1.1 GENERAL INTRODUCTION.

Despite the promotion of sown exotic pastures in recent years a relatively high proportion (74% approximately) of the pastures of the Northern Tablelands and North Western Slopes of N.S.W. are still dominated by native and naturalised species (Whalley et al. 1978). Further, little research concerned with the autecology of most of the native grass species or of their responses to management either as individual species or as assemblages of species has been carried out and a bias towards the study and use of exotic pasture species in Australia generally, has been obvious (Whalley 1970).

The last decade however, has, as a result of a depressed state of the rural economy and the large capital outlays demanded by current pasture improvement techniques, seen more emphasis being placed on the development of a better understanding of the native and naturalised pastures as an economically viable basis for primary animal production.

Cook et al. (1976), Robinson and Lazenby (1976), and Lodge (1979) have shown that some native Australian grasses in Northern New South Wales are productive and capable of responding to fertility. Grazing by Merino sheep of both exotic and native pastures will produce dramatic species zonation (Hilder and Mottershead 1963, Taylor and Whalley 1975). Taylor (1980) has indicated that the pattern of species distribution in the natural pastures is associated with the distribution of sheep faeces and that in a large native pasture, the major differences in species

richness and floristic composition are a function of the camping behaviour of Merino sheep.

The extent of return of nutrients by the grazing animal has been well researched: (Sears and Newbold 1942; Sears, Goodall and Newbold 1948; Sears 1949; Melville and Sears 1953; Sears 1951; 1953a; 1953b; Sears and Evans 1953; Sears and Thurston 1953; Watkin 1954; Wolton 1955; Watkin 1957; Wheeler 1958; Bromfield 1961; Barrow and Lambourne 1962; Hilder and Mottershead 1963; Hilder 1964; 1966). In summary, urination and defaecation by sheep is concentrated on the camps and accordingly, these areas are zones of high nutrient accumulation. Approximately 70% of ingested nitrogen is excreted in the urine as is approximately 50% of ingested sulphur. Approximately 75% of the ingested phosphorus is excreted as inorganic phosphorus in the faeces. Further, as plant nutrients build up where sheep regularly rest or camp there is a concomitant depletion of nutrients from other areas of the paddock. The intensity of this redistribution has been gauged from measurements of dung concentrations, there being 34% of dung on 10% of the paddock and 22% on 3% of the paddock (Hilder 1966).

The existence then of nutrient gradients radiating from sheep camps and that they control the associated species' zonation in native and naturalised pastures appears a highly acceptable hypothesis.

1.2 SCOPE OF THE STUDY.

This project attempts to investigate the importance in the formation and maintenance of the species associations and zonations associated with sheep camps on unimproved pastures of the Northern Tableland of N.S.W. of:

(a) The different responses of selected native and naturalised grass species to different nutrient levels and

(b) The effects of nutrient gradients on selected native and naturalised grass species in multi-species competition.

1.2.1 The Research Program.

The investigation involved the selection of several field sites on unfertilised natural pastures with well developed sheep camps. The zonation of pasture species surrounding these camps was studied and a series of soil analyses completed to determine the nature and existence of the associated nutrient gradients.

The differing responses of selected native and naturalised grasses to mineral nutrient applications were studied in a series of monoculture factorial pot trials.

Finally, a series of pot trials was undertaken in order to ascertain the extent of the interactions between selected native and naturalised grasses in multispecies competition when grown in environments of varying nutrient levels selected from a transect of a natural

pasture.

In this way it was hoped to gain a better understanding of the importance of the nutrient gradients in the establishment and maintenance of the zonation of grass species around sheep camps in native pastures on the Northern Tablelands of N.S.W.

CHAPTER 2

THE NATIVE AND NATURALISED PASTURES OF THE NORTHERN TABLELANDS OF N.S.W.

- A REVIEW -

2.1 THE PHYSICAL ENVIRONMENT OF THE NORTHERN TABLELANDS OF N.S.W.

2.1.1 Topography:

The average elevation of the Northern Tablelands Statistical Division (Fig. 2.1) is 750 m (Smith and Johns 1975) but the region contains some of the highest country in Australia and a topography as diverse as any Australian region of comparable size (Walker 1977). The eastern edge of the Tablelands is well defined by sharp escarpments. To the west, however, the Tablelands blend with little distinction into the hilly country of the western slopes.

2.1.2 Geology:

Geologically the Tablelands are composed of three basic parent material types (Fig. 2.1). The southern section of the region is predominantly Palaeozoic Basement which consists of low grade metamorphic rock laid down during the Devonian and Carboniferous and undergoing slight metamorphism during the early Permian. It is an intergrade of Woolven and Sanden beds and is commonly know as "traprock". The parent material of the northern section of the Tablelands is principally granite in origin while the Macintyre and Walcha shires have Tertiary Basalts as their dominant parent material.

2.1.3 Soils:

On the Northern Tablelands of N.S.W. the boundaries of the soil associations often co-incide with boundaries showing changes in lithology, indicating that the soils are governed by the nature of the

underlying rock in many areas (McGarity 1977). However, the varying nutrient status of the soils of the region is not necessarily detectable by an examination of the parent material alone. The major soil nutrient deficiencies in the region are phosphorus, nitrogen, sulphur, potassium and molybdenum (McDonald 1968). The status of each of these critical nutrients in the soils of the region, together with its relationship to the original parent materials is as follows:

PHOSPHORUS:

The strong influence of parent material on the phosphorus status of soils is confirmed by many reports (Ignatieff and Callister 1953; McGarity and Munns 1955; Storrier and Walker 1955). Phosphorus contained in the parent rock is commonly retained tenaciously in the solum during weathering and soil formation and for this reason the phosphorus content of a soil tends to be very much a function of the phosphorus content of the parent material.

Wild (1958) published data on samples drawn from the Dividing Range of Eastern Australia and gave average values of 0.428% phosphorus pentoxide for the basalts, 0.115% for the granites and 0.130% for the sedimentary and metamorphic rocks. Spencer and Barrow (1963) supported these findings with the different phosphorus levels of the soils being reflected in the phosphorus supply available to plants in a series of pot trials. The basaltic soils showed no deficiency or a slight deficiency, whereas sedimentary rocks and the granites and porphyries gave rise to moderately deficient soils. Fig. 2.1 would thus tend to indicate phosphorus deficiency in the soils; the basaltic regions of the MacIntyre and Walcha shires being exceptions.

NITROGEN:

Most of the Tablelands soils which have not been improved through legume or fertilizer addition are deficient in nitrogen. Jensen (1914) carried out soil analyses in the region and concluded that the nitrogen status of the granite-derived soils was low. Soils derived from sedimentary rocks (Palaeozoic Basement) received only brief mention. They were noted as being acid, very deficient in humus and poor in mineral nutrients. Basaltic soils were found to have the highest nitrogen status. This information is consistent with the findings of Spencer and Barrow (1963) who observed a low nitrogen content of the granitic and sedimentary derived soils with values of 0.1% nitrogen in the top 10 cm of soil being common. Soils derived from basalt soils were found to support pasture species very responsive to nitrogen thereby indicating a much higher nitrogen status in these soils.

SULPHUR:

In contrast, deficiency of sulphur does not appear to be related to the nature of the parent material. One feature of sulphur deficient environments seems to be a low annual accession of sulphate in rainfall. The findings of Hutton and Leslie (1958) that appreciable penetration of sulphur did not occur beyond 10 miles from the ocean in Victoria suggests that cyclic salt is unlikely to be an appreciable source of sulphate to any part of the Tablelands under the present climate as the eastern edge is not closer than 40 miles from the ocean. The absence of any industrial activity in the area precludes any sizable contribution from sulphurous gases directly or in rainfall. McLachlan (1955) collected soils from a wide area in eastern Australia, extending from south-western Victoria to southern Queensland. Sulphur deficiency

occurred almost as frequently as phosphorus deficiency; 75% of the soils analysed were deficient in both sulphur and phosphorus; 31% of the soils were deficient in phosphorus, sulphur and molybdenum. However, a deficiency in any one element was no indication of deficiency or sufficiency of either of the other two.

POTASSIUM:

Potassium deficiency is most common along the coastal plains of N.S.W. (Stephens and Donald 1958) although there are known responses on the Southern Tablelands and on the Dorrigo Plateau just east of the Northern Tablelands proper (Spencer and Roe 1962). Such a distribution would appear to relate the incidence of potassium deficiency to rainfall and these three responses recorded by Spencer and Barrow (1963) are of interest as it extends the known region of potassium deficiency into a drier environment. It is probable that the more permeable soils in the wetter areas are more deficient.

MOLYBDENUM:

The adequate molybdenum status of most the the Northern Tablelands contrasts with that of much of the Southern Tablelands. The higher pH of the Northern N.S.W. Tablelands soil (up to 1 unit higher for comparable podsolic soils) may well mean that the molybdenum present is more available. On the eastern fringe of the Tablelands where similar Great Soil Groups occur under high rainfall and the soil pH is lower, molybdenum deficiency is more common (Spencer and Roe 1963; McArthur and Spencer 1963).

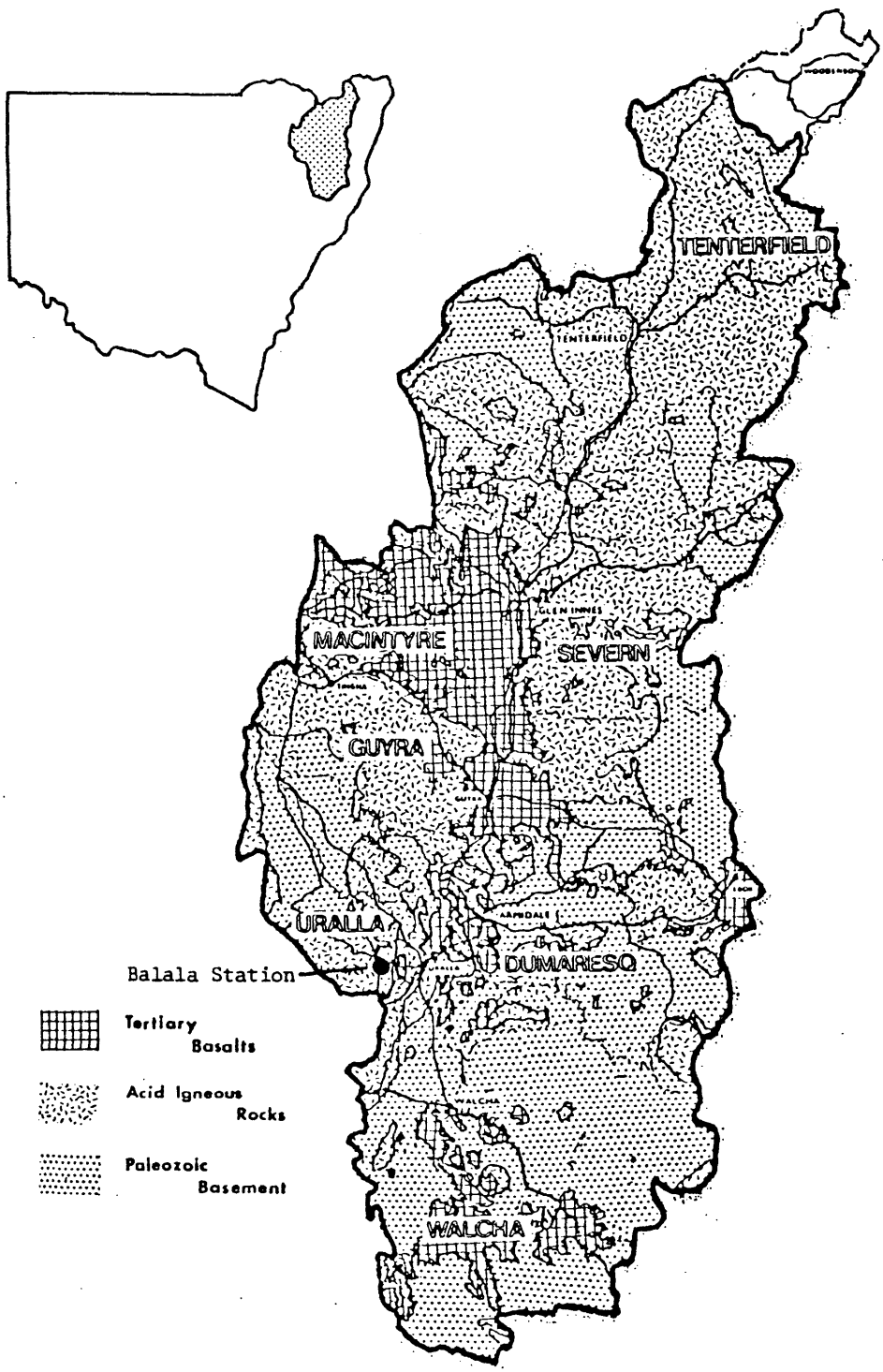


Fig. 2.1 The Northern Tablelands of N.S.W. showing location, the shires, major towns and the distribution of major rock types. (After Harrington 1977).

NOTE: Field site, Balala station, is situated on Palaeozoic Basement.

2.2 CLIMATE

Using the data tabulated in Strahler (1960) which defines the different climatic areas of the world according to the Koppen-Geiger World Climate System, the Tablelands region may be climatically classified as Cfb with the warmer areas being Cfa. This would give the impression that the region has a temperate (mesothermal) climate with sufficient precipitation in all months. However, specific regional research indicates a pronounced rainfall gradient from west to east across the region with the average annual rainfall ranging from 660 mm in the west to 1010 mm on the eastern escarpment (Smith and Johns 1975). Rainfall is summer dominant with 60% falling between October and March (Anon 1969), but on average it is only in the winter months that rainfall exceeds the demands of plant growth. However, at any time in a particular year, rainfall may exceed the demands of evapotranspiration but, equally, may fall far short of meeting these needs (Hilder 1964).

Most of the area experiences moderately cold winters and cool to warm summers, the north-western section being the warmest. The coldest areas are the highest parts of the Tablelands. Frosts are common in winter throughout the region, preventing growth of frost susceptible herbaceous species, while winter temperatures are sufficiently low to limit the growth of frost tolerant species.

2.3 HERBACEOUS VEGETATION ON THE NORTHERN TABLELANDS OF N.S.W.

2.3.1 Evolution of the Eastern Australian Herbaceous Vegetation:

During the 70 million year span from Cretaceous to the present a number of significant events occurred in Eastern Australia which probably had a paramount effect in the moulding of the present day vegetation. The most significant were climatic fluctuations and the periodic outflows of basic igneous rocks which represented inputs of essential mineral nutrients for plants.

Over this time Australia experienced a number of fluctuations in rainfall and temperature and the drastic effects of long periods of aridity on the Australian flora and fauna are discussed by Crocker and Wood (1947); Crocker (1959); Keast (1959) and Gentilli (1961). The more recent periods of aridity have encouraged species migration, adaptation or extinction. Taxa thus became adapted to varying degrees of aridity with some surviving in more moist refuges such as the Eastern Highlands. The Australian herbaceous vegetation has consequently been subjected to a series of climatic fluctuations especially as regards temperature and rainfall and these taxa,having survived severe periods of aridity,constituted the original Australian native pastures.

Tertiary basalt outflows occurred in the east during the Oligocene with isolated smaller flows up to the Pliocene (Beadle 1966; Whalley 1973). These outflows were relatively high in phosphorus and provided increased phosphate levels in the soils derived from them. During the Pliocene and early Pleistocene the elevation of the eastern and southern ranges continued, and the erosion of the highlands has

operated until the present time, with subsequent deposition of the alluvium on the flood plains of the western flowing rivers. These deposits have provided the parent material for the present soils of the inland plains of Eastern Australia with a general decrease in soil phosphate levels from east to west (Beadle 1966). A mosaic of rainforest, sclerophyllous forest and woodland developed with soil fertility exercising a controlling influence (Beadle 1966).

2.3.2 The Impact of Settlement on the Herbaceous Vegetation:

Before settlement in Australia, the native plant communities were adapted to light and intermittent grazing by indigenous marsupials as well as recurrent burning (Moore 1959). The introduction of domestic livestock into these communities led to severe disturbance of the vegetation directly by the defoliation, trampling and manuring of the animals, and indirectly by the clearing of trees to promote grass growth.

Deleterious changes to the pasture vegetation arose from its exploitation by the early squatters as they capitalised on the high wool prices of the 19th Century. The gold rush of the 1850's compounded the problem when meat prices for both sheep and cattle soared dramatically (Peel 1973). The 1880's brought several factors for further pasture exploitation. The rapidly increasing sheep numbers, government decreed reduction in the size of leaseholds, the rapidly multiplying rabbit, and the introduction of the sheep blowfly into Australia, led to increased stock numbers being grazed on decreasing areas of land.

"In addition, the treading and grazing of millions of sheep and

cattle were steadily changing, and in parts destroying, the indigenous vegetation . . . ." (Heathcote 1965).

Regular burning of the pastures was undertaken in an attempt to remove unwanted plants and improve pasture quality (Moore 1962). Under heavy grazing, trampling and nutrient cycling of the 19th Century livestock industries, changes in the botanical composition of the native pastures were inevitable. The original species were not adapted to those severe conditions and hence decreased in abundance. A more permanent claim to the lands by the granting of freeholds in the 1880's led graziers to invest in buildings, fences and watering points and thus a more intensive system of grazing evolved. Associated with this change to intensive production was the search for suitable exotic pasture species and the seeds of the better pasture plants of England were imported. Many of these imported species were successful in the more reliable rainfall areas of south-eastern Australia. The use of artificial fertilizer (mainly superphosphate) for topdressing of pastures began early this century on sown pastures and its use on native pastures followed several years later (McDonald 1968).

2.3.3 Species Changes in South-Eastern Australia:

The general trend in the composition of native grassland in south-eastern Australia as a result of confined grazing by domestic livestock was from warm season perennial grasses to cool season annuals (Moore 1965). Concurrently with this change there was an increase in the amount of nitrogen in the surface of the soil at the end of summer. In addition, grasses from more arid environments tended to invade grazed pastures.

Themeda australis was the pre-settlement dominant over extensive areas of southern Australia but has disappeared with sheep grazing (Moore 1965). In addition, the use of superphosphate on podsolic soils increased the rapidity and completeness of the change to annual species characteristic of soils high in available nitrogen. Moore's research in south-eastern Australia has also indicated that the higher the levels of nutrients such as nitrogen, sulphur, phosphorus and calcium available in soils, the greater the similarities in the communities resulting from grazing. Two examples noted by Moore are worthy of special mention at this point. *Hordeum leporinum*, a species characteristic of red-brown earths and grey-brown soils of heavy texture, increases markedly in communities on podsolic soils to which superphosphate has been applied for a number of years. *Trifolium subterraneum* raises soil nitrogen to high levels and in the absence of perennial grasses there may be an invasion of nitrophilous weeds such as *Cirsium vulgare, Carduus pycnocephalus* and *Onopordum acanthium.*

2.3.4 Species Changes on the North-West Slopes and Northern Tablelands of N.S.W.:

Harradine (1976) makes special mention of the similarity with respect to the changes in the botanical composition of native species resulting from the grazing of domestic livestock in south-eastern Australia as outlined by Moore (1965) and those investigated by himself on the north-west slopes of N.S.W. He states that the original native grass communities of the area were probably dominated by *Stipa aristiglumis, Poa sieberana* var. *cyanophylla* and *Themeda australis.* The primary change in the vegetation following grazing is consistent with Moore's investigations resulting in a decrease in abundance of

the tall, principally summer growing, tussocky perennials. They disappear or become minor components of communities dominated by shorter, mainly cool season grasses, e.g. *Danthonia* spp. Excessive grazing of these cool season grass communities generally has led to an increase in abundance of short warm season perennials including *Eragrostis* spp., *Aristida* spp., *Bothriochloa macra, Chloris truncata* and *Enneapogon nigricans*. Further changes in species composition are related to soil type in terms of texture and fertility, compounded with the pasture management factors. Where the soil phosphate level is relatively high either naturally, or as a result of superphosphate application, a further stage in this disclimax succession occurs as further heavy grazing leads to an invasion firstly by *Medicago* spp. and later by the naturalised annual species of the genera *Bromus, Hordeum* and *Vulpia*. On lighter textured soils heavy grazing leads to an increase in *Aristida* spp.; which may become dominant to the point of exclusion of almost all other species (Harradine 1976). Durham (1953), in a description of the vegetation of the Keepit catchment area, states that on country which for years has been overstocked and subject to rabbit infestation and burning off, the *Danthonia* spp. and *Eragrostis* spp. have been almost entirely replaced by *Aristida* spp. and *Bothriochloa macra*.

2.3.5 Evidence of Differing Responses to Nutrient Applications of some Native Grass Species:

Harradine and Whalley (1978) in their studies with the grass *Aristida ramosa* found that seedlings of this species responded negatively to nitrogen application. In a series of trials designed to investigate this response, it was observed that several forms of nitrogen *viz.;* $NaNO_3$, NH_4Cl and NH_4NO_3 all produced the same growth depression and/or

death. A significant nitrogen-phosphorus interaction was recorded with the negative effect of nitrogen being less at high soil phosphorus levels. A dosage mortality relationship was calculated with an application of 200 p.p.m. nitrogen resulting in kills of 100% and 87% of *Aristida ramosa* seedlings at 0 and 50 p.p.m. phosphorus levels respectively. In comparison at the same nitrogen levels the growth of *Danthonia linkii* was enhanced at the higher phosphorus level and not affected at the lower level.

The results of a field trial to determine the effect of applied fertilizer on the growth of an *Aristida ramosa* dominated native pasture near Armidale showed that applied nitrogen and phosphorus led to marked changes in botanical composition. The fertilizer application induced influx of annual grasses and legumes into the pasture, the rapid growth of these species smothering the *Aristida* so that its percentage of total dry matter decreased from 55% where no fertilizer was applied to 12% where 'Nitram' and superphosphate were applied at 280 and 400 kg ha^{-1} respectively (Harradine 1976).

Robinson (1976) investigating productivity and response to nitrogen fertilizer of *Danthonia racemosa* var. *obtusata* concluded from his pot experiments that *Danthonia* was as equally responsive as *Phalaris tuberosa* to nitrogen fertilizer. However plants of *Themeda australis* and *Bothriochloa macra* died in treatments receiving 90.0 kg N ha^{-1} applied as sulphate of ammonia in three equal dressings in spring, summer and autumn for three years 1970-73. This was the highest nutrient application used in the experiment.

Cook et al. (1976) in his studies of comparative responses of the exotic species *Lolium perenne* and *Bothriochloa macra* to

temperature, moisture, fertility and defoliation provided a high fertility treatment by applying a mixture of salts containing phosphorus, sulphur, nitrogen and trace elements in comparison to no nutrients applied to low fertility treatments. The fertility response of *Bothriochloa macra* indicated that it is a species not only able to grow under low fertility conditions but also to respond to increased fertility levels. Similar trends have been demonstrated for *Themeda australis* (Groves et al. 1973) and *Poa labillardieri* (Fisher et al. 1974).

Cook's et al. (1976) fertility treatment included 200 kg ha^{-1} nitrogen applied in the form of ammonium nitrate. The differing response of *Bothriochloa macra* and *Themeda australis* to simple nitrogen application as compared to a balanced fertility treatment is worthy of note. Both species died in treatments receiving 90.0 kg N ha^{-1} only but responded favourably to an application of 200.0 kg N ha^{-1} when added as part of a nutrient mixture.

Lodge (1979) investigated the effect of fertility on the yields of selected native perennial grasses in pot culture and field experiments. He concluded that the application of either P, S or N positively increased the yield of *Chloris truncata, Eragrostis leptostachya, Bothriochloa macra, Dichanthium sericeum, Danthonia linkii,* and *Stipa variabilis* but not of *Sporobolus elongatus* or *Aristida ramosa* in a glasshouse experiment. In a field experiment the application of superphosphate increased the green leaf yield of all species except *Dichanthium sericeum* and *Stipa variabilis*. Although the glasshouse data indicated that some native grasses respond to single nutrient application it is worth considering whether, in the light of Cook's (1976) work, the same responses would apply in a balanced fertility

treatment experiment particularly as regards the negative response of *Sporobolus elongatus*. The plant mortalities that did occur appear to support the work of Harradine and Whalley (1978) and Robinson (1976) and relate to a high level of nitrogen application. A logical conclusion from these data is that some native grasses may be susceptible to large imbalances of phosphorus, nitrogen and sulphur.

2.3.6 Evidence of Species Composition Zonation Associated with Nutrient Gradients in Pastures: A Chronology of Recent Research on the Pastures of the Northern Tablelands of N.S.W.

Hilder and Mottershead (1963); Hilder (1964); Hilder (1966); Hilder (1969) and Lange (1969), have all produced substantial evidence to suggest that sheep grazing patterns re-distribute nutrients available in improved pastures and that the distribution of sheep faeces and urine, under free grazing conditions shows considerable concentration on sheep camp areas.

Hilder and Mottershead (1963) ascertained that plant nutrients build up where the sheep regularly rest or camp, and concurrently are depleted from the distant parts of the paddock. More specifically, the accumulation of faeces and urine is associated with high concentrations of potassium, phosphorus and other plant materials in the surface soil.

Hilder (1964) observed that, after several years of continuous grazing of a paddock near Armidale, sheep alone were able to transfer sufficient potassium from the large non-camp area to create a severe plant nutrient deficiency on most of the paddock's non-camp.

Associated with this mineral re-distribution, botanical changes become apparent on sheep camps. On improved pasture sites it was noted that the original white clover had gradually weakened from a former high yielding dominant position to comparative insignificance while the accompanying grass, phalaris, rye grass or fescue, also became less productive with time.

Hilder (1966) suggested that, since potassium is excreted largely in the urine, large changes in soil potassium levels on the sheep camps indicate that the urination pattern of Merino sheep bears strong relation to the faecal distribution and that the phenomenon of uneven excreta and urine distribution occurs widely with Merino sheep in Australia. He also recorded marked differences in pasture yields on and off sheep camps in improved pastures of the Northern Tablelands of N.S.W. and attributed the high yields of sheep camps to nutrient transfer by the grazing animals.

Taylor and Whalley (1975) noted faecal concentrations on the sheep camps of native pastures. Their research also indicated that pasture growth in the winter period is much greater on the sheep camps and close surrounds than on the remainder of the paddock. Further, associated with the differences in faecal concentration were differences in species composition. Winter growing, naturalised Mediterranean annuals such as *Hordeum leporinum* and *Vulpia myuros* dominated the sheep camp, whilst species such as *Bothriochloa macra* and *Agropyron scabrum* were conspicuous in the areas remote from the sheep camp.

Whalley et al. (1978) postulated that the three major

pasture types which occurred on the Northern Tablelands, prior to European settlement were:

1. At the higher elevations dominated by *Poa sieberana* and *Themeda australis*.
2. At the lower elevations:
   2a. On fine textured soils dominated by *Themeda australis*, *Poa sieberana* and *Sorghum leiocladum*.
   2b. On coarse textured soils dominated by *Themeda australis*, *Aristida ramosa* and *Cymbopogon refractus*.

The subsidiary species composition of these pasture types is also suggested and the effects of grazing on the species composition of native pastures described (Fig. 2.2). The research also indicated that the grazing behaviour of Merino sheep leads to a striking zonation of herbaceous species resulting from uneven grazing intensity and distribution of dung and urine.

Taylor (1980) conducted an experiment in order to obtain more information about the development of a sheep camp. The behaviour of ten sheep in a 0.1 ha paddock, which did not contain a sheep camp, was intensively observed over a period of about two weeks. The paddock originally was reasonably uniform in botanical composition and there were no sheep in the adjacent paddocks for the duration of the experiment. Two weeks before the experiment commenced the pasture was mown to 2.5 cm and a water point located at the centre of the paddock. The paddock was divided into 63 grid cells for animal observations and there was a difference of 2.15 m in elevation within the paddock, the highest point being in the south-west corner.

Throughout the experiment the sheep chose the 6 cells in the highest corner of the camp for nocturnal camping. Further, 50.4% of the time spent in diurnal resting was spent in the same 6 cells plus 3 adjacent cells. Sheep were actually recorded grazing in these 9 cells, designated as camp, in only 15 of the 8,020 animal observations. Taylor (1980) therefore concluded that the ecological impact of the sheep in creating a camp and affecting floristic change is largely a function of their damaging plants by trampling and lying and nutrient enrichment of the site through faeces and urine return and not due to defoliation.

The proportion of sheep faeces dropped on the camp area decreased from 62% at the start of the experiment to 49% at the end. The camp represented about 14% of the total paddock area and the average weight of faeces per unit area on the camp was 31 to 39 times the paddock average. Taylor (1980) also observed that 74% of observed defaecation events occurred either on the camp or within 10 minutes after an on-camp rest period. The sheep used in the experiment were wethers and urination events could not be recorded accurately. However, Taylor (1980) suggested that, even if the urination events were not correlated with defaecation events but were evenly distributed throughout the day and night, the majority of the urine must be deposited on the sheep camp area.

No statistically significant result was obtained between animal activity and herbage reduction except for the time spent standing during the first observation period which probably affects the trampling and crushing by lying that occurred on or about the camp in the short time after the flock was introduced to the pasture.

One month after the grazing had ceased, the camp appeared to have more herbage mass and was dominated by *Bromus* sp. with little of the original species composition in evidence.

Taylor (1980) therefore postulated that sheep camp creation and sheep camp maintenance are two separate processes. The initial vegetation change appearing to be the result of trampling and crushing of the existing vegetation followed by the effects of the deposition of large quantities of sheep faeces (and presumably urine). However, well developed sheep camps in native pastures are particularly heavily grazed during winter and early spring when the proportion of green leaf on the rest of the paddock is usually low. The heavy grazing and continued trampling and input of faeces and urine all contribute to the maintenance of the sheep camps.

Taylor (1980) further measured the species composition of sheep camps in individual paddocks of a fertilizer by stocking rate trial at Shannon Vale Nutrition Station. This experiment had been in progress for nearly 20 years and consisted of 12 long, thin plots running roughly east and west, with the western end of each plot at the highest elevation. Four stocking rates (8, 11, 14 and 16 wethers ha^{-1}) were applied annually.

The pasture originally was dominated by warm season species including *Themeda australis*, *Bothriochloa macra*, *Sporobolus* sp., *Paspalum dilatatum* and *Sorghum leiocladum* with *Aristida* sp., *Eragrostis* sp., *Poa* sp., *Panicum* sp. and cool season species being minor components. Taylor's (1980) results indicated that the species composition of the sheep camps was markedly influenced by the different fertiliser by stocking rate combinations though he expresses the need for caution in detailed interpretation of the results because of the lack of replication.

Phalaris aquatica was prominent on sheep camps with low stocking rates and high superphosphate while *Danthonia pilosa* occurred on the camps with low superphosphate. The prominence of *Trifolium repens* was less consistent than that of the other two palatable, year long green species. *Bromus brevis* and *Hordeum leporinum* were the only species with a frequency greater than 20% on the S_{14} P_{188} and S_{16} P_{376} treatments (where "S" represents the stocking rate ha^{-1} and "P" the phosphorus addition in kg ha^{-1}). Taylor (1980) further observed that the species composition of the sheep camps was more complex at the higher stocking rates and low fertilizer levels than at the lower stocking rates and higher fertilizer levels.

Taylor (1980) also examined the nature of the camping-related vegetation patterns in a native pasture (Walker's paddock on 'Balala' Station) long grazed by Merino sheep. Results indicated that in the paddock there were species representing the range from heavy grazing and high fertility-tolerant, introduced species to low fertility, grazing-intolerant native species that were probably among the dominants of the original pastures. Five sheep camps were detected in the paddock and whilst there were species in common, the actual floristic composition of the five camps differed. Differences in the weight of faeces suggested that this, in part, reflected the intensity of use and concurred with the observations of the eleven camps at Shannon Vale.

The greater part of the mosaic of intrapaddock pasture types appears largely attributable to the camping behaviour of sheep. On the Northern Tablelands, in particular, Taylor (1980) strongly contends that camping, not grazing, results in the greatest floristic, nutritional and productivity differences.

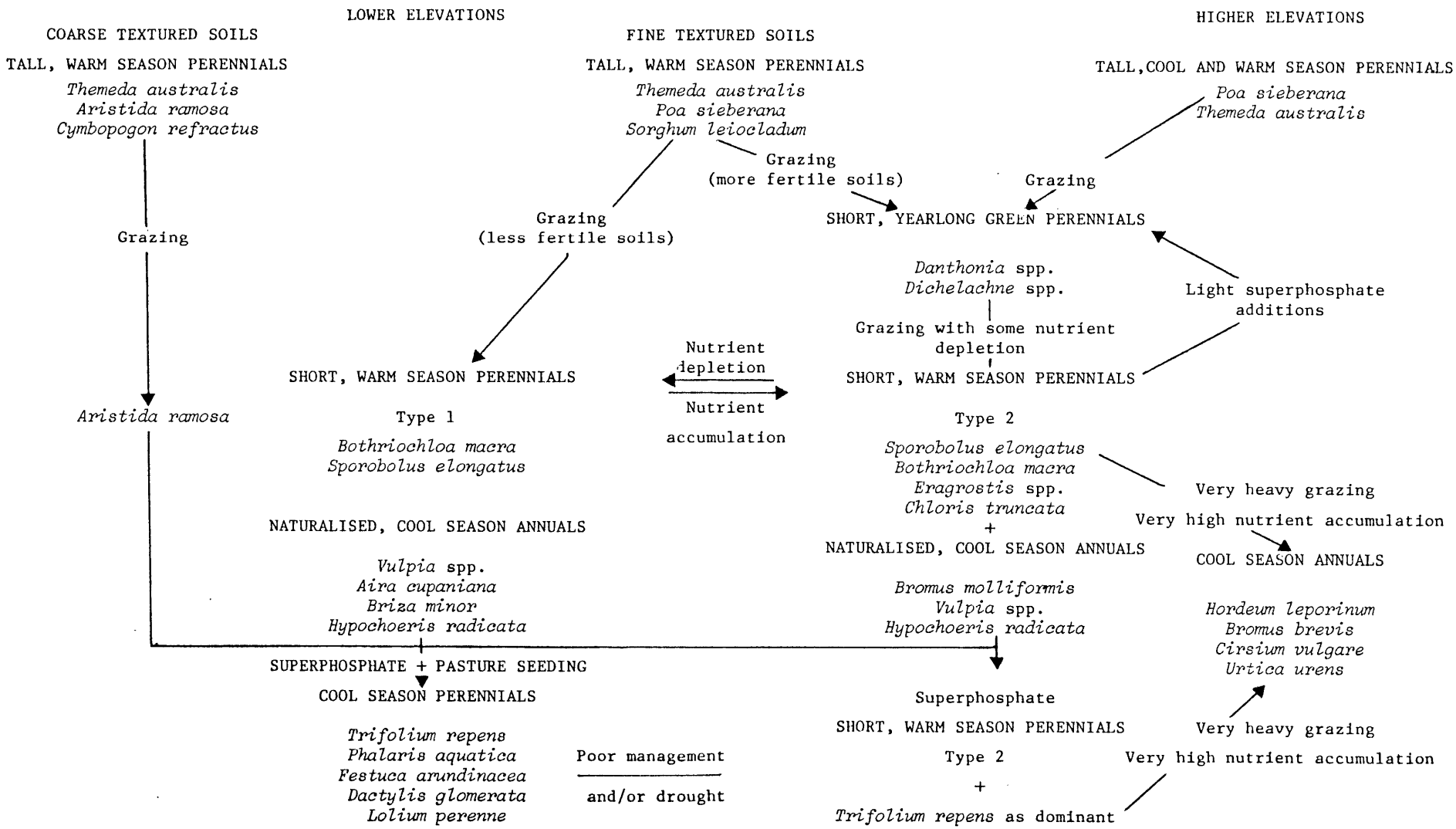


FIG. 2.2 Relationships among the postulated original (top) and present pasture types on the Northern Tablelands of N.S.W. as related to grazing intensity and soil fertility changes.

From Whalley et. al. (1978)

2.4 CONCLUSIONS.

A description of the physical environment of the Northern Tablelands region of N.S.W. reveals a region which, to a large degree, is topographically and geologically diverse. Climatically it is both diverse and variable. The soils of non-basaltic origin in the region are generally of low nutrient status, being deficient in phosphorus, nitrogen and sulphur in particular.

The present day native herbaceous vegetation of the region is typical of that found in Eastern Australia, reflecting a series of unique environmental, evolutionary and disturbance events. The past species composition changes appear related partially to changes in the nutrient status of the soils. These changes may be a result of either management policy through fertilizer additions and stocking rates or by sheep grazing patterns and camping behaviour, or both. Further, there is evidence which suggests that increasing nutrient availability accelerates species composition change and that different species may respond to application of different nutrients.

Soil nutrient gradients have arisen in native pastures as a result of sheep grazing habits. However, the importance of these nutrient gradients in the zonation of species, which is readily observable in the field, requires elaboration.

This project, then, attempts to elaborate on the differing responses of selected native and naturalised grasses to mineral nutrient applications in a series of monoculture factorial pot trials. Further, it attempts to ascertain the extent to which interactions between

selected native and naturalised grasses in multispecies competition explain species associations along nutrient gradients as observed in native pastures on the Northern Tablelands of N.S.W.

The monoculture factorial pot trials involved the use of soils collected at three different distances from well developed sheep camps. Second leaf and first tiller emergence time together with above surface biomass yield at the end of a six weekly period were the data collected. The results were analysed using analyses of variance as the statistical model.

The multispecies competition experiments involved the selection of a transect from a well developed sheep camp in an unfertilized pasture and the preliminary analysis of soils from twenty selected sites along the transect. Using a principal component analysis technique, nitrogen, sulphur and phosphorus values were ordinated and factor scores determined to ascertain the nature of the multinutrient gradient, with respect to distance, along the transect. Sixteen sites were then selected along the same transect and soil cores collected. Five species were grown in monoculture (without replication) coincident with the same five species in mixture (with replication). The above-surface biomass for each species was determined after a growing period of approximately three months. The data were analysed using a regression method and an ordination method (Gower's (1966) Principal Co-ordinates Analysis). The regression analysis was used as an exploratory data-analysis tool rather than a probablistic hypothesis testing procedure in accordance with Austin (1979). Two such experiments were conducted, one involving naturalised cool season annual grasses and the other, native warm season perennials.

CHAPTER 3

EXPERIMENTAL

FACTORIAL POT TRIALS

3.1 FIELD SITE DESCRIPTION.

3.1.1 Introduction.

Field sites without a history of pasture improvement were preferable for studies of the importance of mineral nutrient levels in the formation and maintenance of species zonation on native and naturalised pastures of the Northern Tablelands. Such sites were available at "Balala" Station, approximately 17 km west of Uralla on the Kingstown road. The property is located towards the western edge of the Northern Tablelands Statistical Division (Fig. 2.1 and 3.1).

3.1.2 Topography.

The area is characterised by undulating hills with frequent outcrops of traprock. Several sheep camps are usually located at the highest points in each paddock with the greatest development on the eastern side (Taylor 1980 and Fig. 3.1). The Blue Hill camp has a gentle slope (average 2.2°) and therefore little wash of dung occurs during heavy rain. The Sandy Flat camp is steeper (average slope 5.5°, Fig. 3.2) but most of the run-off from this camp was observed to flow through the fenceline into Walker's paddock. The extent of this transfer appeared limited to within 20 metres of the fenceline.

3.1.3 Vegetation.

The dominant woody species in the selected field area are *Eucalyptus blakelyi*, *Eucalyptus dealbata*, *Eucalyptus laevopinea*, *Eucalyptus albens* and *Eucalyptus melliodora* together with *Angophora floribunda*.

Topographic Map Scale 3.0 cm represents 1 km

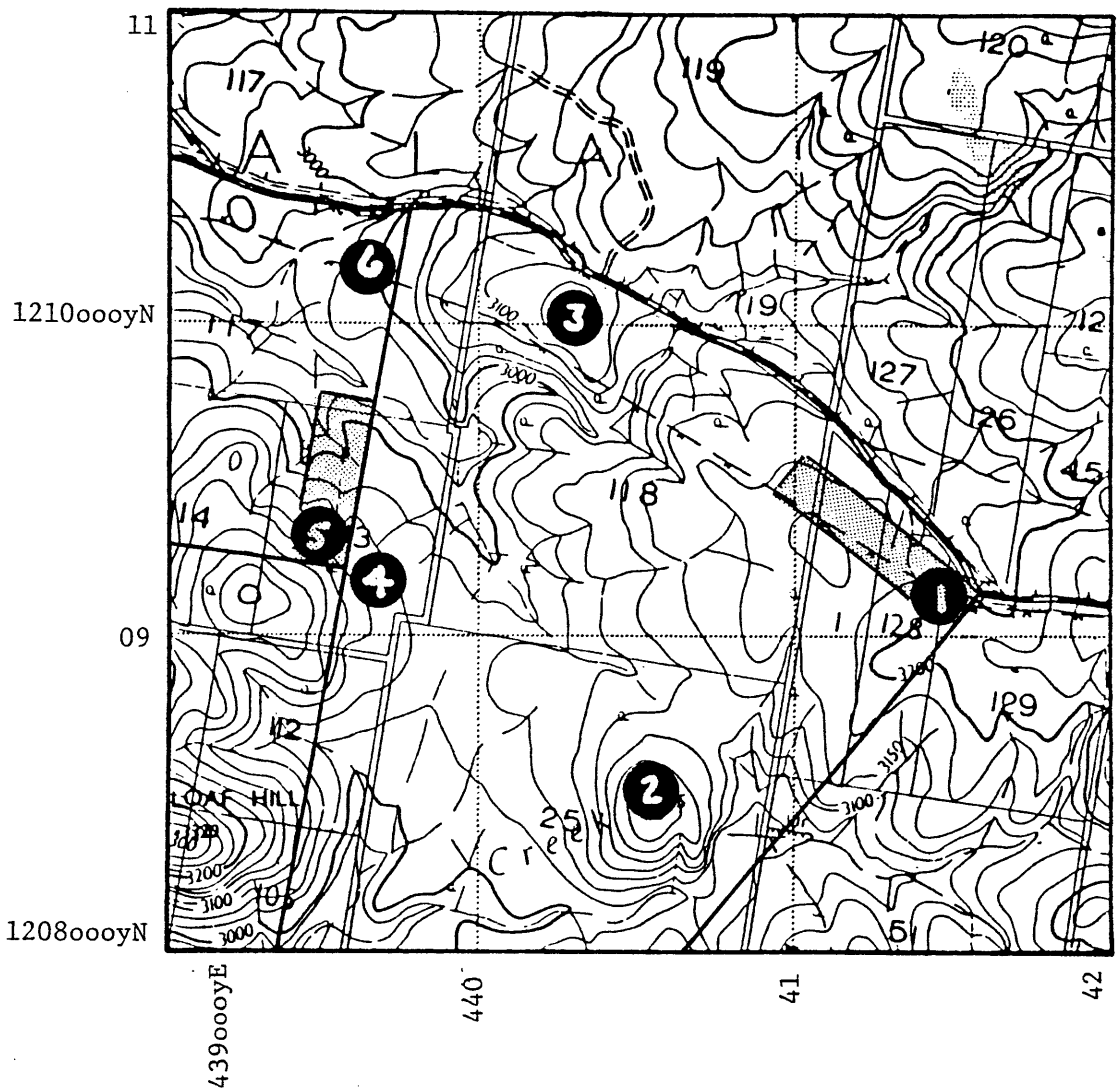


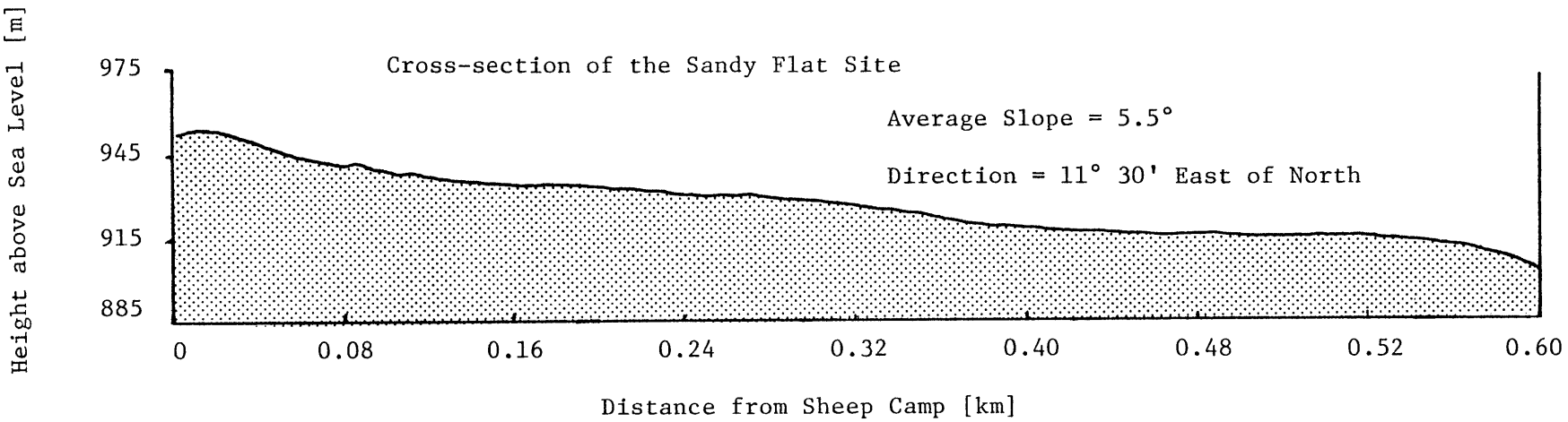
Fig. 3.1 Topographic map of Balala Station indicating:

(a) Fencelines

(b) Field site transects used for analyses

(c) The major sheep camps in Walker's paddock and the adjacent Sandy Flat Paddock

Key to Sheep Camps:
1 = Blue Hill Camp
2 = Walker's Hill Camp
3 = Adam's Hill Camp
4 = Barnden's Hill Camp
5 = Sand Flat Camp
6 = Lower Adam's Hill Camp



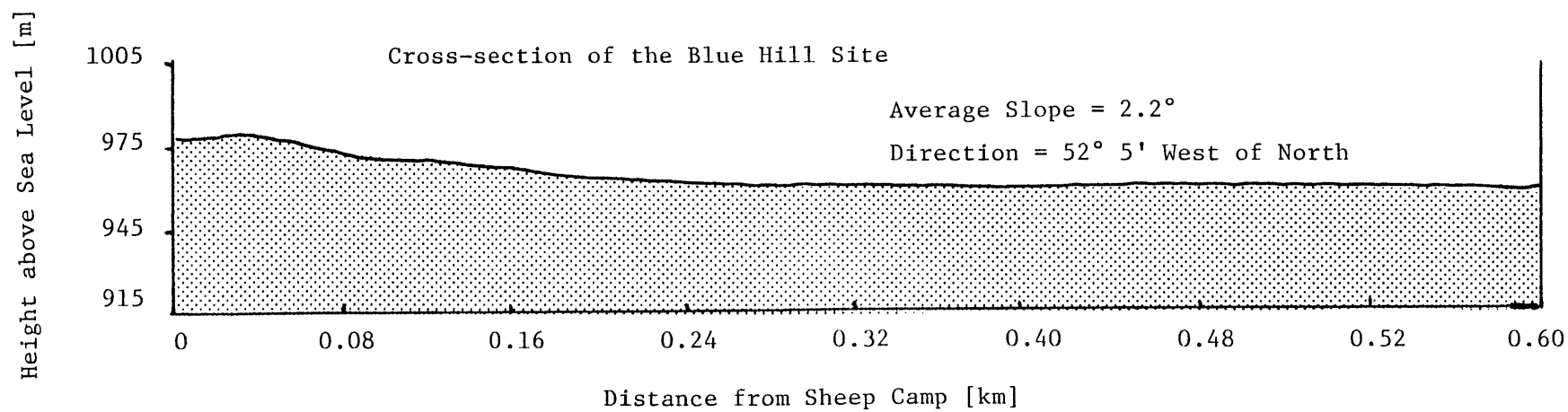


Fig. 3.2 Slope and Aspect of Field Sites.

The pastures in Walker's paddock are complex with much spatial and temporal variation (Taylor 1980). Sheep camps are usually dominated by cool season annual grasses with the remainder of the paddock dominated by warm season perennial grasses such as *Bothriochloa macra* (Plate 3.1).

Plate 3.1

The pasture of the Blue Hill camp in early autumn 1982, indicating the obvious dominance of *Bothriochloa macra* off camp while the dominant on camp species at this time of the year is the cool season annual *Hordeum leporinum*.

3.2 SOIL COLLECTION AND ANALYSIS.

3.2.1 Introduction.

Soils were collected from the Sandy Flat paddock, within the shaded area indicated in Fig. 3.1 on two occasions. Firstly in April 1976 and again in September of the same year. The aim was to determine the difference in nutrient status and soil profile characteristics between the sheep camp and the paddock extremity of the Sandy Flat camp.

3.2.2 Methods and Materials.

3.2.2.1 Sample Collection.

The soil was collected from three separate areas on and near the Sandy Flat sheep camp.

(i) Sheep camp, i.e. up to 20 metres from the southern fence and within the range of 20 metres either side of the transect which ran parallel to the eastern boundary fence and 30 metres from it.

(ii) Between 160 and 200 metres from the southern fence and with similar east-west boundaries as the sheep camp zone.

(iii) Between 280 and 340 metres along the transect and with similar east-west boundaries as the previous two zones.

Within each zone seven subsamples were taken. Each was 50 cm x 50 cm x 10 cm and was sieved through a 1.5 mm sieve. The subsamples were then air dried and the seven samples from each zone thoroughly mixed.

3.2.2.2 Sample Preparation.

(i) A sub sample of the soils collected was retained for soluble and exchangeable cations, pH, total sulphur, organic content approximation, soil moisture and relative bulk density determination.

(ii) A further sub sample was ground using a pestle and mortar to pass through a 180μ sieve for total nitrogen and total inorganic and organic phosphorus determination.

3.2.2.3 Nitrogen.

Total nitrogen was determined by the Kjeldahl method according to Bremner (1965, p. 1163).

3.2.2.4 Phosphorus.

Total soil phosphorus was determined by igniting a 100 g sample of 180μg soil at 530°C for 30 minutes and extracting with 100 mls, in H_2SO_4 by shaking for 16 hours. The chlorostannous-reduced Molybdophosphoric blue colour method (Jackson 1958, p.141) was used to determine the amount of phosphorus in the extract. Inorganic phosphorus was determined by the same method, but with an unignited sample. Organic phosphorus was calculated by subtraction of inorganic phosphorus from total phosphorus.

3.2.2.5 Total Sulphur.

Total sulphur was determined using a Technicon Auto Analyser (Mottershead 1971).

3.2.2.6 Soluble and Exchangeable Cations.

Two g of 2 mm air-dry soil was mixed with 2 g of acid-washed sand. This was placed in a funnel containing a 9 cm filter paper. The sample was then leached with 100 mls of 60% (V/V) 2-propanol at a rate of 4 drops per minute. The extract was then evaporated to dryness and re-made to 100 mls with 10 mls of 0.5N HCl and distilled water. This solution was retained for analysis of soluble cations. The soil was then leached with two successive 100 ml aliquots of 1N CH_3COONH_4 adjusted to pH 7.0. This reagent also contained approximately 0.1 Moles per litre of chloride ion as NH_4Cl. A subsample of CH_3COONH_4 leachate was retained for analysis of exchangeable cations.

Calcium and magnesium were determined by Atomic Absorption Spectrophotometry using La_2O_3 to ensure against heavy metal interference. Sodium and potassium were determined by Flame Photometry against a background of Li_2SO_4.

3.2.2.7 Cation Exchange Capacity.

The soil residue from the preceding determination was placed in a Kjeldahl flask with 25 ml of distilled water and steam-distilled, in the presence of MgO, into boric acid mixed indicator. The cation exchange capacity of each sample was calculated after titration with standard H_2SO_4.

3.2.2.8 pH.

pH was determined in a 1:2.5 soil:water ratio (10 g soil) using a Glass Electrode.

3.2.2.9 Loss on Ignition.

Total organic content was approximated by igniting an oven-dried soil sample for 30 minutes at 530°C. 2 g of sample was used.

3.2.2.10 Relative Bulk Density.

Relative values of bulk density of the samples were approximated by determining the mass of a 24 ml volume of each soil sample. A cube of 24 ml volume was used and the ratio of mass to volume of each sample determined and the values compared. Each cube sample was gently shaken for settling to occur.

3.2.2.11 Percentage Water Composition.

Moisture determination of 2.0 g of each air-dried soil sample was recorded by placing the soil sample in an evaporating basin and allowing to stand in a drying oven set at 110°C overnight. Each sample was then cooled in a desiccator for half an hour and then weighed.

3.2.3 Results.

3.2.3.1 Nitrogen, Phosphorus and Sulphur.

Figs. 3.3,3.4 and 3.5 indicate a marked accumulation of nitrogen, phosphorus and sulphur on the sheep camp. In addition, the values were all higher in April than September on the sheep camp and to a lesser extent, in the 160-200 m zone; there was little difference at the 280-340 m zone.

The nutrient distribution appears to follow the same trend as the organic content. The higher the organic content the higher the nutrient status of the soil.

3.2.3.2 Soluble Cations.

Table 3.1 indicates a concentration of soluble cations on the sheep camp in both April and September. The differences between the sheep camp values and the 160-200 m zone values are consistently greater than the difference between the 160-200 m zone and the 280-340 m zone. This further indicates nutrient accumulation occurring predominantly on the sheep camp with a sharp decrease within a relatively short distance from the camp followed by a more gradual decreasing gradient in concentration with increasing distance towards the paddock extremity. Soluble Mg^+, K^+ and Na^+ were considerably higher in September than April on the sheep camp but there was little difference at the other two zones. The only exception was that K^+ was higher in September in the 280-340 m zone.

3.2.3.3 Exchangeable Cations and Cation Exchange Capacity.

The exchangeable cation values reveal a similar trend to those of the soluble ions with distinct nutrient accumulation on the sheep camp (Table 3.2). However, the differences between the April and September samplings were much reduced or did not exist. There was good agreement between the total of the four exchangeable cations determined and the cation exchange capacity.

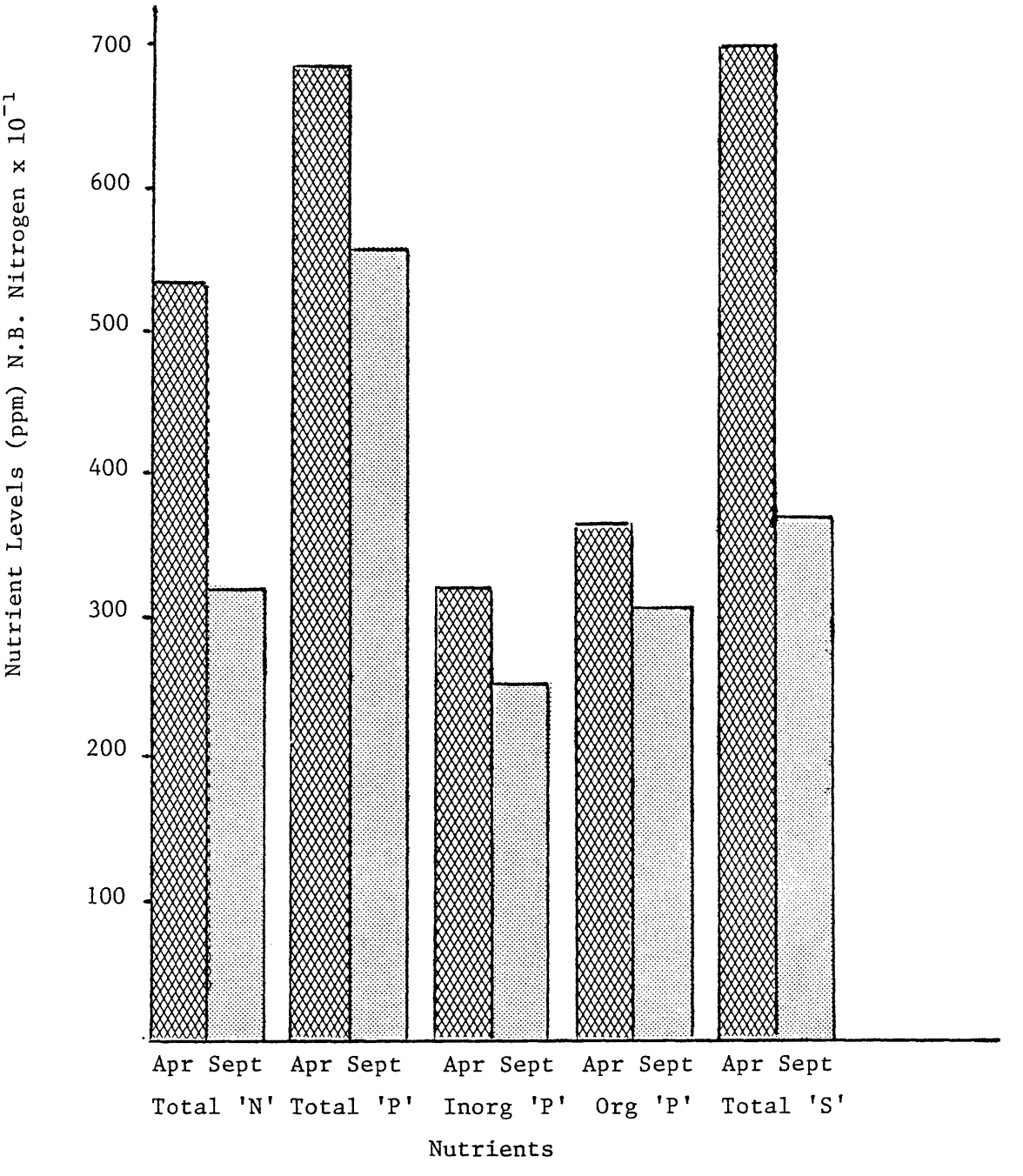


Fig. 3.3 Nitrogen, phosphorus and sulphur (ppm) of Sandy Flat soil, 0-10 cm depth, collected in April and September 1976 and within 0-20 m zone along the transect.

Range of Data (ppm)

ZONE	TOTAL N		TOTAL P		INORG P		ORG P		TOTAL S	
	Apr	Sept	Apr	Sept	Apr	Sept	Apr	Sept	Apr	Sept
Sheep Camp	±40	±4	±35	±15	±10	±15	±15	±35	±31	±2

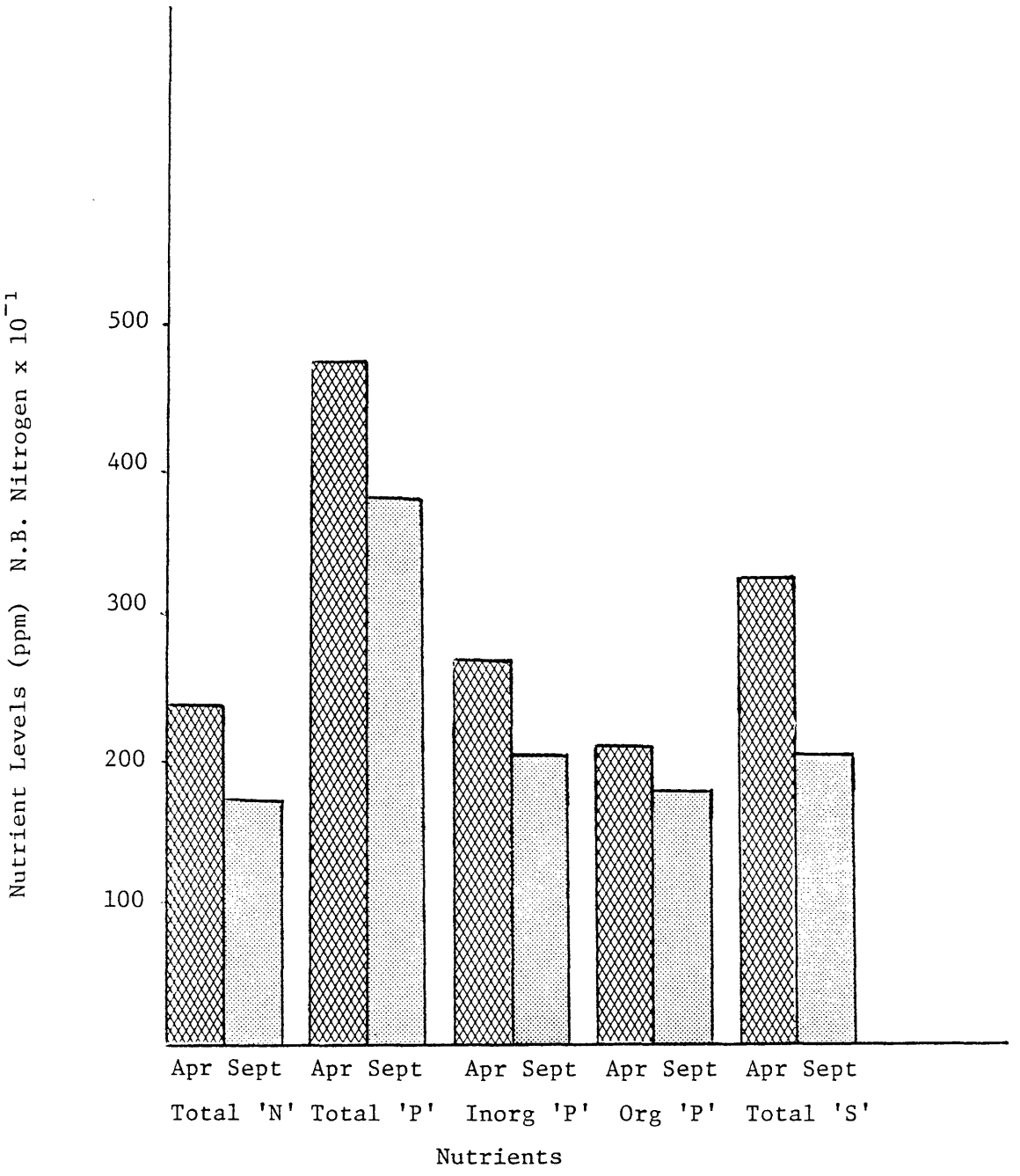


Fig. 3.4 Nitrogen, phosphorus and sulphur (ppm) of Sandy Flat soil, 0-10 cm depth, collected in April and September 1976, and within 160-200 m zone along transect.

Range of Data (ppm)

ZONE	TOTAL N		TOTAL P		INORG P		ORG P		TOTAL S	
	Apr	Sept	Apr	Sept	Apr	Sept	Apr	Sept	Apr	Sept
160-200 Metre Zone	±10	±10	±10	±5	±5	±10	±15	±5	±19	±0

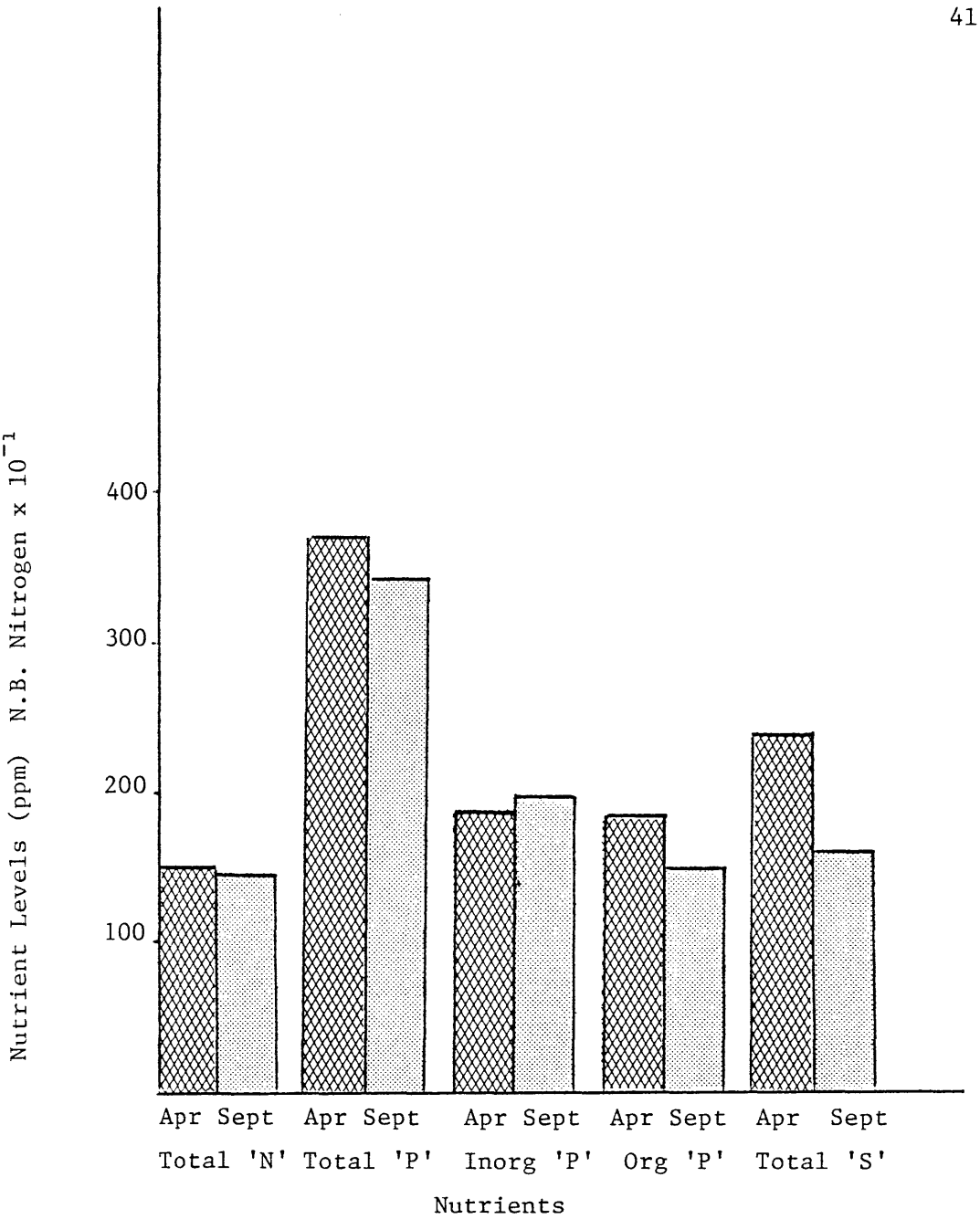


Fig. 3.5 Nitrogen, phosphorus and sulphur (ppm) of Sandy Flat soil, 0-10 cm depth, collected in April and September 1976, and within 280-340 m zone along the transect.

Range of Data (ppm)

ZONE	TOTAL N		TOTAL P		INORG P		ORG P		TOTAL S	
	Apr	Sept	Apr	Sept	Apr	Sept	Apr	Sept	Apr	Sept
280-340 Metre Zone	±4	±5	±30	±15	±5	±5	±25	±10	±5	±2

TABLE 3.1

Soluble cation levels for the three soils, (0-10 cm) depth, collected in April and September 1976 along the Sandy Flat transect.

(Mean of 2 samples; ± values indicate range).

AREA SAMPLED	CONCENTRATION OF SELECTED CATIONS (m.e./100 g of soil)							
	Ca^{2+}		Mg^{2+}		K^{+}		Na^{+}	
	Apr	Sept	Apr	Sept	Apr	Sept	Apr	Sept
Sheep Camp	0.30 ±0.00	0.26 ±0.01	0.48 ±0.03	0.23 ±0.02	1.01 ±0.01	0.59 ±0.01	7.02 ±2.97	3.69 ±0.90
Within Zone 160-200 metres from sheep camp.	0.16 ±0.00	0.18 ±0.01	0.40 ±0.04	0.21 ±0.01	0.38 ±0.00	0.43 ±0.01	2.25 ±0.72	2.61 ±0.45
Within Zone 280-340 metres from sheep camp.	0.18 ±0.01	0.14 ±0.00	0.19 ±0.01	0.12 ±0.00	0.33 ±0.01	0.51 ±0.00	2.43 ±0.18	2.43 ±0.63

3.2.3.4 pH, Organic Content and Relative Bulk Density.

pH and relative bulk density values appear to be related to the level of organic content. The higher the organic content the lower the pH and the higher the relative bulk density of the soil (Table 3.3). The relationships again indicate the same general pattern as seen in previous results. With the organic matter concentrated on the sheep camp, its pH was understandably more acid than that of the other two zones. Similarly its relative bulk density was the lowest of the three sampled zones. In all cases the differences between the sheep camp and the 160-200 metre zone were greater than those between the 160-200 metre zone and the 280-340 metre zone.

3.2.4 Discussion.

The results indicate a dynamic system of nutrient accumulation and depletion with nutrient levels at the end of the summer period generally higher than at the end of the winter season. This was particularly true of the sheep camp. Richards (1976) measured bacteria, fungal spores and fungal mycelium populations on pasture sites and observed maximum values in the months of January/February and lowest values in August. Accordingly, it would be expected that mineralization would thus be maximal and minimal respectively during these periods.

The organic matter appeared to reflect the faecal concentrations and thus the sheep grazing patterns on the different zones. Faecal pellet counts decreased in a similar pattern to the phosphorus, nitrogen and sulphur differences between the zones (Taylor 1980).

TABLE 3.2

Exchangeable cations and cation exchange capacity values for the three soils, (0-10 cm) depth, collected in April and September 1976 along the Sandy Flat transect. (Mean of 2 samples; ± values indicate range).

AREA SAMPLED	CONCENTRATIONS OF SELECTED CATIONS (m.e./100 g of soil)									
	Ca^{2+}		Mg^{2+}		K^{+}		Na^{+}		C.E.C.	
	Apr	Sept	Apr	Sept	Apr	Sept	Apr	Sept	Apr	Sept
Sheep Camp	9.63 ±1.86	5.13 ±0.63	2.03 ±0.12	1.18 ±0.04	4.50 ±0.06	4.00 ±0.00	4.75 ±0.43	3.00 ±0.65	21.15 ±1.99	13.41 ±0.47
Within Zone 160-200 m from sheep camp.	5.86 ±1.86	3.86 ±0.63	1.73 ±0.04	1.58 ±0.04	3.75 ±0.06	2.50 ±0.06	2.25 ±0.11	2.50 ±0.00	14.39 ±0.94	10.68 ±0.29
Within Zone 280-340 m from sheep camp.	3.00 ±1.25	3.25 ±0.00	0.93 ±0.04	0.86 ±0.04	2.25 ±0.06	2.00 ±0.00	2.25 ±0.11	1.75 ±0.11	8.56 ±0.36	8.67 ±0.17

TABLE 3.3

pH, percentage organic matter (loss on ignition) and relative bulk density values for the three soils,(0-10 cm) depth, collected in April and September, 1976 along the Sandy Flat transect.

(Mean of 3 samples; ± values indicate Range).

AREA SAMPLED	pH		% Org. Matter		Rel. Bulk Density (g/cc)	
	Apr	Sept	Apr	Sept	Apr	Sept
Sheep Camp	5.75 ±0.05	5.80 ±0.00	23.00 ±5.00	11.00 ±0.50	0.79 ±0.04	0.86 ±0.03
Within Zone 160-200 metres from sheep camp.	6.25 ±0.00	6.30 ±0.05	9.00 ±0.50	7.00 ±0.50	0.92 ±0.03	0.96 ±0.03
Within Zone 280-340 metres from sheep camp.	5.90 ±0.10	6.20 ±0.05	6.50 ±0.50	6.00 ±0.50	0.98 ±0.03	1.04 ±0.02

The soluble ion concentrations were higher than expected. A possible explanation is that the months of April and September are usually the driest of the year, resulting in minimal loss through leaching during the period of sample collection (Fig. 3.6).

The high levels of soluble Na^+ and the relatively low levels of exchangeable Na^+ probably results from the cation replacement series in soils. Sodium, being less likely to occupy exchange sites, has relatively high values in the soluble form (Foth and Turk 1972).

The relatively high values of K^+ ions especially on the sheep camp, are consistent with the frequent urination occurring in this zone and the high K^+ level in the urine (Hilder 1966).

The nutrient level differences generally agree with those determined by Hilder and Mottershead (1963) on improved pasture sites. Further, the relative bulk density results appear related to nutrient status. Low relative bulk densities indicate a high organic matter content which, in turn, indicates low pH values and relatively high nutrient status.

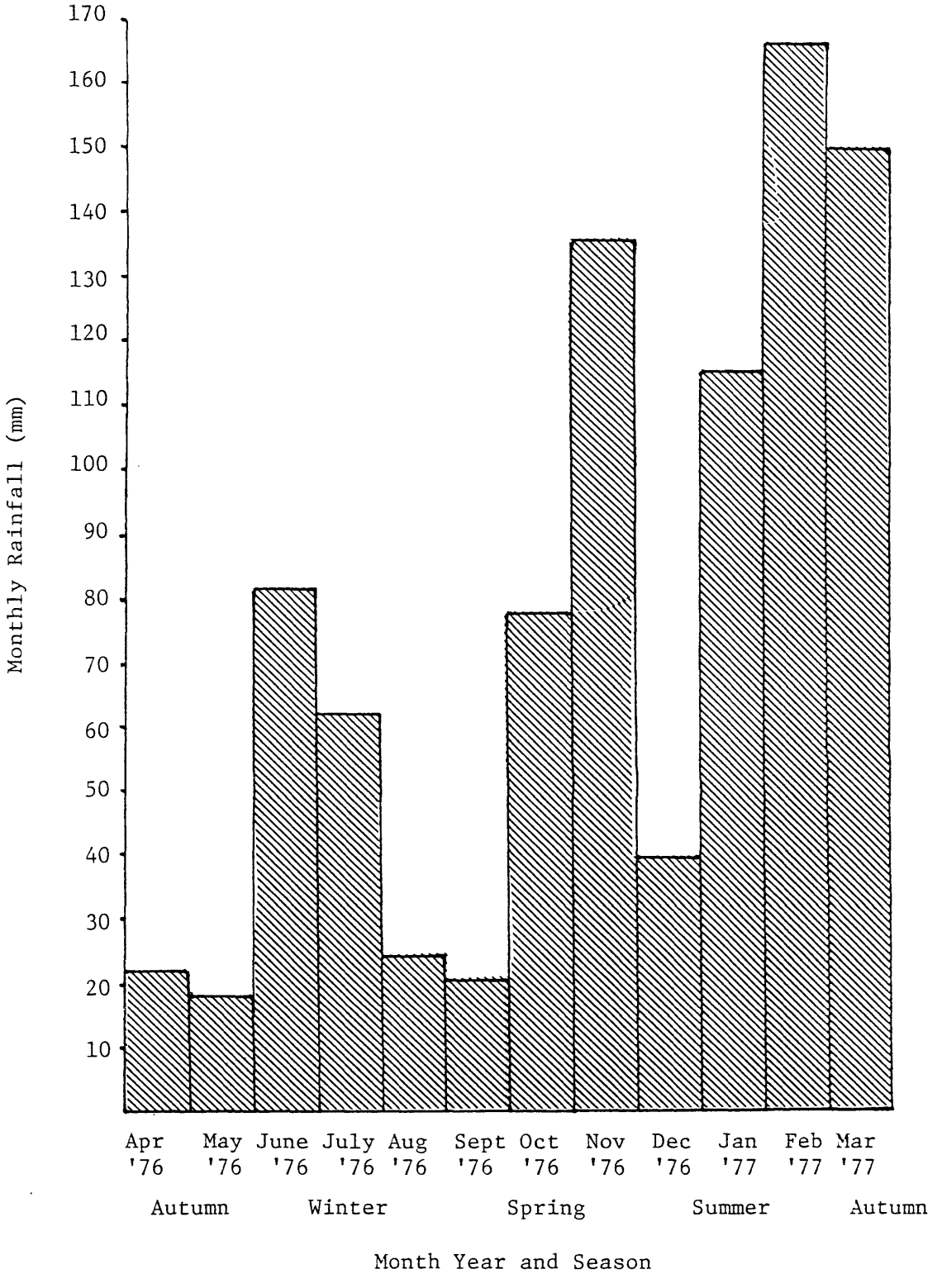


Fig. 3.6 Rainfall recorded at Balala Station during the period of soil collection.

3.3 FIELD SITE SPECIES ZONATION.

3.3.1 Introduction.

The obvious differences in species composition betweeen sheep camps and paddock extremities on native and naturalised pastures have been referred to earlier. These differences are illustrated in the Frontispiece and Plate 3.1. An investigation was conducted to obtain qualitative data on these differences.

3.3.2 Materials and Methods.

A 340 metre transect was laid out from the fenceline on the Sandy Flat sheep camp to the creek to the north. The area covered by the transect is shown in Fig. 3.1. The transect was divided into seventeen 20 metre intervals. At each interval 9 x 1 square metre quadrats were examined; one being directly on the line of the transect and four either side and in a line perpendicular to the transect. Each sampled quadrat was separated from the next adjacent one, by one unsampled square metre. Within each quadrat the grass species present were recorded and at each interval along the transect the frequency of each species was calculated. Finally, the total for each species was calculated for the 0-20 metre zone of the transect, the 160-200 metre zone and the 280-340 metre zone.

3.3.3 Results.

The cool season annuals, *Hordeum leporinum* and *Bromus brevis* dominated the sheep camp with the former in greater abundance (Fig. 3.7). However, the dominance of these species disappeared as one moved towards

the 160-200 m zone, both of these winter annuals becoming conspicuously absent within a short distance from the sheep camp. A wide variety of perennial species increased in abundance from the sheep camp to the 160-200 m zone including *Bothriochloa macra, Sporobolus elongatus, Eragrostis leptostachya, Aristida ramosa, Chloris truncata* and *Panicum effusum.* Between 160-200 m and 280-340 m from the sheep camp a reduction in the frequency of many of these perennial species became evident, *Bothriochloa macra* being an exception (Fig. 3.7). *Eleusine tristachya* and *Cynodon dactylon* were absent from the paddock extremity whereas the two cool season perennials, *Agropyron scabrum* and *Dichelachne michrantha* appeared to increase in frequency as one moved towards the 280-340 m zone (Fig. 3.7). *Vulpia myuros,* a naturalised cool season annual, appeared consistently throughout the whole transect and had a similar distribution to *Bothriochloa macra.*

The preferences of specific species for specific zones are indicated on Fig. 3.7. In addition, species such as *Bothriochloa macra* and *Vulpia myuros* appeared throughout the transect although their frequency in the sheep camp zone was lower than elsewhere.

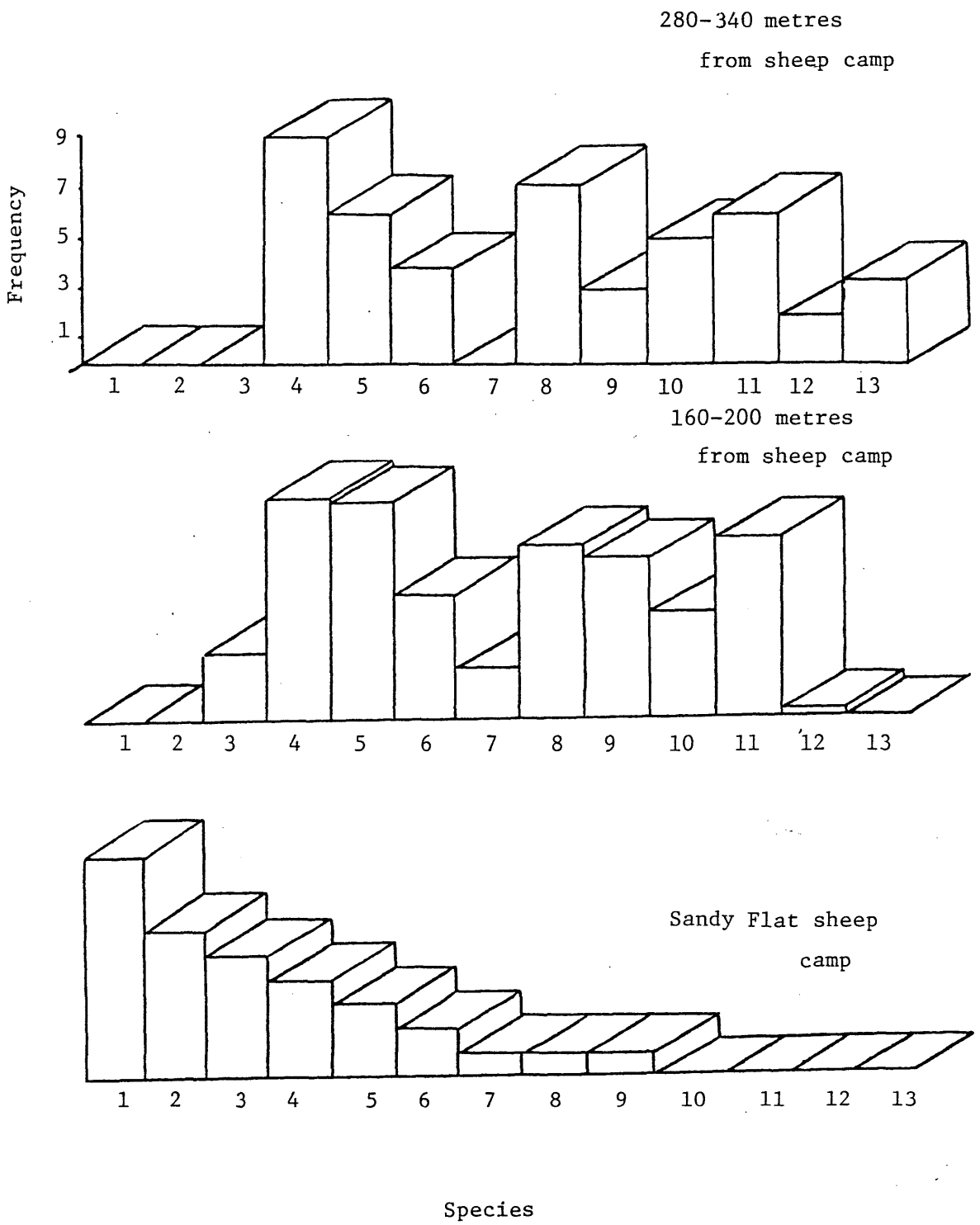
3.3.4 Discussion.

J. A. Taylor (pers. comm.) using the same technique determined the species composition of the Blue Hill site at a similar time of the year (Fig. 3.8), and Taylor and Whalley (1975) determined species composition by biomass of the Blue Hill site (Fig. 3.9). The general pattern of the distribution on both the Sandy Flat and Blue Hill sites were very similar. Similar distribution of the naturalised cool season annuals, *Hordeum leporinum* and *Bromus* spp.,occurred. The increase in frequency and biomass of *Agropyron scabrum* towards the paddock extremity

Fig. 3.7 Relative species frequency of 13 grasses on the Sandy Flat site.
Frequency distribution of species is indicated for the sheep camp, 160-200 m zone and the 280-340 m zone.

Key to Species.

NO.	SPECIES	TYPE
1	*Hordeum leporinum*	Naturalised cool season annual
2	*Bromus brevis*	Naturalised cool season annual
3	*Cynodon dactylon*	Naturalised warm season perennial
4	*Bothriochloa macra*	Native warm season perennial
5	*Vulpia myuros*	Naturalised cool season annual
6	*Sporobolus elongatus*	Native warm season perennial
7	*Eleusine tristachya*	Naturalised warm season perennial
8	*Eragrostis leptostachya*	Native warm season perennial
9	*Aristida ramosa*	Native warm season perennial
10	*Chloris truncata*	Native warm season perennial
11	*Panicum effusum*	Native warm season perennial
12	*Dichelachne micrantha*	Native cool season perennial
13	*Agropyron scabrum*	Native cool season perennial


280-340 metres
from sheep camp
Frequency
9
7
5
3
1
1 2 3 4 5 6 7 8 9 10 11 12 13
160-200 metres
from sheep camp
1 2 3 4 5 6 7 8 9 10 11 12 13
Sandy Flat sheep
camp
1 2 3 4 5 6 7 8 9 10 11 12 13
Species

is also consistent with the distrubution noted on the Sandy Flat site. *Eleusine tristachya* is generally confined to a narrow belt on the borders of the sheep camps. This species is absent from the paddock extremity of both the Blue Hill and Sandy Flat sites. *Bothriochloa macra* and *Vulpia myuros* display a wide distribution throughout both sites.

A total of 103 species has been recorded in the vicinity of the Blue Hill sheep camp (Taylor 1980). The position of the sheep camp appears to be the dominating influence determining just where individual species occur. It is suggested that the nutrient accumulation on the sheep camp may be the dominant factor affecting this distribution. Some of the cool season annuals conspicuously absent from the lower nutrient status soils may have the ability to respond to the high nutrient levels. Further, species absent from the high nutrient zone may not necessarily be incapable of responding to high nutrient environments but excluded from these areas because of competition from species better able to respond.

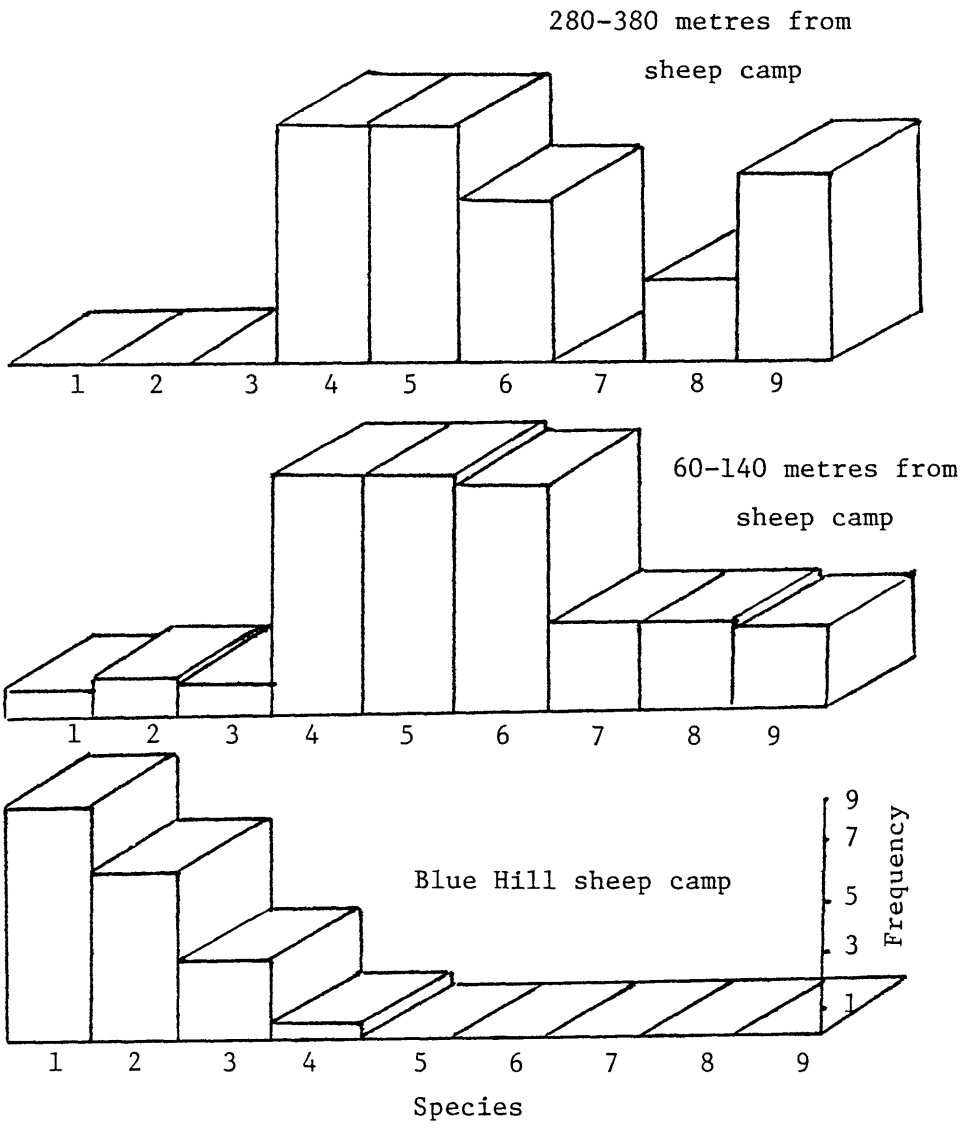


Fig. 3.8 Relative species frequency of 9 grasses on the Blue Hill site.

(Data by J. Taylor, January 1977).

Key to Species.

NO.	SPECIES	NO.	SPECIES
1	*Hordeum leporinum*	6	*Sporobolus elongatus*
2	*Bromus brevis*	7	*Eleusine tristachya*
3	*Cynodon dactylon*	8	*Chloris truncata*
4	*Bothriochloa macra*	9	*Agropyron scabrum*
5	*Vulpia myuros*		

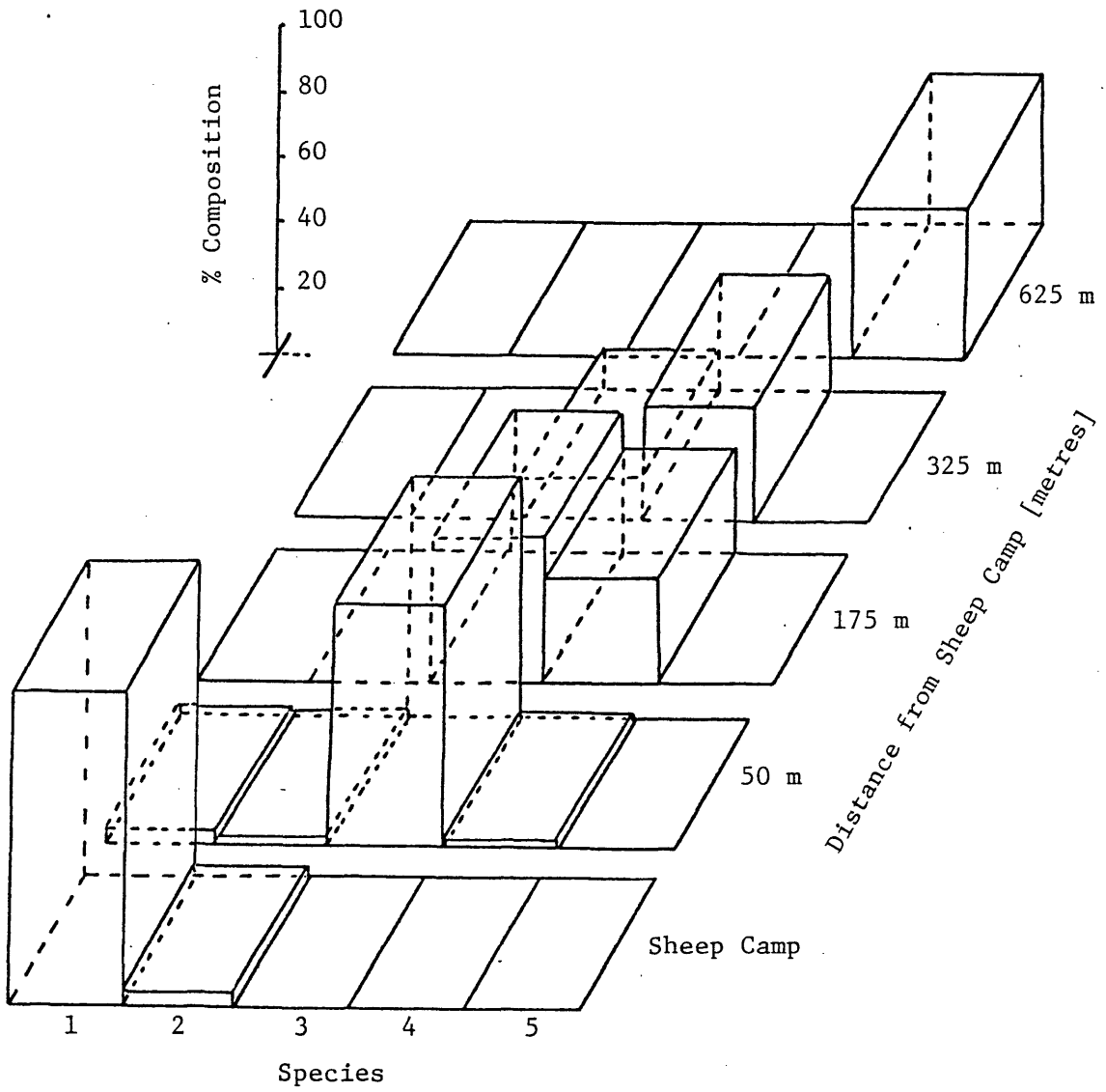


Fig. 3.9 Percentage composition of selected species at 5 sampling sites at different distances from the Blue Hill sheep camp. (After Taylor and Whalley 1975).

Key to Species.

NO.	SPECIES	NO.	SPECIES
1	*Hordeum leporinum*	4	*Bothriochloa macra*
2	*Bromus* sp.	5	*Agropyron scabrum*
3	*Vulpia myuros*		

3.4 FACTORIAL POT TRIALS.

3.4.1 Introduction.

A series of pot trials was undertaken in order to investigate:

1. Responses of selected native and naturalised grass species in monoculture to soils of varying nutrient status.
2. Which nutrients were the most important, as determined by the optimum physiological responses of the species to varying nutrient applications in soils of varying nutrient status.
3. Whether different species respond differently to varying nutrient environments.

The size of the experiments was limited by the glasshouse space available but, more importantly, by the number of pots in a trial which could be managed daily as regards watering, observing, recording, etc. The maximum manageable trial consisted of about 450 pots.

3.4.2 Methods.

3.4.2A The following procedures were common to all pot trials:

3.4.2A.1 Species Selection and Seed Germination Trials conducted contained cool season perennials, native yearlong green perennials, naturalised cool season annuals and native warm season perennials. The species were selected because of their different distributions on the field sites. Unfortunately, seed of the selected species from the field sites was not available, and so seed from diverse sites, which may have been different ecotypes from those at Balala Station, was used as they were the only viable seed

samples available (Table 3.4). *Bromus molliformis* was used in all pot trials so that growth responses of the species in different trials could be related.

All seeds were germinated on germination pads, moistened with tap water in petri dishes and incubated at alternating temperatures (20/30°C for 16/8 hours). Seedlings were planted in the pots when the radicles were approximately 1 cm long. The seed sowings were staggered so that seedlings of all species could be planted out at the same time (the germination time for each species having been pre-determined by preliminary trials). Five seedlings of one species were placed in each pot and the number later reduced to three.

3.4.2A.2 Pot Preparation.

Ten centimetre diameter plastic pots lined with a polythene bag were filled with 325 g of air-dried soil collected from the Sandy Flat field site. The soils were collected as described in 3.2.2 from the sheep camp, 160-200 metre zone and the 280-340 metre zone. The pot capacity of each soil type was determined and pots in the trials were kept to pot capacity by daily weighing and watering with demineralised water.

3.4.2A.3 Nutrient Applications.

Appropriate amounts of different nutrients were added to each pot in each experiment by injecting an appropriate solution onto the surface of the soil in each pot by means of a syringe and immediately watering each pot. The form in which each nutrient was added is

TABLE 3.4

Species used for Factorial Pot Trial Experimentation.

SPECIES	DATE AND LOCATION OF SEED COLLECTION	TYPE	DISTRIBUTION OF FIELD SITES
Bothriochloa macra	26/4/76 Walker's paddock, Balala Station.	Native warm season perennial.	Wide; borders of sheep camp to paddock extremity.
Bromus molliformis	15/12/74 Box Hill Drive, Armidale.	Naturalised cool season annual.	Sheep camps.
Eragrostis molybdea	26/4/76 Walker's paddock, Balala Station.	Native warm season perennial.	Paddock extremity.
Hordeum leporinum	10/11/69 Gilgandra.	Naturalised cool season annual.	Sheep camps.
Microlaena stipoides	14/4/76 Invergowrie, 16 km west of Armidale.	Native yearlong green perennial.	Borders of sheep camps.
Agropyron scabrum	6/1/75 Deepwater Station.	Native yearlong green perennial.	Paddock extremity.
Chloris truncata	22/3/76 Walker's paddock, Balala Station.	Native warm season perennial.	Wide; borders of sheep camp to paddock extremity.
Cymbopogon refractus	23/2/76 Pine Ridge, Balala Station.	Native warm season perennial.	Paddock extremity.
Sorghum leiocladum	10/2/72 Armidale.	Native warm season perennial.	Paddock extremity.
Sporobolus elongatus	8/8/73 6 km west of Bendemeer, Manilla.	Native warm season perennial.	Wide; borders of sheep camp to paddock extremity.
Themeda australis	28/1/73 University of New England, Armidale.	Native warm season perennial.	Paddock extremity.
Vulpia myuros	5/11/68 Warialda Rd., 14 km from Inverall.	Naturalised cool season annual.	Wide; borders of sheep camp to paddock extremity.

indicated in Table 3.5.

TABLE 3.5

Compounds used as sources of nutrients for pot trials.

NUTRIENT REQUIRED	COMPOUND USED
Nitrogen	NH_4NO_3
Phosphorus	$CaH_4(PO_4)_2 \cdot H_2O$
Potassium	K Cl
Sulphur	$Na_2SO_4 \cdot 10H_2O$

3.4.2A.4 Glasshouse Management.

The experiments were carried out in semi-controlled glasshouses with temperatures maintained daily within the range 16-27°C. Each pot trial was run for a period of six weeks. For each experiment the available glasshouse space was divided into equal sections according to the number of replicates used (usually 3 replicates of each treatment). A single replicate of each treatment was placed in each section in a random arrangement. The sections were rotated, in a clockwise direction, weekly and the pots of each section re-randomized during the transfer process to allow for environmental gradients within the glasshouse.

3.4.2A.5 Results Recorded.

During the period of seedling growth, time for 2nd leaf emergence and 1st tiller emergence of each plant was recorded. At the end of the six week period the plants were harvested at soil surface level and the plant tops from each pot dried at 80°C for 72 hours and weighed. All data were then subjected to an analysis of variance.

3.4.2B Procedures for Specific Pot Trials.

3.4.2B.1 Experiment 1: Nitrogen and Phosphorus Distribution Within Pots.

In order to investigate the distribution of nutrients within each pot, resulting from the method of nutrient addition, 3 replicates of each of the three soil types used, both with and without the maximum nutrient application (100 ppm nitrogen and phosphorus) were placed in the glasshouse and treated identically (including watering) to the other pots in the 1st trial. These pots were not planted with seedlings. The pots were weeded regularly and at the end of the six week period the soil was removed from each pot, divided into four equal sub-samples (by depth) and air-dried (Fig. 3.10). Each sub-sample was then analysed for total nitrogen and phosphorus and differences evaluated using an Analysis of variance.

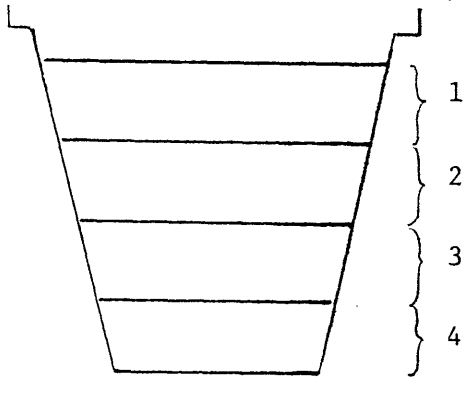


Fig. 3.10 Sub-sample divisions taken for phosphorus and nitrogen distribution analysis.

3.4.2B.2 Experiment 2: Nutrient Responses of Selected Native and Naturalised Cool Season Perennial and Annual Grasses.

This experiment was designed as an incomplete factorial involving 3 replications, 4 species, 3 soil types (sheep camp, 160-200 m zone and 280-340 m zone), 3 levels of nitrogen, 3 levels of phosphorus and 3 levels of potassium. The species selected were *Bromus molliformis*, *Hordeum leporinum*, *Agropyron scabrum* and *Microlaena stipoides*. The three levels of nutrients added were 0, 50 and 100 ppm. All combinations of nitrogen and phosphorus applications were used. The only treatments which included potassium were: $N_0P_0K_{50}$, $N_{100}P_{100}K_{50}$, $N_0P_0K_{100}$ and $N_{100}P_{100}K_{100}$.

3.4.2B.3 Experiment 3: Sulphur Response of Selected Cool Season Species Grown in Paddock Extremity Soil.

This experiment was run immediately following Experiment 2 in which plants grown in paddock extremity soils showed symptoms similar to those produced by sulphur deficiency (Jones et al. 1951). Accordingly, a pilot trial including sulphur was conducted on soil from the paddock extremity, i.e. the 280-340 m zone. This trial was an incomplete factorial involving 3 replications, the same 4 cool season species as used in the previous experiment, 1 soil type, 2 levels of nitrogen (0 and 100 ppm added), 2 levels of phosphorus (0 and 100 ppm added) and 2 levels of sulphur (0 and 50 ppm added). Treatments not included were $N_0P_{100}S_{50}$, $N_0P_{100}S_0$, $N_{100}P_0S_0$ and $N_{100}P_0S_{50}$.

3.4.2B.4 Experiment 4: Nutrient Responses of Selected Native Warm Season Perennial Grasses.

This experiment was a complete 3x3x3x2x2x3 factorial involving 3 replications, 3 species, 3 soils (sheep camp, 160-200 m zone and 280-340 m zone), 2 levels of nitrogen (0 and 100 ppm added), 2 levels

of phosphorus (0 and 100 ppm added) and 3 levels of sulphur (0, 50 and 100 ppm added). The species selected were *Chloris truncata* and *Cymbopogon refractus* together with the naturalised cool season annual, *Bromus molliformis*.

3.4.2B.5 Experiment 5: Nutrient Responses of Selected Native Warm Season Perennials and a Naturalised Cool Season Annual.

This experiment was a complete 3x4x3x2x2x3 factorial involving 3 replications, 4 species, 3 soils (sheep camp, 160-200 m zone and 280-340 m zone), 2 levels of nitrogen (0 and 100 ppm added), 2 levels of phosphorus (0 and 50 ppm added) and 3 levels of sulphur (0, 50 and 100 ppm added). The species selected were *Eragrostis molybdea, Sporobolus elongatus* as the two warm season perennials and *Vulpia myuros* and *Bromus molliformis* the two naturalised cool season annuals.

3.4.2B.6 Experiment 6: Nutrient Responses of Selected Native Warm Season Perennial Grasses.

This final preliminary pot trial was a complete 3x4x3x2x2x2 factorial involving 3 replications, 4 species, 3 soils (sheep camp, 160-200 m zone and 280-340 m zone), 2 levels of nitrogen (0 and 200 ppm added), 2 levels of phosphorus (0 and 100 ppm added) and 2 levels of sulphur (0 and 50 ppm added). The species selected were *Bothriochloa macra, Sorghum leiocladum* and *Themeda australis,* all native warm season perennial grasses together with the naturalised cool season annual, *Bromus molliformis*.

3.4.3 Results.

3.4.3.1 Experiment 1: Nitrogen and Phosphorus Distribution Within Pots.

Nitrogen:

No evidence of nitrogen accumulation was obvious in any sub-sample of the sealed pot units (Table 3.6). The overall means were 2782 ppm nitrogen in the pots receiving no nitrogen application as compared to 2914 ppm nitrogen in the pots receiving 100 ppm nitrogen as added nutrient. The significant difference in nitrogen status between the 3 soil types used is consistent with the results obtained from the soils analysis (Figs. 3.3, 3.4 and 3.5).

Phosphorus:

Added phosphorus appears to have been confined to the top two sub-samples as adding phosphorus had no significant effect on the phosphorus levels of the bottom two sub-samples (Table 3.7). However, the phosphorus distribution was not uniform in the sub-samples of the pots either with or without applied phosphorus.

TABLE 3.6

Nitrogen levels (ppm) in four sub-samples of pots containing three different soil types. Values shown are the average of both nitrogen addition rates.

Values followed by the same letter are not significantly different at the 5% level (Duncan's multiple range).

ZONE OF SOIL	SUBSAMPLE 1	SUBSAMPLE 2	SUBSAMPLE 3	SUBSAMPLE 4
Sheep Camp	4678 a	4311 a	4426 a	4488 a
160-200 metre zone.	2351 b	2308 b	2384 b	2244 b
280-230 metre zone.	1680 c	1680 c	1787 c	1848 c

TABLE 3.7

Phosphorus levels (ppm) in 4 soil sub-samples from pots as affected by phosphorus application averaged over three soil types. Values followed by the same letter are not significantly different at the 5% level (Duncan's multiple range).

PHOSPHORUS APPLICATION (ppm)	SUBSAMPLE 1	SUBSAMPLE 2	SUBSAMPLE 3	SUBSAMPLE 4
P_0	365 c	412 b	402 b	346 c
P_{100}	487 a	465 a	430 b	352 c

A significant difference in phosphorus status between the 3 soil types was again consistent with the results of the previous soils analysis (Table 3.8).

TABLE 3.8

Phosphorus levels (ppm) in each of the 3 soil types. Values are averages over both phosphorus addition rates. Concentrations followed by the same letter are not significantly different at the 5% level (Duncan's multiple range).

ZONE OF SOIL	sheep camp	160-200 m ZONE	280-340 m ZONE
Phosphorus concentration (ppm)	604 a	338 b	280 c

3.4.3.2 Response of Species to Soil Types.

3.4.3.2.1 Experiment 2.

Biomass averaged over all nitrogen and phosphorus treatments indicated significant differences in response by all species to the different soil types. Further, within each soil type the individual species responded differently. These differences were most marked in the growth of species on sheep camp soil, less so in the 160-200 m zone soil and non-significant in the 280-340 m zone soil (Fig. 3.11)

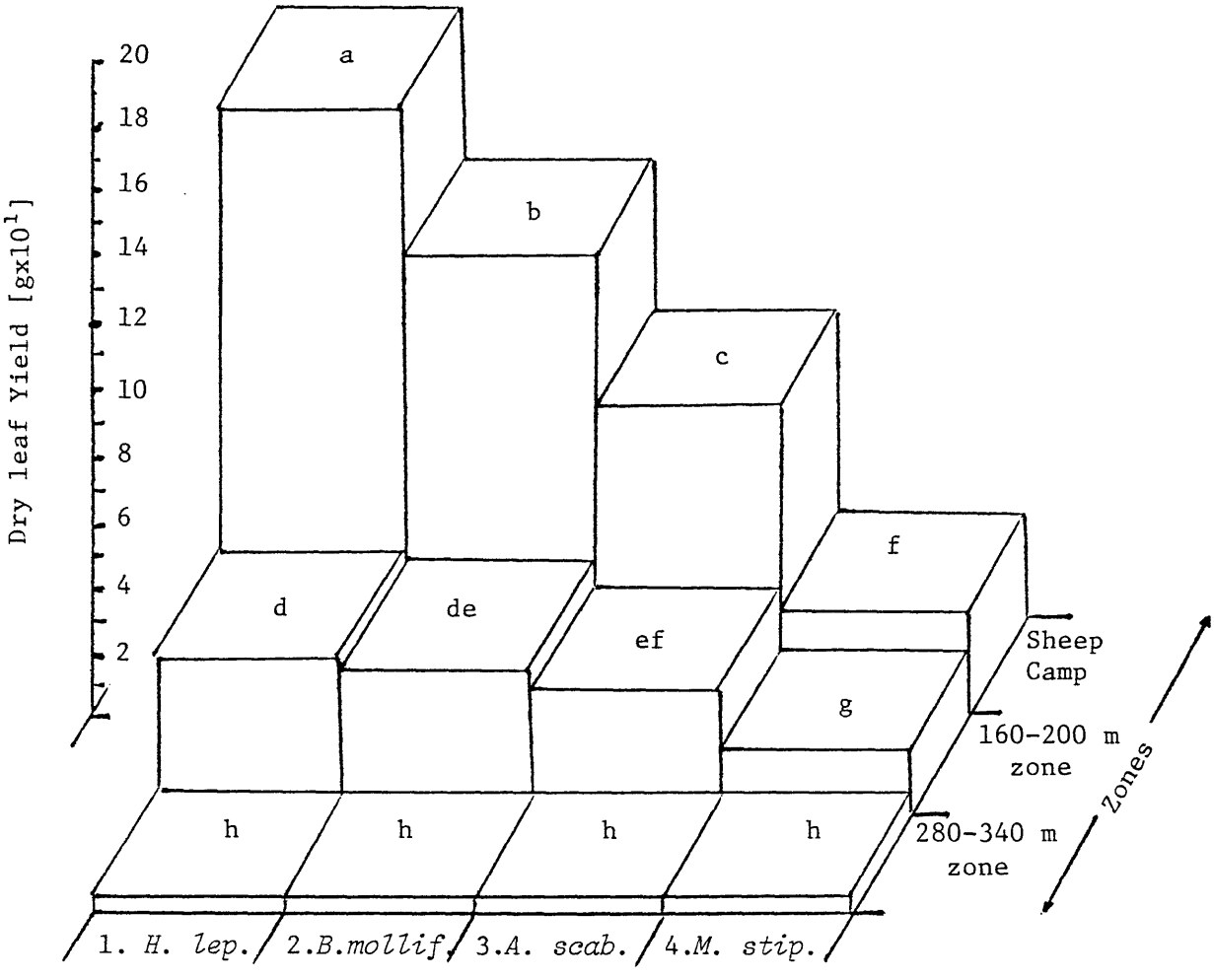
3.4.3.2.2 Experiments 4, 5 and 6.

The biomass averaged over all nitrogen, phosphorus and sulphur treatments indicated significant differences in response by all species to the different soil types in each of the experiments 4, 5 and 6, as was the case with Experiment 2. Again, the individual species responded differently within each soil type and the most marked differences were observed in the sheep camp soil, less so in the 160-200 m zone soil and least in the 280-340 m zone soil (Figs. 3.12, 3.13 and 3.14).

3.4.3.3 Which Nutrients Produced the Best Physiological Responses in the Species?

3.4.3.3.1 Experiment 2: Potassium Addition.

Potassium addition did not produce significant biomass differences. No nutrient application containing potassium produced significant increases in the biomass of species when grown in paddock extremity soil (280-340 m zone). However, potassium addition did significantly lengthen the 2nd leaf emergence time and 1st tiller emergence time of *Microlaena stipoides* when grown in sheep camp soil (Fig. 3.15).

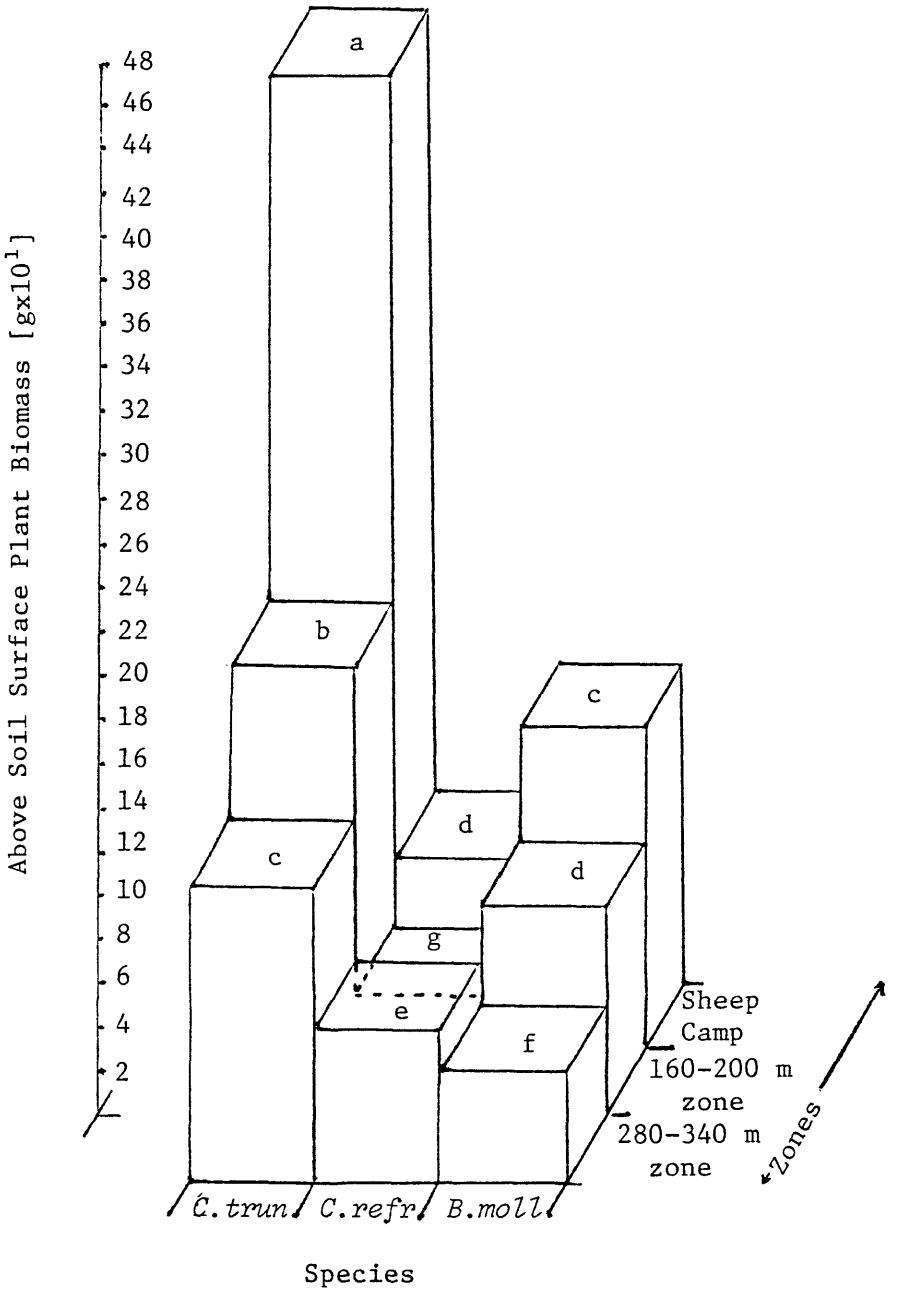


Experiment 2

Fig. 3.11 Dry leaf yield (Biomass) of various cool season grasses grown in soils collected from different distances from a sheep camp.

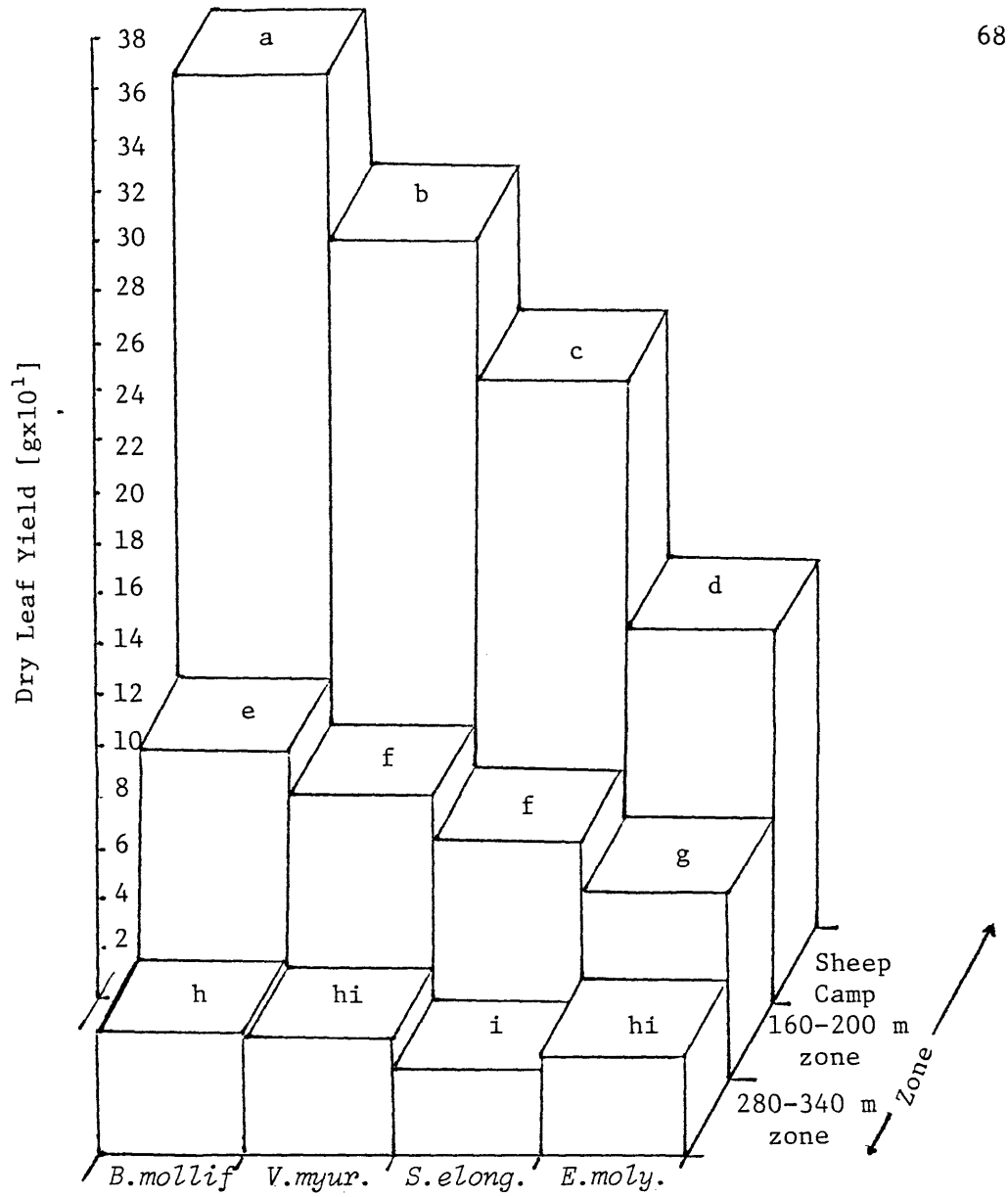
Values shown are the average of all treatments.

Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).



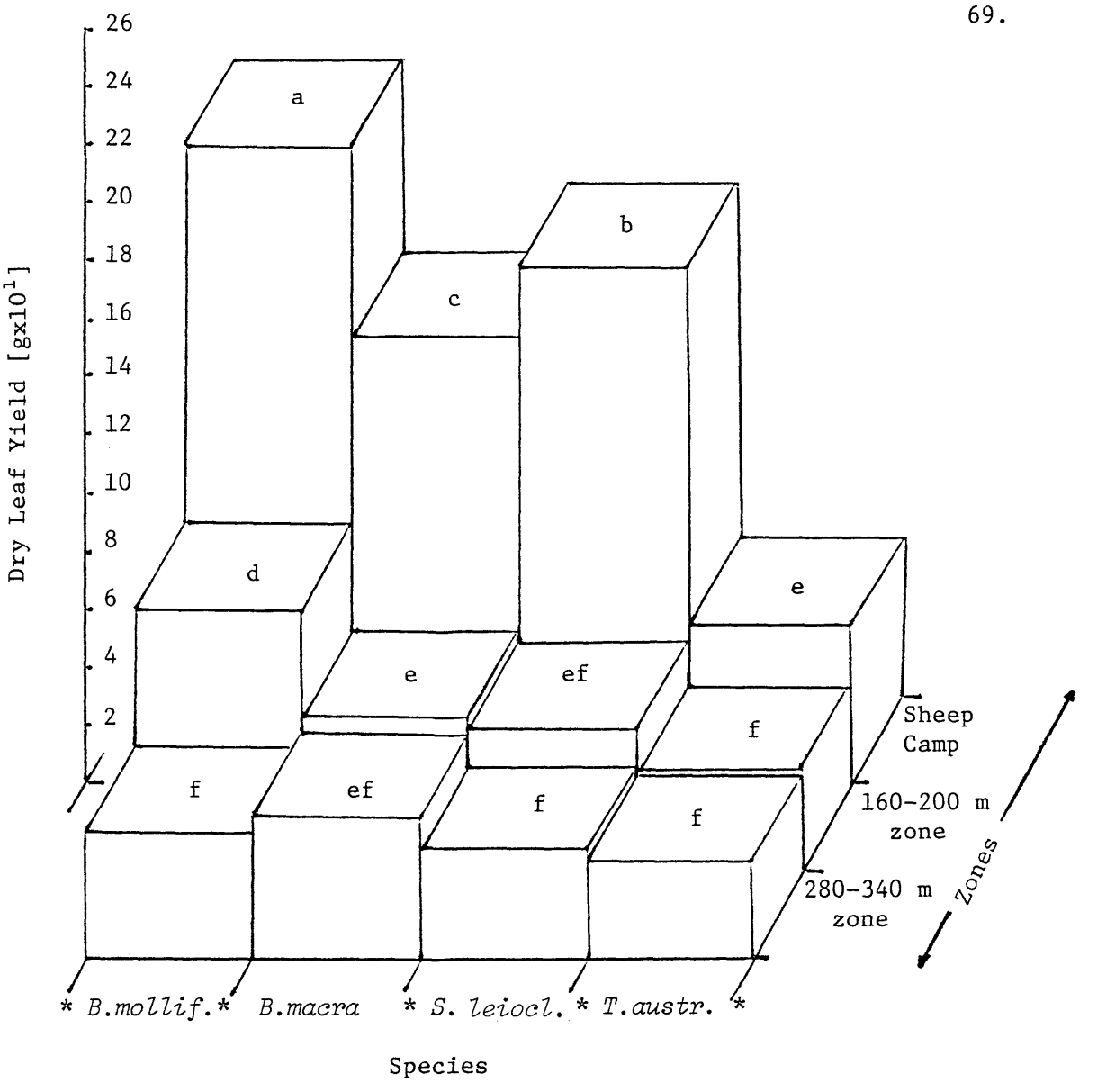
Experiment 4

Fig. 3.12 Yield (above soil surface Biomass) of two warm season perennials as compared to a cool season annual when grown in soils collected at various distances from a sheep camp. Values are means of all fertilizer treatments.
Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).



Experiment 5

Fig. 3.13 Dry leaf yield (Biomass) of two native summer perennial grasses and two naturalised cool season annuals when grown in soils collected at various distances from a sheep camp.
Values are means of all fertilizer treatments.
Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).

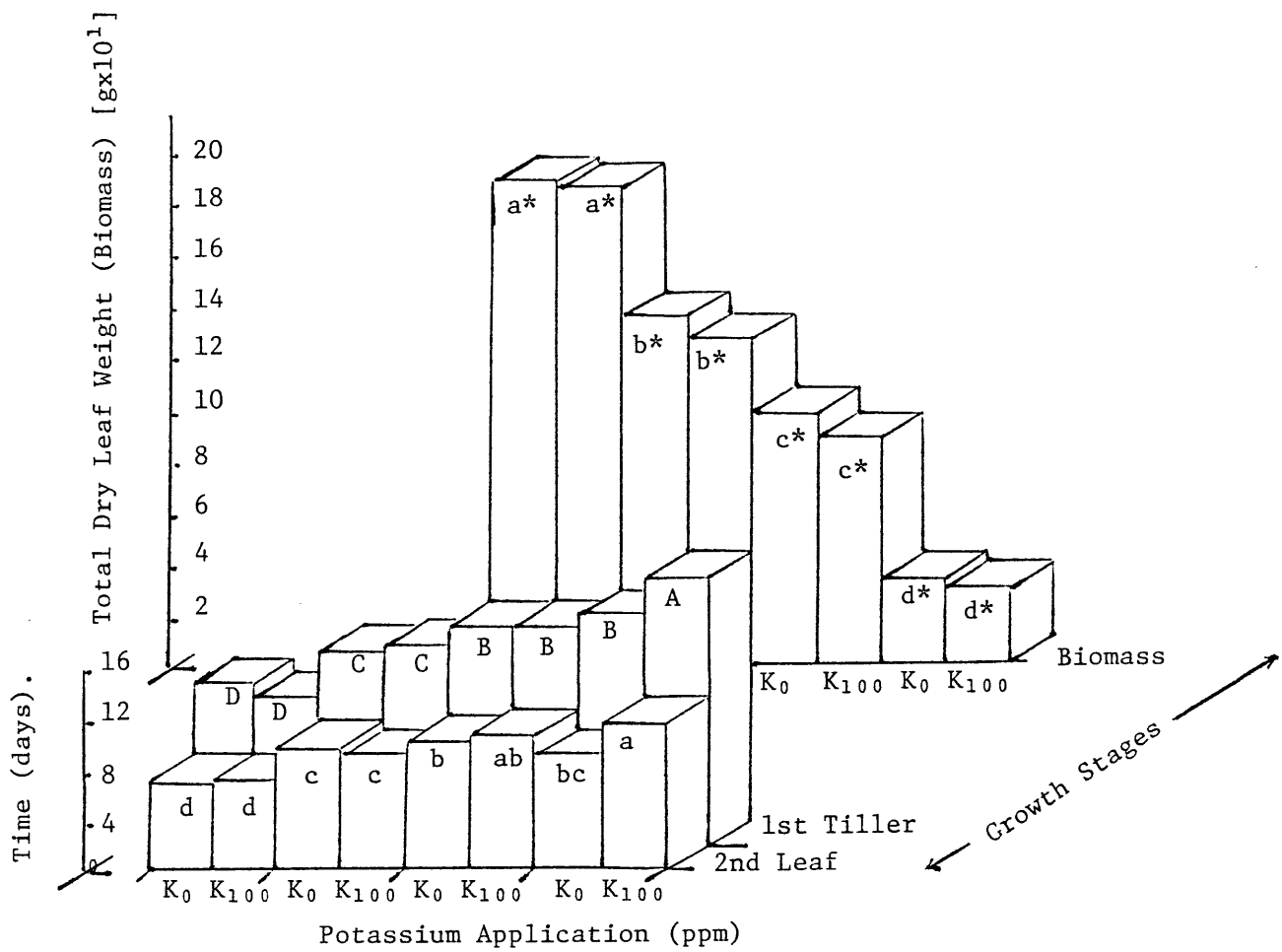


Experiment 6

Fig. 3.14 Dry leaf yield (Biomass) of three native warm season perennial species as compared to a cool season annual when grown in soils collected at various distances from a sheep camp.

Values are means of all fertiliser treatments.

Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).



* *H.lep.* * *B.moll** *A.scab** *M.stip**

Species

Fig. 3.15 Effect of potassium addition on 2nd leaf emergence time, 1st tiller emergence time and total dry leaf weight (Biomass) of selected cool season native and naturalised grasses grown in sheep camp soil.

Values shown are averages of all nitrogen and phosphorus addition.

Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).

Comparisons are only made within each growth stage.

3.4.3.3.2 Experiment 3: Sulphur Response of Selected Cool Season Species Grown in Paddock Extremity Soil.

The addition of sulphur, nitrogen and phosphorus, in combination, significantly increased biomass averaged over all species. There was also a significant difference among the yields of the species averaged over all nutrient levels with *Microlaena stipoides* giving the lowest yield and *Agropyron scabrum* the highest. There was a strong species x sulphur x nitrogen and phosphorus interaction with *Agropyron scabrum, Hordeum leporinum* and *Bromus molliformis* giving a significantly greater sulphur x nitrogen and phosphorus interaction than *Microlaena stipoides* (Fig. 3.16). Further, the maximum nutrient combination used in the experiment produced biomass yields of all species which were at least comparable with the yields obtained by the same species grown in sheep camp soil in Experiment 2 (Table 3.9), with no nutrient addition.

3.4.3.3.3 Experiment 4.

Chloris truncata recorded the highest yield with $N_{100}P_{100}S_{50}$ nutrient addition which was significantly different from yields obtained from $N_{100}P_{100}S_{0}$ and $N_{100}P_{100}S_{100}$ applications. A reduction in biomass between $N_{100}P_{100}S_{50}$ and $N_{100}P_{100}S_{100}$ was also noted for both *Bromus molliformis* and *Cymbopogon refractus* but the differences were not significant (Table 3.10).

3.4.3.3.4 Experiment 5.

All species indicated a positive response to nitrogen application. Further, the response to nitrogen was significantly different when all species were compared with each other (Table 3.11). Similarly, all species indicated a positive response to phosphorus application with the response being significantly different when all species were compared with each other (Table 3.12).

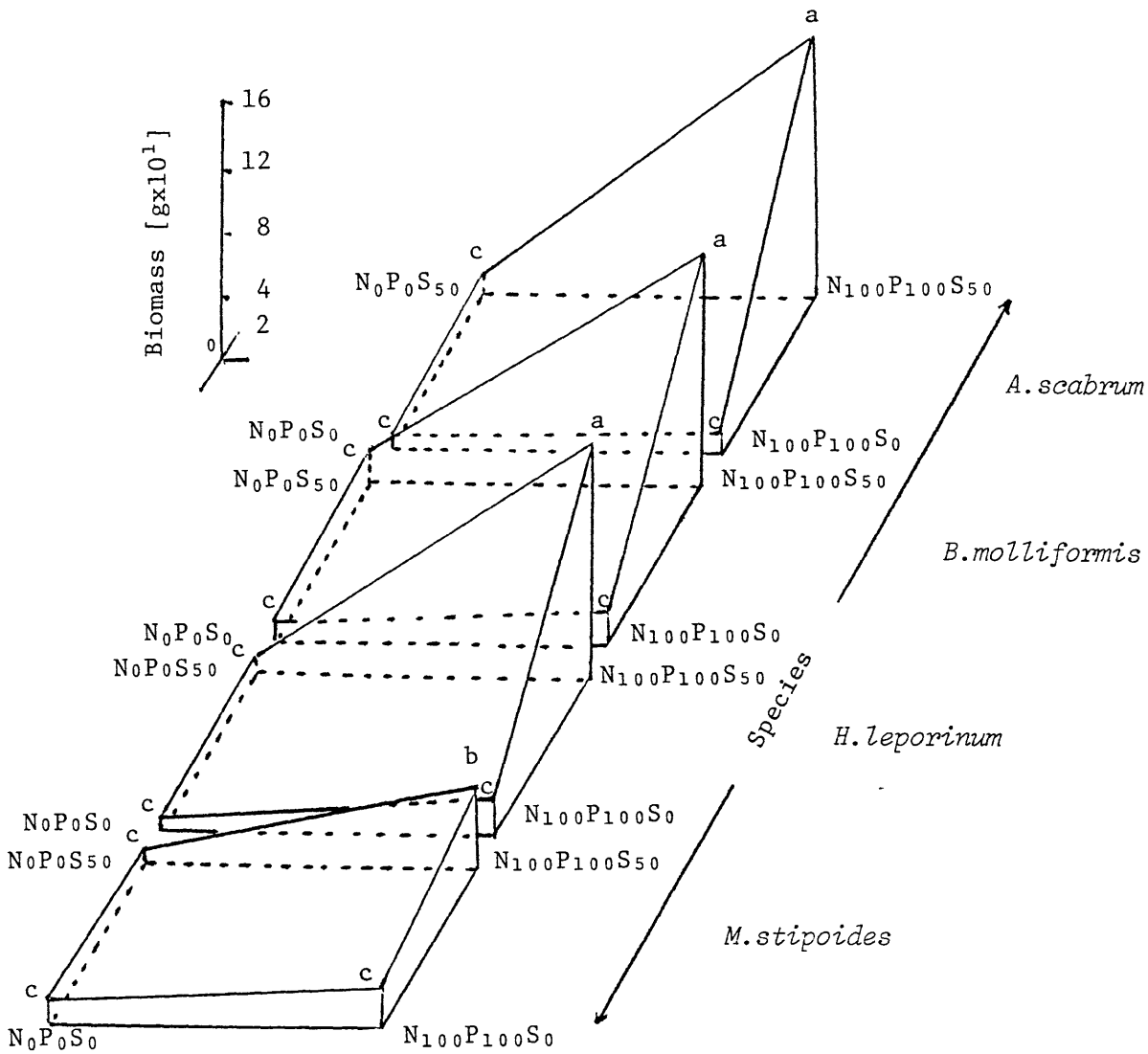


Fig. 3.16 Effect of sulphur addition on biomass of selected cool season native and naturalised grass species grown in paddock extremity soil.

Values are means of three replicates.

Means not significantly different at the 5% level are indicated by the same letter across all species and treatments (Duncan's multiple range).

TABLE 3.9

Comparison of biomass yields of native and naturalised species grown in sheep camp soil without nutrient application and paddock extremity soil with $N_{100}P_{100}S_{50}$ nutrient application.

SPECIES	SHEEP CAMP	280-340 M ZONE + $N_{100}P_{100}S_{50}$	
	Biomass Yield (g) Experiment 2	Biomass Yield (g) Experiment 3	% of Sheep Camp Yield Experiment 2
Microlaena stipoides	0.38	0.52	136.8
Hordeum leporinum	1.88	1.54	81.9
Bromus molliformis	1.42	1.50	105.6
Agropyron scabrum	0.88	1.66	188.6

TABLE 3.10

Average biomass (g) over all three soil types of *Bromus molliformis*, *Cymbopogon refractus* and *Chloris truncata* at varying applications of nitrogen, phosphorus and sulphur (ppm). Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).

PHOSPHORUS (PPM)		P_0					
NITROGEN (PPM)		N_0			N_{100}		
SPECIES		*B. mollif.*	*C. refr.*	*C. trunc.*	*B. mollif*	*C. refr.*	*C. trunc.*
SULPHUR (PPM)	S_0	0.78 de	0.47 e	1.95 cd	0.91 de	0.48 e	2.25 cd
	S_{50}	0.83 de	0.47 e	2.13 cd	1.00 de	0.50 e	2.64 c
	S_{100}	0.78 de	0.47 e	1.88 cd	0.94 de	0.41 e	2.45 c
PHOSPHORUS (PPM)		P_{100}					
NITROGEN (PPM)		N_0			N_{100}		
SPECIES		*B. mollif.*	*C. refr.*	*C. trunc.*	*B. mollif.*	*C. refr.*	*C. trunc.*
SULPHUR (PPM)	S_0	0.87 de	0.72 de	2.86 c	1.07 de	0.89 de	2.95 bc
	S_{50}	0.97 de	0.74 de	2.22 cd	1.46 d	0.95 de	4.38 a
	S_{100}	0.92 de	0.68 de	2.28 c	1.42 d	0.89 de	3.59 b

TABLE 3.11

Biomass (g) response of selected native and naturalised grass species to nitrogen addition (ppm). Values are means of all soil types, phosphorus and sulphur applications.
Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).

NITROGEN APPLICATION (PPM)	SPECIES			
	B. molliformis	*V. myuros*	*E. molybdea*	*S. elongatus*
N_0	1.61 b	1.41 c	0.84 f	1.15 d
N_{100}	2.01 a	1.61 b	0.92 e	1.34 c

TABLE 3.12

Biomass (g) response of selected native and naturalised grass species to phosphorus addition (ppm). Values are means of all soil types, nitrogen and sulphur applications.
Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).

PHOSPHORUS APPLICATION (PPM)	SPECIES			
	B. molliformis	*V. myuros*	*E. molybdea*	*S. elongatus*
P_0	1.72 b	1.42 d	0.75 h	1.18 f
P_{100}	1.90 a	1.61 c	1.02 g	1.31 e

The upper two levels of sulphur application did not produce significant differences in biomass yields and only *Bromus molliformis* and *Vulpia myuros* produced significant biomass differences when the first and second level of sulphur application was considered. However, as was the case with other nutrient applications, all species responded differently when compared with each other, at each sulphur level averaged over the whole experiment (Table 3.13).

When all nutrient applications were considered, the biomass yields, averaged over all species and soil types, indicated that a significant difference and optimum yield was obtained at the maximum nitrogen and phosphorus application and the mid sulphur application, i.e. $N_{100}P_{50}S_{50}$ (Table 3.14).

A comparison of species responses to no nutrient application with optimum nutrient application in each zone is illustrated in Table 3.15. Although all species gave reduced yields in the sheep camp soil with $N_{100}P_{50}S_{50}$ nutrient addition, only *Vulpia myuros* produced a significant reduction in yield. All species except *Eragrostis molybdea* had significant increases in biomass yield in the 160-200 metre zone soil with $N_{100}P_{50}S_{50}$ nutrient addition. All species had the most significant increase in biomass yield in paddock extremity (280-340 m) soil with $N_{100}P_{50}S_{50}$ nutrient addition. Although the paddock extremity soil indicated the greatest increase in biomass at the $N_{100}P_{50}S_{50}$ nutrient level when compared to the response of the same species to no nutrient addition in this zone, this zone also indicated the least differences in biomass yields between species at each nutrient level. In sharp contrast, sheep camp soils indicated the greatest biomass differences between the species at each nutrient level.

TABLE 3.13

Biomass (g) response of selected native and naturalised grass species to sulphur addition (ppm). Values are means of all soil types, nitrogen and phosphorus applications.

Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).

SULPHUR APPLICATION (PPM)	SPECIES			
	B. molliformis	*V. myuros*	*E. molybdea*	*S. elongatus*
S_0	1.65 b	1.46 d	0.86 f	1.23 e
S_{50}	1.85 a	1.56 c	0.94 f	1.29 e
S_{100}	1.93 a	1.53 c	0.85 f	1.21 e

TABLE 3.14

Biomass (g) response of selected native and naturalised grass species to nitrogen, phosphorus and sulphur application.
Values are means of all soil types and species.
Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).

SULPHUR APPLICATION	PHOSPHORUS APPLICATION (PPM)			
	P_0		P_{50}	
	NITROGEN APPLICATION		NITROGEN APPLICATION	
	N_0	N_{100}	N_0	N_{100}
S_0	1.28 c	1.28 c	1.37 b	1.27 c
S_{50}	1.28 c	1.24 cd	1.26 c	1.86 a
S_{100}	1.19 cd	1.32 bc	1.14 cd	1.86 a

TABLE 3.15

Biomass (g) yields of selected native and naturalised grass species in each of the three soil types with no nutrient addition and with $N_{100}P_{50}S_{50}$ nutrient addition.
Values are means of all replicates.
Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).

SOIL ZONE	NUTRIENT APPLICATION	SPECIES			
		B.molliformis	*V.myuros*	*E.molybdea*	*S.elongatus*
Sheep Camp	$N_0P_0S_0$	3.79 a	3.00 b	1.72 e	2.74 bc
	$N_{100}P_{50}S_{50}$	3.71 a	2.58 c	1.53 ef	2.33 cd
160 - 200 m	$N_0P_0S_0$	0.92 fg	0.97 fg	0.73 g	0.79 g
	$N_{100}P_{50}S_{50}$	2.15 d	1.71 e	1.02 fg	1.22 f
280 - 340 m	$N_0P_0S_0$	0.22 h	0.21 h	0.19 h	1.02 fg
	$N_{100}P_{50}S_{50}$	1.55 ef	1.54 ef	1.41 ef	1.63 e

3.4.3.3.5 Experiment 6.

Only *Bromus molliformis* and *Bothriochloa macra* gave a positive response to nitrogen. Neither *Sorghum leiocladum* and *Themeda australis* responded to nitrogen application. *Themeda australis* gave the lowest biomass yield when compared with the other species in the trial (Table 3.16). However, all species gave a positive response to phosphorus application with the responses being significantly different when all species were compared with each other (Table 3.17). Response to sulphur addition indicated different responses by the species to those with phosphorus or nitrogen addition. *Bromus molliformis* was the only species to significantly increase its biomass yield with sulphur addition. Both *Bothriochloa macra* and *Themeda australis* did not produce a significant increase in biomass yield and *Sorghum leiocladum* had its biomass yield significantly decreased with sulphur addition (Table 3.18). *Themeda australis* had the lowest biomass yield with or without sulphur addition when compared with the other species as was the case with both the addition of nitrogen and phosphorus.

A comparison of species responses between no nutrient application and maximum nitrogen, phosphorus and sulphur combined application in each soil type is made in Table 3.19. *Bromis molliformis* responded positively as it had done in all previous experiments. This response is in sharp contrast to the responses of the three native warm season perennial grasses; whereas *Themeda australis* did not appear to be significantly affected on sheep camp soil with maximum combined nutrient addition, both *Bothriochloa macra* and *Sorghum leiocladum* had their yields reduced. No significant increase or decrease in yield was recorded for the three native warm season perennial grasses, in the 160-200 m soil zone but

in the paddock extremity soil a different response again resulted. All three grasses gave significant increases in biomass yield to the maximum combined nutrient addition. Further, when the 160-200 m and the 280-340 m zone responses are compared, no significant differences in biomass yield were recorded between the species in each soil type without nutrient addition.

3.4.3.4 Experiments 4, 5 and 6: The Effects of Nitrogen, Phosphorus and Sulphur Addition to Paddock Extremity Soils.

In all three experiments combinations of nitrogen, phosphorus and sulphur were applied in order to provide further evidence of the importance of the nutrients. Similar results to those obtained in Experiment 3 were obtained. Markedly increased biomass yields were produced in paddock extremity soils (280-340 m zone) with the addition of nitrogen, phosphorus and sulphur in combined application. It appears that a decrease in phosphorus application may markedly decrease the biomass yield in paddock extremity soil. Experiment 5 included an application of only 50 ppm phosphorus compared with Experiments 4 and 6 which included 100 ppm phosphorus.

Experiment 5 produced the lowest percentage comparison of biomass yields of species grown in paddock extremity soil, plus combined nutrient application, with that of the same species grown in sheep camp soil without nutrient addition (Table 3.20). The effect of 100 ppm sulphur compared to 50 ppm sulphur was shown in Experiment 5. Nitrogen, on the other hand, when increased to 200 ppm in Experiment 6 had no directly observable effect on overall biomass yield of the species.

TABLE 3.16

Biomass (g) response of selected native warm season perennial grasses to nitrogen addition (ppm). Values are means of all soil types, phosphorus and sulphur applications.

Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).

NITROGEN APPLICATION (PPM)	SPECIES			
	B. molliformis	*B. macra*	*S. leiocladum*	*T. australis*
N_0	0.93 b	0.77 c	0.88 b	0.45 d
N_{200}	1.41 a	0.93 b	0.89 b	0.40 d

TABLE 3.17

Biomass (g) response of selected native warm season perennial grasses to phosphorus addition (ppm). Values are means of all soil types, nitrogen and sulphur additions. Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).

PHOSPHORUS APPLICATION (PPM)	SPECIES			
	B.molliformis	*B. macra*	*S.leiocladum*	*T. australis*
P_0	1.02 b	0.77 d	0.72 d	0.33 f
P_{100}	1.34 a	0.93 c	1.05 b	0.51 e

TABLE 3.18

Biomass (g) response of selected native warm season perennial grass species to sulphur addition (ppm). Values are means of all soil types, nitrogen and phosphorus applications. Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).

SULPHUR APPLICATION (PPM)	SPECIES			
	B. molliformis	*B. macra*	*S.leiocladum*	*T. australis*
S_0	0.99 b	0.85 c	0.92 b	0.40 d
S_{50}	1.36 a	0.85 c	0.85 c	0.46 d

TABLE 3.19

Biomass (g) yields of selected native warm season perennials in each of three soil types with no nutrient addition and with maximum nutrient addition ($N_{200}P_{100}S_{50}$). Values are means of all replicates. Values indicated by the same letter are not significantly different at the 5% level (Duncan's multiple range).

SOIL ZONE	NUTRIENT APPLICATION	SPECIES			
		B.molliformis	*B. macra*	*S.leiocladum*	*T. australis*
Sheep Camp	$N_0P_0S_0$	1.37 cd	1.68 c	2.01 b	0.79 e
	$N_{200}P_{100}S_{50}$	2.87 a	1.21 d	1.51 cd	0.54 ef
160 - 200 m	$N_0P_0S_0$	0.61 ef	0.30 fg	0.42 f	0.34 fg
	$N_{200}P_{100}S_{50}$	1.81 bc	0.71 ef	0.61 ef	0.63 ef
280 - 340 m	$N_0P_0S_0$	0.15 fg	0.12 fg	0.12 fg	0.06 g
	$N_{200}P_{100}S_{50}$	1.64 c	1.29 d	1.20 d	0.77 e

TABLE 3.20

Sheep Camp biomass compared with 280-340 m soil biomass and 280-340 m soil plus nutrient application, biomass.
All yields are means of three replicates. Values indicated by the same letter in each experiment are not significantly different at the 5% level (Duncan's multiple range).

EXPERIMENT & SPECIES	SHEEP CAMP YIELD (g)	280-340 M SOIL		280-340 M SOIL & NUTRIENTS	
		YIELD (g)	% OF SHEEP CAMP YIELD	YIELD (g)	% OF SHEEP CAMP YIELD
EXPERIMENT 4		NUTRIENT APPLICATION $N_{100}P_{100}S_{50}$			
		(g)	%	(g)	%
B.molliformis	1.35 bc	0.29 d	21.5	1.23 bc	91.1
C.refractus	0.93 c	0.34 d	36.6	1.65 b	177.4
C.truncata	4.13 a	0.40 d	9.7	3.94 a	95.4
EXPERIMENT 5		NUTRIENT APPLICATION $N_{100}P_{50}S_{50}$			
B.molliformis	3.79 a	0.22 h	5.8	1.55 ef	40.9
V.myuros	3.00 b	0.21 h	7.0	1.54 ef	51.3
E.molybdea	1.72 e	0.19 h	11.0	1.41 ef	82.0
S.elongatus	2.74 bc	1.02 fg	37.2	1.63 e	59.5
EXPERIMENT 6		NUTRIENT APPLICATION $N_{200}P_{100}S_{50}$			
B.molliformis	1.37 cd	0.15 fg	10.9	1.64 c	119.7
B.macra	1.68 c	0.12 fg	6.0	1.29 d	76.8
S.leiocladum	2.01 b	0.12 fg	6.0	1.20 d	59.7
T.australis	0.79 e	0.06 g	7.6	0.77 e	97.5

3.4.4 Discussion.

The method of nutrient application used in these experiments seemed to be satisfactory and was certainly quick and convenient. Nitrogen was uniformly distributed throughout the pots (Table 3.6) while the added phosphorus tended to remain in the upper layers of the pots. However, the phosphorus distribution was not uniform in the pots without applied phosphorus as an accumulation of phosphorus occurred in the middle layers (Table 3.8).

A comparison of the results from Experiments 2 and 3 suggested that nitrogen, phosphorus and sulphur gave a far stronger interaction, as measured by the species physiological responses, than nitrogen, phosphorus and potassium. This response was further supported by similar nitrogen, phosphorus and sulphur interactions obtained with other species in Experiments 4, 5 and 6.

Although potassium addition did not significantly reduce the biomass of the cool season annuals, the data suggest that higher potassium values may decrease the biomass yield of *Agropyron scabrum* and *Bromus molliformis* and in part explain why *Hordeum leporinum* is dominant on the high nutrient sheep camp soil rather than *Bromus molliformis*. Potassium addition significantly lengthened the tillering time of *Microlaena stipoides*. Again this could have significant bearing on the absence of *Microlaena stipoides* from the centre of sheep camps with high potassium concentration.

All species used in the trials, whether cool season annual or warm season perennial, responded uniquely to the three different soil types. Each species produced a significantly greater biomass yield

on sheep camp soils than on the other two soil types. However, the biomass yields of individual species on the sheep camp soils were also significantly different. Further, the consistent and therefore predictable response of *Bromus molliformis* in all trials, tends to support cautious comparison between the trials. Both *Hordeum leporinum* and *Bromus molliformis* indicated significant differences in all three soil types, thereby suggesting a requirement for high nutrient levels for optimum growth. This is consistent with the work of Taylor (1980). On the other hand, *Themeda australis,* although exhibiting a significant positive response to the high nutrient soils, gave considerably lower yields than *Bromus molliformis.* The same may be said for *Microlaena stipoides* and *Cymbopogon refractus.* All other species indicated a strong positive response to sheep camp soil when compared with the other two soil types. *Chloris truncata* was the only species other than *Hordeum leporinum* to surpass the biomass yield of *Bromus molliformis* in any of the five experiments. Thus *Chloris truncata* gave a greater response to nutrient applications than the cool season annuals which, in their season of growth, dominate the high fertility sheep camp zones. However, its significant reduction of biomass yield with high sulphur applications is worthy of note since its response to high nutrient status appears incompatible with its field distribution.

Agropyron scabrum gave a marked response to applications of nitrogen, phosphorus and sulphur and produced more biomass in sheep camp soil and the 160-200 m zone soil than *Microlaena stipoides.* It did not respond differently from *Hordeum leporinum, Bromus molliformis* or *Microlaena stipoides* in the low nutrient, paddock extremity soil, where it most frequently appears.

$N_{100}P_{100}S_{50}$ nutrient application to paddock extremity soil produced a biomass of *Agropyron scabrum* comparable with that of the winter annuals, *Hordeum leporinum* and *Bromus molliformis*, grown under the same environmental conditions.

Vulpia myuros was the only species in Experiment 5 to display a reduction in biomass yield on sheep camp soil with additional nutrient ($N_{100}P_{50}S_{50}$) application. Similarly, *Bothriochloa macra* in Experiment 6 had its biomass significantly reduced in sheep camp soil with additional nutrient ($N_{100}P_{100}S_{50}$) application. These two species have a very similar distribution in native pastures and are both absent from the centre of well developed sheep camps. The high nutrient status of such sites would seem, at least, to be a contributing factor regarding their similar field distributions.

Sorghum leiocladum not only had its biomass yield significantly reduced on sheep camp soils with $N_{100}P_{100}S_{50}$ application but also in the presence of sulphur addition alone. It further did not respond to nitrogen application but responded to phosphorus. In contrast both *Eragrostis molybdea* and *Sporobolus elongatus* did not develop significant differences in biomass yield with sulphur addition but did respond to phosphorus and nitrogen application. In paddock extremity soils with nutrient ($N_{100}P_{50}S_{50}$) application, these two species produced equivalent biomass yields to *Bromus molliformis* and *Vulpia myuros*.

Overall the results obtained support the hypothesis that native species have the potential to respond to improved fertility levels (Lodge 1979) especially as regards combined applications of nitrogen, phosphorus and sulphur. The results suggest that species have an

optimum nutrient requirement in order to produce maximum biomass yield in the shortest possible time. Further, this nutrient optimum may well differ for each individual species. It would seem feasible, therefore, that an individual species may acquire significant competitive advantage in the environment which contained a nutrient status similar to its optimum requirement. The extent to which this idea explains species zonation in native pastures of the Northern Tablelands of N.S.W. requires further investigation.

Austin and Austin (1980) provided data which indicated that the response curves of species grown in monoculture may differ from those when grown in mixtures with other species. Such data suggests that preliminary experiments, attempting to elaborate on the relationships between nutrient status and species zonation in field situations, should include species in competition in a series of soils of different nutrient status.