% P). In contrast, herbage from the clover component of these swards often exhibited a phosphorus content below the mean critical level for white clover, over this seasonally warm, drier part of the year. In the cut swards, clover phosphorus level was below the lower value of the range given for white clover (0.30 to 0.40% P) during spring-summer of the latter two years. McNaught (1970) pointed out that dry soil conditions greatly reduce the phosphorus concentration in pasture plants, and cautioned against sampling herbage for diagnostic purposes during prolonged dry weather. Seasonally low values for phosphorus content in both clover and grass herbage have been recorded in several studies in this country (reviewed by Metson & Saunders 1978a), generally over the period December-January to March-April. This association between soil moisture and herbage phosphorus levels is reflected in the very low values recorded for all treatments over spring-summer of year II (Table 12), when the experimental site was subject to unusually dry weather (Section II, Table 1).

Proposed mean critical levels for potassium (clover 2.0; ryegrass 2.2% K) were exceeded in all measured values for grass and clover herbage under seasonally cool, moist conditions (Table 13). Over spring-summer and summer-autumn they were also always exceeded in herbage from the grazed swards and in the grass component of the cut swards. In the clover component of the cut swards a value below the mean critical level was recorded during summer-autumn of the final year. However, it was not outside the range given for clover (1.8 to 2.3% K). McNaught (1970) reported that critical potassium

levels in leaf tissues from summer growth appear to be about three-quarters those for late autumn and early spring growth, for both clover and ryegrass.

All measured values for magnesium and calcium (Tables 14 & 15) exceeded the proposed mean critical levels. Magnesium contents of both the clover and grass components were frequently double the critical levels (0.13 and 0.11% Mg, respectively). Calcium levels in the clover component always exceeded the diagnostic criterion (0.7% Ca) by at least 50%, while levels in grass herbage were frequently double the proposed critical level for ryegrass (0.25% Ca).

(b) Soil 'Quicktest' values

With mature dry sheep as defoliators, removal of nutrient elements from the soil-plant complex would have been negligible in the grazed treatments. That soil phosphate (Table 16a) and potassium (Table 16b) levels either increased or were maintained under grazing over the course of the study indicates that the basal fertiliser policy for these two elements was adequate. However, substantial removal of these nutrients occurred with the continual harvesting of herbage from cut swards, and this is reflected in the corresponding soil test values (Tables 16a & 16b), which were maintained for phosphate only in the control treatment but otherwise declined over the study period. Annual phosphorus removal in herbage averaged 58 and 66 kg P/ha for cut treatments NO and N448 respectively, so was a little less than annual fertiliser input (67.5 kg P/ha). By contrast, annual removal of potassium in herbage from these two treatments averaged 410 and 580 kg K/ha respectively; amounts which were greatly in excess of fertiliser input (120 kg K/ha/an). The result was a marked drop in potassium test levels, in spite of the inherently excellent potassium-supplying properties (Kc values; Metson 1968) of the soil at this site (Ball et al. 1978).

Phosphate test levels in the vicinity of 20 to 30 are interpreted as 'medium', while values below 20 are 'low' and considered to indicate the likelihood of phosphate responsiveness (Anon. 1979). Values recorded

below the cut swards on conclusion of the experiment were marginal, especially from treatment N448. For potassium, values of 9 or over are interpreted as 'high', while values below 7 are rated as 'low' and considered to indicate the likelihood of potassium responsiveness (loc. cit.). Values recorded below the cut swards were marginal, irrespective of nitrogen treatment, when the study finished All other recorded potassium tests were above 9.

Averaged over all treatments, topsoil magnesium and calcium test values declined a little over the three-year study period (Tables 16c & 16d), with no consistent difference between defoliation or nitrogen treatments. Neither magnesium nor lime was included in the basal fertiliser programme. However, all magnesium and soil pH (Table 16e) test values recorded throughout this study are considered to exceed values likely to restrict growth of a mixed pasture. It is of interest that the fall in soil pH was exaggerated in treatment N448. Use of lime-ammonium nitrate, which contains some 35% by weight of precipitated calcium carbonate, did not completely offset the acidifying effect of the ammonium nitrate. Also of passing interest is that while some 750 kg $CaCO_3$/ha was applied annually with the nitrogen in treatment N448, this was not reflected in higher calcium 'Quicktest' levels for that treatment, on conclusion of the study.

(c) Assessment of basal fertiliser policy

The diagnostic criteria given by McNaught (1970) are for white clover and ryegrass herbage. In the present study, the clover component was almost entirely white clover. The grass component, while 80 to 90% ryegrass, included herbage from other non-leguminous constituents (grasses other than ryegrass and weeds, in roughly equal proportions; Section II, C, 1). Accordingly, comparisons are treated only as guidelines.

When viewed together, results from herbage analyses and soil 'Quicktests' indicate little likelihood of any restriction to pasture growth through magnesium or calcium availability, or through soil pH. While the

same may be concluded for phosphate and potassium in the grazed treatments, the possibility of marginal deficiency of these two nutrients for growth in the cut swards cannot be dismissed.

The recent alluvial soil at the site had low phosphate-fixing properties, with a P retention (Saunders 1965) value of 7% (Brock 1973). That fertiliser input exceeded phosphorus removal in the cut treatments each year would argue against any likelihood of induced phosphate deficiency. In the final year, phosphorus content in the herbage from cut swards (Table 12) met or exceeded the diagnostic criteria over both cool, moist seasons. While the level in clover herbage did fall below 0.3% P on one occasion, there was no indication of a progressive decline in the phosphorus content of herbage from the cut swards, as the experiment proceeded. Substantially lower levels were measured in herbage from both cut and grazed swards in spring-summer of year II than in herbage from the cut swards in year III (Table 12). When the influence of season and weather (McNaught 1970) is taken into account, it is concluded that serious phosphate deficiency was not a likelihood during this experiment. If deficiency did occur, it would have been confined to the cut treatments and have been more likely at the heavier rates of nitrogen input where phosphorus removal was enhanced. Further, as a subsidiary field study at the site had diagnosed marginal phosphate deficiency before this experiment commenced, any phosphate stress exerted on the cut swards would have been a consistent feature throughout the study rather than induced during its course.

Quite clearly, potassium was exploited from soil below the cut swards as the experiment proceeded: removal each year was three or four times annual input; soil 'Quicktest' levels fell dramatically; and there was a clear indication that potassium levels in herbage from the cut swards (Table 13) declined year by year. In the final year, potassium content of cut grass exceeded

the mean critical level for ryegrass over all 4 seasons. However, in mixed pastures the clover component is considered the more sensitive indicator of nutritional status (McNaught 1970; Jackman & Mouat 1970), and potassium levels in cut clover fell below the mean critical level during summer-autumn of year III. As with phosphorus, mean critical levels for potassium were exceeded in clover herbage from the cut swards over both cool, moist seasons during the final year. Again, when the influence of season and weather on mineral composition is taken into account, serious potassium deficiency seems unlikely on the basis of these herbage analyses.

Even in the final year of this study, potassium levels in clover herbage from the cut swards were considerably higher than those reported from a comparable study in the United Kingdom (Brockman et al. 1970), where weighted annual means of 1.22 to 1.36% K were measured. Following a previous study at Palmerston North, Melville & Sears (1953) reported weighted mean potassium contents of 2.4 to 3.3% K in clover herbage from mixed swards subjected to repeated cutting, without return of animal excreta, over a period of three years.

When herbage analyses and soil test values are considered together, a possibility that potassium deficiency was induced by continual cutting cannot be ruled out for this study. As with phosphate, potassium stress would have been more likely in cut swards receiving the higher rates of nitrogen, where nutrient removal was enhanced. Unlike any possible phosphate stress, potassium deficiency would not have been a feature in the early stages of this experiment. The subsidiary field study gave no indication of potassium responsiveness and initial soil test values were high. To the extent that potassium deficiency may have developed, it would have been confined to cut swards and would have been unlikely before the final year.

It was not practicable to carry out total sulphur analyses for herbage samples in association with this study. From average dry herbage yields, assuming an average total sulphur content of 0.33% S for the mixed herbage (McNaught 1970; Metson & Saunders 1978b), average annual removal in herbage from the cut swards is estimated to have been 47 and 59 kg S/ha, for treatments N0 and N448 respectively. When viewed against the annual fertiliser input of 82.5 kg S/ha, applied in split dressings, any possibility of sulphur deficiency seems unlikely (P.E.H. Gregg, pers. comm.). That sulphur deficiency was unlikely is also indicated by results from the associated preliminary field trial, which gave no indication of sulphur responsiveness at this site.

3 A Brief Analysis of Fertiliser Nitrogen Responses, and Their Possible Modification by Potassium Deficiency

There is a classical pattern to nitrogen responses by well managed, grass-clover swards; total dry herbage yield increases, with the response coming from the grass component of the sward, while clover herbage yield falls (Walker *et al*. 1954; Donald 1963; Crofts 1965; Whitehead 1970). Where the control sward has a relatively high clover content, and the response pattern to a wide range of nitrogen rates has been examined, it has been observed that total herbage nitrogen yield may show an initial decline at the lower rates of nitrogen input, but exhibit a more or less linear response to higher rates as clover is progressively displaced from the sward. A response pattern of this type was reported by Linehan & Lowe (1960), and is considered the more common pattern of response in United Kingdom studies (Richards 1976). The general form of nitrogen response curves (Viets 1965) dictates that the linear phase will become curvilinear, and eventually negative, if a sufficiently large range of nitrogen rates is tested.

Characteristically, clover herbage has a higher

nitrogen content than grass herbage (Table 8). The stimulation of grass growth with relatively small inputs of nitrogen results in clover displacement, presumably because of shading (Donald 1963) but possibly also as a result of competition for nutrients and/or moisture (Walker 1956b). When a decline in total herbage nitrogen yield occurs, it reflects the partial replacement of clover herbage by grass herbage of lower nitrogen content. Application of nitrogen to swards with a high clover content has been cautioned against in the New Zealand literature (Lynch 1953; During 1972; Ball & Field, in press).

As an 'inflexion point' has been recognised at the lower end of the more general response curve, it follows that the nitrogen response observed in any particular study will depend on both grass/clover balance and the range of nitrogen rates studied. The relationship of this type reported by Richards (1976) indicates a more or less linear response, only after the contribution by grasses to total herbage nitrogen yield has reached 70 to 75%. Mowing commonly inflates the clover content of mixed swards (discussed in Sections II, A & II, C). It is quite possible then, as an artifact of that method of measurement, that nitrogen responses have been underestimated in previous studies in this country, where long-term mowing trials have been involved (Hudson & McPherson 1933; Hudson 1934; Sears 1953b; Walker *et al*. 1953).

A question of immediate relevance to this country's agriculture is whether or not successful use can be made of fertiliser nitrogen on reasonably well developed, grazed pastures, with white clover contributing only 20 to 30% of total yield each year. Swards of this type might be expected to exhibit a linear response to a substantial range of fertiliser nitrogen inputs, used under appropriate climatic conditions. The much smaller clover population provides less scope for clover suppression, hence any negative contribution to either dry herbage or herbage nitrogen yields, as a consequence

of nitrogen use. Assuming nutrient and moisture adequacy, under these conditions any reduction in the clover yield from mixed swards in receipt of fertiliser nitrogen is attributable to the direct and indirect effects of shading by the taller grasses (Donald 1963). Defoliation management is likely to be the major determinant of the extent of clover suppression following nitrogen use (Walker et al. 1953; Walker 1956b; Donald 1963; Brougham et al. 1978). The study by Walker and associates in Canterbury (Walker et al. 1953) involved very long regrowth intervals under ideal climatic conditions for pasture growth. Throughout the growing season the site was subject to water deficit during only one month, yet spells of 70 to 100 days occurred between successive defoliations. While plant nutrition appears to have been adequate, with those extreme management contrasts a marked decline in white clover yield was observed as regrowth interval increased, whether or not fertiliser nitrogen was applied (loc. cit.).

The general pattern of nitrogen response recorded in the present study follows the less common of the two relationships described by Richards (1976): fertiliser nitrogen increased grass nitrogen yield and decreased clover nitrogen yield, but total herbage nitrogen yield increased in proportion to fertiliser input over the range of rates studied (Table 10 & Fig. 5). It seems most likely that this form of response was reproduced because relatively frequent, close defoliation was practised throughout the study, and because serious nutritional stress was avoided in the mixed sward.

Richards (1976) has associated this pattern of response, in which fertiliser nitrogen and clover performance are viewed as compatible, with soils of high potassium availability. Lowe (1966) also reported that the clover suppression associated with lower rates of nitrogen input could be partly offset by concomitant potassium application. Can some of the variability among past results be resolved on these grounds? Much

of it probably can. Sward failure in early studies at Marton (Hudson & McPherson 1933; Hudson 1934) is clearly attributable to potassium deficiency (Section II, D).

Initial comment is again directed towards experimental method. Any form of 'harvest and removal' management involves depleting the soil of large quantities of minerals, especially potassium. That applies equally whether the technique used involves the more common approach of mowing and discarding herbage, or grazing with animals harnessed to prevent return of excreta (e.g. Sears 1953a; Watkin 1954). Annual removal of potassium in cut herbage averaged some 410 to 580 kg K/ha during the present study, a somewhat larger figure than the three-year average reported by Melville & Sears (1953). Because of the longevity of the potassium influence on plant growth in both urine and dung-affected areas of pasture (During & McNaught 1961; During et al. 1973; Weeda 1977), a considerable proportion of total area may be benefiting at any point in time (Richards & Wolton 1976). Obviously, a substantial contrast in soil potassium status is likely to develop below cut and grazed swards, unless precautions are taken to prevent depletion under cutting. To maintain a potassium balance in soil during the present study, about one tonne/ha of either muriate or sulphate of potash would have been required as a basal dressing to cut swards each year.

In the introduction to this section, overseas studies were cited in which applied nitrogen decreased or failed to increase the total herbage nitrogen yield from mixed swards. Those studies involved either an experimental method (Linehan & Lowe 1960; Dilz 1965) or individual treatments (Watkin 1954) in which 'harvest and removal' management was imposed. Even where basal fertilisers were applied, the possibility of induced potassium deficiency cannot be dismissed because of the very large quantity removed in herbage. Linehan & Lowe (1960) reported their results after consideration of

treatment means following 6 years of continual cutting with removal of herbage. Lowe (1966) was later to report a strong influence of potassium availability on clover content in mixed swards. Watkin (1954) recorded consistent nitrogen responses only from grazed swards receiving animal urine, with its contained potassium. Potassium deficiency at the site was later implicated (Wolton 1955). The spectre of potassium deficiency interfering with field experimentation of this nature is also contained in reports from North Wyke. Total herbage nitrogen yield from cut, mixed swards exhibited little response to a range of nitrogen inputs (0 to 200 kg N/ha/an), because clover suppression offset increased grass yields (Shaw et al. 1966). Concurrent studies at the same experimental station, reported later (Brockman et al. 1970), demonstrated acute potassium deficiency at the site, with clovers responding markedly to potassium fertiliser. While not meaning to overstate his view, the writer concludes that potassium availability must be suspect in any study involving a 'harvest and removal' technique. The above experiments are open to that criticism. To avoid it, careful diagnostic scrutiny of both herbage and soil, throughout the course of an experiment, would be required.

While pronounced potassium deficiency may exert a quite spectacular influence on sward composition (Lowe 1966; Brockman et al. 1970; During 1972) and the form of nitrogen responses (Richards 1976), there remains the possibility that what may be only marginal potassium deficiency for a conventional grass-clover association could be quite serious in the event of nitrogen use on a mixed sward. Jackman (1971b) described the relatively weak position of clovers in mixed pastures as follows: '.... a species in a competitive situation which requires a higher supply of a nutrient, is more susceptible to shading and is less able to withstand moisture stress ...'. To that description might be added a seasonal dimension. Differences in temperature optima for the growth of

temperate grasses and clovers result in their main periods of growth being separated in time (Mitchell 1956; Brougham 1959). As pointed out by Blaser & Brady (1950), a lower optimum temperature allows grasses to start vigorous growth earlier in the season, when the clover associates are relatively inactive. If available potassium is low, grasses absorb much of it before any appreciable clover growth occurs (loc. cit.). Yet those are the very seasonal conditions under which tactical inputs of fertiliser nitrogen to mixed pastures are likely to have most application to New Zealand farming practice (During 1972; Field & Ball 1978).

Heightened competitive stress against white clover, in nitrogen-treated swards, is graphically illustrated in Fig. 8. This record was obtained when swards were at grazing stage during early spring, in the final year of this experiment. Clovers can be seen in the control sward but were completely overgrown by ryegrass in treatment N448, which sward was exhibiting a response to the heavy input of nitrogen at the start of regrowth over late winter-early spring. The sward of treatment N112 is intermediate between those two in this respect, but with ryegrass obviously much less nitrogen deficient than in the control sward. (A view of the cloverless sward is included for completeness. These photographs were taken about 5 months after sward rennovation in late autumn 1974, and testify to its success. Imperial units are displayed on the blackboard used for treatment identification).

Working with swards of Ladino clover and mixed grasses, Blaser & Brady (1950) found that a quite drastic suppression of white clover, resulting from early-season nitrogen application, could be substantially offset by concomitant application of potassium. The stimulatory effect of a heavy potassium dressing on clover performance was still observable over the following year (loc. cit.). Obviously, their results would only apply to sites exhibiting potassium deficiency, and may not be so applicable to clovers with better cool-

FIGURE 8 - Pastures at grazing height; early spring 1974

Control sward (NO)

Treatment N448

FIGURE 8 (Cont'd)

Treatment N112

Cloverless sward

season growth, such as 'G. Pitau'. However, the general principles seem likely to apply equally to any site where a nutrient other than nitrogen is deficient. Use of nitrogen on mixed swards to stimulate cool-season production, when potassium, phosphate or sulphur is in short supply, seems likely to exaggerate clover suppression because the more intense shading of clover further reduces its ability to compete for the limiting nutrient(s).

Little investigative research has been undertaken to assess the influence of other nutrients on nitrogen responses in New Zealand. A 'rule-of-thumb' viewpoint has been adopted, to the effect that if nutrient levels are sufficient to maintain an active clover component in mixed pastures, clovers are not likely to be seriously jeopardised by nitrogen use, providing that over-spelling is avoided (Lynch 1953; Ball & Field in press). Lammerink (1959, 1962) reported a two-year study involving spring application of potassium and nitrogen to a flood-irrigated sward in Canterbury. His results give no support to the contention that nitrogen responses are modified by potassium availability, as a potassium response was recorded only in the control sward, with grass/clover ratio little affected, and a small suppression of clover was observed in all nitrogen-treated swards during summer. Experimental conditions almost certainly influenced results: plots were mown fortnightly, and white clover contributed 50% of the yield from control swards over the mid spring-early summer period (loc. cit.).

In the writer's view the role of nutrient availability, especially potassium, in modifying nitrogen responses by mixed pastures, is a field urgently requiring research in this country.

4 Herbage Intake and Digestibility

Similarity among nitrogen treatments in apparent dry herbage intakes (Table 17a) indicates that comparable grazing pressure was exerted on all swards during the

study. Measurement of stubble yields to ground level, on commencement of the experiment, showed that similar quantities of dry herbage remained after defoliation, whether by grazing or cutting and irrespective of fertiliser nitrogen rate (Section II, D, 1). No attempt was made to analyse for differences in apparent intake between years or between seasons because of changes in cultural practices, including the frequency of defoliation, and the age and size of grazing animals throughout the study.

Average values over the final year (Table 17a) indicate that, relative to control, apparent dry herbage intake was 20% lower among sheep grazing the pure grass swards but 9% higher for sheep on treatment N448. After studying grazing patterns of both set-stocked (Keogh 1973) and periodically mob-stocked sheep, Keogh (1975) concluded that ryegrass dominant areas in mixed pastures were preferentially avoided in grazings over summer and autumn. Similarly, in the present study it became apparent that sheep were reluctant to graze herbage in the pure grass swards. With no input of nitrogen from either clovers or fertiliser, herbage acceptability declined. By year III, herbage nitrogen content (Table 8) was low in relation to that of other treatments. To effect a common level of utilisation among treatments, higher sheep densities were required on the cloverless swards. This was reflected in the reduced apparent dry herbage intake by sheep grazing the Grass treatment during the final year.

In reviewing the influence of fertiliser nitrogen on herbage palatability and animal intake, Whitehead (1970) notes conflicting reports of effects on palatability, but presents a body of evidence indicating that the level of nitrogen had no effect on intake under a variety of experimental conditions. An exception arose from one study in this locality. Bryant & Ulyatt (1965), concluded that even relatively massive inputs of lime-ammonium nitrate to a ryegrass sward (3 545 kg N/ha, between July and October) had no

marked deleterious effects on animal health or intake. However, ad libidum intake by the test sheep receiving the 'high nitrogen' grass was reduced in one of their two studies. Keogh (1973, 1975) reported a pronounced preference by sheep for pasture affected by recent animal urinations, irrespective of the botanical composition in 'urine patches'. In those studies over summer and autumn, mixed ryegrass-white clover areas were preferred over ryegrass dominant areas in the remainder of the sward. The clover content of the N448 sward was considerably lower than that of grass-clover control in the present study (Section II, Table 3). Therefore, one might speculate from the limited evidence for enhanced dry herbage intake on swards receiving a substantial input of fertiliser nitrogen (Table 17a) that the preference shown by sheep for urine-affected pasture over summer and autumn results from some aspect of the elevated nitrogen status of such herbage.

Whitehead (1970) reports that herbage digestibility is generally affected only slightly by application of nitrogen to pure grass swards, but that this practice can significantly lower digestibility where it reduces the proportion of clover in mixed swards. Such an effect was not apparent in the results from in vitro DM digestibility estimates (Table 17b) for samples of mixed herbage taken over late spring-summer of the final year, even though the clover content of swards receiving N112 and N448 (29 and 20%, respectively) was considerably below the 40% measured in the control sward over that period.

The role of both fertiliser nitrogen (Whitehead 1970) and legumes (Ulyatt 1973; Thomson 1977) in modifying intake, digestibility and quality of forage from mixed swards is complex. It should be pointed out that, in this experiment, test animals were not maintained on diets of forage from the various nitrogen treatments, except during the pre-feeding period of 1 to 1½ days and the 3 to 5 days' grazing required at each defoliation. No animal production measurements could

be attempted, as the sheep were maintained under common management between defoliations. Possible effects on apparent intakes through prolonged exposure of sheep to the test swards were not assessed. Nevertheless, under the experimental conditions, these results give no indication of any adverse effect of fertiliser nitrogen on average intakes of herbage from grass-clover swards, nor on digestibility of the mixed herbage over summer-autumn.

E CONCLUSIONS

1. Grazing raised total herbage nitrogen yield each year, by 18 to 22% over cutting. Over the first year, elevated herbage nitrogen content contributed to this result but in subsequent years the yield superiority of grazing more directly reflected treatment differences in dry herbage yields. Apparent recovery in herbage of nitrogen cycled in animal excrement was no better than 20%, possibly less, on average over the three years.

2. Total herbage nitrogen yields were large, averaging 560 kg N/ha/an from the control grass-clover sward. Yet under the experimental conditions, linear responses were recorded in the yearly averages for total and grass herbage nitrogen yields, over the full range of nitrogen rates tested. The heaviest rate (448 kg N/ha/an) increased total herbage nitrogen yield every year, by 30 to 43% over control. While fertiliser nitrogen treatments exerted only a minor influence on the nitrogen content of clover herbage, they increased foliar levels in grass, with the result that treatment differences in total herbage nitrogen yield were more pronounced than the differences in dry herbage yield reported earlier. Apparent recovery in herbage of fertiliser nitrogen averaged 44% over the three years.

3. While herbage of the grass component from grass-clover control swards generally contained higher levels

of total and nitrate nitrogen than did that from the pure grass swards, no treatment difference in yearly grass herbage nitrogen yield was recorded until the third year. It is suggested that white clover exerted a repressive effect on yield of associated grasses, thereby negating any effective transfer of symbiotically-fixed nitrogen over the first and second years.

4. Basal fertiliser policy appears to have been adequate. While considered unlikely, the possibility of marginal phosphate deficiency in the cut treatments cannot be ruled out entirely, nor can the possibility of induced potassium deficiency in the cut treatments over the final year.

5. Field observation and grazing records provided limited evidence for enhanced apparent DM intakes by sheep grazing mixed swards receiving the heavier rates of nitrogen input, especially over the spring-summer period. Differences in DM digestibility (*in vitro* estimates) were not apparent for mixed herbage sampled over late spring-summer in the final year, from control, N112 and N448 swards, even though clover content differed substantially between treatments.

SECTION IV

SOIL NITROGEN AND NITROGEN BALANCES

A INTRODUCTION

A mass balance for nitrogen cannot be compiled using results from most field experiments, as changes in soil total nitrogen are not generally monitored accurately, if at all (Allison 1966). Because of the relatively long residence time for nitrogen in soil organic matter (Clark & Paul 1970; Henzell & Ross 1973), this very large pool acts as a 'reservoir' or storage compartment for nitrogen. Depending on whether prevailing natural and cultural influences are 'nitrogen-gaining', 'nitrogen-losing' or 'nitrogen-stable' (O'Connor 1974), the effects will be reflected in a corresponding increase, decrease or lack of change in soil total nitrogen. Accordingly, monitoring soil total nitrogen to detect any changes in the pool size over time is mandatory to compiling a nitrogen balance during ecosystem studies.

Characteristics of the New Zealand pastoral industry were considered briefly in Section I. In an ecosystem typical of that used for intensive grassland farming, with well developed permanent pastures under continual grazing management, for all practical purposes any substantiative change in nitrogen retention within the soil-plant-grazing animal complex will be encompassed by monitoring soil total nitrogen throughout an experiment. Compared with this pool, all other nitrogen pools are relatively small (Henzell & Ross 1973). They may exhibit considerable variation over the short term. For instance, the nitrogen pool in livestock may vary according to the seasonal phase of a farming enterprise; herbage nitrogen will fluctuate according to severity of grazing and stage of regrowth, while soil mineral nitrogen may even be subject to daily changes. However, such short term vagaries in

these production-related nitrogen pools can be viewed as fluctuations around their long term averages, within any well developed pastoral ecosystem. Residence time for such nitrogen is relatively brief. While of vital importance to the productive process, over a period of years the production-related pools do not serve a 'storage' function.

Attention has already been drawn to the very large quantities of nitrogen involved in intensive grassland farming, whether using grass-clover associations or nitrogen-fertilised grass swards (Section I). Henzell (1970) made a rather forthright call for better accountability for the large quantities of fertiliser nitrogen used for intensive grassland farming in Europe and North America. In this writer's view, there is an equally alarming gap in knowledge concerning the nitrogen balance in grazed grass-clover ecosystems. In sheep and beef farming, nitrogen retention during animal growth is only about 25 kg N per tonne liveweight gain (Whitehead 1970; Henzell & Ross 1973). So at the highest levels of animal production recorded from grazed pastures in this country, nitrogen removal during fat lamb (Harris & Hickey 1978) and beef production (Brougham et al. 1975) would only have been some 25 and 50 kg N/ha each year, respectively. Even with intensive dairyfarming, nitrogen retention for animal growth plus outgoings in milk, together, comprise only some 70 kg N/ha each year (Whitehead 1970; Henzell & Ross 1973). In a developed pastoral ecosystem, with soil nitrogen near 'steady-state' (Jackman 1964a, b), the nitrogen input required each year to meet such outgoings in animal production is quite modest. Accordingly, it is difficult to understand how the agricultural fraternity of this country have accepted estimates of several hundred kg N/ha for annual nitrogen input by clover fixation, without expressing concern over what must then be substantial unaccounted-for nitrogen outgoings from grazed ecosystems. The author's scepticism over accepted views is heightened

by the fact that observed values for soil nitrogen accumulation below well managed, developing pastures have not greatly exceeded 100 kg N/ha annually (Walker et al. 1959; Jackman 1964a, b).

Relatively poor accountability for nitrogen is commonly a feature of heavy fertiliser nitrogen use in intensive grassland farming (Woldendorp et al. 1966; Henzell 1970). Even in pure grass swards, apparent recovery generally amounts to only 55 to 70% of that applied, the actual figure varying with experimental conditions (Whitehead 1970). Is it in order to assume that the problem of unidentified nitrogen outgoings does not equally beset intensive grassland farming based on grass-clover associations?

This study was undertaken to gain further information on nitrogen relationships in highly productive grass-clover associations. To provide information on differences between grazed and cut swards, aspects of the performance of a relatively well developed ryegrass-white clover pasture were monitored under both grazing and mechanical defoliation. At the same time, a range of nitrogen treatments was included to test the view that nitrogen availability imposes an upper limit to total herbage production from grass-clover associations, and to gain information on the nitrogen status of the experimental site. Treatment effects on dry herbage yields and sward characteristics are reported in Section II. Section III covers influences on total and nitrate nitrogen levels in herbage, herbage nitrogen yields, and treatment effects on the mineral characteristics of herbage and soil. In this section are reported treatment influences on soil total and mineral nitrogen pools, estimates for symbiotic nitrogen fixation, and mass balances for nitrogen in the grazed and cut systems.

B MATERIALS AND METHODS

1 Site and Climate

This study was carried out at Grasslands Division,

Palmerston North, over the period autumn 1972 to winter 1975 inclusive. Detailed descriptions of the site and climatic conditions throughout the study period have been presented (Sections I, B & II, B, and Section I, Table 1, respectively). However, some aspects of the history of the site, including recent cultural practices, may be reflected in results reported in this section, so are considered here in detail.

In its original state soil at the site comprised Manawatu fine sandy loam (Cowie 1972). The general area was undulating, and had been intensively dairyfarmed for many years. In 1967-'68, the area was levelled. To achieve this, topsoil and subsoil were stripped and stockpiled separately. Underlying material (a mixture of bedded medium and coarse sands, with localised inclusions of deeper sandy loam) was levelled, then subsoil and topsoil were replaced evenly and in order. In its modified state the profile typically comprised some 45 cm of fine sandy loam, overlying bedded medium and coarse sand, in turn overlying gravel at about 2.75 m depth.

Pasture was sown in 1968, and grazed by sheep. In its undisturbed state, the soil is free-draining and inclined to summer drought. Localised areas with impeded drainage became apparent in the levelled soil. Lack of earthworms was considered a possible reason, but the more likely explanation was that compaction had occurred when heavy machinery was involved in levelling and spreading soil. In spring 1970 the experimental site was subsoiled to a depth of 46 cm. Sub-soiling was carried out at 0.5 m spacings, in two directions at right angles. This cultural practice had the effect of lifting the *in situ* soil by 5 to 10 cm, fracturing the profile in the process, and left in the subsoil a series of channels through which the angled foot of the subsoiler had been drawn.

In autumn 1970 the site was deep-ploughed (20 cm) and the experimental sward was successfully established. Fertilisers and lime were applied over the period 1969-

'71. In association with resowing, the ploughed area received 2.5 t lime/ha and 375 kg potassic superphosphate/ha (22.5 kg P/ha, 60 kg K/ha and 27.5 kg S/ha). These were worked into the topsoil. Subsequent inputs during pasture establishment comprised 25 kg P/ha, 22.5 kg N/ha and 15 kg Mg/ha. An active population of earthworms was established.

Treatments were imposed in autumn 1972, four years after the site had been levelled. By that time, the area supported a vigorous 'Grasslands Ariki' ryegrass (*Lolium* x [(*multiflorum* x *perenne*) x *perenne*])-'Grasslands Huia' white clover (*Trifolium repens*) sward, which had been managed under periodic mob-stocking with sheep for the two years from sowing. There was then no sign of impeded drainage in any part of the field. The soil was expected to behave in a manner similar to any other comparable, recent alluvium (J.D. Cowie, pers. comm.), with the advantage for small plot studies that it was considerably more uniform than when in its natural state. The author would consider this soil as reasonably representative of any comparable alluvial soil, which had been subjected to repeated cropping over a period similar to that involved when levelling, ploughing and resowing took place.

Chemical characteristics of the soil have been presented (Sections II, B, 1 & III, B, 1, and Section III, Table 16). Analyses of representative samples taken before the study commenced indicated a relatively uniform, fertile site. Topsoil C/N ratio was 9.5 (organic C = 1.74%; total N = 0.183%) and pH was 6.1 (CEC = 11.4 me %; base saturation = 97%). A basal fertiliser policy was pursued throughout with the aim of precluding deficiency of any nutrient other than nitrogen. As discussed previously (Section III, D, 2, c), the possibility of marginal phosphate deficiency and induced potassium deficiency cannot be ruled out entirely, where swards were continually cut and the herbage removed.

2 Treatments

A detailed account of treatments has been given (Section II, B, 2, a).

(a) Method of defoliation

The performance of swards was compared when subjected to periodic mob-stocking with dry sheep (grazing), or repeated mechanical defoliation with a shearing handpiece (cutting).

Small paddocks (0.025 ha) were used for measurements under grazing. Sheep were pre-fed for 24 to 36 h on pasture receiving the relevant treatments, before entering the experimental swards, and were managed to minimise fertility transfer.

Small plots (3.72 m^2) were randomly located within small paddocks of the appropriate grazed treatments, for measurements under repeated cutting. They were adequately protected from animals during grazing. All material harvested from the cut swards was removed from the experimental area. Otherwise, management was common to both defoliation treatments, with measurements carried out at the same time and in a common manner.

(b) Nitrogen treatments

A comprehensive range of measurements, relevant to formulating nitrogen balances, was carried out on only 4 of the 7 nitrogen treatments imposed. The 4 treatments were:

1 (N0) = grass-clover, control sward;

3 (N112) = grass-clover sward receiving a total of 112 kg N/ha, in split dressings over the period late autumn to early summer (c 9 months);

5 (N448) = grass-clover sward receiving a total of 448 kg N/ha, in split dressings as above;

7 (Grass) = a sward maintained free of clovers, and receiving no fertiliser nitrogen.

All 4 treatments were measured under both grazing and cutting.

Clovers were removed from the original sward to create treatment 7 (Grass), by spraying with a selective

herbicide (Section II, B, 2, b). Volunteer clovers were subsequently hand-weeded or spot-sprayed as necessary.

Nitrogen treatments were maintained within individual, small paddocks to preclude the possibility of nitrogen transfer between treatments during grazing.

3 Experimental Procedure

Detailed accounts of sward management and experimental procedure associated with herbage measurements have been given (Sections II, B, 3 & III, B, 3).

(a) Field sampling procedure

Total soil nitrogen was monitored under both grazed and cut swards. It was measured in the top 45.7 cm of the profile, at 4 depths (0-7.6, 7.6-15.2, 15.2-30.4 and 30.4-45.7 cm). At least one set of measurements was made annually, but not all plots nor soil depths were sampled at each measurement. Individual soil cores (c 2.5 cm dia.) were drawn from the plots on a stratified, random sampling basis (Petersen & Calvin 1965). For each sample, cores were taken in proportional numbers from sections of a grid within that plot, but cores were obtained from individual microsites at random. Immediately before treatments were imposed, duplicate samples each comprising 50 separate cores were taken from within each of the grazed paddocks, and single samples each comprising 10 separate cores from the cut plots. A subsequent study of sampling errors indicated that the latter sampling intensity was insufficient. Thereafter, both grazed and cut treatments were sampled in duplicate, but each sample from below cut swards comprised only 40 bulked cores. Where applicable, mean values from duplicate measurements within plots were used in subsequent statistical analyses.

An endeavour was made to carry out the field sampling under similarly moist soil conditions (near, but not exceeding field capacity) at each measurement.

Each core was taken to a depth exceeding 46 cm. It was then carefully transferred from the tube sampler by sliding it onto a half-round, graduated p.v.c. holder, and cut into the 4 separate sampling depths. After the 50 (or 40) plugs from each depth had been assembled, they were check-counted, then bulked within sampling depths to give 4 composite samples per plot. Duplicate samples within plots were separately identified On the same day as they were taken, field-moist samples were placed in forced-air ovens ($< 30^{o}C$). When air-dried, samples were weighed for volume weight determinations. Sub-samples (c 500 g) were then obtained using a quartering technique, ground (< 2 mm) and stored in airtight tins pending analysis. Additional sub-samples (2 x 20 g) were taken from each sample to determine moisture content. During the field sampling, any cores obviously compacted or mutilated on removal from the tube sampler were discarded. Minor compression (3 to 6 mm in 460 mm) occurred consistently, and was disregarded in calculating volume weights. The diameter of replaceable cutting tips on tube samplers was accurately recorded. Holes formed by removal of soil cores were immediately filled with dry river sand, to minimise any effects on soil water movement and/or soil aeration. Inclusion of a coarse sand fraction provided a 'marker' for previous sampling holes, during subsequent samplings.

Soil carbon was measured in half the samples taken for total soil nitrogen determinations (two of the four replicates) to assess any influence of treatments on soil carbon-nitrogen relationships.

Nitrogen fixation ($N_2(C_2H_2)$ fixation; Hardy et al. 1968) was assayed in the grazed treatments only, during the final full year of the study, following the technique described by Hoglund and Brock (1978). Fourteen cores, each 0-7.6 cm, were taken from each small paddock on a stratified, random sampling basis, using a 2.54 cm diameter tube sampler. Cores were bulked in one litre incubation jars, which were sealed

and placed into a sunken, water-filled trough as sampling proceeded. A further set of 14 cores was taken to a depth of 30.4 cm from representative pasture, and divided into 4 equal 7.6 cm depths to assess percentage activity at different depths. On completion of sampling, 50 ml air in the incubation vessels was replaced with acetylene (c 10% acetylene atmosphere), and the samples were incubated one hour near midday. A gas blank was also incubated. Periodic inclusion of soil blanks gave no indication of ethylene production from this soil, nor in an adjoining experiment (Hoglund & Brock 1978). Regular checks during these incubations confirmed that temperatures of the water in the trough, and of soil at 5 cm depth, were within 1°C. The trough and jars were protected from direct sunlight during incubation. On completion of incubation, gas samples were transferred to evacuated 5 ml vials, using double-ended needles. $N_2(C_2H_2)$ fixation was assayed twice per regrowth period, near the middle and finish of each.

Mineral nitrogen levels were measured in the top 45.7 cm of the profile, in the grazed treatments only during the final full year of the study. Eight cores were taken from each small paddock on a stratified, random sampling basis, with field procedure otherwise the same as for total nitrogen sampling. Individual soil plugs were bulked and, immediately after collection, were placed in polyethylene bags and stored under ice in an insulated bin. Within 4 h of collection, but generally sooner, the field-moist samples were mixed thoroughly and sub-samples were drawn using a quartering technique, for both mineral nitrogen and water content determinations. Twelve g samples of field-moist soil (c 10 g dry soil) were extracted for one h by shaking with 100 ml 2 M KCl, and the extracts were filtered through a Whatman No. 42 paper. Filtrates were stored (5°C) until analysis the next day. The balance of each field-moist sample was also stored (-18°C) to allow for any repeat analyses. Sampling was normally carried out twice per regrowth period, but sampling frequency

was increased over late autumn, when the sampled profile was rewetting after seasonally dry summer-early autumn weather. In calculating pool sizes for mineral nitrogen, volume weight data obtained in association with total soil nitrogen measurements were used.

(b) Analytical procedure

Chemical and gas analyses followed standard practices within Grasslands Division's analytical services. Soil water was determined by drying 20 g sub-samples, generally in duplicate, at 105°C for 16 h. For total soil nitrogen and carbon analyses, a small representative quantity of soil was obtained from each of the bulk (< 2 mm) sub-samples, using a tube to take several cross-sectional sub-sub-samples vertically through the content of each storage tin. The bulked sub-sub-samples were finely ground (< 100 mesh B.S. sieve). For total nitrogen, 1.4 g soil was digested by the Kjeldahl method (selenium catalyst) and nitrogen was determined colourimetrically on the diluted (c 1 N H_2SO_4), centrifuged digest, using a Technicon AutoAnalyser, by the hypochlorite-phenol reaction with ammonium (Williams & Twine 1967). No provision was made for recovery of nitrate nitrogen during total soil nitrogen determinations (Goh 1972) as levels were found to be generally low at the time of sampling. For the preliminary study into sources of error associated with total soil nitrogen determinations, analyses were conducted on reference topsoil and subsoil bulk samples, and sub-samples from individual soil cores. Soil carbon was determined on 1 to 1.5 g sub-samples by chromic acid digestion (Barkoff 1954). Methods for gas analyses have been reported in detail (Hoglund & Brock 1978). A ratio of 3:1 for ethylene produced (after allowance for a gas blank):N_2 fixed was used (Hardy et al. 1968), with time and area factors used for calculating kg N fixed/ha-7.6 cm/day. Nitrogen fixation in the profile was then calculated using the percentage activities at each depth, from the 30.4 cm deep sample. On average, 80% of activity was recorded

at 0-7.6 cm. Ammonium and nitrate nitrogen were determined concurrently in the filtered KCl extracts, using automated colourimetric techniques. Ammonium was determined using the hypochlorite-phenol reaction, with sodium nitroprusside addition to accentuate colour development (Brown 1973) and nitrate as nitrite following hydrazine reduction, by the sulphanilamide-naphthyl ethylene diamine method (Henzell et al. 1968). Periodic checks were made for nitrite nitrogen in extracts, but none was found.

Standard checks on quality control were used routinely throughout the chemical analyses. For total soil nitrogen and carbon, duplicates of reference topsoil and subsoil bulk samples were taken through the full analytical procedure, during every analytical run. Mineral nitrogen analyses were initially cross-checked against steam distillations, and later against extracts of known composition. For all chemical determinations, analyses were duplicated on 10% of 'unknowns'. Analyses were repeated in those few instances where serious discrepancies occurred, or where there was doubt about individual values.

Two terms used in this report require definition. 'Nitrogen content' is used in the conventional sense (g N/100 g soil). Those results are reported on an air-dry soil basis (average correction = x 1.008). The term 'pool' is used to denote the weight of nitrogen in the profile at various sampling depths. Those results are reported on a dry soil (105^{o}C) basis. (Note: where appropriate, an individual depth is specified to denote the sampled profile to that depth. Thus, the nitrogen pool 'to 15 cm' or 'to 45.7 cm' is the weight of nitrogen (kg N/ha) throughout the profile to that sampling depth. Likewise, the term 'kg N/ha-15 cm' or 'kg N/ha-45.7 cm' denotes the nitrogen pool from the surface to the sampling depth specified. When necessary, individual sampling depths are specified, viz '0-7.6 cm', '7.6-15.2 cm' and so on).

4 Design and Statistical Procedure

Nitrogen treatments were randomly assigned to plots within each of 4 replicates. Small plots for measurements under cutting were located, using randomised co-ordinates, within corresponding grazed areas. Analyses of variance were carried out using conventional statistical procedure, including tests for main treatment (defoliation method and nitrogen treatment) effects, and interactions between these where appropriate.

Two to four significant figures were included in raw data for statistical analyses. Means have been severely rounded in some cases to facilitate tabulation. Unadjusted means are presented throughout this section.

C RESULTS AND DISCUSSION

1 Soil Total Nitrogen

Experimental swards occupied an area of about one ha in this study, on a flat, ostensibly uniform site (Section II, Fig. 1). Nevertheless, it was appreciated from the outset that difficulty would be encountered in attempting to measure any small changes likely to occur from year to year, relative to the very large pool of total soil nitrogen which normally exists under pasture. The profile to 45.7 cm contained on average 8 100 kg N/ha. Change would not normally be expected below 15 cm (Jackman 1966), but deep-ploughing two years before the study commenced raised this possibility. On the basis of change in the top 15 cm of soil only, to detect a movement of 100 kg N/ha required sampling and measurement procedures of sufficient precision to detect a change of approximately 0.006% in total nitrogen content of the topsoil samples (one in 32, for the average 3 200 kg N/ha-15 cm).

Difficulties associated with obtaining representative soil samples, and errors of observation have been reviewed (Petersen & Calvin 1965; Kempthorne & Allmaras 1965). Studies reviewed by Beckett & Webster (1971)

were mostly concerned with spatial variability in soils sampled for mapping and/or advisory purposes. Few detailed studies have been concerned with recording changes in the nitrogen or organic matter content of soils over relatively short periods of time, to follow the effects of different cultural practices. In the absence of literature relevant to measurements in New Zealand pastures, it was decided to undertake a preliminary study into errors associated with soil total nitrogen determinations.

(a) Preliminary error studies

Bulk reference samples of topsoil (0-7.6 cm) and subsoil (15.2-30.4 cm) were assembled, made up of individual cores taken from the experimental site on a stratified, random sampling basis. These samples were prepared for analysis as described under 'materials and methods'. Repeated analyses, cross-referenced to results obtained by steam distillation, indicated an unacceptable level of error in existing laboratory procedure. A commonsense approach was adopted to reducing these errors to a level compatible with the experimental objective, but no attempt was made to quantify the various sources of error associated with laboratory measurements.

Several sources of error were identified. The mineral component of soil interfered with colourimetric readings in a variable manner: overcome by including soil ash (from the appropriate depth) in ammonium standards, and centrifuging diluted digests before filling sample holders. Evaporation from sample holders occurred, exaggerated by long analytical runs: overcome by enclosing and humidifying the immediate environment of the sampling table. Baseline shift often occurred during long runs: surmounted by reducing the number of samples per run, and including a long wash period, with baseline adjustment if necessary, between analytical runs. Small errors were apparent in reading peak heights from pen traces, both in drawing up the standard curve and reading unknowns:

reduced by duplication of colourimetric readings for standards and samples.

The final procedure incorporated all the aforementioned modifications. All determinations were carried out by the same personnel over an unbroken period, after the field work had been completed. Digestions were not duplicated (except 10% for routine checks). A single run for determining ammonium levels in the diluted digests comprised 6 standards, one reference sample, 8 unknowns, a further reference sample then repeat standards, all analysed in duplicate. In preparing standard curves and reading unknowns, mean peak heights were used. Using this methodology, total error associated with laboratory measurements was reduced to an acceptable level. Values listed in Table 18a are for repeated analyses of sub-samples from two bulk reference samples, put through the analytical procedure as 'unknowns' in different runs spanning a period of several weeks. The standard deviation was 0.77% (0.45%) of the mean for topsoil (subsoil) samples, or about one third of that initially encountered in the method.

Total nitrogen content was then determined in sub-samples from numerous individual soil cores to gain an assessment of errors likely to be associated with both field sampling, and subsequent mixing and sub-sampling. These cores were from the initial sampling, immediately before treatments were imposed. While selected at random, cores were included from two small paddocks and corresponding small plots of each replicate. Further, 16 pairs of composite samples were assembled, using standard mixing, grinding and quartering techniques. Each composite consisted of equal proportions, one eighth, of the soil from the individual cores taken from that paddock or small plot. Analytical results from both the surface and a deeper soil depth are reported in Table 18b.

Compared with the laboratory, the field was a potential source of enormous error. Collectively, the single measurements on individual cores (Table 18b)

TABLE 18 - Variability in measured values for soil total nitrogen content: (a) among repeated analyses of reference samples; (b) among individual cores drawn from within small paddocks and small plots

		No. (†)	Mean (% N)	Range (% N)	S.D. (±)
(a) Reference samples					
Topsoil		21	0.1825	0.178 - 0.185	0.0014
Subsoil		11	0.1327	0.132 - 0.134	0.0006
(b) Individual cores					
I A Paddock:	topsoil‡	27	0.188	0.146 - 0.228	0.025
	subsoil	27	0.155	0.068 - 0.253	0.047
I a Small plot:	topsoil	6	0.192	0.153 - 0.222	0.027
	subsoil	6	0.151	0.138 - 0.164	0.011
I B Paddock:	topsoil	27	0.184	0.132 - 0.236	0.027
	subsoil	27	0.167	0.106 - 0.250	0.034
I b Small plot:	topsoil	6	0.146	0.129 - 0.170	0.015
	subsoil	6	0.112	0.088 - 0.145	0.027
II A Paddock:	topsoil	27	0.181	0.132 - 0.242	0.027
	subsoil	27	0.148	0.076 - 0.238	0.044
II a Small plot:	topsoil	6	0.173	0.142 - 0.224	0.029
	subsoil	6	0.156	0.106 - 0.203	0.031
II B Paddock:	topsoil	27	0.190	0.138 - 0.234	0.028
	subsoil	27	0.151	0.097 - 0.213	0.033
II b Small plot:	topsoil	6	0.185	0.145 - 0.257	0.047
	subsoil	6	0.160	0.110 - 0.214	0.038
III A Paddock:	topsoil	27	0.184	0.127 - 0.227	0.026
	subsoil	27	0.151	0.108 - 0.209	0.031
III a Small plot:	topsoil	6	0.162	0.140 - 0.197	0.019
	subsoil	6	0.142	0.120 - 0.210	0.034
III B Paddock:	topsoil	27	0.202	0.125 - 0.318	0.041
	subsoil	27	0.146	0.063 - 0.215	0.031
III b Small plot:	topsoil	6	0.215	0.177 - 0.290	0.040
	subsoil	6	0.140	0.108 - 0.180	0.030
IV A Paddock:	topsoil	27	0.154	0.121 - 0.211	0.020
	subsoil	27	0.115	0.065 - 0.193	0.034
IV a Small plot:	topsoil	6	0.155	0.132 - 0.184	0.021
	subsoil	6	0.111	0.098 - 0.135	0.014
IV B Paddock:	topsoil	27	0.193	0.110 - 0.310	0.048
	subsoil	27	0.136	0.072 - 0.280	0.045
IV b Small plot:	topsoil	6	0.189	0.143 - 0.217	0.026
	subsoil	6	0.142	0.097 - 0.195	0.034

† No. of observations: (a) repeat analyses; (b) single analyses.

‡ Values tabulated are for 0-7.6 and 15.2-30.4 cm sampling depths.

indicate that total nitrogen content in the basic sampling unit varied by a factor of three or four, within sampling depths, over the experimental site. Within depths, variation among values for individual cores drawn from the same paddock or small plot often exceeded two-fold. On average over all sampling depths, variability among individual values from small plots (3.7 m^2) was almost as great as variation among those from small paddocks (250 m^2).

When endeavouring to measure change over time in any soil parameter, one is dealing with the difference between consecutive measurements, each of which includes associated error. As such, differences exhibit substantially greater error variance than that encountered at either of the individual measurements. In investigating treatment effects under these circumstances, one is comparing differences with differences. Taking these considerations into account, an analysis of variance was carried out on the results to obtain estimates of sampling intensity required to overcome soil heterogeneity in the field, to allow detection of treatment differences of specified magnitude. As variance was quite similar among values obtained from all 4 sampling depths, the data were amalgamated. With 4 replicates, those estimates were:

	Paddocks	Plots
Cores/plot, to detect a treatment difference of 0.01% N	42	34
Cores/plot to detect a treatment difference of 0.005% N	170	137
(Standard error of mean total soil N%)	($\pm$0.0332)	($\pm$0.0299)

Analytical values from the composite samples (S.E. $\pm$ 0.0016) indicated that the combined effect of all errors associated with measurements, following removal of the basic sampling units from the field, was relatively minor. Vallis (1973) reached a similar conclusion in an error study into sampling for soil

total nitrogen changes in large areas of grazed pasture, in Queensland.

This error study was undertaken in association with the first soil sampling, and results were applied to subsequent samplings. That variation in small plots was almost 80% of that in paddocks was unexpected, and indicated that the intensity of sampling below the cut swards had to be greatly increased. It was not practicable to collect the very large numbers of samples indicated by this preliminary study, neither in terms of the work-load nor the influence that such intensive sampling may have had on pasture performance in small plots. The compromise adopted was to take duplicate samples of 50 cores (40 cores) from each small paddock (small plot), in all 4 replicates. This was estimated to allow detection between treatments of differences as small as 0.005% N, at 10% probability.

Biggar (1978) has reviewed the topic of spatial variability in soil total nitrogen and organic matter contents. From consideration of data in the world literature, he arrived at the following general conclusions of relevance to this study: that up to one half of the variance within a field may be present in any m^2 of that field; that total nitrogen is no more variable in its distribution than organic matter; that variability in subsoil organic matter is consistently neither more nor less than that in surface soil; and that the variance for unaltered landscapes is generally less, for both organic matter and total nitrogen, than for similar areas of cultivated land.

The information gathered in this error study is largely in accord with the above generalities. A weakness is that the work was carried out on a soil which had been disturbed. Sampling depth coincided almost exactly with the depth of soil which had been stockpiled and redistributed after levelling of the subsoil. While the view is held that the sampled profile would have exhibited greater variability in its natural state, then a mosaic of elevated, drier areas

and damp hollows, the extent to which these results are generally applicable remains open to question. An early study (Robinson & Lloyd 1915) indicated that soils formed on transported materials are inherently more variable than sedentary soils derived from bedrock *in situ*. In a previous study at Grasslands Division on an older alluvial soil (Karapoti silt loam; Cowie 1972), which had been surface-cultivated, considerable spatial variability was observed in total nitrogen content of the surface soil (Harris & Brougham 1968). This was related to the micro-distribution of constituent species in a mixed pasture (*loc. cit.*).

Petersen & Calvin (1965) put forward the general view that heterogeneity is more pronounced in surface than deeper soil. These field results do not concur, at least for total nitrogen at this site. However, the laboratory analyses do (Table 18a), suggesting that either sample heterogeneity, hence sub-sampling error, was greater with topsoil than subsoil, or that the analytical method was more variable at a higher nitrogen content. In this context it is pertinent to note that the total soil nitrogen content of surface soils under permanent pasture in New Zealand is frequently very much higher than that observed in this study. While values greater than 0.3% are common (Walker 1968), nitrogen content approaches 1% at 0-7.6 cm in some allophanic soils (Jackman 1960a). To the extent that the present results are generally applicable, difficulty would increase in attempts to measure small changes in the soil total nitrogen pool resulting from treatment effects, as soil nitrogen content and the size of the pools increased. This is a particularly vexing problem to studies in permanent pastures, where pool sizes are large, and important agronomic influences (e.g. annual nitrogen input by biological fixation) represent only a small fraction of the total pool. As noted by McGarity (1959), when faced with this dilemma in New South Wales:

'Preliminary studies of total nitrogen ... showed that

the inherent variability, coupled with high total content, would eliminate any possibility of a meaningful determination of the soil nitrogen increment by direct measurements, after only one or two years of sod-seeded pasture'. That author was commenting on soils for which the average total nitrogen content was 0.29%, with his actual study conducted on a grassland soil of 0.45% N. On the other hand, Vallis (1973), working in Queensland, concluded that the practical problems could be surmounted by use of mechanical methods for taking sufficient numbers of soil cores, and by use of automated analytical methods. He studied spatial variability for total soil nitrogen in five pasture soils and found that variation increased with sampling area up to, but not beyond, 1.2 to 2.4 ha. The most efficient method of sampling for changes in total nitrogen content was to sample repeatedly a fixed set of small sites, allocating one to three cores per site. The number of cores required to measure a change in the total nitrogen pool at 0-15 cm in a field, with a probability of 0.8 that the mean change would be within $\pm$ 50 kg N/ha, ranged from 150 to 1 000 among different pastures. While the total nitrogen content (average $\leq$ 0.14%) of the soils studied was relatively low for grassland, estimates for the number of cores required for a stated level of precision was not closely related to soil nitrogen content (*loc. cit.*).

(b) Sampling schedule

Initial sampling in autumn 1972 included all depths of all treatments. Rainfall and supplementary irrigation (discussed in Section II, B, 1) had rewetted the soil profile by the time that sampling took place. Dry conditions the following autumn delayed, and made sampling very difficult. So a decision was made to abandon autumn sampling in favour of mid winter, when moist soil conditions coupled with low rainfall would normally be expected. Even under ideal conditions, a full sampling required many weeks' field work. Complete samplings were carried out in the mid winters of 1973 and 1975. In 1974, only the 0-7.6 and 7.6-15.2

cm depths of all treatments were sampled.

While pointing out that these were not calendar years, samplings in successive years have been designated O, I, II and III for tabulation. For consideration of any change in parameters over time, the period between samplings O and I is referred to as 'year I', and so on. Data from sampling O are likely to be less reliable than those from later samplings, when the intensity of sampling from the smaller, cut plots was increased.

In association with the changeover from autumn to winter sampling, one replicate was sampled completely in autumn 1973. Values obtained (32 data points) were compared with corresponding values from the preceding (autumn 1972) and following (winter 1973) samplings. Analyses of variance indicated that no change in nitrogen content, volume weight or the size of total soil nitrogen pools had occurred in association with this shift in time of sampling.

(c) Changes over time

To assess any general pattern of change over the course of the experiment, analyses of variance were conducted on all available data to test for differences between consecutive samplings. Results are summarised in Fig. 9 and Fig. 10. Significant changes between samplings are shown, and an indication of error variance is given in the tabulated values for coefficient of variation (CV).

Averaged over all treatments there was no significant change between samplings in the nitrogen pool observed in the measured soil profile, during the three-year study period (Fig. 9). However, the average size of this pool declined significantly, from 8.08 to 7.76 t N/ha, between the initial and final sampling (result*). Significant differences were detected within individual depths: a decline of 95 kg N/ha at 0-7.6 cm, between samplings O and I; and of 50 kg N/ha at 7.6-15.2 cm, between samplings I and II (Fig. 9).

Soil carbon was measured in samples from only two

FIGURE 9 - General trends in soil total nitrogen pools and C/N ratio over the course of the experiment; (significant changes between consecutive samplings are indicated)

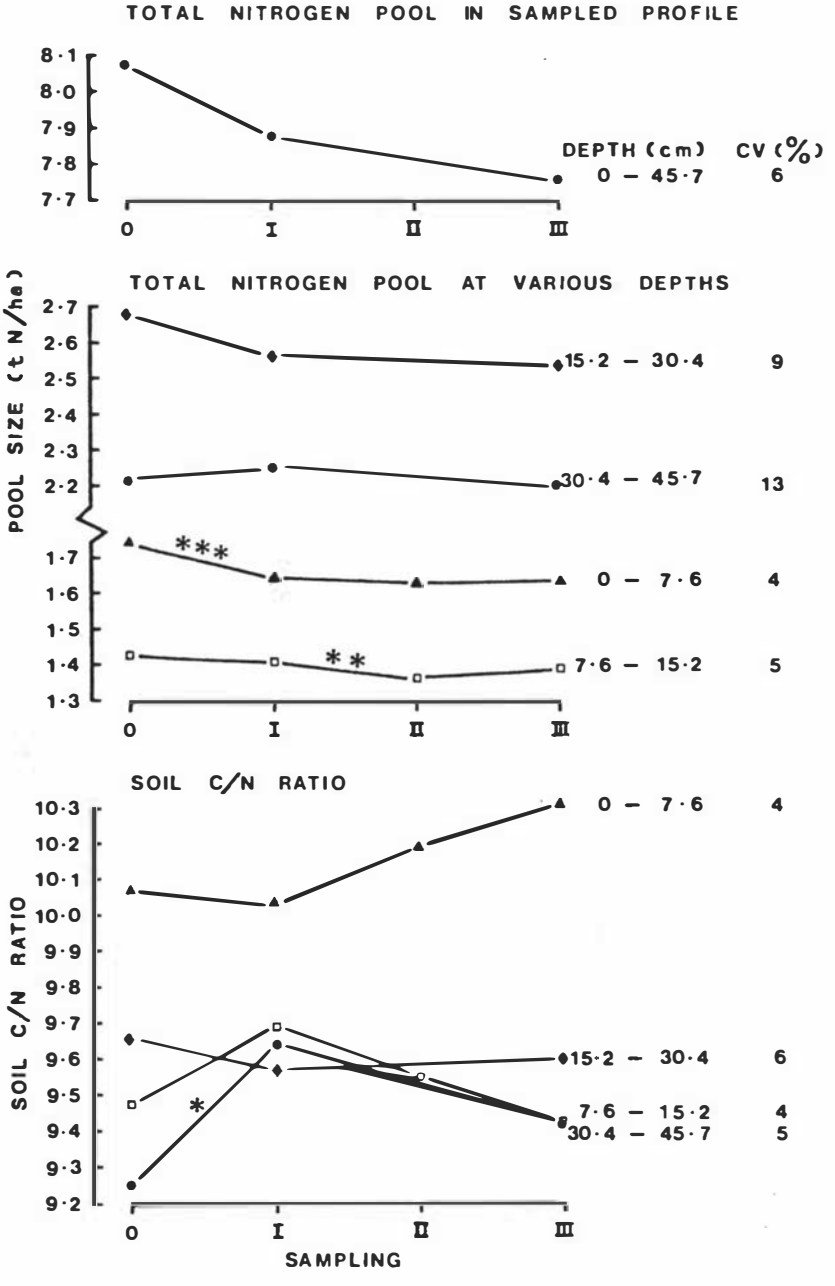
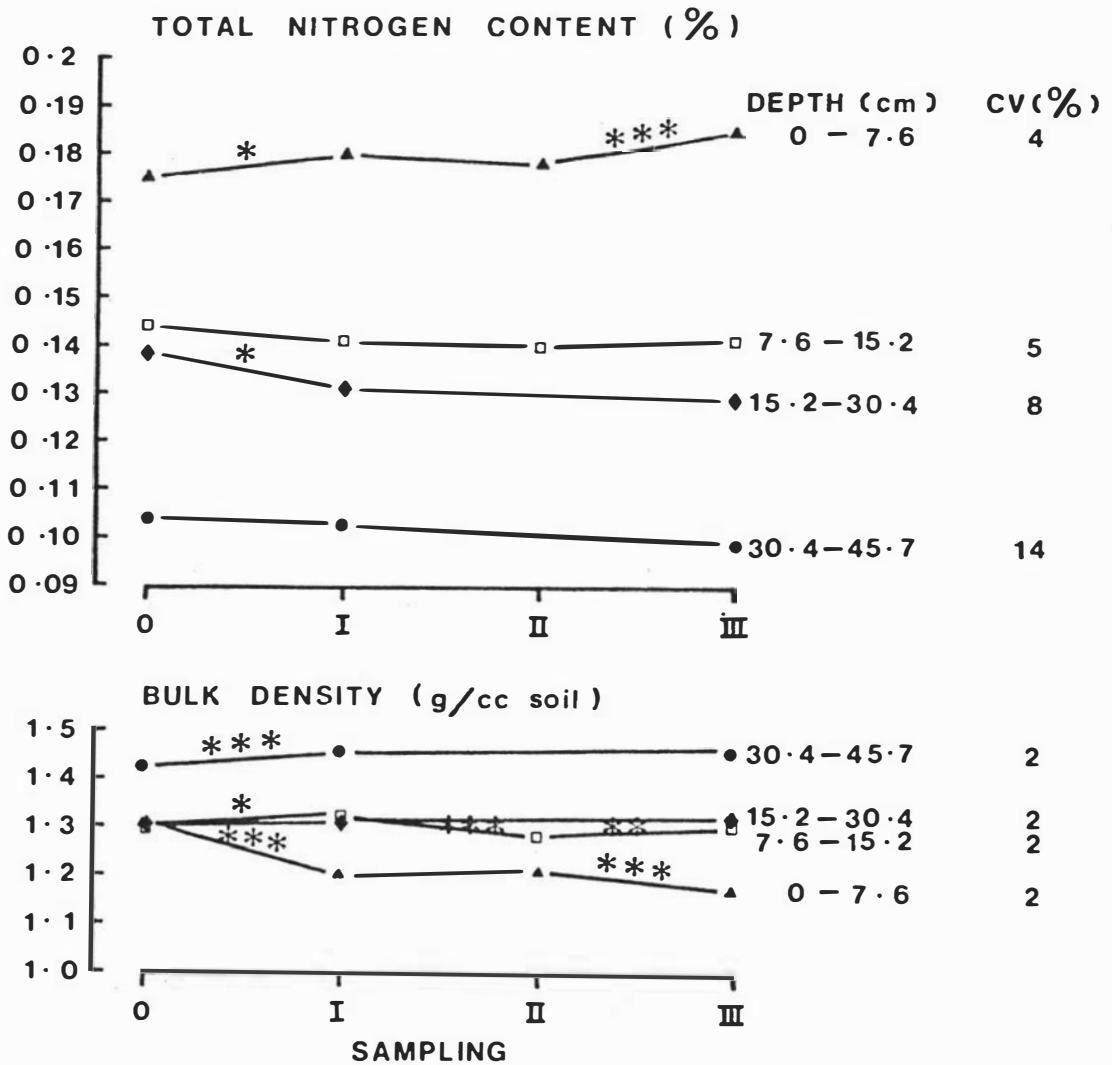


FIGURE 10 - General trends in soil total nitrogen content and bulk density over the course of the experiment; (significant changes are indicated)



of the four replicates, so there was little likelihood of measuring small changes over time or small treatment differences, because of the stringency of the associated statistical tests. Amalgamation of data from all treatments indicated a highly significant increase in the carbon content of the surface soil between the start and finish of the study (from 1.81 to 1.92% C) and a highly significant decline at 15.2-30.4 cm (from 1.36 to 1.25%). No difference was detected between the initial and intermediate samplings.

The only significant change over time in soil C/N ratio was between samplings O and I, in the deepest soil sampled (Fig. 9). No likely explanation can be offered for this result. As the corresponding value on conclusion of the experiment had fallen back, more in line with the initial observation, it seems likely that the result associated with the intermediate measurement was fortuitous. The increasing C/N ratio of the surface soil, when viewed in association with the increasing total nitrogen content at that depth (Fig. 10), reflects a measure of organic matter accumulation in the top 7.6 cm of the profile, at least between the start and finish of the study.

In calculating the size of soil total nitrogen pools, one is considering the product of total nitrogen content and weight of dry soil in that sampling depth. Obviously, a change in either will result in a change in nitrogen pool size. The only significant changes recorded in total nitrogen content (Fig. 10) were increases in the top 7.6 cm of soil, over years I and III, and a decrease at 15.2-30.4 cm between samplings O and I. Both these changes have an agronomically acceptable explanation. The study was initiated on a site which had been deep-ploughed (20 cm) only two years before. An increase in total nitrogen content in the top 7.6 cm of soil might have been expected to continue over a period of 5 to 10 years (Jackman 1966). Conversely, the previous deep burial of topsoil during ploughing would have been expected to have been followed by a decline in nitrogen content in the buried

soil, over a similar period (loc. cit.). An organic matter-enriched zone was clearly apparent at the top of cores taken from the 15.2-30.4 cm depth, during field sampling.

Several differences were recorded in bulk density of soil between consecutive samplings (Fig. 10). A very highly significant decline was observed in the top 7.6 cm over both years I and III, and a very highly significant increase in the lowest depth sampled, over the first year. Those changes have a likely explanation, again related to previous cultural practices at the site. Bulk density is relatively low in surface soils under pasture. Reported values for mineral soils are about 1.1 (Russell 1973), or even below 1 (Hoogerkamp 1973), but increase with depth. Previous cultivation had resulted in a situation where bulk density was almost identical at all but the deepest sampling depth when the experiment started (Fig. 10). Some reduction in bulk density would have been expected in the topsoil, certainly at 0-7.6 cm and probably also at 7.6-15.2 cm, during a period under permanent pasture. Such an effect was observed in the top 7.6 cm. An increase in bulk density in the subsoil would certainly not normally be expected. However, the site was intensively subsoiled to a depth of 46 cm two years before the measurements were carried out. The increase recorded over year I is considered to have arisen from subsoil reconsolidation. The smaller increase (not significant) in subsoil bulk density between samplings I and III (Fig. 10), indicates that this process became less apparent as the study proceeded.

Significant changes in measured parameters between consecutive samplings raise the question of bias (Allmaras 1965). These results may embody some such effects. The relatively small error variance (low CV% values) and large number of observations would both argue against recording differences in bulk density by chance. Yet no likely agronomic explanation can be offered for the successive increase, decline and

subsequent rise of the bulk density value recorded at 7.6-15.2 cm (Fig. 10). The decline in bulk density over year II was reflected in a decline in the total nitrogen pool at that depth, as nitrogen content remained virtually unchanged (Fig. 10). When viewed as a whole, the results indicate some interruption to an agronomically likely pattern of topsoil development at sampling II (Fig. 10). At that point, a general decline in bulk density at 0-7.6 cm was halted, as was a general rise in nitrogen content in the surface soil. This interruption points to some form of bias operating during field sampling in winter 1974. That winter was exceptionally wet (Section II, Table 1). However, reasonable care was taken to avoid sampling wet soils above field capacity. Moreover, if soil compression could explain the absence of an expected decrease in bulk density at 0-7.6 cm over year II, it would probably also have been reflected in results from the next depth. There was a break in routine procedure, in that the two lower depths were not sampled in 1974. In itself, that should not have created bias, but may have resulted in some systematic error in aligning and cutting up cores into sampling depths. The unexplained decline in bulk density at 7.6-15.2 cm and absence of any decline at 0-7.6 cm, together would point towards some bias in the division of cores into depth samples, in quantitative favour of the surface depth. Such an explanation is also in sympathy with the relatively low total nitrogen content recorded in the surface soil at that sampling. Clement & Williams (1964) have discussed, as closely related problems, both defining the surface of a soil and correcting for variations in bulk density, during successive samplings.

(d) Treatment effects

Changes in the size of the total soil nitrogen pool throughout the sampled profile, and within the various sampling depths, are reported in Table 19. Only main treatment effects are tabulated, as no test of the defoliation x nitrogen treatment interaction

TABLE 19 - Changes in total soil nitrogen pools (d kg N/ha) throughout the sampled profile, and at various sampling depths, between successive measurements

Year	Defoliation		Nitrogen treatment†				S.E.
	Grazed	Cut	0	112	448	Grass	(±)
			0-45.7 cm				
I	-91	-300	-200	-224	-195	-164	
	*			ns	ns	ns	65
(II + III)	-91	-155	-84	-51	-114	-243	
	ns			ns	ns	ns	51
(I + II + III)	-182	-455	-284	-275	-309	-408	
	*			ns	ns	ns	94
			0-7.6 cm				
I	-49	-141	-70	-111	-42	-155	
	*			ns	ns	ns	36
II	-13	-11	-28	13	-35	1	
	ns			*	ns	ns	12
III	34	-31	10	-36	34	-2	
	***			*	ns	ns	13
			7.6-15.2 cm				
I	7	-42	-31	-36	25	-28	
	*			ns	ns	ns	18
II	-36	-55	-38	-7	-58	-79	
	ns			ns	ns	ns	14
III	27	33	33	28	29	30	
	ns			ns	ns	ns	12
			15.2-30.4 cm				
I	-96	-121	-85	-123	-186	-42	
	ns			ns	ns	ns	46
(II + III)	-46	-19	-25	2	15	-120	
	ns			ns	ns	ns	30
			30.4-45.7 cm				
I	47	4	-14	47	8	60	
	ns			ns	ns	ns	65
(II + III)	-57	-72	-35	-51	-98	-74	
	ns			ns	ns	ns	35

† Statistical comparisons are between control (NO) and other nitrogen treatments.

proved significant.

The pattern of results confirms a general trend of declining soil nitrogen pools over time, as indicated in Fig. 9, with few significant treatment differences. Successive measurements indicate that the pool in the sampled profile fell in all treatments over the course of the study. During the first year, the decline observed under cutting (300 kg N/ha - 45.7 cm) was greater than that under grazing (91 kg N/ha - 45.7 cm). The full profile was not sampled at the third measurement, but no significant difference between defoliation treatments was detected in the rate of decline over the latter two years of the experiment. Over the three-year study period, the total nitrogen pool declined by 182 kg N/ha - 45.7 cm under grazing, and 455 kg N/ha - 45.7 cm where herbage was cut and removed. The difference, 270 kg N/ha, was significant and represents about 3.5% of the total nitrogen pool in the sampled profile.

Significant differences were recorded between defoliation treatments for changes in the surface soil. Over year I, the decline in pool size was less under grazing than cutting, while in year III an increase of 34 kg N/ha-7.6 cm below the grazed pastures contrasted with a commensurate decrease under cutting. Similarly, during the first year a minor gain at 7.6-15.2 cm was recorded below the grazed swards in contrast to a fall of 42 kg N/ha under cutting.

Only two significant differences were recorded in comparisons between control (N0) and other nitrogen treatments. Recorded values indicated a small increase during year II in the pool size to 7.6 cm under treatment N1l2, followed by a commensurate reduction over the final year. As 39 treatment comparisons were involved, those two results may have arisen by chance. They are self-cancelling, which suggests that they reflect sampling error, so no agronomic importance is attached to either result.

Statistical comparison of changes between the first

and last samplings simply confirmed the results presented in Table 19. No difference was apparent between defoliation treqtments in the extent of soil nitrogen change at either 15.2-30.4 cm or 30.4-45.7 cm. Nor was any significant difference among nitrogen treatments indicated. During the course of the study, the soil total nitrogen pool declined throughout the sampled profile under all grass-clover swards, irrespective of fertiliser nitrogen receipt (Table 19). Over the three-year period, this decrease was quite similar among those three treatments, averaging 290 kg N/ha-45.7 cm. The decline under cloverless swards (410 kg N/ha-45.7 cm) was not markedly greater than that recorded below control.

Among 48 treatment comparisons for changes in soil carbon content (data not presented), only two were significant: over year I at 0-7.6 cm depth, an increase (+0.08% C) under the grazed swards contrasted with a small decrease (-0.03% C; result *) under cutting; and a similar result was observed at 7.6-15.2 cm in year II (grazed, +0.009% C; cut, -0.05% C; result **). There were no differences between grass-clover control and any other of the nitrogen treatments in this respect.

(e) Conclusions

It is appreciated that the methodology, the intensity of field-sampling in particular, used in determining changes in soil total nitrogen pools was at the limit of its precision in relation to the size of any changes which occurred. However, it cannot be suggested that replication, sampling intensity or laboratory precision was inadequate to the point that any substantial main treatment differences could have been missed. Accordingly, the following conclusions are drawn from the observed results.

(i) Over the course of the experiment, total nitrogen pools throughout the sampled profile declined.

(ii) The decline was enhanced by continual cutting

and removal of herbage.

(iii) Soil total nitrogen pools fell below all the grass-clover swards, irrespective of a range of fertiliser nitrogen inputs.

(iv) While a larger decline was observed below cloverless swards, it was beyond the precision of methodology to identify any difference between that and other nitrogen treatments.

2 Nitrogen Fixation in Grazed Swards

(a) Results

$N_2(C_2H_2)$ fixation estimates were carried out in the grazed swards only, during the final year of the study. Results at the individual sampling dates are presented in Fig. 11. Measurements at which treatment differences were recorded are indicated. Also indicated are the dates at which split dressings of fertiliser nitrogen were applied.

Treatment effects were recorded at all measurements, except two in mid summer, when pasture growth was adversely affected by dry conditions (Section II, Table 1; see also Fig. 12). Otherwise, $N_2(C_2H_2)$ fixation was always higher in grass-clover control swards than in those receiving N448, and higher than in those receiving N112 at half the measurements. On all occasions when the pure grass swards were sampled, fixation rates were only a small fraction of those recorded in control (N0).

Daily rates for $N_2(C_2H_2)$ fixation from individual measurements were integrated over time to provide estimates for fixation during the four production periods coinciding with dry herbage and herbage nitrogen yields (Section II, C, 1 & Table 3a), and the full year. As shown in Table 20a, $N_2(C_2H_2)$ fixation in grass-clover swards was invariably depressed by application of fertiliser nitrogen. With one exception, treatment differences were significant for both seasonal and

FIGURE 11 - Daily $N_2(C_2H_2)$ fixation rates (kg N/ha) in grazed treatments during the final year

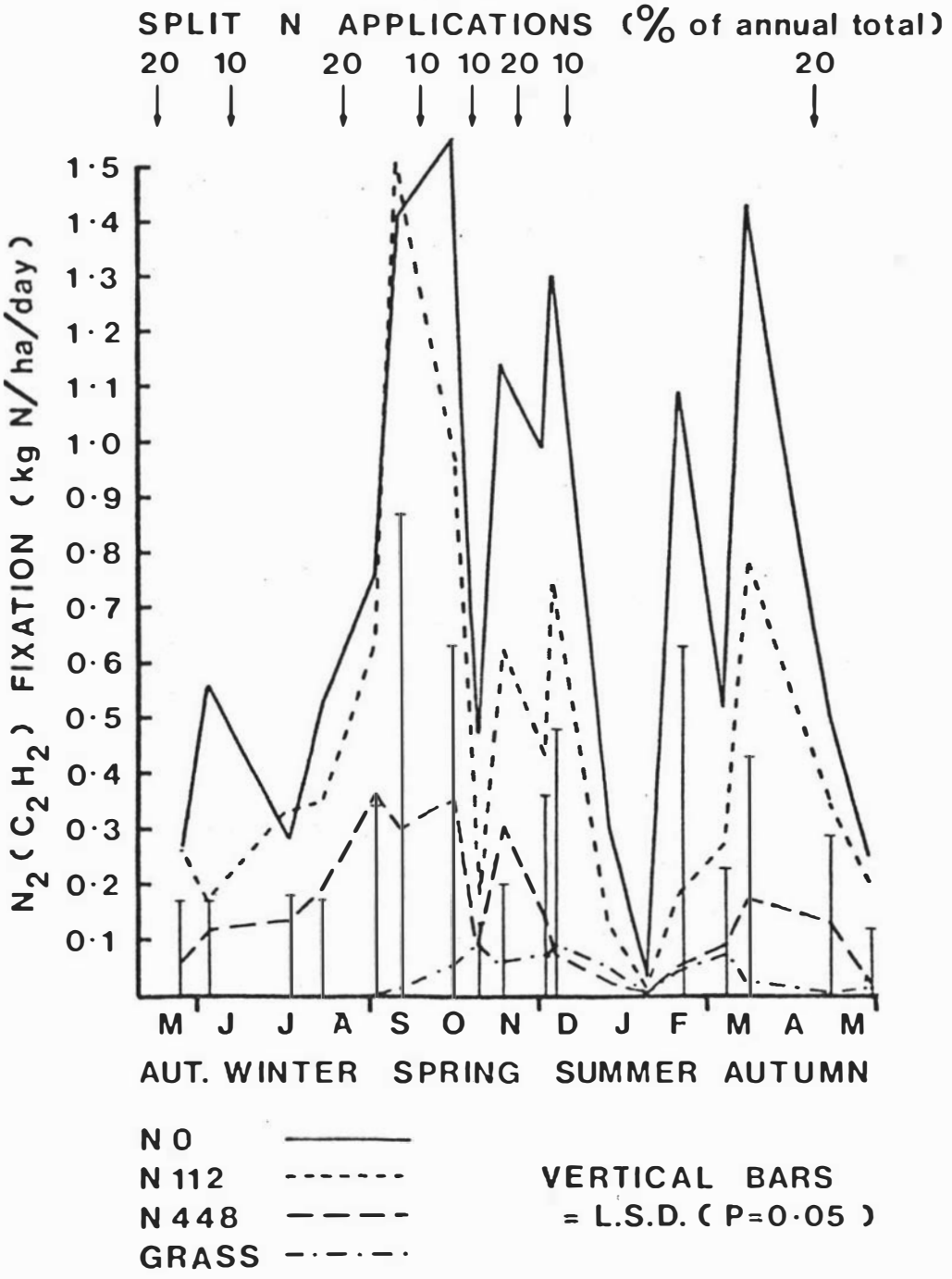


TABLE 20 - Seasonal and annual estimates for $N_2(C_2H_2)$ fixation (kg N/ha), and fixation efficiency (kg N fixed/t clover dry herbage measured) in grazed swards

(a) $N_2(C_2H_2)$ fixation

	Nitrogen treatment†				L.S.D.
	N0	N112	N448	Grass	(0.05)
Autumn-winter	47	35	14	0	
		*	***	***	10
Winter-spring	103	77	27	3	
		ns	***	***	31
Spring-summer	49	25	5	4	
		**	***	***	13
Summer-autumn	65	28	7	3	
		***	***	***	17
Year	263	165	53	10	
		**	***	***	55

(b) Fixation efficiency

	Nitrogen treatment†			L.S.D.
	N0	N112	N448	(0.05)
Autumn-winter	67	38	21	
		**	***	17
Winter-spring	81	85	61	
		ns	ns	-
Spring-summer	69	52	16	
		ns	*	35
Summer-autumn	42	25	9	
		*	**	15
Year	61	48	23	
		ns	***	14

	Production periods‡				L.S.D.
Year	Aut.-wint.	Wint.-spring	Spring-sum.	Sum.-aut.	(0.05)
44	42	75	45	25	
	ns	***	ns	*	16

† See footnote to Table 19.

‡ Statistical comparisons are between the annual value ('year') and values for individual seasonal periods.

annual totals. Estimates for fixation below the pure grass swards were less than those for any of the grass-clover pastures, although significantly lower than N448 only during autumn-winter. Over the year, estimated fixation in the control sward was 263 kg N/ha/an, falling to 63% and 20% of that value in treatments N112 and N448 respectively. The estimate for annual fixation in pure grass swards, 10 kg N/ha, was only 4% of that recorded in grass-clover control.

'Fixation efficiency' estimates (kg N fixed/t clover dry herbage measured; Hoglund et al. 1979) were calculated from corresponding $N_2(C_2H_2)$ fixation data and clover DM yields, for individual production periods and the year. No allowance was made for any non-symbiotic, biological fixation which may have been included with the $N_2(C_2H_2)$ fixation measurements in the mixed swards. As shown in Table 20b, relative to control, treatment N448 reduced fixation efficiency during all production periods except winter-spring. The intermediate rate of nitrogen resulted in lower fixation efficiency values only over summer-autumn and autumn-winter. In the estimates based on annual totals, treatment N448 depressed fixation efficiency to little more than one-third of the control value, while a less pronounced depression at the intermediate nitrogen rate just failed to attain significance at the conventional probability level.

A pronounced seasonal contrast was apparent among fixation efficiency values. There was no indication of any significant production period x nitrogen treatment interaction among the pooled data, so comparisons between production periods are included in Table 20b. Averaged over all three fertiliser nitrogen treatments, fixation efficiency was very much higher over winter-spring, and very much lower over summer-autumn, by comparison with the value based on annual figures. Fixation efficiency did not differ among the yearly, autumn-winter or spring-summer values.

(b) Discussion

The pattern of $N_2(C_2H_2)$ fixation rates recorded in the control sward over the autumn-winter-spring-early summer period (Fig. 11) was similar to that reported during a dry year, from a previous study at Palmerston North (Brock & Hoglund 1979). Using similar techniques, both studies gave estimates for fixation rates in grazed, grass-clover pastures not receiving fertiliser nitrogen, of 0.25 to 0.5 kg N/ha/day over late autumn-winter, rising to peak rates of 1.0 to 1.5 kg N/ha/day over spring-early summer, then falling to very low rates with the onset of seasonally dry conditions by mid summer. In association with periods of positive water balance thereafter (see Fig. 12), daily fixation rates exceeding 1.0 kg N/ha were recorded at single measurements in the control sward during both February and March (Fig. 11); rates more in line with the values reported by Brock & Hoglund (1979) under moist summer conditions. In that study, annual $N_2(C_2H_2)$ fixation averaged 210 kg N/ha, with average clover dry herbage yields similar to the 4.4 t/ha measured in grazed control over the final year of this experiment.

Clearly, fertiliser nitrogen depressed $N_2(C_2H_2)$ fixation in these grazed grass-clover swards. This effect was apparent with treatment N448 at all measurements, except two in January, when fixation rate in all treatments was relatively low under the seasonally dry conditions (Brock & Hoglund 1979). In general, fertiliser nitrogen treatments exerted their most pronounced effect on $N_2(C_2H_2)$ fixation rates over the late summer-early autumn period, when nitrogen applications had been discontinued (Fig. 11). Treatment N112 had only a relatively minor effect on $N_2(C_2H_2)$ fixation rates over late winter-early spring. Nitrogen responses recorded at that time (Section II, Table 3b & Fig. 2) indicate that the mixed pastures were then suffering nitrogen stress, from which the lower rate of nitrogen input gave only partial relief.

While there can be little debate about the relative

values for $N_2(C_2H_2)$ fixation rates recorded for treatments at individual measurements, their integration over time to obtain seasonal and annual rates (Table 20a) may be questioned. Limitations and possible errors associated with integration of single measurements over time have been discussed elsewhere (Hoglund & Brock 1978; Hoglund et al. 1979). An additional consideration, peculiar to the manner in which the assay was used in this study, is that $N_2(C_2H_2)$ fixation rate has been reported to vary with stage of regrowth of both a cut white clover sward in autumn (Moustafa et al. 1969) and a grazed, grass-clover sward in spring (Hoglund & Brock 1978). Inspection of the data from treatment NO revealed no consistent relationship between stage of regrowth and fixation rates recorded. Measurements were not normally made until at least ten days' regrowth had occurred, thereby avoiding the very low values associated with early regrowth, as reported from both the above studies. It was felt that for the purpose of this study it was valid to integrate rates from individual measurements over time, bearing in mind that the values obtained could only be viewed as coarse estimates. Obviously, if the individual measurements had been carried out more frequently, estimates for seasonal and annual rates could be viewed with more confidence.

The low values for $N_2(C_2H_2)$ fixation recorded in the cloverless sward reflect the activity of non-symbiotic, nitrogen-fixing organisms (Jensen 1965; Whitehead 1970). When field sampling, any randomised microsite within 15 cm of a volunteer clover seedling was rejected. Periodic soil blanks failed to indicate any natural evolution of ethylene from this soil, so the $N_2(C_2H_2)$ values obtained are considered genuine. Asymbiotic fixation requires a readily available energy source, and is favoured by a low oxygen partial pressure (Whitehead 1970). Peak rates were recorded over late spring-early summer, and again in mid autumn (Fig. 11), when it might be expected that the availability of carbon substrates from decomposing

litter would have been relatively favourable.

Relative to control, fertiliser nitrogen reduced both the dry herbage and herbage nitrogen yields of clover (Section II, Table 3 & Fig. 2; Section III, Table 10 & Fig. 5). This suppression of clover yields would be expected to reduce symbiotic fixation, per unit area over time, through reduction of the nitrogen requirement for clover growth. It is also well established that fertiliser nitrogen can substitute for symbiotic fixation in meeting the nitrogen requirement for clover growth (Allos & Bartholomew 1959; Moustafa et al. 1969). Fixation estimates reported in Table 20a embody both these influences. For instance, in the grazed swards over the final year, treatment N448 reduced clover dry herbage yield to 53% of that recorded from control, but reduced $N_2(C_2H_2)$ fixation to 20% of the control value.

A number of experimenters have expressed symbiotic fixation as a quantity per unit of clover dry herbage measured, both on a common time basis (i.e. 'fixation efficiency', Hoglund et al. 1979). In field studies, this parameter has been used to indicate the extent to which cultural practices and/or seasonal influences may have modified the proportions of clover herbage nitrogen arising from each of the two alternative, interactive sources; symbiotic fixation and assimilation of soil mineral nitrogen (Karraker et al. 1950; Sears et al. 1965a; Hoglund et al. 1979). Results reported in Table 20b indicate that substantial substitution of soil nitrogen for symbiotic fixation occurred, both as a consequence of fertiliser nitrogen treatments and in response to changing seasonal patterns of soil nitrogen availability.

The estimate for fixation efficiency in the control treatment over the year (61 kg N/t clover DM) was very close to the average value (63) recorded in a two-year study of grazed, grass-clover swards receiving no fertiliser nitrogen, at 8 sites throughout New Zealand (Hoglund et al. 1979). In obtaining the latter value,

experimenters avoided possible errors arising from stage of regrowth at which measurements were made, by carrying out assays in pasture at all stages of regrowth during each measurement (Hoglund & Brock 1978). The annual value for control from this study was a little less than another reported from this locality, viz 67 (Sears et al. 1965a), from a study involving a 'mowing and return' technique to simulate grazing.

Reasonably good agreement in fixation efficiency estimates is encouraging, and increases confidence in the manner in which the acetylene reduction assay was applied in this study. Differences between the present estimate for annual fixation in the grazed control pasture (263 kg N/ha) and comparable values from other studies (390, Sears et al. 1965a; 185 (average), Hoglund et al. 1979) largely reflect differences in measured clover yield.

It is quite clear from the fixation efficiency values (Table 20b) that soil-derived nitrogen substituted for symbiotic fixation in the nitrogen-treated pastures. Over the year, fixation efficiency in treatment N448 was only 23 kg N/t clover DM, or about 40% of the value for control. Results provide clear evidence for a marked carry-over effect of fertiliser nitrogen during summer-autumn (Table 20b), when nitrogen applications were discontinued. A residual effect from previous nitrogen applications was also observed over this period in grass/clover balance in swards (Sections II, Fig. 2 & III, Fig. 5). Differences in fixation efficiency between seasonal periods exhibited a similar pattern to that described following an extensive study throughout this country (Hoglund et al. 1979). Over the winter-spring period, relatively high values were recorded irrespective of nitrogen treatment. In contrast, relatively low fixation efficiency values were observed during summer-autumn (Table 20b), indicating ready availability of soil nitrogen to white clover at that time of year.

(c) Conclusions

Under the conditions of this experiment, use of fertiliser nitrogen clearly depressed daily $N_2(C_2H_2)$ fixation. Differences were recorded between control and N448 at all measurements, except two in January when low rates in all treatments were associated with dry weather. Integration of daily rates over time indicated that with treatment N112, annual $N_2(C_2H_2)$ fixation was depressed by almost the same amount as the quantity of fertiliser nitrogen applied; with N448, by only about half.

This depression in symbiotic fixation did not simply reflect clover suppression in the nitrogen-treated pastures. Seasonal differences in fixation efficiency indicated that the extent to which soil nitrogen substituted for symbiotic fixation in meeting the nitrogen requirement for white clover growth, varied throughout the year. Provision of fertiliser nitrogen increased the substitution of soil-derived nitrogen for fixation, but no significant treatment difference was detected among nitrogen treatments over winter-spring.

$N_2(C_2H_2)$ fixation in the cloverless sward was only 4% of that recorded in control.

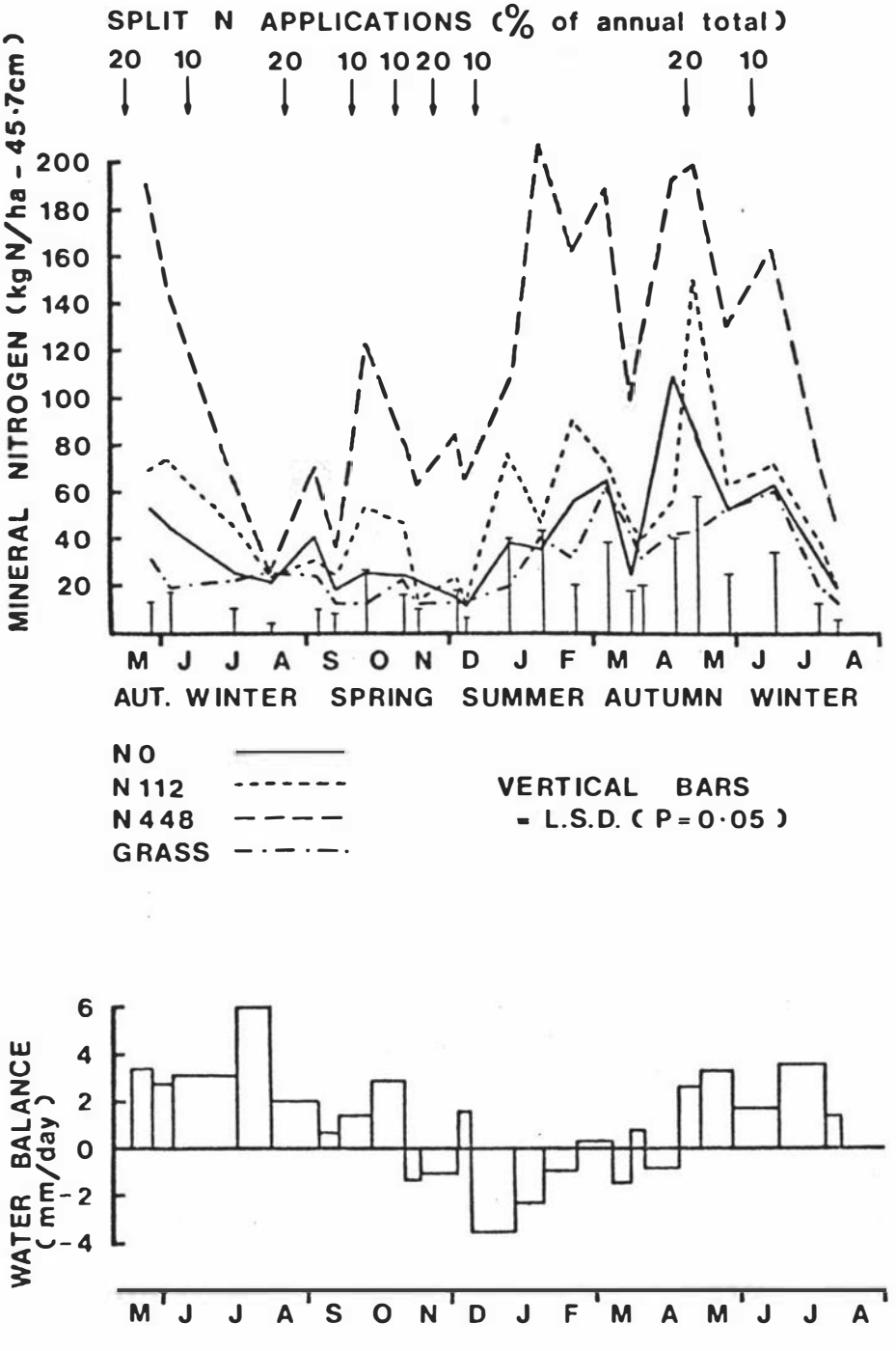
3 Mineral Nitrogen Pools

(a) Results

Mineral nitrogen (NH_4-N & NO_3-N) was determined in the top 45.7 cm of the profile during the final year of the experiment, only in grazed swards. Measurements were continued into winter 1975 to follow the pattern of decline under leaching conditions. Mineral nitrogen pools in the sampled profile are presented in Fig. 12. Also indicated are the dates for split applications of fertiliser nitrogen, and an estimated water balance (rainfall minus 0.8 raised pan evaporation) for each interval between samplings.

Significant differences between control and at least one other treatment were recorded at all 23

FIGURE 12 - Soil mineral nitrogen pools in the sampled profile (kg N/ha-45.7 cm) below grazed pastures over the final 15 months; also shown, the water balance between consecutive samplings



measurements. The quantity of mineral nitrogen in the sampled profile of treatment N448 always exceeded that below grass-clover control and the cloverless sward, and generally exceeded that below treatment N112. Such clear-cut differences were not apparent among the other three treatments. Over the first set of late autumn-mid winter measurements, the mineral nitrogen pool below N112 exceeded that below control, but a significant treatment difference was recorded at only one measurement over the corresponding period a year later. In general, the mineral nitrogen pool was greater in the sampled profile below N112 than NO, but this difference was significant at only 8 observations. At only one measurement (late April) the value for treatment NO exceeded that for N112; a result which may indicate a treatment difference in immobilisation-mineralisation relationships or, alternatively, simply reflect sampling error. Mineral nitrogen levels recorded below the pure grass sward were generally lower than those recorded below control, but significantly so on only 6 occasions. There were few significant differences between these two treatments over the late winter-spring-early summer period.

(b) Discussion

Field variability poses a major sampling problem in soil mineral nitrogen measurements below grazed swards. Thompson & Coup (1940a) reported substantial variation in nitrate levels among individual topsoil cores drawn from ostensibly uniform areas of pasture. Variation was as high as eight-fold between cores drawn within 4 cm of each other. In a subsequent study (Thompson & Coup 1940b), it was found that below localised patches of pasture, exhibiting a 'burnt-up' appearance from urinations under hot dry conditions, nitrate levels reached several hundred ppm. The comparable level in soil unaffected by recent urination was less than 10 ppm. Even when the urine-affected pasture had resumed normal growth, the underlying soil contained nitrate at levels 20 to 70 times those in soil below unaffected pasture (loc. cit.). A recent,

detailed study of the time-course for nitrogen transformations in soil below urine-affected pasture (Ball *et al*. 1979) gave results in accord with those early studies.

Tham (1971) measured mineral nitrogen levels in single soil cores from permanent, mixed swards. Variability was much greater in the surface soil (0-7.6 cm) than in his three sampling depths below that. To surmount field variability, he sampled surface soil with twice the intensity used at other depths. In this study, significant treatment differences were observed at all 23 measurements (Fig. 12), indicating that the intensity of sampling was sufficient to observe major treatment differences. Doubtless, collection of larger numbers of cores during field sampling would have given greater precision, and may have yielded more information on smaller differences between the less disparate treatments.

Bearing in mind limitations in sampling procedure, the pattern of results presented in Fig. 12 reflects an interplay between nitrogen treatments and weather. Large changes occurred in pool sizes between consecutive samplings. Harmsen & Kolenbrander (1965) describe a single measurement of soil mineral nitrogen as a 'snapshot', pointing out that only repeated measurements over time are likely to yield agronomically useful information. Hebert (1965) reported that fluctuations may occur very suddenly in grassland soils, sometimes in one day, in response to weather changes. Notwithstanding the ephemeral nature of soil mineral nitrogen, and difficulties associated with its measurement below grazed pastures, some patterns are apparent in the data collected (Fig. 12).

With the exception of treatment N448, pool sizes remained relatively small across the main growing season, late winter-spring-early summer. The substantial input of fertiliser nitrogen over this period in the former treatment was reflected in some mineral nitrogen accumulation. Over that time, however, the

average pool size observed below N448 was only about one-third of the peak values observed in late summer, when nitrogen applications had been discontinued. In all treatments, mineral nitrogen accumulated in the profile over the seasonally warm, dry late summer-autumn period, then declined over late autumn-winter. This seasonal decline largely over-rode treatment differences, in spite of relatively heavy inputs of fertiliser nitrogen, with small pools recorded below all treatments in both late winters. Hindsight indicates that this seasonal influence may have been better described with two additional observations, in both the month preceding and that following this series of measurements.

The pronounced, temporary drop in pool sizes observed in mid autumn followed reinstatement of a positive soil water balance, after a prolonged period under drying conditions (Fig. 12). Neither leaching nor plant uptake could account for a decline of that magnitude (up to 85 kg N/ha). The most likely explanation lies with temporary immobilisation of mineral nitrogen, associated with a flush of renewed microbial activity as re-wetting of the profile commenced (Birch 1958, 1960). Subsequently, when readily-available carbonaceous substrates in the soil were exhausted, and/or temperatures fell, much of the nitrogen reappeared in the mineral nitrogen pools following the breakdown of microbial biomass.

Unfortunately, the method of measurement does not allow any quantitative conclusion to be drawn regarding leaching of nitrate from the soil. The nitrogen which accumulated in the surface soil under seasonally warm, dry conditions (Fig. 12), was mainly in the nitrate form. Levels recorded below the control sward over summer reached 15 to 20 ppm NO_3-N, with corresponding levels of 50 to 90 ppm in the surface soil of treatment N448. Even below the cloverless sward, which was quite nitrogen deficient by the final year, 9 to 18 ppm NO_3-N was measured over summer. Ammonium levels were

generally confined to the range 1 to 15 ppm N in the surface soil of all treatments throughout the study. However, unusually high ammonium levels (40 ppm N below treatment NO) were observed in surface soil at one sampling in mid autumn, confirming that breakdown of microbial protein largely accounted for the peak pool sizes observed over mid-late autumn. Conversion of much of this ammonium to nitrate followed quickly. While large quantities of nitrate nitrogen 'disappeared' from the sampled profiles under leaching conditions over mid autumn-winter in both years, it cannot be stated with certainty which of the several possible avenues for movement the nitrate followed. Possibilities include leaching, plant uptake, microbial immobilisation and denitrification. It is a reasonable assumption that some, if not the major part, of this nitrate was leached. In reviewing lysimeter studies, Allison (1965) concluded that if much nitrogen is added or released as nitrate in the late autumn, leaching losses are likely to be large. On the other hand, the presence of a perennial sward is likely to reduce such losses (loc. cit.).

(c) Conclusions

The mineral nitrogen pools displayed a similar seasonal pattern to that reported from studies in developed pastures in both New South Wales (Simpson 1962) and Canterbury (Tham 1971): a 'nitrogen-rich' mid summer-autumn period; a nitrogen-depleting winter; a nitrogen-poor late winter-spring period, and an increasing accumulation of mineral nitrogen over the early summer months.

The influence of fertiliser nitrogen can be viewed as superimposed on that seasonal pattern. Treatment N448 always increased the size of the mineral nitrogen pool relative to that in the sampled profile below the control sward. A great deal of mineral nitrogen accumulated in the surface soil of treatment N448, mainly as nitrate, over summer. As fertiliser nitrogen applications were discontinued in early summer, it

appears that this carry-over into summer was effected through accumulation of a pool of 'labile' soil organic nitrogen in response to nitrogen applications under the preceding cool, moist conditions. With the warm, drier conditions of summer, much of that 'labile' pool was mineralised. Differences between control (N0), the intermediate rate of nitrogen and the cloverless sward were not nearly so marked. In general, the mineral nitrogen pool below treatment N112 was a little larger, and that below the pure grass sward a little smaller, than was observed below grass-clover control.

It is not possible to reach any quantitative conclusion regarding leaching of nitrate. Nevertheless, it seems probable that much of the decline observed in the mineral nitrogen pools under leaching conditions over late autumn-winter, especially below treatment N448 where the fall averaged more than 150 kg N/ha, reflected leaching losses.

4 Nitrogen Balances in Grazed and Cut Treatments

(a) Results

Values reported in Table 21 are based on annual averages, derived from data obtained over the three-year study period. Explanatory notes are contained later in this section. Values estimated by difference are enclosed in brackets.

Under grazing, nitrogen losses of between 380 and 560 kg N/ha each year are indicated from the grass-clover systems. Estimated losses were substantially greater from treatment N448 than control. From the cloverless treatment, the annual losses indicated are about 90 kg N/ha, arising mainly from a fall in soil total nitrogen.

Under cutting, minimal estimates for fixation in mixed swards each year ranged from 380 kg N/ha in the control sward down to 75 kg N/ha in treatment N448. The nitrogen outgoing in herbage from the cloverless sward was in close agreement with the observed fall in soil total nitrogen, after allowance for 'background'

TABLE 21 - Nitrogen balances in grazed and cut systems; all data are annual averages (kg N/ha)

	Inputs			Soil total N	Outgoings	
	Background†	Fixation	Fertiliser	(d to 45.7 cm)	Production‡	Losses
Grazed swards						
NO	15	319	0	-69	20	(383) §
N112	15	218	112	-55	20	(380)
N448	15	90	448	-36	25	(564)
Grass	15	0	0	-84	10	(89)
Cut swards						
NO	15	(377)	0	-121	513	?
N112	15	(306)	112	-128	561	?
N448	15	(76)	448	-170	709	?
Grass	15	0	0	-188	215	('Nil')

† Nitrogen inputs other than symbiotic fixation and fertiliser nitrogen.

‡ Estimates for animal protein yield from grazed swards, but herbage N removed from cut swards.

§ Figures in parentheses have been estimated by difference.

nitrogen input.

(b) Discussion

It should be stated at the outset that these balances are considered as no more than approximations. Explanation of some assumptions involved in their calculation follows in this section. Statistical analyses were carried out on the individual parameters making up the balance, but no statistical treatment was given the parameters estimated by difference (i.e. losses under grazing and fixation under cutting) as the data embrace large errors. Statistical finesse may create an illusion of accuracy which is not intended. This point can best be illustrated by consideration of changes in soil total nitrogen. For changes throughout the sampled profile over the three-year period, the standard error of nitrogen treatment means was $\pm$ 94 kg N/ha (Table 19) with no treatment difference observed. Except possibly for the cloverless treatment, it could be argued that the change in soil nitrogen pools could be adequately represented by main treatment means, for all grazed and cut treatments respectively, as a significant difference was observed only between defoliation treatments. It was decided to use individual treatment means in compiling these balances, considered the best available estimates of treatment changes in soil nitrogen, at the same time bearing in mind the error associated with individual observations. After a little contemplation, it is appreciated that use of either individual or main treatment means makes little difference to derived estimates, and no difference to the general tenor of conclusions drawn from the results. The same might be said of estimates for animal protein yield from the grazed swards. Animal production was not recorded. The annual yield of 25 kg N/ha ascribed to treatment N448 represents an animal liveweight gain of one tonne/ha each year, which is considered generous for mature dry sheep. Again, it is largely irrelevant to the conclusions drawn whether the actual yield of animal protein was one half

or double the estimated figures.

The term 'background nitrogen' was coined (Sears et al. 1965a) to encompass inputs from all sources other than symbiotic fixation and fertiliser nitrogen. Possible sources include asymbiotic fixation by free-living organisms, nitrogen receipt in rainfall, absorption of atmospheric ammonia, and nitrogen receipt in pollen or dust (Henzell & Ross 1973). A small, annual accretion of nitrogen by the soil-plant complex in a cut, pure grass sward led Sears and associates to conclude that background nitrogen receipt totalled some 15 kg N/ha each year (loc. cit.). Little has emerged in the literature, nor from this study, to upset that conclusion. Miller (1961) measured an annual nitrogen input in rainfall at Taita of 3 kg N/ha, and cited results from Lincoln and Gore reporting annual inputs of 2 and 7 kg N/ha, respectively. At Otara, with industrial activity nearby, a three-year average was 8.5 kg N/ha/an (N.Z. Fertiliser Manufacturers' Ann. Rep. 1978-79). Asymbiotic fixation appears to be of only minor significance in fertile swards (Whitehead 1970; Bergersen 1973). Annual input from this source in well aerated pasture is considered to be generally less than 10 kg N/ha (Henzell & Ross 1973). Associated clover yields and $N_2(C_2H_2)$ fixation estimates led Grant & Lambert (1979) to conclude that asymbiotic fixation contributed 12 to 21 kg N/ha in undeveloped swards on moist hill country, during a one-year study. Application of the acetylene reduction assay in this study provided an estimate of 10 kg N/ha for non-symbiotic fixation in the grazed, cloverless pasture during the final year (Table 20a). There is little evidence that ammonia absorption from the atmosphere is an important avenue for nitrogen accretion, except near industrial centres and feedlots (Henzell & Ross 1973). It is also unlikely that any significant contribution from air or water-borne soil or plant material occurred in this study. With vigorous swards in an area free of erosion, it seems likely that a very small annual input

by these avenues would mirror a commensurate annual outgoing. Accordingly, an annual value of 15 kg N/ha for 'background' inputs has been incorporated into all nitrogen balances (Table 21).

Henzell & Ross (1973) draw attention to the possibility of lateral movement of nitrate in soil water. Upward movement of water from below sampling depth, under drying conditions, could also influence the pattern of mineral nitrogen accumulation observed throughout the year (Fig. 12). Neither of these possibilities is considered a likelihood at this site. There was a large excess of rainfall over potential evapotranspiration during winter-spring each year (Section II, Table 1). The site was ostensibly level and free-draining, and the permanent water table, which was monitored throughout the study, was always below the surface of the gravel at 2.75 m depth. A temporarily perched water table was observed within the sampled profile, under conditions of heavy and continual rain, on two or three occasions during the study: a feature no longer apparent 24 h after the cessation of heavy rainfall.

Symbiotic fixation in the grazed swards was calculated, using data obtained by application of the acetylene reduction assay to grazed swards in the final year. To allow for differences in clover yield between years, appropriate fixation efficiency values (Table 20b) were used to calculate fixation, in association with corresponding clover DM yields from grazed pastures for individual seasons and nitrogen treatments. The annual averages are reported in Table 21.

The origin of values for annual fertiliser nitrogen inputs to grazed and cut systems is self-evident. Production, in terms of animal protein, from the grazed swards has been discussed. 'Production' from the cut treatments (Table 21) is the yearly average for nitrogen yields measured in herbage removed from those plots.

Under grazing, nitrogen outgoings from the soil-plant-animal complex ('Losses') were calculated by

difference between total inputs, and outgoing in animal products, taking into account the drop in soil total nitrogen throughout the sampled profile. It is of interest that even in the pure grass sward, an annual loss of 90 kg N/ha is indicated. Recognition of such large, unaccounted-for losses of nitrogen from grazed grass-clover systems (380 to 560 kg N/ha each year, depending on nitrogen fertiliser rate) raises many unanswered questions. However, it does reconcile an apparent contradiction in this country's grassland literature, as discussed briefly in the introduction to this section: claims for substantial levels of symbiotic fixation, which appear to have been reflected commensurately in neither output of animal protein nor accumulation of soil nitrogen below grazed pastures. This, of course, is a problem facing anyone who attempts to draw up a mass balance for nitrogen in a productive, grazed ecosystem, whether based on grass-clover associations or nitrogen-fertilised grass swards. Whitehead (1970) side-stepped the issue by assuming substantial accumulation of soil nitrogen in his balances. However, that avenue for nitrogen retention within an ecosystem is finite, and does not continue indefinitely below well managed, permanent pastures (Jackman 1964a, b).

That the acetylene reduction assay was applied to grazed swards only during the final year of this study may well be questioned. It was only because of concurrent developments in field-application of the methodology, by colleagues within Grasslands Division (Hoglund & Brock 1978), that the assay could be used at all. It is conceded that confidence in the calculated values for symbiotic fixation in grazed swards (Table 21) would be greater if the $N_2(C_2H_2)$ fixation values had been obtained each year. On the other hand, as discussed previously in this section (C, 2) good accord between the fixation efficiency values obtained for treatment NO in this study, and those reported by other researchers working with white clover-based swards, would suggest that this parameter is reasonably

'portable'. Again, the point is made that quite substantial errors could exist in the estimates for symbiotic fixation in the grazed treatments, without substantially altering the conclusions reached. For instance, even if it were assumed that symbiotic fixation was negligible in treatment N448 (not suggesting that there is any basis for such an assumption), one would still be confronted with unaccounted-for nitrogen outgoings of 475 kg N/ha each year.

That soil total nitrogen pools decreased over the course of the study has had the effect of exaggerating the size of unaccounted-for losses from the grazed swards. A drop in soil nitrogen is, in effect, a nitrogen input insofar as the mass balance is concerned. If not reflected as an increase in productive output, then the nitrogen must have been lost from the soil-plant-animal complex. The annual decline in total nitrogen pools under grazing was not large.

Under cutting, symbiotic fixation was estimated as the difference between outgoings in the form of harvested herbage and other inputs, taking into account the drop in soil total nitrogen. As discussed elsewhere (Ball 1977) these are only partial nitrogen balances. No assessment of nitrogen outgoings as unaccounted-for 'losses' can be made for the cut systems, so the estimates for symbiotic fixation must be viewed as minimal. However, the writer is not aware of any information which would cause him to suspect significant, unidentified nitrogen losses from the soil-plant complex in any treatment other than N448, when swards are subjected to continual cutting management with removal of herbage. Data from the cut, cloverless treatment indicate no loss at all. The average outgoing in herbage nitrogen each year, perhaps fortuitously, was almost exactly matched by the input of background nitrogen and the average fall in the soil total nitrogen pool (Table 21).

Karraker *et al.* (1950) observed nitrate leaching

from lysimeters containing white and red clovers under cutting management, but only when harsh winter conditions resulted in plant death. Leaching was very slight below actively growing clovers and from lysimeters containing cut grass-clover associations (loc. cit.). In general, lysimeter studies indicate that little leaching of nitrate occurs below cut perennial swards (Allison 1965). In compiling the nitrogen balance for a cut grass-clover association under conditions prevailing in southern England, Whitehead (1970) concluded that no undetermined losses from the soil-plant complex would occur. All these observations would suggest that the annual estimate for fixation in the cut control sward is reasonably complete (380 kg N/ha; Table 21), but its accuracy will be determined by that of associated measurements. However, nitrogen relationships in the treatment receiving the larger input of fertiliser nitrogen would have been quite different from those in control. As discussed by Woldendorp et al. (1966), the magnitude of undetermined losses appears to increase as the rate of nitrogen input to swards increases. It seems likely that unaccounted-for losses would have occurred from treatment N448, resulting in underestimation of the input by symbiotic fixation. This is a problem of technique discussed by Henzell (1970).

The decline in soil nitrogen pools had the effect of reducing estimates for symbiotic fixation. In previous studies at Palmerston North, following which much larger estimates for symbiotic fixation in cut swards were reported, an increase in soil total nitrogen was observed. Sears & Evans (1953) measured an average, annual increase of almost 60 kg N/ha-5 cm below a cut grass-clover association, and reported that 'the most conservative estimate' for nitrogen input by clovers was approximately 620 kg N/ha yearly. In a later study (Sears et al. 1965a), an average annual increase of 190 kg N/ha-30 cm was measured below grass-clover associations from which mown herbage was discarded. The corresponding estimate for nitrogen fixation by white

clover, based on measurements made over the final three years of that seven-year study, averaged 610 kg N/ha/an.

(c) Conclusions

Under the conditions of this experiment, nitrogen balances for the grazed grass-clover associations indicate large, unidentified losses of nitrogen from the soil-plant-animal complex. Because of errors included in associated measurements, the estimates are not considered to have a high level of precision. Nevertheless, it is not considered possible that unaccounted-for outgoings of this magnitude (several hundred kg N/ha/an) have been observed in all three treatments by chance. An annual outgoing of 90 kg N/ha in unidentified losses was also indicated for the cloverless system.

In the cut treatments, the average annual outgoing of nitrogen in herbage from the cloverless sward almost exactly matched the fall in soil total nitrogen and an allowance for background nitrogen inputs. This, and other evidence cited, is considered to indicate that unidentified nitrogen losses from the soil-plant complex of the cut grass-clover control would have been small. Within the limits of error included in associated measurements, symbiotic fixation by white clover is estimated at 380 kg N/ha/an in the absence of fertiliser nitrogen, falling to 75 kg N/ha in treatment N448. The latter estimate is considered minimal, and may be an underestimate to the extent that unidentified losses occurred from the soil-plant complex as a consequence of the substantial fertiliser nitrogen input.

5 Nitrogen Mineralisation as Indicated by Herbage Nitrogen Yields from a Cut, Cloverless Sward

Annual nitrogen yield from the continually cut, pure grass sward declined a little over time: 253, 203 and 188 kg N/ha for years I to III, respectively. That fall-off may reflect differences in weather conditions between years as well as depletion of soil nitrogen. The average yearly herbage nitrogen yield (215 kg N/ha;

Table 21) represents 8.5% of the soil total nitrogen pool to 15 cm, or 4.5% of that measured to 30 cm in this treatment.

Walker and associates (Walker et al. 1954), after considering results from a variety of sources, conjectured that some 28 kg N/ha would be mineralised over a growing season for every 0.1% N in topsoil, and that two-thirds (19 kg N/ha) of the nitrogen mineralised should be recovered in grass herbage. The total nitrogen content of topsoil below this cut cloverless sward averaged 0.16% N to 15 cm, or 0.14% to 30 cm. On the above basis, annual herbage nitrogen yield from the continually cut cloverless sward should have been about 27 kg N/ha, but the three-year average was almost eight times that figure (Table 21).

D GENERAL DISCUSSION

1 Changes in Soil Total Nitrogen Pools

A great deal of care and effort went into monitoring changes in soil total nitrogen. While substantial error is associated with individual estimates, it is extremely unlikely that the general pattern of decline observed over three years, which was significant between the first and last samplings (Fig. 9), arose by chance. This result is clearly at divergence with the view that soil nitrogen accumulates below perennial grass-clover associations, as widely expressed in the New Zealand grassland literature (Watkin 1949; Sears & Evans 1953; Walker 1960, 1968; Jackman 1964a, b, 1966; Sears et al. 1965a).

Possibly some 'situation-specific' feature of this study gave rise to the observed results. For this reason a detailed account of previous cultural practices was given earlier in this section (B, 1). While the history of the site is highly unusual, the writer remains of the opinion that it was unlikely to have been seriously influencing the

pattern of nitrogen relationships observed 5 to 8 years after levelling. On commencement of the study, topsoil total nitrogen content averaged 0.175% N at 0-7.5 cm and 0.144% N at 7.5-15 cm (Fig. 10). Any suggestion that it was at or near 'steady-state' for grassland in this locality can be dismissed. The total nitrogen content reported from a reference site of Manawatu fine sandy loam under 'rough pasture' in the same locality (Cowie 1978), was 0.55% N at 0-5 cm and 0.36% N at 5-23 cm. In an older but heavier alluvial soil at Grasslands Division, topsoil total nitrogen contents in excess of 0.3% have been observed below mixed swards (Watkin 1949; Sears & Evans 1953). The writer has been involved in studies on an older alluvial terrace adjoining this experimental site (Ball *et al.* 1979b), where a topsoil nitrogen content below pasture of 0.23% N at 0-15 cm was encountered. To rule out any possibility that a difference in soil texture could account for the lower value observed during this study, topsoil was sampled from an old permanent pasture on a coarser alluvial soil nearby. Total nitrogen content to 7.5 cm was almost 0.4% N. Further, soil nitrogen content did increase in the surface depth throughout the course of this study, on average over all treatments (Fig. 10).

A heavy dressing of lime was worked into the topsoil immediately prior to establishment of the experimental swards. Liming of acid soils has been reported to enhance mineralisation of organic nitrogen below permanent grassland (Harmsen & Kolenbrander 1965). In both *in vitro* and glasshouse studies, Jackman (1960c) found that raising the pH of a Taupo pumice soil from 5 to near neutrality increased the rate of organic matter breakdown. However, that influence was considered to be effected on otherwise stable complexes between organic matter and allophane-like colloids, so the general applicability of that observation to a non-allophanic soil of the type involved here is unclear. Surface soil pH (10 soil:25 water) was raised from an initial value of 5.0 to 5.2, to 6.3 when the study commenced (Section

III, Table 16). Treatments were imposed two years after lime application. As discussed by Russell (1973), the influence of liming on the organic matter content of field soils has not been well studied. In general, liming a very acid soil will reduce its organic matter content, but this may simply reflect breakdown of partially decomposed organic residues rather than any reduction in soil humus content (loc. cit.). Classical studies at Rothamstead (Richardson 1938; Russell 1973) showed that liming increased both the organic matter and total nitrogen contents of an old meadow soil. It is concluded that liming is unlikely to have caused the general pattern of changes observed during this study. Resident organic matter was of the mull type, with soil C/N ratio below 10, so it would be expected that humification was near complete (Flaig et al. 1975). Further, a decline in soil total nitrogen pools throughout the sampled profile was still continuing 3 to 4 years after lime application (Fig. 9).

These results by no means stand alone. Failure of soil nitrogen to accumulate below grass-clover associations has been reported from several other studies. McGarity (1959), following an extensive study in northern New South Wales, concluded that the practice of sod-seeding mixed legumes into dairy pastures is better regarded as 'fertility maintaining' rather than 'fertility building' in respect of this element. Russell and Harvey (1959) followed up a soil survey of 30 years before, sampling soil at 40 reference points in an area of South Australia used for intensive dairyfarming on irrigated grass-clover pastures. Compared with values obtained in 1929, soils of high initial total nitrogen content exhibited a decline over the 30 years. Sites with initially low total nitrogen contents showed an increase, while intermediate values (c 0.5% N) remained unchanged. Work in Queensland (Vallis 1969, quoted by Henzell 1970) demonstrated that the net change in soil nitrogen below some pasture systems may be nil or negative, in spite of independent evidence for substantial symbiotic fixation by legumes

in the mixed association.

Finally, the general tenor of this section might be reversed by directing fair criticism at some past New Zealand research. In the classical study by Sears and associates (Sears 1953a, c), main treatments were unreplicated in space. Soil measurements were made only at the finish of that study. In view of the relatively huge spatial variability observed in soil total nitrogen content in this (Table 18) and other studies (Beckett & Webster 1971; Vallis 1973; Biggar 1978), previous conclusions regarding the influence of agricultural practices on soil nitrogen (Sears & Evans 1953; Sears 1953c) could well have been erroneous.

2 Influence of Grazing and Cutting on Changes in Soil Total Nitrogen

It is generally accepted that grazing as opposed to cutting a sward ('pasture' vs 'meadow' management; Williams & Clement 1966) will enhance both soil nitrogen and organic matter accumulation (Whitehead 1970). Insofar as that the drop in soil total nitrogen was greater under cutting than grazing (Table 19), results from this study are in qualitative agreement with the above generalisation. Nevertheless, little satisfaction can be derived from this result. Over the three-year study period, an estimated 60 kg N/ha was removed in animal protein from grazed pastures while 1 630 kg N/ha was removed in herbage from cut swards (Section III, Table 10). Yet the decline in the soil total nitrogen pool observed throughout the sampled profile under cutting was only 275 kg N/ha greater than under grazing (Table 19).

Again, available literature on this subject is not very consistent. Sears and colleagues carried out parallel studies in Manawatu, Southland and Canterbury (Sears et al. 1953). On conclusion of the Manawatu study, a higher nitrogen content was measured in soil to 5 cm where dung and urine had been returned (0.35% N)

compared with where they had been withheld (0.28% N) over a five-year period (Sears & Evans 1953). By contrast, in Canterbury no difference was observable between treatments in either carbon or nitrogen (0.23 to 0.26% N) contents of soil to 7.5 cm following 4 years of either returning or withholding animal excrement from grazed swards (Metson & Hurst 1953). These measurements, in which treatment differences in soil to only 2.5 cm could not be detected, were conducted rather more rigorously than those at Palmerston North. Changes were compared between samples drawn at the start and on completion of the study (loc. cit.). From the United Kingdom, Wolton (1955) reported only a small effect in this respect. In a two-year grass-clover ley, on average all treatments accumulated 135 kg N/ha-7.5 cm. Return of dung and urine together, but not separately, increased the accumulation of soil total nitrogen by some 70 kg N/ha-7.5 cm above that observed below grazed swards receiving no excreta, over the 18-month period of observation (loc. cit.). Similarly, Clement & Williams (1967) reported only small differences between pasture and meadow managements in the rate of soil nitrogen accretion: 440 and 300 kg N/ha-15 cm respectively below a three-year grass-clover ley. The advantage attributable to grazing by sheep as opposed to cutting and removal of herbage was only a meagre 50 kg N/ha-15 cm yearly. Working with mixed grass-subterranean clover (T. subterranean L.) pastures, on virgin soils of very low nitrogen content (0.06% N) in Western Australia, Watson & Lapins (1964) observed an increase of 65 kg N/ha-10 cm for every 100 kg N/ha measured in clover herbage. Over the two-year study period, soil nitrogen accumulated at an annual rate of 80 kg N/ha-10 cm, irrespective of whether swards were grazed or cut, and irrespective of whether the cut herbage was discarded or returned to plots after drying and grinding (loc. cit.).

When results from the field studies reviewed above and the information gathered in this experiment are

viewed collectively, the following conclusion emerges with considerable clarity: that retention within the soil-plant complex of nitrogen 'recycled' in animal excreta is extremely poor. Under meadow management, the annual outgoing of nitrogen in cut herbage is very large, generally several hundred kg N/ha/an. Under grazing management, especially that involving sheep, the annual nitrogen outgoing in animal protein is relatively small, generally less than 20 kg N/ha/an. In no case have observed differences in soil total nitrogen accumulation under meadow and pasture management provided anything like a quantitative reflection of such differences in outgoings from the soil-plant complex.

3 Influence of Nitrogen Treatments on Changes in Soil Total Nitrogen

Relative to the grass-clover control, no consistent influence of nitrogen treatments on changes in the soil total nitrogen pool was observed (Table 19). The rate of decline throughout the sampled profile below the cloverless sward was a little greater (c 40 kg N/ha/an) than that observed below control, but the difference was not significant. It seems reasonable to conclude that had measurements been continued for a longer period of time, the absence of inputs from both symbiotic fixation and fertiliser nitrogen to the pure grass swards would eventually have been reflected in significant differences in soil nitrogen changes between this and other treatments. Compared with pure grass swards, inclusion of clover in a mixture has been reported to enhance nitrogen accumulation in surface soil (Sears & Evans 1953; Sears *et al*. 1965a). The annual decrease in the soil total nitrogen pool observed under cut grass by Sears and colleagues (*loc. cit.*) was 20 kg N/ha-30 cm, while the average annual increase under cut grass-white clover associations was 190 kg N/ha-30 cm. The total soil nitrogen contents reported (*loc. cit.*) indicate that the rate of soil

nitrogen accumulation differed little between cut grass-clover associations and a cut grass sward receiving some 625 kg N/ha each year as urea. Increased soil nitrogen accumulation below grass-white clover associations, compared with pure grass swards not receiving nitrogen, has also been reported from studies in the United Kingdom (Cowling 1961; Williams & Clement 1966).

The rate of change in soil total nitrogen was unaffected by fertiliser inputs of up to 1 350 kg N/ha over this three-year period (Table 19). The absence of an influence of fertiliser nitrogen on soil nitrogen accumulation below leys has been reported from many studies (Wolton 1955; Eagle 1971; Hoogerkamp 1973). Suggested reasons (Whitehead 1970) include a decreased input of grass root residues where nitrogen is used, clover suppression and/or a 'priming effect' of fertiliser nitrogen on mineralisation of resident soil organic matter. Williams & Clement (1966) reported that application of nitrogen at rates up to 320 kg N/ha/an for three consecutive years had no influence on soil nitrogen accumulation below a grazed grass-clover ley. Under cutting with herbage removed, heavy inputs of fertiliser nitrogen actually reduced the rate of soil nitrogen accumulation. Subsequently, it was reported that nitrogen accumulation under a grazed grass-clover ley was enhanced over three years by an annual dressing of 314 kg N/ha (Clement & Williams 1967). These and other observations led Clement & Williams (loc. cit.) to the viewpoint that under grass-clover or nitrogen-fertilised grass swards, the accumulation of organic nitrogen in soil depends on the supply of carbon from dead roots, leaves and stem bases.

4 Symbiotic Fixation and Fixation Efficiency in Grazed and Cut Swards

Annual averages for symbiotic fixation in grazed swards, derived from $N_2(C_2H_2)$ fixation estimates

(Table 20), may be compared with the minimal annual average estimates for cut treatments, derived by difference (Table 21). In the control and N112 treatments, estimates under cutting were higher than those under grazing, by some 20 and 40% respectively. Similar estimates were obtained in treatment N448, but the value obtained under cutting may be an underestimate to the extent that unidentified nitrogen losses occurred from the soil-plant complex.

Over the measurement year, fixation efficiency values in grazed treatments NO, N112 and N448 were 61, 48 and 23 respectively (Table 20). Amalgamation of fixation estimates in cut swards with corresponding average yearly clover dry herbage yields provides estimates of 65, 57 and 20 for fixation efficiency in cut treatments NO, N112 and N448 respectively. Values indicated for control and treatment N112, where the writer considers that unidentified nitrogen losses from the cut swards would be very small, are only 7 and 19% greater under cutting than grazing, respectively. Within the limitation of the assumptions and errors involved in obtaining these data, they indicate a relatively minor influence of grazing on soil nitrogen availability to white clover, in spite of the prodigious amounts of nitrogen 'recycled' by grazing animals. If soil nitrogen availability were substantially increased by grazing it would be expected that such an influence would have been reflected in very much lower fixation efficiency values for grazed than cut swards.

5 Nitrogen Losses from Grazed Systems

Identification of very large unaccounted-for nitrogen outgoings from the grazed treatments (Table 21) has raised considerably more questions than this study was designed to answer. The pattern of mineral nitrogen accumulation and decline in the sampled profile below grazed swards, over a 15-month period, was presented

(Fig. 12), as it is felt that nitrate leaching is one likely avenue for nitrogen loss from grazed swards. However, even if the entire mineral nitrogen pools measured over mid summer-mid autumn were leached during late autumn-winter, which seems unlikely, this would only account for a fraction of the several hundred kg N/ha unaccounted-for each year in the nitrogen balance for grazed, mixed swards. Tham (1971) monitored soil mineral nitrogen pools below fallow, and cut mixed swards, throughout a year in Canterbury. By comparison of the pattern for movement of nitrate to depth in the fallow and planted soils, with the onset of leaching conditions over late autumn-winter, he concluded that most of the mineral nitrogen which had accumulated below swards over summer-early autumn was not subsequently leached. Rather, it 'disappeared' from the surface soil by some undefined combination of plant uptake, microbial immobilisation and denitrification (loc. cit.). Tham's swards were not subject to any grazing influence during the measurement year.

Urine patches provide a focal point for nitrogen losses from grazed pastures. Recent studies with which the writer has been associated (Ball et al. 1979b, and unpublished data) indicate that retention of urinary nitrogen in the soil-plant complex of improved pasture is little better than 20 to 40%. The writer considers that losses stemming from the aggregation of excess dietary nitrogen into urine patches by grazing animals can largely explain the unaccounted-for nitrogen outgoings from these grazed grass-clover systems. That aspect of nitrogen relationships is considered in detail in the final section (V, A, 6 & 7).

E CONCLUSIONS

1. Spatial variability in soil total nitrogen content creates considerable difficulty with field-sampling, in attempts to measure adequately small changes in the soil total nitrogen pool.

2. Under the conditions of this experiment, the soil total nitrogen pool throughout the sampled profile declined in all treatments. The average decline under grazing (60 kg N/ha/an) was less than that under cutting (150 kg N/ha/an).

3. Neither exclusion of clover nor application of fertiliser nitrogen at rates up to 1 350 kg N/ha/3 years, influenced the observed pattern of decline in the soil nitrogen pool over three years.

4. Nitrogen fixation under grazing, as estimated by field-application of the acetylene reduction assay, was 263, 165 and 53 kg N/ha/an in grass-clover pastures receiving 0, 112 and 448 kg N/ha/an respectively.

5. Large pools of mineral nitrogen accumulated in the sampled profile below grazed grass-clover swards over summer-early autumn. With the onset of leaching conditions, the pools declined to minimal values by late winter. An influence of nitrogen treatments was superimposed on this seasonal pattern, with a peak value of almost 200 kg N/ha observed below the pasture receiving 448 kg N/ha/an. While it is suspected that much of this nitrogen was leached, quantitative conclusions were not possible.

6. Nitrogen balances for cut systems indicated that nitrogen fixation and fixation efficiency, at least in swards receiving 0 and 112 kg N/ha, were not a great deal higher than those measured in grazed swards.

7. Nitrogen balances for grazed systems indicated that unaccounted-for outgoings of several hundred kg N/ha occurred each year from grass-clover pastures. Losses indicated were considerably greater from the pasture receiving 448 kg N/ha/an than from control.

SECTION V

PERSPECTIVE COMMENTS AND MAJOR CONCLUSIONS

A PERSPECTIVE COMMENTS

It is 25 years since an attempt was made to quantify nitrogen relationships in New Zealand pastoral agriculture (Walker et al. 1954). As pointed out earlier (Section I, 3, a & c), both farming and knowledge have progressed during those 25 years. The purpose of this section is to discuss several topics, in which progress has been made, as they relate to results from this and other relevant studies. An attempt is made to reconcile divergent viewpoints where possible.

A recent treatise (Whitehead 1970) provided a comprehensive review of research findings and their implications to nitrogen relationships in grassland farming, with particular emphasis on conditions in the United Kingdom. Those well acquainted with the subject will appreciate the complex nature of the 'nitrogen cycle' in pastoral ecosystems, even when attention is confined to temperate agriculture. The input, transformations and outgoings of nitrogen within the soil-plant-animal complex are almost entirely biologically-mediated processes. As such, all nitrogen movements are subject to modification by climate and weather, and can be further modified by management practices. The diversity of environmental conditions and edaphic situations under which pastoral agriculture is practised, even within New Zealand (Levy 1970), adds greatly to the complex nature of these inter-relationships. A recent report (Scott 1977) has also indicated qualitative differences among some aspects of nitrogen relationships, between sheep and cattle-grazed pastures.

These two features, the complexity and diversity of nitrogen relationships in pastoral agriculture, have important implications to research. First, the complex nature of biological inter-relationships makes it

difficult to isolate any single component of the ecosystem for meaningful study. This point is nicely illustrated by results obtained from pure grass swards in the present experiment. Removal of clover resulted not only in cessation of the nitrogen input by symbiotic fixation, but also in a changed physical environment for grass growth in the cloverless swards. In the absence of competition from white clover, presumably expressed through a reduction in basal shading of grasses (Mitchell 1953) and possibly also through reduced competition for moisture and soil nitrogen over summer-autumn, grass performance was altered. As discussed previously (Sections II, D, 3 & III, D, 1, c), the frequency of grass tillers increased, annual dry herbage yield from grasses was little affected, and it was not until the third year that the grass component in grass-clover control displayed a significant superiority in terms of herbage nitrogen yield, over grass grown in the absence of clover. This result cannot be construed to mean that no transfer of the nitrogen fixed by white clover to grass associates occurred until the final year. Rather, associated changes affected nitrogen relationships, masking any nett annual transfer of nitrogen until the third year. It seems quite apparent that had the study been continued over a longer period, more pronounced differences would have emerged between treatments in this respect. Second, diversity among pastoral ecosystems creates difficulty in deriving principles of general application, even when whole systems have been studied over a period of years, as has been the case here. This point can be amply illustrated by extension of the above discussion. It is self-apparent that had this study been conducted on a site of very low soil nitrogen status, a different set of results would have been obtained. They may have been in better agreement with those from past research at this station (Melville & Sears 1953; Sears *et al.* 1965a) and shown a relatively substantial nett transfer

of nitrogen from clover to associated grasses, and have been apparent from the first year.

Both the complex, interactive nature of nitrogen relationships in pastoral ecosystems, and the diversity of conditions under which pastoral agriculture is practised, have to be borne in mind when seeking generality from results obtained during this and associated research. Throughout this report, the writer has endeavoured to confine attention to highly productive, developed pastures based predominantly on ryegrass and white clover; thereby narrowing the range of ecological situations under consideration. Unfortunately, much of the existing knowledge in this country's literature pertains to nitrogen relationships in developing grassland systems. This point can again be illustrated by consideration of the performance of cloverless swards in this and past studies. During the classical studies by Sears and associates (Sears 1953a, c; Sears et al. 1953) the following annual average herbage nitrogen yields from continually cut, cloverless swards were reported: from Manawatu, 55 kg N/ha (Melville & Sears 1953); and from Southland, 71 kg N/ha (Sears et al. 1953). Herbage nitrogen yields were not reported from Canterbury, but can be estimated from the grass DM yields tabulated (loc. cit.) to have been some 30 to 35 kg N/ha/an over the final two years of that study. In a later study in this locality, the average value reported was 35 kg N/ha/an (Sears et al. 1965a). Under conditions prevailing during the present experiment, the average herbage nitrogen yield from a continually cut, pure grass sward receiving no fertiliser nitrogen was 215 kg N/ha/an (Section IV, Table 21), indicating a much higher level of soil nitrogen availability than has been the case in past studies. Associated clover dominance in swards during that early research has been discussed previously (Section II, D, 1).

1 Soil Organic Matter Quality and Level

A national study was carried out recently into nitrogen relationships in reasonably well developed pastures, grazed by sheep, at 8 climatically diverse sites throughout New Zealand (Ball et al. 1979a). Of the soil characteristics measured, soil C/N ratio related more closely to yearly grass DM yield, $N_2(C_2H_2)$ fixation and fixation efficiency, than did the soil total nitrogen pool to 15 cm. As those are all pasture production parameters considered likely to reflect soil nitrogen availability (Hoglund et al. 1979), this observation points to an inadequacy in seeking an understanding of soil nitrogen relationships on their own. The quality of resident organic matter, especially the C/N ratio, clearly influences soil nitrogen availability (Bartholomew 1965). Only where resident organic matter has a close C/N ratio is soil nitrogen availability likely to be directly related to the size of the soil total nitrogen pool, as suggested by Henzell & Ross (1973).

Depending on the quality of resident organic matter, contrasting ecological situations exist. Their description may help reconcile some of the apparent contradiction between conclusions from this study and viewpoints expressed previously. Accumulation of mor-type organic matter is characteristic of acid, infertile soils maintained under short scrub or poor grassland, in moister areas of New Zealand (Barratt 1966). From the writer's experience, such topsoils may contain a substantial pool of total nitrogen (c 0.2 to 0.4% N) rendered largely unavailable by a wide C/N ratio (c 14 to 20). Where resident organic matter is of this carboniferous mor-type, partly decomposed organic residues provide a plentiful energy substrate and foster intense competition by soil microbes for available nitrogen. This feature may provide the reason that agriculturalists observing and researching pasture development in such situations placed so heavy an emphasis on formation of animal urine as the

effective pathway for transfer of nitrogen from clovers to grasses (Sears 1956, 1960; O'Connor 1966; Levy 1970). Acute nitrogen deficiency restricts grass growth and favours clover growth in developing pastures (Sears 1960), so a large part of herbage intake would have been provided by clovers. Only when herbage nitrogen was ingested by grazing animals, separated by ruminant digestion from the carbon with which it was associated in plant material, and then aggregated into urine patches as very large inputs of readily-available nitrogen, could any immediate benefit to grasses be observed. Relatively good retention of urinary nitrogen within the soil-plant complex would be expected, through immobilisation of much of the nitrogen in excess of immediate plant requirements. Clover nitrogen introduced by the alternative pathways of decomposition of root and nodule tissues (Butler & Bathurst 1956; Chu & Robertson 1974) or senescence and decay of above-ground tissues (Brougham 1958, 1966; Hunt 1970, 1971; Korte & Sheath 1978), would be substantially immobilised by microbial decomposers.

Resident organic matter of the mull-type is formed in soils below well managed productive pastures (Barratt 1966), with C/N ratio typically about 10 (Jackman 1964a, b; see also Section IV, Fig. 9). In contrast to the situation described above, carbon substrate for microbial activity is largely limited to recently added organic residues. Nitrogen inputs as clover root and herbage residues would be expected to become relatively quickly available to grass associates. Most of the nitrogen ingested by grazing animals arises from the soil, following plant uptake by these grass-dominant swards. At the same time, there is insufficient available carbon in such soils to prevent substantial nitrogen losses from urine patches.

In light of the above contrast, the writer considers that differences in organic matter quality contribute, in part, to the difference in viewpoints regarding the role of grazing animals in 'recycling'

nitrogen, which have emerged from this and past studies. In a previous study by Sears and colleagues at Palmerston North (Sears 1953a, c) C/N ratios on conclusion of the experiment ranged from 15 to 19 (Sears & Evans 1953), although a closer ratio was reported following earlier observations at the same site (Watkin 1949).

The accumulation of mull organic matter and total nitrogen in soils below well managed pasture follows an asymptotic pattern towards 'steady-state' levels (Jackman 1964a, b, 1966; Whitehead 1970). Obviously, accumulation rates observed during any experiment will be influenced by initial levels in the soil studied. The very large accumulation rates reported from the later study by Sears and associates (the annual average was almost 250 kg N/ha-30 cm in grass-clover swards; Sears et al. 1965a) were recorded on a raw subsoil, with an initial nitrogen content of 0.08% N. Where grassland had been resown after cropping, and initial levels were much higher (Jackman 1960a), the rates of accumulation below well managed pasture were typically about 110 kg N/ha/an over a ten-year period.

It is generally accepted that when arable soils are sown to mixed swards containing active legumes, the content of both organic matter and nitrogen increase, and continue to do so for many years if the soil remains out of cultivation (Russell 1962; Williams & Clement 1966; Clement & Williams 1967; Whitehead 1970; Greenland 1971; Hoogerkamp 1973). The increase is asymptotic, with an equilibrium or steady-state eventually reached when additions of organic matter and nitrogen are balanced by oxidation and losses (Russell 1973). After reviewing world literature from studies in temperate grassland areas, Whitehead (1970) concluded that when previously cultivated land is sown to a grass-legume sward, soil nitrogen normally increases at an initial annual rate of 55 to 165 kg N/ha, and that the rate of accumulation is enhanced by climatic conditions favouring high growth rates, by the presence of legumes,

by grazing and by a plentiful supply of nutrients other than nitrogen. In this respect, results observed during this study are clearly out of line. The writer considered the soil typical of any comparable, recent alluvium, which had been subjected to repeated cropping a few years before measurements commenced. Yet, as considered previously (Section IV, Table 19 & Fig. 9), a general pattern of decline in the soil total nitrogen pool throughout the sampled profile was observed over the course of the experiment, in all treatments. Obviously, this negative change in soil nitrogen has influenced quantitative conclusions drawn from the study, especially estimates calculated by difference in the nitrogen balances (i.e. unidentified nitrogen losses from grazed systems and symbiotic fixation in cut systems; Section IV, Table 21). It was also a high rate of mineralisation which met the nitrogen requirements for the relatively large dry herbage and herbage nitrogen yields from the cloverless swards.

Possible reasons for the observed results have been discussed (Section IV, D, 1). Liming two years before the study commenced may have enhanced both mineralisation and nitrification of soil organic nitrogen; twin processes which may lead to nitrogen losses from the soil-plant complex (Alexander 1965). However, this seems an unlikely cause in view of both the duration of the changes, and information available from other studies. Substantial accumulation of soil nitrogen below grass-clover swards was recorded in a previous study in this locality, involving an equally disturbed alluvial soil of pH 6.4 (Sears *et al.* 1965a). The possibility that soil nitrogen content at this site was at or near a steady-state level has also been dismissed (Section IV, D, 1). While it is considered impossible to be adamant that the pattern of change in soil total nitrogen reflected no particular site-specific soil characteristic(s), the following explanation is considered the most likely. During the conduct of this experiment, a high level of herbage utilisation was achieved throughout. The reasons were two-fold:

previous experience had shown that herbage utilisation in sheep-grazed pasture could be approximated more accurately with the cutting technique used, when relatively close defoliation was practised; and there was a conscious effort to minimise yields of dead herbage, as it was considered that they could not be partitioned reliably between the clover and grass components of the sward. To check whether equivalence was being attained in grazed and cut swards, stubbles were measured to ground level in several nitrogen treatments, immediately after a defoliation in spring of the first year. Average dry herbage yield was 1 090 kg DM/ha, with averages for both methods of defoliation and three nitrogen treatments within the range 1 030 to 1 150 kg DM/ha. Compared with stubble yields from other studies (Smetham 1975) these were small, and indicate a high level of 'utilisation' of herbage grown in both grazed and cut treatments.

It is unlikely that herbage would be utilised to this extent, on a year-round basis, in farming practice (loc. cit.). One practical consequence is that the quantity of aerial tissue available to the soil decomposer network was relatively small, as the input of fresh organic residues via herbage litter is greatly reduced by frequent and intense defoliation (Brougham 1958; Clark & Paul 1970; Hunt 1971; Korte & Sheath 1978). Accordingly, it is contended that an unusually small input of organic residues (alternatively a very high level of herbage utilisation) caused the general pattern of soil nitrogen decline observed during this study. The small input of carbon substrate, most of that presumably arising from senescence of root tissues, was insufficient to match the concomitant oxidation of organic matter. The C/N ratio of resident organic matter was near 10, indicating more or less complete humification (Russell 1973; Flaig et al. 1975), so the only prospect for retention of nitrogen in the soil was through a nett gain in soil organic matter content. The experimental conditions precluded any such gain.

Throughout the sampled profile, more organic matter and nitrogen was mineralised than was accumulated.

A piece of indirect evidence supports the above contention. Apparent dry herbage intakes by animals in the grazed swards were reported previously (Section III, Table 17). Comparison of those values with established herbage intakes for non-lactating, mature sheep (Rattray 1978; R.G. Keogh, pers. comm.) indicates that during years I and II, the total dry herbage yields measured corresponded well with expected animal utilisation. During the final year, considerably fewer sheep were available to graze the experimental swards. Individual grazings took longer, and were less intense than those achieved earlier in the study. Cutting heights were adjusted accordingly. Under these conditions, estimates for apparent dry herbage intake were considerably higher than would be expected, indicating that a significant part of the herbage measured did, in fact, become available to the decomposer network. During the same year, a very highly significant increase in the total nitrogen content of topsoil was recorded (Section IV, Fig. 10).

As discussed previously (Section IV, D, 1, 2 & 3) the results from this study are in line with information from several other sources indicating that factors influencing soil carbon accumulation, rather than the size of nitrogen inputs, determine the extent of soil nitrogen accumulation in a fertile soil. On the other hand, during the conversion of mor-type organic matter to mull, as observed by Walker and associates (Walker *et al*. 1959), assuming good pasture husbandry, the annual input of nitrogen is probably rate-limiting. In that study, substantial accumulation of soil nitrogen occurred with little accompanying change in soil organic matter content over a 25-year period.

2. Grazing vs Cutting

During this study the influence of grazing, as

opposed to cutting with removal of herbage, on measured parameters was not spectacular. A small advantage to grazing was recorded in total dry herbage yields (Section II, C, 1, a & Table 2) and herbage nitrogen yields (Section III, C, 2, b & Table 10), but little influence on fertiliser nitrogen responses (Sections II, C, 1, e & III, C, 2, a) nor on estimates for the various parameters in nitrogen balances for the grass-clover systems (Section IV, C, 4 & Table 21) was observed. Certainly, the sharp contrast in botanical composition, which has been observed in some past grazing vs mowing comparisons (reviewed throughout Section II), was not apparent in this study. It was not until the third year that a significant difference between grazed and cut swards in the annual yield of clover was observed (Section II, Table 2).

This absence of any pronounced influence of defoliation method on nitrogen relationships presumably reflects a number of factors. Important among them is the cutting method employed. As discussed earlier (Section II, D, 1) an electric shearing handpiece was used to cut herbage, as it is considered to allow better simulation of sheep-grazing than the alternative use of a mower. In particular, the operator can harvest clover tissue from among tufted grass plants, in much the same way as sheep do. In contrast, this material would be left behind by a mower operating at a fixed height, favouring subsequent clover regrowth and probably enhancing the population of rooted clover nodes. The latter technique may better represent lax grazing by cattle.

During this experiment, the rate of decline in soil total nitrogen was somewhat less (90 kg N/ha/an) under grazing than cutting. In terms of the results and reasoning presented in this report, the difference is not unacceptably small. A grazing ruminant ingests herbage, metabolises 70 to 80% of the contained carbon, and excretes the residue in dung. For the much greater part of the grazed area unaffected by dung the nett

process is no different from cutting with removal of herbage, insofar as carbon input to the soil is concerned. The difference observed between defoliation treatments in rate of change in soil total nitrogen seems most likely to have been the outcome of dung return to the soil, possibly coupled with a larger input of plant residues in the grazed swards. The latter might be expected on the basis of the higher total yields measured under grazing (20 to 25% annually; Section II, Table 2).

Grazing as opposed to cutting should not greatly influence the rate of soil nitrogen accumulation in a fertile soil, except insofar as that one or other defoliation treatment may influence the provision of organic residues to the soil. Thus, where grazing and associated return of dung and urine have relieved acute potassium deficiency and resulted in greatly increased biomass production (Wolton 1955), an effect on soil nitrogen accumulation would be expected. Alternatively, unequal herbage removal by either grazing or cutting would favour soil nitrogen accumulation in the treatment where herbage removal was less complete.

At this juncture, some past New Zealand research is open to fair criticism. In the initial study by Sears and associates, dung and urine were mixed and applied evenly with a watering can to plots of the 'return' series (Sears 1953a). The benefit to herbage production, as summarised earlier (Section II, Table 7), was substantial but the method of excrement return was so far removed from what happens in the field as to cast serious doubt on the quantitative conclusions drawn. Likewise, in their later study (Sears *et al.* 1965a), 'animal return' was simulated by drying, grinding and spreading evenly over plots, 80% of the herbage harvested. Again, the simulated method of animal return was completely divorced from the grazing situation, both in terms of evenness of return and provision of a carbon substrate in intimate association with the returned nitrogen. In effect, plots of the 'return' series were small-scale compost heaps.

Viewing those experiments with hindsight, the writer concludes that their principal merit is that they provide something of a benchmark for potential symbiotic fixation in grass-clover associations. The results obtained, which have become widely accepted in our own and the international grassland literature, are considered to have little quantitative relevance to productive pastoral ecosystems utilised for intensive livestock production.

In a recent analysis of nitrogen relationships in nitrogen-fertilised grass swards (Richards 1977), it has likewise been noted that the nitrogen redistributed in the urine and dung of grazing animals exerts a relatively small effect on dry herbage and herbage nitrogen yields. The reason suggested was that sward damage associated with grazing offset much of the benefit which might otherwise have accrued from this substantial nitrogen input (loc. cit.). Doubtless, some negative influences are incorporated in the results obtained from grazed swards during this study. However, if sward damage during grazing could effectively offset the yield response to be expected from inputs of nitrogen, then significant defoliation x nitrogen treatment interactions would have been expected. In fact such interactions were not a feature of annual herbage yields (Sections II, C, 1, e & III, C, 2, a). Sward damage seems unlikely to have been an important factor.

3 Mineralisation of Soil Nitrogen

Numerous attempts have been made to estimate nett annual movement of nitrogen from the organic to inorganic pools. In cultivated soils nett mineralisation is normally between 2 and 4% of soil total nitrogen to 15 cm, although the proportion is affected by soil texture and climate (Scarsbrook 1965). In the present study, yearly nett mineralisation, as indicated by the herbage nitrogen yield of a continually cut, cloverless sward, averaged 8.5% of soil total

nitrogen to 15 cm, over three years (Section IV, C, 5). Depending on viewpoint, the difference may be taken to indicate a very high level of soil nitrogen availability, or construed as evidence for atypical behaviour in soil at this site.

On the basis of *in vitro* incubation studies, Broadbent *et al.* (1964) calculated annual estimates of 4 to 11% for organic matter mineralisation in four North Island pasture soils. As stated by the authors, those were probably over-estimates for undisturbed soils under field conditions (*loc. cit.*). Using observed rates for organic matter and nitrogen accumulation, after previously cultivated fields had been returned to well managed pasture, Jackman (1964b) calculated average annual mineralisation rates of 12% for three non-allophanic soils, but only 5% for 5 soils containing allophane-like colloids. When land was cultivated from good pasture at Palmerston North, the annual rate for nett mineralisation was estimated to represent about 5% of soil total nitrogen in the upper 15 cm of soil (Sears *et al.* 1965b). A most appropriate study in this context was carried out in Canterbury (Tham 1971). Tham measured herbage nitrogen yields from a ryegrass sward sown after autumn cultivation, and from older established swards from which clovers had been removed with a selective herbicide. Between March and November, estimates of nett mineralisation as a proportion of soil total nitrogen to 15 cm were 4.5% for the newly-established grass sward, 3.7% for undisturbed grass on the same soil type, and 2.7% for an older pasture. The established swards gave very similar herbage nitrogen yields, the proportional difference reflecting a very much larger soil total nitrogen pool below the older pasture (*loc. cit.*). Brock (1973) measured nitrogen yields from cut ryegrass swards, sown after surface-cultivation of plots in which three different legumes had been grown. Nett mineralisation indicated was 2.5% of soil total nitrogen to 30 cm, estimated by the writer to have been about

4.5% to 15 cm, each year. However, the concurrent decline in soil total nitrogen, monitored over the two-year study period, was substantially greater than herbage nitrogen yields (loc. cit.). Edmeades & Goh (1978) reported estimates for nett mineralisation in four Canterbury pasture soils, based on herbage nitrogen yield in grasses plus soil-derived nitrogen in white clover herbage. From their results, based on 0-20 cm, the writer has estimated annual nett mineralisation rates to 15 cm of between 2 and 4% for the various soils.

Viewed collectively, the foregoing estimates based on herbage nitrogen yields in cut material, with no allowance for root growth, indicate that on an annual basis nett mineralisation may vary between 2 and 5% of the soil total nitrogen pool to 15 cm. By comparison, the average annual value of 8.5% obtained during this study appears unusually high, suggesting that some site-specific characteristic(s) enhanced nett mineralisation of soil nitrogen.

It remains to be established whether this value can be verified at an undisturbed site, under otherwise comparable conditions. It does not appear that previous disturbance of the subsoil resulted in a nett release of nitrogen from soil below the influence of ploughing. The total nitrogen pool in subsoil remained virtually unchanged throughout the study (Section IV, Fig. 9). As has been discussed earlier (Section IV, D, 1) and previously in this Section (A, 1), the writer considers that the two factors most likely to have effected so high a nett mineralisation rate were the low C/N ratio in soil at the site, and the relatively frequent, close defoliation practised. Soil C/N ratios have not generally been reported from other studies, but they ranged between 11.7 and 12.9 at 0-10 cm in the soils studied by Edmeades & Goh (1978). An influence of organic residues on soil nitrogen retention is illustrated in two local studies (Sears et al. 1965b; Tham 1971). Losses of soil nitrogen were greater from

fallow than planted soils, in spite of substantial nitrogen removal from the latter in the respective crop and herbage yields. It was considered that the better nitrogen retention in the planted soils resulted from provision of organic residues, which fostered microbial immobilisation of mineral nitrogen, as opposed to losses from the fallow soils (loc. cit.).

Large estimates for mineralisation rates, based on mathematical interpretation of the dynamics for organic matter and nitrogen accumulation in non-allophanic soils below well managed pastures (Jackman 1964b) are considered to provide evidence for substantial nitrogen outgoings from developed, grazed pastures, quite independently of results arising during this study.

4 Nitrogen Fixation by White Clover, and Fixation Efficiency

Henzell (1970) drew attention to difficulties in compiling a nitrogen balance for grazed pastures. A major deficiency he considered was the non-availability of methods to obtain an accurate assessment of symbiotic fixation in grazed pastures, coupled with considerable reservation over applying values obtained from cut swards to grazed pastures. Recent developments in field-application of a stable isotope labelling technique (Vallis et al. 1967, 1977) and the acetylene reduction assay (Hoglund & Brock 1978) have provided a break-through in this respect. Using the former technique, Edmeades & Goh (1978) obtained estimates for fixation by white clover ranging from 45 to 142 kg N/ha/an among four pastures of varying age in Canterbury. Plots were retired from grazing during the year-long measurement period. Application of the acetylene reduction assay provided an average annual estimate for $N_2(C_2H_2)$ fixation by white clover of 185 kg N/ha, in reasonably well developed pastures grazed by sheep at 8 sites throughout the country (Hoglund et al. 1979). The acetylene reduction assay has been criticised, with evidence given indicating that the one hour incubation

used overestimates symbiotic fixation (Goh et al. 1978). However, estimates of fixation based on the isotopic dilution technique, the standard against which the acetylene reduction assay was compared (loc. cit.), are quite clearly conservative. Nitrogen fixation was calculated from measured clover herbage nitrogen yields, after correction for soil-derived nitrogen. As considered later in this section, there is abundant evidence showing that much of the nitrogen incorporated into biomass by white clover escapes conventional yield measurements.

Recent cultivations at this site should have resulted in experimental swards which were at only an intermediate stage of development (Sears 1960), and this is confirmed by their clover content. While annual dry herbage yields from the grass-clover control treatment were large (14 to 17 t DM/ha; Section II, Table 3a) the contribution by white clover to total yield was substantial, averaging 35% in control over the course of the study. Under these conditions, annual $N_2(C_2H_2)$ fixation of 263, 165 and 53 kg N/ha was measured during the final year, in grazed swards receiving fertiliser inputs of 0, 112 and 448 kg N/ha/an, respectively. Quite clearly, fertiliser nitrogen depressed nitrogen fixation in the grass-clover swards (Section IV, Tables 20 & 21). The difference between the value obtained for control, and that measured in other studies on grass-clover swards receiving no nitrogen, largely reflected a difference in clover herbage yields (Section IV, C, 2 & D, 4). The very large estimates for symbiotic fixation reported from previous studies in this country (600 kg N/ha/an, and over: Sears & Evans 1953; Sears et al. 1965a) have reflected a combination of very clovery swards and substantial increases in soil total nitrogen. In the absence of $N_2(C_2H_2)$ fixation measurements during the first two years, estimates were obtained using fixation efficiency values recorded in the final year. Average annual fixation estimated for the grazed grass-clover system receiving no fertiliser nitrogen (320 kg N/ha; Section IV, Table 21)

reflects the higher clover yields measured earlier in the experiment, especially during the first year.

It was previously considered that assimilation of soil nitrogen by clovers growing in association with grasses was negligible (Walker et al. 1954; Walker 1956b; 1960). A conclusion readily drawn from that viewpoint was that cultural or environmental factors influencing clover yield also exerted a related effect on symbiotic fixation. Experimental evidence for that view was obtained from a glasshouse study by Walker and colleagues (Walker et al. 1956). Labelled nitrate and ammonium salts were added to seedling ryegrass and white clover plants grown both separately and together in a sandy subsoil. Over a wide range of nitrogen inputs, when grass and clover were grown together only some 5 to 6% of the applied nitrogen was recovered in clover herbage and roots. The experimental conditions, involving growth of juvenile plants under glass in summer, would have ensured intense competition between grass and clover for mineral nitrogen. However, as was considered by those workers (Walker et al. 1954), the growth curves of temperate grasses and white clover are not coincident under field conditions. To a considerable extent, intense competition during periods of rapid growth may be averted through separation in time of the growth curves for grasses and clover. Because of species differences in optimum temperature (Mitchell 1956), in many New Zealand environments grass dominance tends to prevail over late autumn-winter-spring, with clover dominance prevailing over summer-early autumn, providing that moisture is adequate for pasture growth (Brougham 1959; Brougham et al. 1978). A reduced potential for growth by ryegrass tillers, following the reproductive phase of growth in spring (Hunt & Field 1978; Field 1979), probably contributes to the seasonal ascendancy of white clover. This seasonal separation between the periods of dominant growth for many temperate grass species and white clover creates the potential for clover to obtain much of its nitrogen

from the soil.

It is quite clear that fixation and uptake of soil nitrogen can comprise alternative, interactive sources of nitrogen for white clover growth (Walker et al. 1956; Allos & Bartholomew 1959; Moustafa et al. 1969; Vallis et al. 1977). The general topic was recently reviewed by Vallis (1978). He concluded that soil-derived nitrogen does not usually constitute a major source of nitrogen for legumes growing in association with grasses, but cited many exceptions to that generality, from recent literature. A previous study (Vallis et al. 1977) had shown that the proportion of soil-derived nitrogen in white clover herbage increased as the clover content of mixed swards increased. It has long been suspected that clovers make substantial use of soil nitrogen when swards are irrigated (B.R. Watkin, pers. comm.; Brougham & Ball, unpublished data): in spite of a two or three-fold increase in clover yield, grasses in irrigated pastures have remained under nitrogen stress during cool-season growth. Using the isotope dilution technique in an irrigated Canterbury pasture, Goh et al. (1978) estimated that 30% of the nitrogen in white clover arose from the soil, during 6 weeks' growth in autumn.

Where summer-autumn conditions are relatively warm and dry, the mineral nitrogen pool below developed pastures displays a seasonal pattern. Relatively low levels have been observed over the main period of grass growth, but the pool size builds up over summer-early autumn (Simpson 1962; Tham 1971). Peak soil temperatures for the year (c 18°C; 0900 h at 10 cm) and wetting-drying cycles have been observed in topsoil below pasture in Manawatu over this period (Ball et al. 1978; see also Sections II, Table I & IV, Fig. 12). Both these seasonal weather characteristics would be expected to enhance mineralisation of soil nitrogen in fertile soils (Birch 1958, 1960; Harmsen & Kolenbrander 1965), at the same time as clover dominance normally occurs in ryegrass-white clover pastures. Such a

seasonal pattern of mineral nitrogen accumulation was confirmed in measurements below grazed pastures in the final year of this study (Section IV, Fig. 12). Differences observed in fixation efficiency between seasonal production periods (Section IV, Table 20) indicate a distinct seasonal contrast in soil nitrogen availability to white clover, as discussed previously (Section IV, C, 3). The average values recorded over winter-spring (75 kg N/t clover DM) and summer-autumn (25) were respectively higher and lower than the average for the year (44 kg N/t clover DM). The influence of fertiliser nitrogen on fixation efficiency was superimposed on this seasonal pattern. No effect was apparent in the grazed swards under winter-spring conditions, presumably because concomitant grass growth provided strong competition for available soil nitrogen irrespective of fertiliser nitrogen practice. On the other hand, fertiliser nitrogen treatments clearly reduced fixation efficiency during the summer-autumn and autumn-winter periods, when grass associates were relatively inactive.

Prior to the advent of the isotopic dilution method, estimates of fixation efficiency from nitrogen balance studies provided an alternative indication of the extent to which soil-derived nitrogen had met the requirements for legume growth. A considerable body of information has built up concerning fixation efficiency for white clover and, as its interpretation reflects quite strongly on current understanding of nitrogen relationships in grass-clover associations, that information will be considered here.

The concept was perhaps first used with a lysimeter study in Kentucky (Karraker *et al*. 1950). When compiling a nitrogen balance for the soil-plant system, these workers found that legumes were nearly twice as 'efficient' in fixing nitrogen when grown with a companion grass, as when grown alone. Average fixation efficiency for white clover grown alone was 59 kg N/t clover DM harvested, but fixation efficiency

rose to 105 when grown in association with bluegrass (*P. pratensis* L.). Those figures were derived following a 10-year study, using a mass balance for nitrogen incorporating nitrogen in harvested herbage, changes in soil total nitrogen and nitrogen outgoings in leachate (very small). The concept was first used in New Zealand by Sears and coworkers (Sears *et al*. 1965a). Again, based on a mass balance for nitrogen in the soil-plant complex (but excluding any outgoings in leachate), they calculated fixation efficiency for white clover grown alone in a continually cut sward as 70 kg N/t DM, rising to 98 when grown with companion grasses. Simulated return of animal excreta to mixed swards reduced fixation efficiency from 98 to an average value of 67 kg N/t DM over the final three years of that study. It was concluded that high fixation efficiency was maintained where the supply of available soil nitrogen was low, and that lower values probably reflected an uptake of soil nitrogen by white clover during periods of rapid mineralisation (*loc. cit.*).

It is salutary to reflect on fixation efficiency values near 100, reported for white clover from two independent, reliable studies (Karraker *et al*. 1950; Sears *et al*. 1965a). First, the figure must be considered minimal. While the writer would not consider that any substantial, unidentified nitrogen losses would occur from a continually cut grass-clover association, to the extent that any did, the value would increase. Second, this value shows that a great deal of the nitrogen input by white clover takes place beyond the scope of conventional yield measurements. If the average nitrogen content of white clover herbage is say 4.2% N (Section III, Table 8), then a fixation efficiency value of 100 indicates that for every tonne of clover herbage cut and removed (containing 42 kg N) the soil-associated grasses gained at least 58 kg N. If a top:root ratio of 2 is assumed for the partitioning of nitrogen during growth of white clover (Walker *et al*. 1954, 1956), then it can be estimated that some 40% of

the nitrogen transferred to soil-associated grasses was by way of root and nodule tissue turnover (Butler & Bathurst 1956; Chu & Robertson 1974) while the remaining 60% of the transfer must have been effected through senescence and decay of top growth. Both Henzell (1970) and Vallis (1978) have cited leaf-fall as a significant avenue for input of legume nitrogen to soils. It is well documented that white clover herbage senesces and decays during regrowth (Brougham 1958, 1966; Hunt 1970, 1971; Korte & Sheath 1978). To the extent that all plant parts of white clover can be viewed as 'annual' (Hollowell 1966), senescence and decay of stolon tissues is also likely to contribute.

A value near 100 is accepted by the writer as an upper limit to fixation efficiency for white clover of the 'G. Huia' type in field studies involving conventional measurement techniques. Unless it can be argued that a change in cultural conditions drastically alters the proportion of clover biomass harvested and/or the partitioning of nitrogen between top and root growth, then any reduction in this value recorded during measurements under otherwise comparable conditions should reflect the extent to which soil nitrogen is substituting for fixation. On that basis, the fixation efficiency value of 59 recorded in pure clover swards by Karraker *et al.* (1950) may be taken to indicate that white clover was obtaining some 40% of its nitrogen from the soil. Similarly, the average value of 67 for swards receiving simulated animal return (Sears *et al.* 1965a) would indicate that some 30% of clover nitrogen was arising from the soil.

Considerably more research is required to establish the 'portability' of fixation efficiency values among grass-clover systems. To date, this parameter appears to be a useful agronomic guide to the degree of substitution for fixation by soil nitrogen in field studies. Application of the concept to $N_2(C_2H_2)$ fixation values and clover yields measured in grazed pastures has given annual fixation efficiency values

which correlate with edaphic factors between sites (soil C% and C/N ratio; Hoglund et al. 1979), nitrogen fertiliser inputs (Section IV, Table 20), and seasonal values considered likely to reflect changing patterns in soil nitrogen availability to white clover (Section IV, Table 20; Hoglund et al. 1979). As a rough approximation, annual values near 60 observed in ryegrass-white clover pastures not receiving nitrogen, in both this study (Section IV, Table 20) and as an average from other sites (Hoglund et al. 1979), might be taken to indicate that white clover was acquiring some 40% of its nitrogen from the soil, but could also reflect more complete measurement of clover growth than in previous studies. During this study values near 25 arose as both a seasonal average for all treatments over summer-autumn, and as a treatment average for the year in pasture receiving the heavier input of fertiliser nitrogen. Such low fixation efficiency values are taken to indicate that factors increasing soil nitrogen availability to white clover, both seasonal and cultural, may result in considerably more than 50% substitution for fixation by soil-derived nitrogen.

Estimates for fixation efficiency in cut swards from this study can only be derived from minimal estimates for symbiotic fixation, obtained by difference in nitrogen balances (Section IV, Table 21), and the corresponding annual averages for clover dry herbage yield. In grass-clover systems receiving 0 and 112 kg N/ha/an, for which the writer considers fixation estimates to be fairly complete (Section IV, C, 4 & D, 4), respective estimates for annual fixation efficiency were 65 and 57. These are little larger than comparable values obtained under grazing (Section IV, Table 20), and substantially below the upper value of 100 obtained in previous studies involving cutting and removal of herbage. The value for control is again taken to indicate significant substitution of soil-derived nitrogen for nitrogen fixation during white clover growth, with fertiliser nitrogen increasing the extent

of substitution. That clover in the cut swards was assimilating soil nitrogen was indicated by herbage nitrate levels. After almost two years of continual cutting, clover herbage nitrate exceeded 450 ppm N over summer-autumn, even in the absence of fertiliser nitrogen inputs. Fertiliser nitrogen greatly increased herbage nitrate content (Section III, Table 9). Hoglund & Brock (1978) found that the nitrate level in clover herbage substantially reflected the nitrate level in topsoil, and implicated these parameters with others in determining daily $N_2(C_2H_2)$ fixation rate by field-grown white clover.

The above indications for soil nitrogen uptake by white clover, perhaps approaching 40% in a developed grass-clover pasture receiving no fertiliser nitrogen, are high compared with annual estimates of 7 to 19% in four Canterbury pastures, obtained using the isotope dilution technique (Edmeades & Goh 1978). However, it remains to be proven that labelling the surface layer of soil with a nitrate salt, the basis to that technique, adequately reveals the proportion of soil-derived nitrogen in clover herbage. As used, the technique assumes that white clover and associated grasses assimilate mineral nitrogen in the same proportions from all depths in a soil, and that no discrimination or preference with respect to nitrate is shown by one or other of the major sward components.

Overemphasis of this parameter, or attempts to exaggerate its accuracy, may be criticised on several grounds. As a ratio, fixation efficiency values are likely to exhibit greater error variance than that exhibited by either of the measurements from which they are derived. A considerably higher coefficient of variation was reported for $N_2(C_2H_2)$ fixation rate than clover yield, following measurements in a grazed, grass-clover pasture at Palmerston North (Hoglund & Brock 1978). Values could be affected to the extent that cultural or treatment differences may influence the partitioning of clover biomass above and below

measurement height. For instance, differences between studies in white clover type (Brougham et al. 1978; Williams & Cornege 1979), cutting height or defoliation frequency might all influence the proportion of total clover biomass which is measured. Finally, the writer has some reservation over the application of this parameter to seasonal comparisons. Seasonal changes in the proportion of photosynthate and nitrogen apportioned to root and stolon tissue formation in white clover could exert a seasonal influence on values, quite independently of seasonal changes in nitrogen fixation-uptake relationships. Crush (1979) reported that the prostrate growth form of white clover growing under drought conditions in Canterbury resulted in underestimation of dry herbage yield.

It is concluded that very large estimates for symbiotic fixation in past New Zealand research reflected experimental conditions which gave rise to both very clovery swards and substantial accumulation of soil nitrogen. As such, those values are best viewed as a potential for symbiotic fixation by clovers in mixed swards. Measurements of $N_2(C_2H_2)$ fixation in reasonably well developed pastures, where clover yields have been lower and soil nitrogen has failed to accumulate, have provided values which are only about half those previously reported. There is convincing evidence for substitution of soil nitrogen for fixation, in meeting the nitrogen requirements for growth of white clover in developed pastures. Seasonal influences on grass/clover balance and mineral nitrogen availability to white clover are viewed as the major cause. Fertiliser nitrogen reduces clover fixation through the combined influences of reducing clover yield and increasing the proportion of clover nitrogen derived from the soil. This pattern of relationships may be substantially altered in developed pastures where the grass associates include a summer-active species, or where environmental conditions are conducive to vigorous grass growth over the summer-early autumn period.

5 Nitrogen Transfer from Clover to Grasses

The contribution of clovers to crude protein yield from mixed swards is clearly established. In this study (Section III, Table 10), and many others (Melville & Sears 1953; Sears et al. 1953, 1965a; Harris & Thomas 1973) herbage nitrogen yield from grass-clover mixtures has been substantially greater than that from a cloverless sward receiving no fertiliser nitrogen. There is, however, considerable room for conjecture over the mode and effectiveness of the transfer of nitrogen fixed by clovers to associated grasses.

On the basis of observed and estimated relationships between the herbage nitrogen yields of clover and associated grasses in mixed swards, measured under a variety of conditions, Walker and associates (Walker et al. 1954) used multiple regressions to derive a relationship describing the combined contributions of soil nitrogen, clover fixation and fertiliser nitrogen to the herbage nitrogen yield from grasses in mixed swards. It was concluded that, in the absence of fertiliser nitrogen, each kg of nitrogen harvested in clover herbage was associated with an 'underground transfer' of one kg of nitrogen to associated grasses, two-thirds of which was measured in grass herbage and the remainder retained in grass roots (loc. cit.). Attention has already been drawn to the very long regrowth intervals under ideal growing conditions during their study (up to 70 and 100 days; Walker et al. 1953), the data from which best fitted their derived model. It is probable that a great deal of nitrogen turnover through death and decomposition of herbage, especially clover (Brougham 1958, 1966; Hunt 1970, 1971), occurred outside the compass of those yield measurements. In reinterpreting those results, O'Connor (1961) obtained a better fit with a multiple regression excluding clover herbage nitrogen as a variable, but replacing it with defoliation frequency. He concluded that over the short term, clover may so little affect the relationship between grass and fertiliser nitrogen, that grass nitrogen yield from a mixed sward may

simulate that from a non-leguminous sward (loc. cit.). The general relationship described (Walker et al. 1954) has been criticised on the grounds that it incorporates inter-dependent variables (Stewart & Chestnutt 1974) and its application is not considered to be as general as was suggested by the authors (Vallis 1978). Following an extensive study of nitrogen relationships in cut mixed swards, Stewart & Chestnutt (1974) concluded that the previous year's clover nitrogen yield was better related to any increase in grass nitrogen yield than was the current year's clover yield. In a recent national study into nitrogen relationships in grass-clover pastures receiving no fertiliser nitrogen (Hoglund et al. 1979), no simple relationship was observed between annual values for clover yield or $N_2(C_2H_2)$ fixation and either grass dry herbage or herbage nitrogen yields. In the present study, removal of clovers from a mixed sward did not influence yearly grass nitrogen yield until the third year (Section III, Table 10). Obviously, the mode of transfer for nitrogen from clovers to grasses is not straightforward.

It is generally accepted that in grazed pastures, ingestion of clover nitrogen and subsequent excretion of nitrogen in urine and dung is the principal pathway for nitrogen transfer (Sears 1953c, 1960; Walker 1956a; O'Connor 1966; Levy 1970; Whitehead 1970). The writer questions that viewpoint on dual grounds. First, the aggregation of dietary nitrogen into discrete urine and dung patches by ruminant animals is so pronounced that only a minor proportion of a grazed area is benefiting at any point in time. Second, in developed grass-clover pastures by far the major part of dietary nitrogen is aggregated into urine patches, which provide only a short-lived nitrogen benefit. Accordingly, it would seem that the influence of urine and dung is not significantly linked to nitrogen relationships in a grazed area considered as a whole.

Urine and dung patches occupy a relatively small area compared with that from which forage was obtained.

Various estimates have been made of the parameters associated with aggregation of dietary nitrogen by grazing animals, both the proportion of area influenced by urine and dung during a year's grazing, and the related size of the nitrogen pools in excretal patches. However, the numbers reported must be viewed as very situation-specific, being subject to numerous cultural, seasonal and site influences. Reported pool sizes for nitrogen aggregated into individual excretal patches range from several hundred to about one thousand kg N/ha for both urine (Thompson & Coup 1943; Doak 1952; Petersen et al. 1956; Jackman 1960a; Whitehead 1970; Barlow 1974; O'Connor 1974) and dung (Petersen et al. 1956; MacDiarmid & Watkin 1972a; During & Weeda 1973; Weeda 1977; O'Connor 1974). Under field conditions, the extent of lateral dispersion of voided urine will reflect such practical variables as soil texture, moisture status and plant cover (Doak 1952; Lotero et al. 1966), ground surface slope (During & McNaught 1961) and even such esoteric considerations as wind velocity at the time of urination (loc. cit.). Because of the lateral spread of plant roots and diffusion of nitrogen in soil, there is a zone of influence around the periphery of excretal patches. The nutrition of adjacent pasture benefits for some distance outside both urine (Doak 1952; Dale 1961; Lotero et al. 1966) and dung patches (MacDiarmid & Watkin 1971; During & Weeda 1973), effectively diminishing the size of an excretal nitrogen pool while extending its area. As both urine and dung are deposited in much smaller patches by sheep than cattle (Jackman 1960a; Whitehead 1970) this peripheral effect is proportionately more important in pastures grazed by sheep, and should lead to better apparent recovery of excretal nitrogen in such pastures.

At any point in time, the proportion of pasture area benefiting from nitrogen returned in urine and dung will depend not only on the proportion of total area covered by excreta, including any extension to that area

by peripheral effects, but also on the duration of the nitrogen effect (Richards & Wolton 1976). Using available data, Jackman (1960a) calculated the proportion of pasture area likely to be influenced by urine, assuming completely random behaviour during grazing by cattle and sheep continuously at pasture. From those results it may be estimated that over a year, with comparable stocking rates of 15 adult sheep or 2.5 cows/ha, some 24 and 18% of total area respectively would be covered by one or more urinations. Accepting that the duration of any nitrogen benefit in urine patches does not extend beyond a few months (Sears 1951; During & McNaught 1961; Richards & Wolton 1976; Ball et al. 1979b, and unpublished data), then Jackman's data indicate that only a very small proportion of total area would be benefiting from urine at any point in time. Using a response period of three months, MacDiarmid & Watkin (1972b) estimated that only about 5% of total area would be benefiting from dung during any individual regrowth period in an intensively utilised Manawatu dairyfarm pasture. Assuming average three-month and two-year response periods for urine and dung respectively, Richards & Wolton (1976) calculated for a sward grazed by cattle, that at any point in time some 23% of total area may be exhibiting a nitrogen response to urine, and 17% to dung.

Considered collectively, the above information, which makes no allowance for transfer of nitrogen to unproductive areas (Goodall 1951; During 1972), supports a general conclusion that nitrogen 'recycling' in the excreta of grazing animals does not affect nitrogen relationships in the major part of a grazed area, at any point in time. Some transfer of nitrogen from clovers to associated grasses does occur this way, but the restricted proportion of total area influenced by urine and dung and the limited duration of the nitrogen benefit in urine patches both argue that this pathway is not as important as has been suggested. In effect, a developed pastoral ecosystem encompasses a

mosaic of nitrogen relationships. The larger part of total area is unaffected by excreta during any regrowth period, and may remain so throughout a year. A limited proportion of total area is exposed to relatively massive inputs of nitrogen in discrete patches, of which only dung provides any durable nitrogen benefit. As discussed later in this section (A, 6 & 7), attendant nitrogen losses from urine patches cause the grazing process *in toto* to be nitrogen-losing in a developed pastoral ecosystem.

An early theory based on direct transfer of nitrogen as clover nodule exudates which were subsequently assimilated by grass associates ('underground transference', Walker 1956a) has been considered in detail elsewhere (Walker *et al*. 1954; Butler & Bathurst 1956; Butler 1957; Butler *et al*. 1959; Vallis 1978). The original studies forming the basis to this theory were conducted in an environment providing seasonally long, cool days with low light intensity. Significant nitrogen exudation from nodules appears to be confined to such climatic situations (Vallis 1978). Research with white clover at Palmerston North (Butler & Bathurst 1956; Butler 1957) led those workers to conclude that the required environmental conditions were so exacting as to make unlikely any significant transfer of nitrogen in this manner. A considerable amount of field evidence counter-indicates any significant direct nitrogen transfer from clover to grasses. This includes results from several studies in which grasses have failed to respond, in terms of either dry herbage or herbage nitrogen yield, when associated with clovers in mixed swards (in Canterbury only, Sears *et al*. 1953; Simpson 1965, 1976; Sinclair *et al*. 1977; see also Section III, D, 1, c); the progressive rather than immediate nature of any benefit to grass performance, attributable to the presence of clovers in a mixed sward (Melville & Sears 1953; Cowling *et al*. 1964; Bakhuis & Kleter 1965; Simpson 1965, 1976; see also Section III, D, 1, c), and the recent

report that any benefit to grass nitrogen yield related better to the previous than the current year's clover nitrogen yield (Stewart & Chestnutt 1974). Viewed collectively, this indirect field evidence indicates nitrogen transfer mainly after mineralisation of clover residues, which have entered the soil organic matter pool.

The writer concludes that in a developed pastoral ecosystem, the major transfer of nitrogen from clovers to associated grasses is effected through an ill-defined process involving provision of organic residues by clovers to soil organic matter, and their subsequent mineralisation. The restricted proportion of total area influenced by urine and dung, and the short-lived nitrogen benefit in urine patches, together seriously limit the effectiveness of transfer in the excreta of grazing animals.

6 Nutrient 'Recycling' by Grazing Animals

For nutrient elements that are reasonably immobile in soil, and which impart a benefit of considerable duration to plants in the vicinity of dung and/or urine patches (e.g. potassium and phosphorus), 'recycling' in animal excreta is relatively efficient (Richards & Wolton 1976). While non-random behaviour by grazing animals may result in substantial nutrient transfer within a grazed ecosystem (Suckling 1959, 1975; Hilder 1966; Gillingham & During 1973), retention within the soil-plant complex is relatively good. Only transfer of excreta to non-productive sites (Goodall 1951; During 1972) represents a complete loss of nutrients from the soil-plant complex. These features largely apply to nitrogen excreted in dung, which may constitute some 20 to 25% of the nitrogen ingested by sheep and cattle grazing productive grass-clover swards (Henzell & Ross 1973). The positive influence of cattle dung on surrounding pasture has been reported to last at least three months (MacDiarmid & Watkin 1971), with a nitrogen response observable even in the second year after dung

deposition (Weeda 1977).

The fate of nitrogen voided in urine is quantitatively much more important to the nitrogen economy of grazed pastures than is that of dung. Some 65 to 75% of ingested nitrogen is excreted as urine, by sheep and cattle grazing pasture containing 3.5% N (Henzell & Ross 1973). In contrast to dung, urinary nitrogen is subject to rapid biological transformations which render it highly mobile in the soil-plant complex. Any nitrogen benefit to the localised areas of improved pasture influenced by urine patches is relatively short-lived. The initial effect may be negative, where 'scorch' occurs under dry conditions, with little influence on soil nitrogen availability observable two to three months after deposition (Sears 1951; Doak 1952; During & McNaught 1961; Richards 1977; Ball *et al*. 1979b, and unpublished data).

The writer has recently been engaged in associated studies into the nitrogen balance in urine-affected areas of pasture, in this locality (Ball *et al*. 1979b, and unpublished data). Urine was applied to a mixed sward at likely *in vivo* rates (300 and 600 kg N/ha, representing sheep and cattle urine patches, respectively) under seasonally representative climatic conditions. The fate of urinary nitrogen was then followed by application of a mass balance for nitrogen in urine-affected and control pasture. In 'sheep' (N300) urine patches, loss of urinary nitrogen by ammonia volatilisation was 15, 80 and 5% under warm-moist, warm-dry and cool-moist conditions respectively. Corresponding figures for apparent nitrogen recovery in herbage were 37, 15 and 55%. As no increase in soil total nitrogen could be detected below urine-affected areas of pasture, it was concluded that the remainder of the urinary nitrogen was lost by some undefined combination of leaching and denitrification. Evidence for nitrate leaching below urine patches was obtained (*loc. cit.*). Application of the average estimate for losses of urinary nitrogen from that set of experiments, to data obtained during the present study, can largely

explain the substantial but unaccounted-for nitrogen outgoings from the grazed grass-clover systems (Section IV, C, 4).

Herbage measurements in this study (Section III, Table 10) indicate that sheep ingested 650 kg N/ha on average each year. Using an average nitrogen content of 3.5% for the mixed herbage (Section III, Table 8), then employing data summarised by Henzell & Ross (1973), the nitrogen ingested by sheep can be partitioned as follows (kg N/ha/an & %):

Intake	=	Growth	+	Urine	+	Dung
650 (100)		35 (5)		465 (71)		150 (23)

If it were assumed that average recovery of urinary nitrogen in herbage was one-third throughout the year, then losses by a combination of ammonia volatilisation, leaching and denitrification in urine patches would total over 300 kg N/ha each year. Losses of that magnitude would account for some 80% of the estimates for unidentified nitrogen outgoings from the grazed swards of control and treatment N112 (Section IV, Table 21).

The above estimate for combined losses of urinary nitrogen (c 300 kg N/ha/an) is based on the average for grazed treatments. Observed differences among nitrogen treatments in estimates for unidentified nitrogen outgoings are in sympathy with likely treatment effects on urinary nitrogen formation within the grazed systems. Treatment N448 increased annual dry herbage yield by almost 25% on average (Section II, Table 3a) and annual crude protein yield by 33% on average (Section III, Table 10 & Fig. 6), relative to control. At the prevailing total nitrogen levels in mixed herbage (Section III, Table 8) any increase in dietary crude protein content would result in greater production of urinary nitrogen, but little if any change in the quantity of nitrogen retained for growth and excreted in dung, per unit of nitrogen ingested (Henzell & Ross 1973). Relative to control, both the larger dry herbage yields and their higher nitrogen content would

argue for much greater formation of urinary nitrogen in treatment N448. This treatment difference should then have been reflected in larger nitrogen losses from urine patches in treatment N448. Such a difference is indicated in the contrasting estimates for unidentified outgoings from the grazed control and N448 systems (380 and 560 kg N/ha/an respectively; Section IV, Table 21). Conversely, it can be reasoned that the smaller herbage yields of lower nitrogen content measured from the cloverless sward would result in formation of much less urinary nitrogen in that treatment than in control. Accordingly, nitrogen losses from urine patches would be of a much smaller magnitude than those observed below control: a conclusion in sympathy with the estimate of 90 kg N/ha/an for unidentified outgoings from the cloverless system (Section IV, Table 21).

Exact concurrence between estimates for nitrogen losses from urine patches and estimates for all unaccounted-for losses from the soil-plant-animal complex would not be expected. Other avenues for nitrogen loss from grazed pastures can be envisaged. MacDiarmid & Watkin (1972a) measured small nitrogen losses by ammonia volatilisation from cattle dung in this locality. If their result were applied to the foregoing estimate for formation of dung-nitrogen in the grazed treatments of this experiment, it would account for an average outgoing of less than 10 kg N/ha each year. Possibly of more importance is the 10 to 20% of total nitrogen generally 'unaccounted-for' even in very detailed balance studies (Allison 1955, 1965, 1966), and presumably lost from swards by denitrification (Woldendorp et al. 1966; Whitehead 1970). Precision on this avenue for losses is not possible with present knowledge, but they could well account for the shortfall between the above coarse estimates for outgoings from urine patches and total unidentified outgoings from the grazed pasture systems. Large quantities of nitrogen must have been mineralised each year to sustain herbage production in these grass-

clover associations. Vigorous nitrification is indicated by the high nitrate levels recorded in herbage from swards not receiving lime-ammonium nitrate (Section III, Table 9). A recent report to the effect that denitrification is a normal side-issue to aerobic nitrification (Bremner & Blackmer 1978) would indicate another possible avenue for small losses.

In broad perspective, these results and concepts should be generally applicable to developed, well utilised pastures. It may be argued that some site-specific characteristic(s), by causing a decline in soil total nitrogen pools during the course of this study, inflated the estimate for nitrogen losses from grazed pastures (Section IV, Table 21). However, even if the small average decline observed (c 60 kg N/ha yearly) were replaced with an equivalent gain, one would still be contemplating unaccounted-for nitrogen outgoings totalling several hundred kg N/ha yearly, from the grazed grass-clover associations. Associated studies into the nitrogen balance of urine-affected areas of a developed pasture were conducted on an older alluvial soil (Ball *et al*. 1979b). Other than previous cultivation, it had nothing of the unusual cultural history described for soil at this experimental site (Section IV, B, 1), yet apparent recovery in pasture herbage of urinary nitrogen applied at 600 kg N/ha averaged only 24% (*loc. cit.*). Lower apparent recovery of urinary nitrogen in pasture herbage has been reported from a previous study (During & McNaught 1961). Nitrogen losses from urine patches in developed pastures grazed by cattle are likely to be even more pronounced than those from sheep-grazed pastures, as cattle aggregate urinary nitrogen much more effectively than do sheep (Jackman 1960a; Whitehead 1970).

Assuming more or less random behaviour by animals grazing improved pastures, it is concluded that nutrient 'recycling' may be quite efficient for elements which are relatively immobile in soils (potassium, phosphorus,

magnesium and calcium). Much the same applies to nitrogen in dung, which is voided in intimate association with carbon, in forms requiring microbial decomposition prior to formation of mineral nitrogen (Whitehead 1970; Henzell & Ross 1973). On the other hand, a much greater proportion of dietary nitrogen is separated from carbon during ruminant digestion, and aggregated into urine patches. Subsequent biological transformations render urinary nitrogen highly mobile, and substantial losses from the soil-plant complex occur. This avenue for losses may account for nitrogen outgoings of several hundred kg N/ha each year from developed, well utilised grass-clover ecosystems. The extent of losses should increase as pastures are more intensively utilised, but is likely to be reduced by resident organic matter with a wide C/N ratio.

7 An Alternative Hypothesis for the Role of Grazing Animals

The writer contends that the presence of grazing animals is the cause of substantial but hitherto largely unrecognised nitrogen outgoings from highly productive, well managed pastoral ecosystems. This contention is based on the following evidence gained from this and associated studies:

(i) The influence of grazing as opposed to meadow management on herbage nitrogen yields was minor (discussed in Section III, D, 1, a). Both grazed and cut systems displayed a more or less linear response, in terms of total herbage nitrogen yield, to fertiliser nitrogen. Yet apparent recovery in herbage of nitrogen 'recycled' by sheep was less than 20%. By contrast, apparent recovery of fertiliser nitrogen by mixed swards was about 45%. That figure would be higher if it were possible to correct for the substitution of soil-derived nitrogen for symbiotic fixation, which occurred in the nitrogen-treated swards (Section IV, Tables 20 & 21).

(ii) The influence of grazing as opposed to meadow management on changes in soil total nitrogen was

relatively minor (Section IV, Table 19). In this and several other studies cited (Section IV, D, 2), the difference between grazing and cutting in rates of change of soil total nitrogen below grass-clover associations has been less than what the writer would estimate was excreted as dung-nitrogen by the grazing animals.

(iii) The absence of any influence of fertiliser nitrogen on rate of change in soil total nitrogen, noted in this (Section IV, Table 19) and several other studies cited (Section IV, D, 3), is taken to indicate that factors influencing soil carbon accumulation are more important to organic nitrogen accumulation in fertile soils than is the size of nitrogen inputs to the soil-plant system.

(iv) The influence of grazing as opposed to meadow management on fixation efficiency by white clover was relatively small. On the other hand, the influence of fertiliser nitrogen was marked. The contrast (discussed in Section IV, D, 4) indicates that grazing did not greatly increase soil nitrogen availability to white clover.

(v) Mass balances for nitrogen indicated annual outgoings of several hundred kg N/ha from grazed, grass-clover associations (Section IV, Table 21).

While still somewhat speculative, the writer puts forward the following hypothesis: that grazing ruminants cause very large nitrogen losses from developed grass-clover ecosystems. Under such conditions, the grazing animal ingests relatively proteinaceous forage. In the process of digestion, the bulk of ingested nitrogen is separated from the carbon with which it was associated in herbage, and is excreted in urine. Even assuming completely random behaviour by animals at pasture, the proportion of area influenced by urine is very small in relation to the total area from which forage nitrogen was gathered. Biologically 'labile' nitrogen is aggregated at several hundred kg N/ha in urine patches. Such rates of

application are far too high to allow effective recovery by plants. The mull organic matter in developed pastoral soils provides insufficient carbon substrate for microbial immobilisation, so substantial losses of nitrogen from the soil-plant complex occur in urine patches. The major avenue of loss is influenced by prevailing climatic conditions; ammonia volatilisation predominates under warm, dry conditions, while an undefined combination of denitrification and/or leaching predominates under moist conditions. The nitrogen in dung, which is quantitatively much less important to the nitrogen balance of a grazed ecosystem, is excreted in association with partially decomposed carbon. Accordingly, retention of dung nitrogen in the soil-plant complex is likely to be much better than is that of urinary nitrogen.

8 Fertiliser Nitrogen

Little incisive research has been carried out in New Zealand into nitrogen relationships in mixed swards receiving fertiliser nitrogen. On the basis of experience gained during the course of this study, the writer finds little reason to view them as anything other than an extension to the changing pattern of nitrogen relationships observed during conventional pasture development.

Pasture development under lowland conditions has been described by Sears (1960) and Walker (1960, 1968), and principles were considered briefly in the introduction to this report (Section I, 2). A changing pattern of soil nitrogen availability occupies the focal position in such development sequences, as all limiting nutrients other than nitrogen are applied in fertiliser form, often at very heavy rates. Progressive improvement in soil nitrogen availability is responsible for observed changes in botanical composition, especially an increasing grass/clover ratio, and for the higher levels of production eventually sustained from developed swards dominated by ryegrass

(Sears 1960, 1962; Donald 1963; Levy 1970). Wolfe (1972) found that the transition period between clover dominance and grass-clover balance could be substantially shortened by judicious use of fertiliser nitrogen in a development programme. Nitrogen input by symbiotic fixation declines as development proceeds (Ball 1969).

In broad perspective, use of fertiliser nitrogen under appropriate climatic conditions on a developed, well managed pasture simply results in an extension to those ecological changes: total herbage yield is increased; the response arises from the grass component of the sward, and clover content is reduced to a greater or less extent (Walker et al. 1954; Donald 1963; Crofts 1965; Whitehead 1970; During 1972; O'Connor & Cumberland 1973; Ball & Field, in press; see also Section II, Table 3 & Fig. 2). Use of fertiliser nitrogen also depresses symbiotic fixation (Sinclair et al. 1977; see also Section IV, Tables 20 & 21). Many exceptions to the above general description of nitrogen responses can be found in a voluminous literature on the subject. However, as considered in detail throughout Section III, the writer considers that much of that diversity can be attributed to experimental method, and/or site and management influences.

Several New Zealand workers have suggested that the combined input, cycling and retention of nitrogen within our grass-clover ecosystems must set an ultimate limit to pasture production, within limits imposed by climate, species and management (O'Connor 1966; Ball 1969; Jackman 1971a, b). Results obtained during this study provide support to that view. Fertiliser nitrogen was applied to a highly productive, well managed pasture at annual rates up to 448 kg N/ha. Over a three-year period, more or less linear responses were displayed in annual total dry herbage and herbage nitrogen yields. The results are considered to authenticate a view developed 10 years earlier by the writer (Ball 1969), to the effect that nitrogen relationships impose an

upper limit to production from well managed grass-clover associations.

B MAJOR CONCLUSIONS

A number of conclusions have been presented at the end of each section of results (II, E; III, E & IV, E). Those considered of a minor nature are not repeated here. After consideration of results from this study, and relevant information available from the literature, the following major conclusions are reached concerning nitrogen relationships in a developed grass-clover system.

1. The performance of pastures subjected to relatively frequent, close defoliation by mob-stocked sheep was reasonably reproduced in cut swards from which herbage was removed, for a period of approximately two years. Cutting herbage with an electric shearing handpiece allowed better simulation of clover herbage removal by sheep than is possible with mowing. It is considered that both cutting technique and avoidance of nutrient depletion (especially of potassium) in cut treatments were important in determining the pattern of results. Differences between grazing and cutting became more pronounced with time. Not until the third year was a difference recorded in yearly clover dry herbage yield between grazed and cut swards.

2. Under these conditions, grazing increased total dry herbage (herbage nitrogen) yield each year by from 13 to 24% (18 to 22%). Annual turnover in urine and dung is estimated to have averaged some 650 kg N/ha, with apparent recovery in herbage less than 20% on average over the three years. Plant recovery of the very large quantity of nitrogen 'recycled' in the excreta of grazing animals was very limited.

3. Annual total dry herbage (herbage nitrogen) yield from this ryegrass-white clover association was substantial, averaging 15.6 t DM/ha (560 kg N/ha) each year without fertiliser nitrogen. Application of

nitrogen at the heaviest rate, 448 kg N/ha/an, increased total dry herbage (herbage nitrogen) yield each year by from 20 to 25% (30 to 43%). The response was classical, arising from the grass component of the sward, with the clover component suppressed to a greater or less extent. On average over the three years, total herbage responses were more or less linear, and apparent recovery of fertiliser nitrogen averaged 44%. This figure would be higher if it were possible to correct for enhanced soil nitrogen uptake by clover in the nitrogen-treated swards. Quite clearly, nitrogen availability limited total herbage production from this well managed grass-clover association.

4. Main treatment (defoliation method x nitrogen treatment) interactions were largely absent from annual production data. Comparison of results from grazed swards with those from cut swards, and results from swards receiving 448 kg N/ha/an with those from grass-clover control, indicated that these two main treatments exerted similar, but certainly not the same effects. Major points of contrast were a pronounced influence of grazing on the ryegrass population measured in late autumn, but a restricted influence on ryegrass yield during each year; and a pronounced influence of fertiliser nitrogen on yearly ryegrass yield, but only a restricted influence on ryegrass population. On average, fertiliser nitrogen also substantially increased grass yield and suppressed clover over winter-spring and spring-summer, when grazing did not; but grazing reduced clover yield over summer-autumn and autumn-winter. The influence of sheep-grazing cannot be viewed as a straightforward response to 'recycled' nitrogen. Other influences, including selective defoliation of clovers under seasonally dry conditions, were involved.

5. Under these conditions, the soil total nitrogen pool throughout the sampled profile declined over the course of the experiment. The average annual reduction under grazing (60 kg N/ha-45.7 cm) was less than under

cutting (150 kg N/ha-45.7 cm). A larger decline was observed below cloverless swards receiving no fertiliser nitrogen, but it was beyond the precision of measurements to identify any difference between it and other nitrogen treatments. Fairly complete utilisation of herbage, coupled with a close C/N ratio ($\underline{c}$ 10) for soil at the site, are considered to provide the most likely explanation for the observed pattern of change. As the decline in soil nitrogen was not influenced by fertiliser nitrogen treatments, it is concluded that factors influencing soil carbon accumulation may be as important, if not more important than the size of the annual input of nitrogen, in determining nitrogen accumulation within a developed grass-clover system.

6. Large pools of mineral nitrogen accumulated in the sampled profile below grazed grass-clover swards over summer-early autumn. With the onset of leaching conditions, the pools declined to minimal values by late winter. An influence of nitrogen treatments was superimposed on this seasonal pattern, with a peak value of almost 200 kg N/ha-45.7 cm observed below the pasture receiving 448 kg N/ha/an. While it is considered that much of this nitrogen was leached, quantitative conclusions were not possible.

7. $N_2(C_2H_2)$ fixation under grazing totalled 263, 165 and 53 kg N/ha/an in grass-clover pastures receiving 0, 112 and 448 kg N/ha/an respectively. Fertiliser nitrogen reduced symbiotic fixation through the combined effects of clover suppression and a reduction in fixation efficiency, the corresponding yearly values for which were 61, 48 and 23 kg N fixed/t clover DM, respectively. Comparison of these values with those from other studies indicates that soil nitrogen was meeting a significant part of the nitrogen requirement for white clover growth in control swards, while the heaviest rate of fertiliser nitrogen so increased soil nitrogen availability that clover nitrogen was more than 50% soil-derived throughout the year. Separation in time of the main growth periods

for white clover and grass associates resulted in a seasonal contrast in nitrogen availability to white clover. Differences in fixation efficiency between seasonal production periods indicate that soil nitrogen was substituting for more than 50% of fixation during the summer-autumn period, on average over all treatments.

8. Using annual averages from results obtained during this three-year study, nitrogen balances were compiled for the grazed and cut systems. While the parameters used and estimated may contain substantial error terms, it seems valid to conclude that unaccounted-for nitrogen outgoings of several hundred kg N/ha occurred each year from the grazed grass-clover systems. Estimated losses were greater with the heaviest rate of nitrogen than from control.

9. Estimated nitrogen removal in animal produce was about 20 kg N/ha/an, while average removal in herbage from cut grass-clover associations was almost 600 kg N/ha/an. Yet the contrast between grazing and cutting systems in several parameters of nitrogen relationships measured in the soil-plant complex was unspectacular. These results support the conclusion that substantial but hitherto largely unrecognised nitrogen losses occurred from the grazed systems.

10. Some established tenets regarding nitrogen relationships in grass-clover associations have been seriously questioned.

Past New Zealand studies, involving mown swards and a nitrogen balance on the soil-plant complex, provided estimates for nitrogen fixation by clovers in excess of 600 kg N/ha/an. Such figures can be viewed only as a potential. Because of the experimental techniques used, those results are inapplicable to field situations. More recent research indicates that symbiotic fixation in developed grass-clover pastures is about a half, or even less, of the above estimate.

It is widely accepted that ingestion of clover herbage and subsequent excretion of nitrogen in

urine and dung constitutes the major pathway for transfer of fixed nitrogen from clovers to grasses in grazed pastures. While some transfer occurs in this way, it is reasoned that this is severely limited, because of both nitrogen aggregation in urine and dung patches and the short duration of any nitrogen benefit from urine. The effective pathway for transfer in a developed grass-clover association is considered to be through an ill-defined process of provision of clover residues, including both below and above-ground tissues, to the soil decomposer network.

Results from previous New Zealand research have led to substantial emphasis being placed on the value of nutrient 'recycling' in the excreta of grazing animals. An alternative hypothesis for the influence of grazing animals on nitrogen relationships in developed pastoral ecosystems has been presented: that grazing animals are the cause of very substantial nitrogen losses. They ingest a proteinaceous herbage, and in the process of ruminant digestion separate the bulk of ingested nitrogen from the carbon with which it was associated in plant material. Biologically 'labile' nitrogen is then aggregated into urine patches at rates which are far too high to allow effective recovery by plants. There is insufficient carbon substrate in the mull organic matter of developed soils to allow significant microbial immobilisation, so substantial nitrogen losses from the soil-plant complex occur in urine patches. Nitrogen in dung, which is quantitatively far less important to the nitrogen economy of a developed ecosystem, is much better retained than that in urine. It is excreted in intimate association with carbon, so its release as mineral nitrogen is largely subject to the activities of the decomposer network.

11. Ancillary studies were undertaken into errors associated with measuring changes in soil total nitrogen, and to provide a site description through the performance of a cloverless sward.

Under these conditions, some 550 to 700 soil cores per treatment were required to detect a difference of 100 kg N/ha-15 cm for change in soil total nitrogen between treatments. Variation did not differ greatly with sampling depth, and some 80% of the variation encountered in small paddocks (250 m^2) was exhibited by small plots (3.7 m^2). Spatial variability in soil total nitrogen poses a major problem for ecosystem nitrogen studies in developed pastures.

The performance of cloverless swards indicated that this study was conducted under conditions where soil nitrogen was freely available. An average annual mineralisation rate of 8.5% of the total nitrogen to 15 cm was indicated by herbage nitrogen yields from cut swards. So high a figure may be taken to indicate that some site-specific soil characteristic(s) influenced nitrogen relationships, but this result most probably simply reflects the close C/N ratio in soil at the site and the fairly complete removal of herbage effected. Comparison of herbage nitrogen yields from this treatment with those from the grass component of grass-clover control swards indicates that no nett annual transfer of nitrogen from clover to associated grasses occurred until the third year of the study. $N_2(C_2H_2)$ fixation measurements in the grazed, cloverless sward indicated an annual total for asymbiotic fixation of 10 kg N/ha.

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ABSTRACT

Performance of a ryegrass-white clover sward subjected to a range of nitrogen treatments was recorded over three years. Herbage was removed either by periodic mob-stocking with sheep or cutting with a shearing handpiece. Nitrogen was applied as lime-ammonium nitrate in split dressings, over the period late autumn-winter-spring-early summer. A cloverless sward receiving no fertiliser nitrogen was included to gain information on the nitrogen status of the experimental site. An unbalanced design was used, with 7 nitrogen treatments represented under grazing but only 4 under cutting.

The performance of pastures subjected to relatively frequent, close defoliation by mob-stocked sheep was reasonably reproduced in cut swards. The cutting technique allowed better simulation of clover herbage removal by sheep than is possible with mowing, and it was not until the third year that a difference was recorded in yearly clover dry herbage yield between grazed and cut swards. Both the cutting technique and avoidance of nutrient depletion (especially of potassium) in cut treatments are considered important in determining the pattern of results. Under these conditions, grazing increased total dry herbage (herbage nitrogen) yield each year by from 13 to 24% (18 to 22%). Annual nitrogen turnover in urine and dung averaged approximately 650 kg N/ha, with apparent recovery in herbage no more than 20% on average over the three years.

Annual total dry herbage (herbage nitrogen) yield from this ryegrass-white clover association was substantial, averaging 15.6 t DM/ha (560 kg N/ha) each year without fertiliser nitrogen. The heaviest fertiliser input, 448 kg N/ha/an, increased total dry herbage (herbage nitrogen) yield each year by from 20 to 25% (30 to 43%). Quite clearly, nitrogen availability limited total herbage production from this well managed grass-clover association. On average over

the three years, total herbage responses were approximately linear, and apparent recovery of fertiliser nitrogen averaged 44%. This figure would be higher if it were possible to correct for enhanced soil nitrogen uptake by clover in the nitrogen-treated swards. $N_2(C_2H_2)$ fixation under grazing totalled 263, 165 and 53 kg N/ha/an in grass-clover pastures receiving 0, 112 and 448 kg N/ha/an, respectively. Fertiliser nitrogen reduced symbiotic fixation through the combined influence of clover suppression and reduced fixation efficiency by clover in the nitrogen-treated swards.

Main treatment (defoliation method x nitrogen treatment) interactions were largely absent from annual production data. Comparison of main treatment effects indicated that sheep-grazing and fertiliser nitrogen exerted similar but certainly not the same effects. Nitrogen removal in animal produce was estimated to have averaged about 20 kg N/ha/an, while average removal in herbage from cut grass-clover associations was almost 600 kg N/ha/an. Yet the contrast between grazing and cutting in the several parameters of nitrogen relationships measured in the soil-plant complex was unspectacular.

The soil total nitrogen pool throughout the sampled profile declined over the course of the experiment. The average annual reduction under grazing (60 kg N/ha-45.7 cm) was less than under cutting (150 kg N/ha-45.7 cm). Fairly complete utilisation of herbage, coupled with a close C/N ratio ($\underline{c}$ 10) for soil at the site, are considered to provide the most likely explanation for the observed pattern of change. No influence of nitrogen treatments was apparent, indicating that factors regulating soil carbon accumulation are inseparable from the size of the annual input of nitrogen, in determining nitrogen accumulation within a developed grass-clover system.

It is concluded from nitrogen balances that unaccounted-for nitrogen outgoings of several hundred kg N/ha occurred each year from the grazed grass-clover

systems. Results from this and associated research indicate that grazing animals cause substantial, but hitherto largely unrecognised nitrogen losses from developed grass-clover ecosystems. Most of the loss stems from aggregation of excess dietary nitrogen into urine patches.

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