AN INVESTIGATION OF SOME DIFFERENCES BETWEEN

ASPECTS IN HILL COUNTRY

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ABSTRACT

Climatic, edaphic and biotic variables were measured, over a twelve month period, at each of four aspects of a hill in the Southern Ruahine ranges. These variables were soil moisture status, soil temperature, air temperature, wind-speed, rainfall, soil nutrient status, sheep-dung deposition, and pasture botanical composition and productivity. Information on sunshine hours, maximum and minimum screen temperatures, relative humidity, and wind direction were obtained from the records of an adjacent meteorological station. Net radiation and potential evapotranspiration were calculated from meteorological data, and actual evapotranspiration from soil moisture data.

Large differences were recorded between aspects for most of the above mentioned variables. The wind during the observational period was a prevailing West/Northwesterly. Differences in net radiation between the north and south aspects were largest during the Winter and smallest during the summer months. In all cases the evapotranspiration values calculated were larger for the north than for the south aspect. Soil moisture tension differences were not detected during the winter months, but during the remainder of the year the north aspect was driest, followed by the east and west aspects, and the south aspect respectively. Differences between aspects, in terms of average monthly 4 cm. air temperature, were not apparent. However, large differences in the average monthly 4 cm. soil temperature of the various aspects were detected: during the January to August period the north aspect was warmest and the south coolest; during the October to December period the east aspect was warmest and the north and south aspects, which had similar average soil temperatures,were coolest.

The south and west aspect soils had greater nutritional limitations to plant growth than did the soils of the east and north aspects. This was probably due, at least in part, to nutrient transfer by grazing animals, and the differential action of soil-forming factors. Nitrogen mineralisation was closely associated with soil total nitrogen status, and was one of the main factors limiting pasture productivity. Soil moisture status was the other major limitation to pasture productivity. Pasture production during the observational period (346 days), for the east, south,west and north aspects respectively, was 9683, 3637, 2959 and 2771 kg./DM./ha. Some of the pasture species present were found

to be distributed in a definite pattern according to aspect, while for other species the pattern was indistinct. For a number of species no distribution pattern was detected. The patterns observed appeared to follow soil nutritional (especially mineral nitrogen) and soil moisture gradients.

Possible reasons for the above-mentioned differences, and some practical implications of these differences, are discussed.

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INTRODUCTION

This section is intended as an introduction to the study which is to be described, and as a means of introducing certain general ideas concerning aspect differences.

"Ecology is the science concerned with living organisms, both plant and animal, in relation to their environment or habitat" (Levy, 1970). Such a definition might not find favour with the more pedantic members of the ecological discipline, but does manage to convey the basic meaning of the term 'ecology' ie. the study of organisms 'at home' (Odum, 1959). Odum (1959) states that many terrestial ecosystems "have a particularly complex structure involving numerous species, marked stratification and variable physical environment, ... In local situations there is much to be gained from singling out a restricted component (for study)....... At the same time it is important that whole systems be studied simultaneously, since certain fundamental interrelationships can not be readily determined by piecemeal study." Any study of variation in a single environmental factor is purely descriptive if only that factor is measured eg. a record of pasture botanical composition differences between aspects, or between any contrasting areas, does not provide any explanation for the differences observed. A complete analysis of edaphic, climatic and biotic differences between aspects would be an extremely large and complicated undertaking. It is, however, possible to elucidate some of the interrelationships existing between the various environmental factors, through the study of selected variables. The selection of the variables which were examined in this study was based on two criteria: firstly, feasibility of measurement, and secondly, the likelihood of differences occurring between aspects, as judged by discussion and by perusal of relevant literature.

The literature reviewed in this study is of two broad categories: firstly, literature dealing with general concepts of aspect differences, and secondly, specific literature, in most cases describing or reviewing experimental studies and the results obtained. The latter category is dealt with in Chapter I and the former is reviewed briefly below.

Microclimatic(1) differences are known to exist between land surfaces which are inclined in different directions, ie. between surfaces of different aspect (Warming, 1909; Braun-Blanquet, 1932; Geiger, 1965; Chang, 1968). Variation in the amount of direct solar radiation

(1) see discussion of the terms 'climate' and 'microclimate' in Introduction to Chapter I.

received by sloping surfaces is one of the main reasons for the existence of these microclimatic differences (Geiger, 1965). The associated differing energy input has a large influence on the energy balances which exist at the surfaces of the various aspects encountered in the hill country situation. A simple energy balance for a bare soil surface may be written as:

$$R_N + B + L + V = 0 \text{ (Geiger, 1965)}$$

where:

R_N = net radiation.

B = sensible heat loss to the ground.

L = latent heat loss due to evaporation.

V = sensible heat loss to the air.

The interrelationships of the elements of this balance are discussed in many texts, eg. Geiger, 1965; Slatyer and McIlroy, 1961; Munn, 1966. The magnitude of R_N is determined by the lack of balance between net incoming short-wave and net outgoing long-wave radiation. Near the ground, incoming short-wave radiation consists of a direct solar beam, and diffuse sky radiation, the latter coming from the whole hemisphere, although more intense in directions close to that of the sun itself (Slatyer and McIlroy, 1961). The proportion of incoming short-wave radiation which is diffuse varies from about 10% under clear-sky conditions, to 100% under overcast conditions. Thus, differences in short-wave radiation input between aspects will be greatest under clear-sky conditions. The proportion of the incoming short-wave radiation which is reflected from the surface it strikes is known as the albedo. The fraction not reflected is the net incoming short-wave radiation. The net outgoing long-wave radiation, mentioned above, represents the difference between terrestial and sky long-wave radiation.

The R_N component of the above balance is expended by sensible heat transfers which directly affect the temperature of the soil and air, and as latent heat during the evaporation of water. Slatyer and McIlroy (1961) point out that of all the variables involved in the energy balance only solar radiation can be regarded as at all independent of the others. Under steady conditions the factors of the balance adjust to come to an equilibrium. Geiger (1965) notes that the situation described above is often complicated by the horizontal transfer, or advection, of heat from surrounding areas, thus introducing an additional factor to the energy balance. Although the balance written above is for a bare soil surface, the addition of a vegetative cover to the surface would little alter the concepts developed in the above discussion.

It was previously noted that variation in the amount of direct solar radiation received by sloping surfaces is one of the main reasons for the existence of microclimatic differences in hill country. Wind also plays a role, in that air movement is involved in the determination of the magnitude of the components of the energy balance. Local winds may arise in mountainous hill country due to regions of different temperature (Geiger, 1965). However, in the New Zealand situation of prevailing winds and overall proximity to the coastline, and especially in the smaller-scale hill country of the North Island, it is probable that wind is only modified, rather than caused, by local topographic variation. Slatyer and McIlroy (1961) state that "wind is of considerable importance in microclimate, both as an element in its own right and because it is of such influence on the atmospheric structure of temperature and humidity". They conclude that the main effect of wind is to reduce extremes of variation in temperature and humidity, both in time and in space.

Local variation in rainfall may also occur in hill country. Geiger (1965) notes that the climate of slopes facing in different directions is affected to a large extent by moisture conditions, as well as radiation and wind, and that the smaller the topographic scale the more the local precipitation is determined by the wind field. In discussing small-scale precipitation differences, Geiger points out that more precipitation is found on the leeward than on the windward side of hills, especially where wind speeds are high. "By general agreement" (Geiger, 1965) precipitation is measured using horizontally disposed collecting surfaces, yet considerable controversy now exists as to the relative merits of using horizontal as opposed to tilted collecting surfaces (Geiger, 1965; Yates, 1970). Doubt also exists as to the proportions of recorded differences between aspects which are attributable to actual precipitation differences and those which are due to wind effects on raingauge catch (Rodda, 1966; Jackson and Aldridge, 1972).

Edaphic differences[1] between aspects might arise for any of a number of reasons. Ross (1971), in his review of aspect as a soil forming factor, notes that aspect, acting through microclimate and its effects on organisms, plays an important role in the ecology and thus soils of hillsides. Sears et al (1948) give figures for the annual nutrient turnover, via sheep excreta, for grazed pasture, and remark that fertilizer programmes should be constructed with reference to the transfer of dung and urine from one part of a paddock to another. Hilder (1966) discusses nutrient accumulation on stock camps under a sheep grazing regime, and also equates this accumulation with a loss from other parts

(1) Soil moisture status and temperature will be considered as climatic rather than edaphic factors; see Introduction to Chapter I.

of the paddock. The potential for nutrient transfer between aspects appears to exist, and coupled with the probable influence of microclimatic and pasture differences between aspects on animal grazing behaviour, such a transfer might be expected to lead to differences in soil and pasture characteristics between aspects. Grazing animals have a number of important effects on plant communities, these effects being due to physical damage, defoliation and the deposition of excreta (Spedding, 1971). Rumball and Grant (1972) go so far as to state that "the trampling, grazing, voiding animal is one of the major determinants of pasture composition."

From basic ecological concepts, variation in pasture structure, composition and productivity would be expected to be associated with the differing environments existing at different aspects.

The detection of variation in edaphic, biotic and climatic factors due to aspect, formed the basis of the study described herein. A hill in the Southern Ruahine ranges of the North Island was selected as an experimental site. Measurements of selected climatic, edaphic and biotic factors were made at each of the north, south, east and west aspects, over a twelve month period. A description of each of the selected factors was the prime aim of the study and the collection of data was cond ɔted with this in mind. However, a secondary aim did exist, namely to elucidate, where possible, the interrelationships existing between the environmental and pasture variables measured.

Throughout this thesis common names have been used, whenever possible, in referring to plant species. The corresponding botanical names have been noted the first time each common name is used in the text. A complete list of the common and botanical names of species encountered in this study is given in Appendix 10.

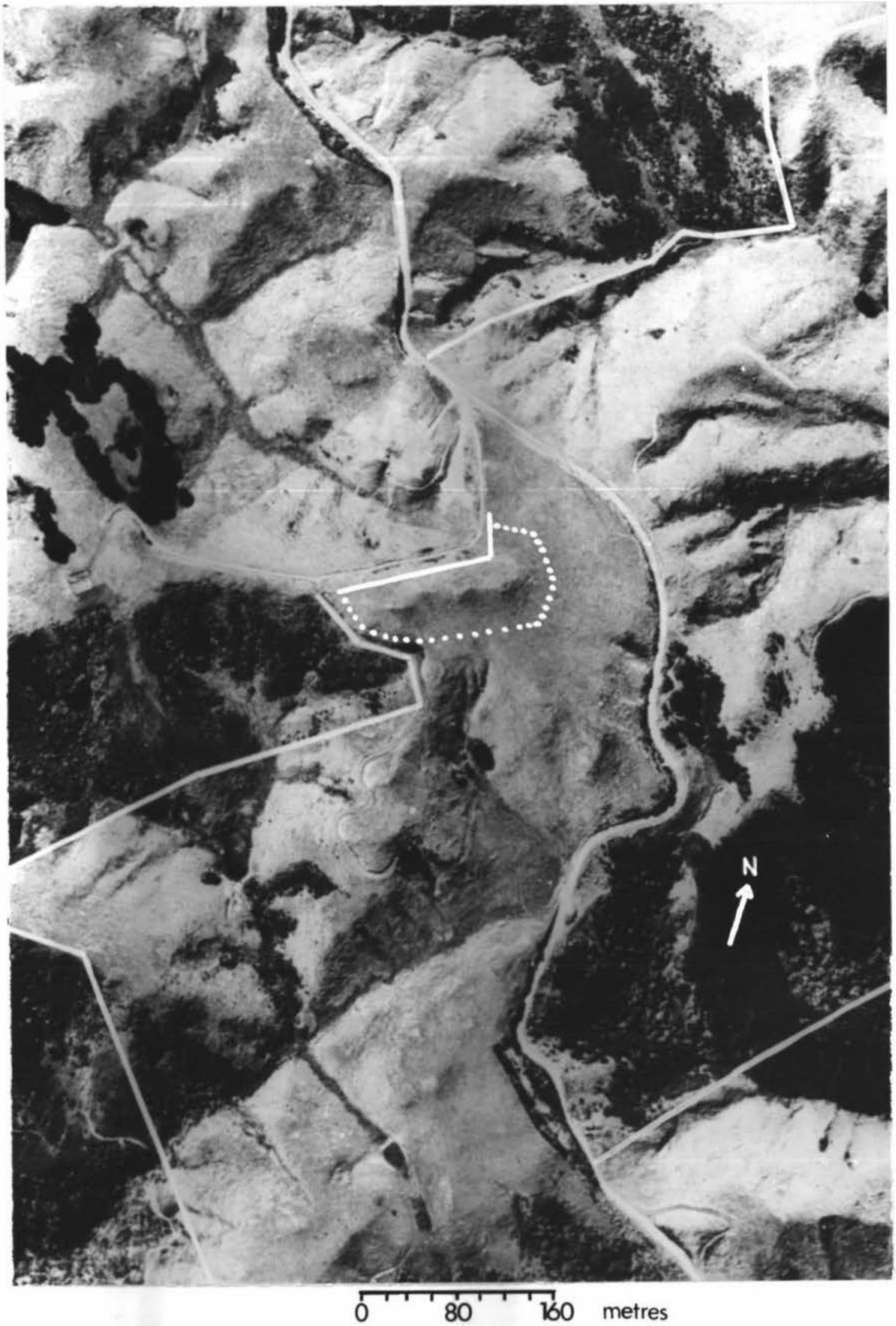


FIGURE I.1 Aerial View of Experimental area and Surrounds

CHAPTER I LITERATURE REVIEW

1. INTRODUCTION

For ease of consideration, the below review will be split into four sections, dealing specifically with differences in pasture, soil, animal and climatic factors between aspects. For purposes of classification, soil moisture status and soil temperature will be considered to be climatic factors. The terms 'climate' and 'microclimate' have been used as synonyms throughout. Slatyer and McIlroy (1961) state that "in the broad sense microclimatology involves the study of the climate near the ground..." Geiger (1965) uses a height of two metres as the boundary of the air layer near the ground. If 'microclimate' is used in this sense the climatic measurements which were made at each aspect were, in fact, microclimatic measurements. The sunshine hours, relative humidity, air temperature, rainfall and wind direction data which were recorded at the Ballantrae meteorological station (see Chapter II) might also be defined as micro-climatic measurements, with the possible exception of wind direction. However, the data recorded were applied to the individual aspects, (see Chapter II) each with a unique microclimate, and on this basis the measurements made at the meteorological station might be considered to be climatic rather than microclimatic measurements. In order to avoid the restrictions imposed by rigid definition, and as noted above, the two words have been used as synonyms.

In reviewing literature pertinent to this study, data from forest situations has largely been ignored. Direct comparisions of species distribution can obviously not be made between pasture and forest vegetation. Many of the herbivors present in either system are not common to both, and microclimatic comparisions are difficult to make in many instances. Geiger (1965) notes that the forest-floor climate, which is under the sheltering influence of the trunk area, is basically different from the climate of an area of bare ground. It is appreciated that the microclimate of a pasture is also different from that of an area of bare ground, but much of the published above-ground microclimatic data concerned with pasture has been collected above the vegetative layer, as opposed to the situation in forest studies. This view is supported by Cooper (1961), who notes that "it is impossible to compare the climate of an open area with that of the forest-trunk space".

2. MICROCLIMATIC DIFFERENCES BETWEEN ASPECTS

Some of the earliest reported data on climatic differences between aspects is noted by Warming (1909), who cites Giltay (1886) as making observations showing differences in temperature and humidity between North and South-facing slopes of sand dunes in Holland. Braun-Blanquet (1932) quotes Rubel (1908) as saying that the 'total light' on a south aspect (in the Northern Hemisphere) is greater than that on a north aspect. It should be noted at this point that although direct comparisons between east and west aspects may safely be made for different hemispheres, a north aspect in the Southern Hemisphere is comparable to a south aspect in the Northern Hemisphere and vice versa. In most of the studies reviewed comparisons have been made only between north and south aspects.

Weaver (1914) recorded atmometer evaporation over prairie vegetation, from May to September, in Washington and Idaho (approx. lat. 46°N). North slope evaporation was 64% of that on the south slope. Weaver attributes the differences recorded to the prevailing SE wind; the average wind velocity at 0.5m., during May, was 2.4 kph. on the north and 7.5 kph on the south aspect.

Shreve (1915), working in the Santa Catalina mountains, South Arizona (approx. lat. 33°N), found that the influence of aspect on various environmental factors increased with altitude. During March to September, North and South-facing sites at 915 to 1525 m. altitude had similar atmometer evaporation rates. Gravimetic soil moisture content was also similar, although only a limited amount of data was presented (March and June 1911, May 1914). At higher altitudes soil moisture was less and evaporation greater on south than on north slopes. In a later study, Shreve (1924) reported that on 10° to 12° slopes the average weekly maximum soil temperature at 7.5 cm. was greater on the north than on the south slope during the spring. As before, this occurred only at 915 to 1525 m. altitude, and at higher altitudes the difference was reversed. Shreve suggests that the lower altitude comparisons may have been conducted on slopes too small to show aspect differences. The soil temperature at noon was similar on the two aspects, but that of the north face continued to rise in the afternoon while that of the south face did not. Shreve comments that the sun was setting North of West, as the summer solstice was approaching, and this may have explained the differences in temperature. He does not consider either the fact that the sun would have been rising North of East, or the possibility of differences in wind velocity influencing soil temperatures on the two opposing faces.

Cottle (1932), working on approximately 30° slopes in SW Texas (approx. lat. 30°N), measured various environmental factors on north and south aspects during three growing seasons. Averages of fortnightly measurements over the three years showed soil moisture content to be less (by 5%), atmometer evaporation greater (by 54%), and relative humidity slightly lower, on the south than on the north aspect. Three-season averages of soil temperatures (taken at two to four week intervals) were 8°C higher at 5 cm., and 5°C higher at 30 cm., on the south than on the north aspect, despite the wind during the measurement period being a prevailing South to Southeasterly.

Aikman (1941), working on approximately 18° slopes in Southern Iowa (approx. lat. 41°N), considered the west aspect to be the most 'xeric', followed by the south, east and north aspects respectively. Temperature data is presented for July, 1931, only. The average air temperatures (from two-hourly thermograph readings) for north, east, south and west aspects were 25.5, 24.9, 24.1 and 25.8°C respectively. The average 5 cm. soil temperatures were 26.0, 27.7, 26.8 and 29.9°C respectively. The greatest differences in atmometer evaporation were between the west and east aspects, and only data for these two are presented by Aikman. The west aspect had a higher atmometer evaporation rate during July and August, and a higher average wind velocity for the period May to September.

Hayes (1941) worked on cleared forest areas at altitudes of 850 to 1710 m. in Northern Idaho (approx. lat. 47°N), during the summer months, for three years. The amounts of precipitation recorded on the north and south slopes were similar. The wind velocity was slightly greater and the average maximum duff surface temperature 25.5°C higher on the south than on the north aspect. Daubenmire and Slipp (1943), working on bare talus slopes in the same area, found that atmometer evaporation tended to be greater on south than on north slopes during June and July, 1941.

Unfortunately, much of the European literature on climatic differences between aspects has not been translated from its language of publication. Geiger (1965) reviews some of the German literature on this topic, and Shul'gin (1965) some of the Russian literature, the latter being especially concerned with soil temperature. Geiger (1965) presents a table by Schedler (1950, 1951) for Vienna (lat. 48°N), showing the amounts of direct solar radiation arriving on various slopes at different timesof the year. In July a 20% north slope would receive 83% of the radiation received by a south slope, and no direct radiation at all in December. The equivalent figures for west and east slopes would be 92% and 46%. These differences are reduced when diffuse radiation is also considered, eg. Geiger (1965) cites Grunow (1952), who derived actual figures for radiation on approximately 30° north and south slopes. Values for the ratio of direct radiation received by the north and south slopes ranged from 2% in December, to 73% in June. When diffuse radiation was included, values of 32% in December and 94% in July were derived.

Bryam and Jemison (1943) found that near the summer solstice, in the Southern Appalachian mountains (approx. lat. 36°N), north faces of 18° slope received almost as much radiation as south faces of similar slope. Gates (1965), working from first principles, states that North-facing slopes at middle latitudes (in the Northern Hemisphere) receive much less solar radiation in the Winter than South-facing slopes. However, in the Summer, North-facing slopes may receive as much or more radiation than South-facing slopes.

Geiger (1965) cites evidence to support his theory that in the Northern Hemisphere the warmest slopes are as a rule those facing South-west rather than South. This theory proposes that although radiation is distributed evenly either side of the noon line (providing cloud cover does not differ between morning and afternoon), radiative heat received in the morning is mainly used to dry the surfaces on which it falls, while in the afternoon most of it is used for heating the soil.

Jackson (1967), working at Taita, New Zealand (approx. lat. 41°S), determined the effects of slope, aspect and albedo, on net radiation and potential evapotranspiration (PET). Jackson computed values for solar and net radiation during 1966 on north and south slopes of 20°. Radiation measurements for a horizontal surface were used as a basis for computation. PET. was calculated, using Penman's method, for north, south, east and west aspects. Net radiation values ranged from +25 and -25 ly./day for north and south slopes in June, to 305 and 280 ly./day in January. During November and December the south values were 88% and 94% of the north values. PET. values for 10° and 20° slopes were highest on north faces, next highest on east and west faces, and lowest on south faces. A differential wind speed function was not incorporated in the Penman calculation and had one been used the relative values obtained may have been significantly different.

Shul'gin (1965) reviews Russian literature on the influence of relief upon soil temperature. In general the review suggests that south slope soil temperatures are usually greater than those of north slopes. However, Shul'gin cites Saprozhnikova (1950) as postulating that differential evaporation rates, as well as different solar radiation inputs, are important in determining soil temperature differences. Saprozhnikova noted that when the soils and vegetative cover on north and south faces were similar, when the slopes were not steep, and when a southerly wind was blowing, soil temperature differences between opposing aspects could be very small. Shul'gin (1965) cites Drozdov (1952) as recording 80 cm. soil temperatures on four aspects. The temperatures for south, west, east and north faces during the Summer were 19.3, 18.5, 18.6, and 15.3°C respectively, and during the Winter 5.3, 5.5, 4.0 and 4.2°C respectively.

McHattie and McCormack (1961) conducted a study on cleared and uncleared forest strips in Ontario (approx. lat. 51°N). The cleared strips had 15° and 30° slopes on the north and a 5° slope on the south aspect. During May to September, 1955, a number of environmental variables were recorded on these cleared strips. Piche evaporation figures were about 20% greater and maximum air temperatures were 1°C cooler on the south than on the north aspect. The south face was always warmer in terms of 10 cm. soil temperatures recorded at approximately 7.30 am., the difference between aspects increasing from May to September. McHattie and McCormack consider that as the angular altitude of the sun became smaller, i.e. as the winter solstice approached, a larger proportion of the radiation reaching the north aspect was intercepted by vegetation, and thus contributed to heating of the air. It is postulated that this increased interception, combined with higher evaporative heat loss on the south aspect, would fit in with the pattern of higher air temperatures, but lower soil temperatures, on the north face. McHattie and McCormack suggest that in the energy budget of a surface the evaporative process may be thought of as "having priority over the radiative and conductive processes in the spending of the heat income" of the surface. This reasoning is supported by the contention that a moist surface may suffer substantial heat loss due to evaporation when it is cooler than its surroundings. Work by Halstead (1954) is cited. Halstead found that directly following rain as much as 85% of net radiation was lost as latent energy. This figure, which is for a grassed area, dropped to less than 20% after a dry period.

Ayaad and Dix (1964) made measurements of various climatic factors on 13° to 18° prairie slopes in Saskatchewan (approx. lat. 52°N). Unfortunately, the average situation is not represented by the data given, as measurements were made only on clear days, and on only four dates during one season. Ayaad and Dix found that the "seasonal average air temperature" (derived from measurements made at different locations at 2.00pm and 5.00pm.) was 0.9°C higher on South than on North-facing slopes.

Average soil moisture contents were slightly lower on the south face, and the average soil surface temperature for the four days was 2.9°C higher on the south slopes than on the north slopes.

Rumball (1966), at Palmerston North, New Zealand (approx. lat. 40°S), found that over the Summer and early Autumn, 'shady' face soils had higher moisture contents than 'sunny' face soils, to a depth of at least 30cm. Radcliffe (1968), investigating soil conditions on tracked slopes of north and south aspects on Banks Peninsula (approx. lat. 44°S), determined soil moisture contents from mid-April to late-November. The average moisture content was always higher on the south aspect, mean values for the entire period being 26.1 and 42.4 g./cc. for the north and south faces respectively.

Temperatures were recorded on approximately 15° to 20° sunny and shady slopes at Te Awa hill country research station (approx. lat. 40°S) over a number of years. 'Readings were taken at 9.30am.daily. Mean monthly 10cm. soil temperatures, calculated from data recorded during the period 1950 to 1968, were in all cases higher on the sunny than on the shady face. However, when examined on a yearly basis, the monthly figures for the shady face were occasionally the same, or higher, than the figures for the sunny face. This occurred during December for four of the nineteen years during which records were kept, and during January for two of the nineteen years. During the remainder of the year the average monthly soil temperature on the sunny face was, without fail, higher than that on the shady face, the difference being greatest during the winter months. During the years 1954 to 1968, minimum grass temperatures and maximum 1 cm. soil temperatures were also recorded. As for the 10cm. soil temperatures, the mean monthly minimum grass and mean maximum soil temperatures for the entire (fifteen year) period were higher on the sunny than on the shady face. When the values for the individual years were examined, the average monthly grass minimum temperature was frequently highest, and the average maximum soil temperature occasionally highest, on the shady face. (Suckling, unpublished data). These results demonstrate the limited value of average temperature data, collected over a long period, when considering a specific shorter period. The data also indicate the dangers involved in attempting to extropolate to the average situation from information recorded over a short period.

Taylor (1967), working on approximately 22° slopes on north, south, east and west aspects of a hill near Aberystwyth (approx. lat. 52°N), in Wales, calculated growth degrees above 5.5°C for 31 selected weeks throughout 1954 and 1955. No data were available for July to September each year. Using the minimum temperature readings of ground level exposed thermometers as a basis for calculation, the following values for growth degrees were obtained: 64.7, 54.2, 47.7 and 44.3 for south, west, east and north aspects respectively.

White et al (1972), working at Hunua, North Canterbury (approx. lat. 43°S), on north and south aspects at an altitude of 500 m., state that there was more wind and greater evaporation on the north aspect, and that for long periods the soil was drier on the north than on the south aspect.

Yates (1970), at Makara (approx. lat. 41°S), found that rainfall, as measured by gauges with horizontal collecting surfaces, varied on north and south aspects according to wind direction. Tables presented show that differences as great as 62% existed between aspects. These differences were greater with increasing wind velocity. Jackson and Aldridge (1972) found a similar pattern of higher rainfall on leeward than on windward aspects, at Taita in the Hutt Valley (approx. lat. 41°S). The interpretation of these differences, in terms of actual differences in rainfall, is difficult, as discussed in the introductory section to this study.

Summary of Microclimatic Differences between Aspects.

A picture of microclimatic differences between aspects emerges from the preceeding review, although contradictions do occur between studies, and at times the picture is somewhat indistinct. The following résumé will consider the studies reviewed, as they might relate to the middle latitudes of the Southern Hemisphere.

Solar and net radiation appear to be similar on north and south faces during the summer months. However, during the major part of the year North-facing slopes receive more radiation than South-facing slopes (i.e. slopes of similar inclination), the differences between the two being greatest during the winter months. The temperature data considered is hard to interpret, due in many instances to inadequate descriptions of the areas investigated and of the sampling techniques used. Soil and air temperatures on south aspects appear to be similar to, or lower than, temperatures on north aspects during the summer months of the year. In general, soil and air temperatures of south faces are lower than those of north faces during the remainder of the year, with differences being greatest during the Winter. Probably the larger differences during the Winter are due to the pattern of radiation differences between aspects. The reason for this pattern is the seasonal variation in the angular altitude and declination of the sun. Wind-speed and wind direction data are non-existent in most of the studies reviewed. The relationship between wind speed, evaporation and air and soil temperatures appears to be an important determinant of the differences in aspect microclimate, however, the most important determinant in the majority of cases is the variation in solar radiation input. The rainfall comparisons which were reviewed are difficult to interpret. Data on relative humidity differences are scant and little can be concluded regarding the variation of this environmental variable with changing aspect. From the limited information available, it appears that average soil temperatures on west aspects are likely to be higher than those on east aspects, although radiational inputs would be identical assuming no diurnal variation in cloud cover.

3. VEGETATIONAL DIFFERENCES BETWEEN ASPECTS

Such differences have long been recognised e.g. Theophrastus (c. 300 B.C.), while 'talking of trees', comments that ......"some love exposed and sunny positions; some prefer a shady place."

Cottle (1932) states that in Southwestern Texas trees and tall grasses predominate on north slopes of the mountains, while on the southern slopes short grasses and other 'xeric' plants are the dominant species. Cottle found that Bouteloua spp. were the dominant species on the south aspects, while on the north aspects B. curtipendula, Andropogon spp. and Sporobolus wrightii formed a dense mat. Although there were approximately the same number of plants per unit area on both aspects, those on the south slopes were smaller. Basal cover measurements showed vegetation on the north aspects to have a cover value of 14.5%, as compared to 7% for the south aspects. Dry matter production on the south aspects was only 5% of that on the north aspects. These production measurements were made on areas which were not protected from herbivors, and this makes interpretation of the results difficult.

Rumball (1966) measured pasture composition on sets of opposing aspects at various sites throughout the lower North Island. In most cases sweet vernal (Anthoxanthum odoratum), browntop (Agrostis tenuis), hawkbit (Leontodon taraxacoides), annual clovers, danthonia (Notodanthonia spp.), and ratstail (Sporobolus capensis) were most abundant on sunny faces, and ryegrass (Lolium perenne) was most abundant on shady faces.

Madden (1940), in discussing his pasture classification into which the study area of this project falls, notes that although browntop is the dominant species, it may largely be replaced by danthonia on warmer and drier slopes. Suckling (1964) makes a similar observation for Te Awa.

Ayaad and Dix (1964), working on 13° to 18° prairie slopes in Saskatchewan, found that some species had narrow ranges of distribution in relation to aspect e.g. Bouteloua gracillis was identified with east and south aspects, and Stipa commata with south aspects. Most species however, had wide ranges of distribution in relation to aspect, showing a gradual increase in importance value (calculated as the sum of relative density and relative frequency) towards a maximum on one or two aspects e.g. Koeleria cristata increased in importance value towards the south aspect, and Stipa spartea towards the east aspect. Only one species (Carex eleocharis) failed to show a recognisable distribution pattern. Ayaad and Dix concluded that the primary axis along which the various species examined were arranged was one of heat budget and moisture regime, and that the secondary axis was one of moisture regime.

Perring (1959), working on chalk slopes in North Dorset, England, found that many of the species investigated were distributed in a manner similar to that described by Ayaad and Dix (1964). Subjective cover estimates were used as a basis for comparison. Some species which had high cover values on certain aspects were also abundant on other aspects. Other species having maximum values on specific aspects were found to have low cover values on all other aspects. Lotus corniculatus was an example of the former pattern of distribution, being most abundant on west and southwest aspects, and sweet vernal was an example of the latter, being mainly distributed on the northwest and east aspects, with low cover values on all other aspects. Perring concluded that the main axis of plant distribution was Southwest-Northeast. Xerophytic species tended to be found on southwest aspects, grading through to mesophytic species on the northeastern aspects.

Suckling (1959), working on hill country at Te Awa, recorded the botanical composition of various broad pasture classes. Point analysis data ('all hits' technique) yielded interesting contrasts between aspects. Some of the data presented have been reworked to give figures which are percentage values. Table I.1 presents values, for 'sunny' and 'shady' faces, recorded in 1949 and 1957. The figures for 1949 are for 'unimproved' areas, those for 1957 for 'improved' areas which had been oversown with legumes, topdressed and stocked at relatively high rates.

TABLE I.1. Botanical Composition (%) on Sunny and Shady Faces. (Suckling, 1959)

		Ryegrass	Crested dogstail	Cocksfoot	Chewings fescue	Danthonia	Browntop	Sweet vernal	Yorkshire fog	White clover	Suckling clover	Sub. clover	Catsear	Bare ground
1949	Sunny	4	3	5	8	2	14	26	11	1	1	0	10	15
	Shady	1	2	0	20	0	22	7	16	11	2	0	15	0
1957	Sunny	13	8	1	7	9	19	3	7	12	1	5	5	0
	Shady	6	12	1	7	2	24	2	17	12	1	1	3	3

These figures indicate that differences in botanical composition between aspects may vary according to management practice. It is also probable that differences observed on a specific area could not easily be extrapolated to other areas, due to variation in climatic, edaphic and management factors. Trends do appear for the botanical composition of the sunny and shady aspects in Table I.1. Danthonia and ryegrass appear to be more abundant on the sunny than on the shady faces, with Yorkshire fog (<u>Holcus lanatus</u>), and browntop more abundant on the shady faces. Suckling (1959) also gives production data for various pasture classes on sunny and shady faces. Table I.2. presents figures for unimproved and improved stockcamps and hillsides.

TABLE I.2. Average Annual D.M. Production (kg./ha.) for the Period 1952 - 56 (Suckling, 1959)

		Sunny	Shady
Unimproved	Stockcamp	12,200	15,900
	Hillside	5,200	5,900
Improved	Stockcamp	17,700	18,500
	Hillside	8,700	8,100

The unimproved sunny face figures are averages for two paddocks, the improved sunny face figures for three paddocks. All shady face figures are for one paddock only. Suckling (1959) appears to place little significance on the only clear cut difference (between aspects) in this table, i.e. between the unimproved sunny and shady face stockcamps, and states that this difference was probably due to high stock concentrations on the sunny hilltop of this paddock. Suckling (pers.comm.) explains that the area from which the unimproved shady stockcamp data was collected had formerly been part of a holding paddock, and as such was atypical. No other outstanding differences in annual dry matter production occur between sunny and shady faces.

White et al. (1972), working on opposing aspects at 500m. in North Canterbury, found that danthonia species were dominant on the sunny slope, while on the shady slope the danthonia was replaced by chewings fescue, (Festuca rubra var. commutata), sweet vernal and Yorkshire fog. In the unimproved state, pasture production was similar on the two aspects (1390 and 1380 kg/ha./year). However, four years after the introduction of clover, production had incrèased 50% on the sunny aspect to 2100 kg./ha., and threefold on the shady aspect to 4190 kg./ha.

4. EDAPHIC DIFFERENCES BETWEEN ASPECTS

Soil moisture status and soil temperature have previously been discussed as microclimatic variables.

Perring (1959), on chalk soils in North Dorset, found that for 0 to 10 cm. soil samples, pH was not related to aspect, nor was the exchangeable phosphate level. However,aspect was found to affect the organic carbon content, exchangeable potassium level, and exchangeable calcium level of the soil. Additional sites at Cambridge and East Riding in England, and Rouen in France, were also investigated, and at these sites exchangeable phosphate levels were also found to vary with aspect. Exchangeable phosphate, potassium and organic carbon levels were all found to be affected by grazing as opposed to non-grazing treatment. The types of grazing animals involved is not specified, but appear likely to be sheep and rabbits.

Rumball (1966), at Palmerston North, found little difference in 0 to 60 cm. soil compaction on sunny and shady faces. Bulk densities also appeared to be similar on the two aspects. Radcliffe (1968), working on two soil types at Banks Penisula, on north and south aspects of mean slope 24° to 32°, found the bulk densities of 0 to 76 cm. samples to be significantly higher on north than on south slopes. Porosity was also higher on the north slopes. Calcium, pH and total nitrogen levels were not significantly different between aspects, but phosphorus and potassium levels were higher on north than on south faces. Organic carbon levels were higher on south than on north faces.

White et al. (1972), working at Hunua in North Canterbury, found that the soil pH on the north aspect under examination was 6.1, while that on the south aspect was 5.6.

Greenland and Owens (1967), working in the Chilton Valley in the Southern Alps, found that the clay content of the soil varied with aspect.

Ross (1971), working on north and south aspects at an altitude of 1180 m. in the Eastern Ben Ohau Range, found that the south slope soils were more acid and had higher cation exchange capacities than the north slope soils. However, the sunny slope soils had higher organic matter contents and greater base saturation values than the shady slope soils. Ross reviews some of the literature regarding aspect as a soil forming factor and notes that although changes in soil properties may occur between different aspects, the nature and extent of these differences is highly variable and depends on local conditions.

5. DIFFERENCES BETWEEN ASPECTS DUE TO ANIMALS

As far as is known, no detailed data has been published on differences between aspects due to animals. Strictly speaking, the term 'animals' includes both micro - and macro - fauna, however no consideration was made of the former in the study described herein, other than indirectly by nitrogen mineralisation studies.

Suckling (1954) noted, during an attempt to bare pasture swards as much as possible prior to oversowing, that when large mobs of sheep and cattle were rotationally grazed the animals tended to congregate on warm sunny faces, while the shady faces were neglected almost completely. Suckling (1964) found that where sunny and shady faces were not separately fenced, weeds established and pasture became long and rank on the shady slopes, thus forcing stock more and more onto the sunny slopes. The possible effects of differential excretal return on soil nutritional status are illustrated by the two studies mentioned below. Sears and Evans (1953), comparing small grazed areas under different levels of animal excretal return, found that the full excretal return areas, as opposed to the non-return areas, had higher soil organic matter, total nitrogen, available phosphorus and exchangeable potassium levels. Hilder (1964), working on sheep-grazed areas, found very high exchangeable potassium, magnesium, calcium and available phosphorus levels, and high total nitrogen levels, in soil samples taken from stock camps, as compared with samples from areas other than stock camps.

CHAPTER II METHODS AND MATERIALS

(A) INTRODUCTION

The experimental area was a small hill approximately 170 m. long and 60 m. wide. The hill is located on Ballantrae, the hill country research station of Grasslands Division, D.S.I.R., situated in the foothills of the Southern Ruahine ranges. The area which was used is adjacent to the Saddle Road, which traverses the ranges between Ashhurst and Woodville. The number one Ballantrae meteorological station is situated approximately 70 m. from the NE end of the hill, and is at longitude 175° 50'E, latitude 40° 18'S. Further mention of the Ballantrae meteorological station may be taken as referring specifically to this station. The hill concerned is elongated rather than conical in shape, runs in a NE-SW direction (see Figures I.1 and II.1) and is at an altitude of approximately 360 m. above sea level.

The soil of the area is Ngamoka hill soil, a silt loam derived from sandy siltstone. The profile comprises 20 cm. of dark brown silt loam, overlying 45 cm. of yellowish brown silt loam, on mottled pale brown and strong brown fine sandy loam. Ngamoka hill soil is strongly leached and the topsoils are moderately acid, very low in citric acid soluble phosphate and high in exchangeable potassium (Cowie, unpublished data). The area was not topdressed in the thirty years preceeding the experimental period, as far as can be determined (Suckling, pers. comm.).

Four sites, each approximately 1.5 m. square, were selected, one on each of the north, south, east and west aspects of the hill. These sites were chosen acccording to two criteria: firstly, approximation to the desired aspect, and secondly, similarity of slope between the four sites. The compass bearings of the sites selected, taking true North as 0°, were 'East' 90°, 'South' 170°, 'West' 300° and 'North' 355° (see Figure II.1). The slopes of the respective sites were 14°, 15°, 10° and 13°. Slope was measured using a device described in Section 4.2 of this chapter, and the above bearings were determined with the aid of a compass.

Throughout 1972 a number of microclimatic variables were measured at, or adjacent to, these 'microclimate sites' (see Figure II.2). These variables were air and soil temperature, soil moisture tension, rainfall and wind run. Data on relative humidity, sunshine hours, screen minimum and maximum temperature, rainfall, and wind direction, which were recorded at the Ballantrae meteorological station, were also utilised in the description of the microclimate of the experimental area.

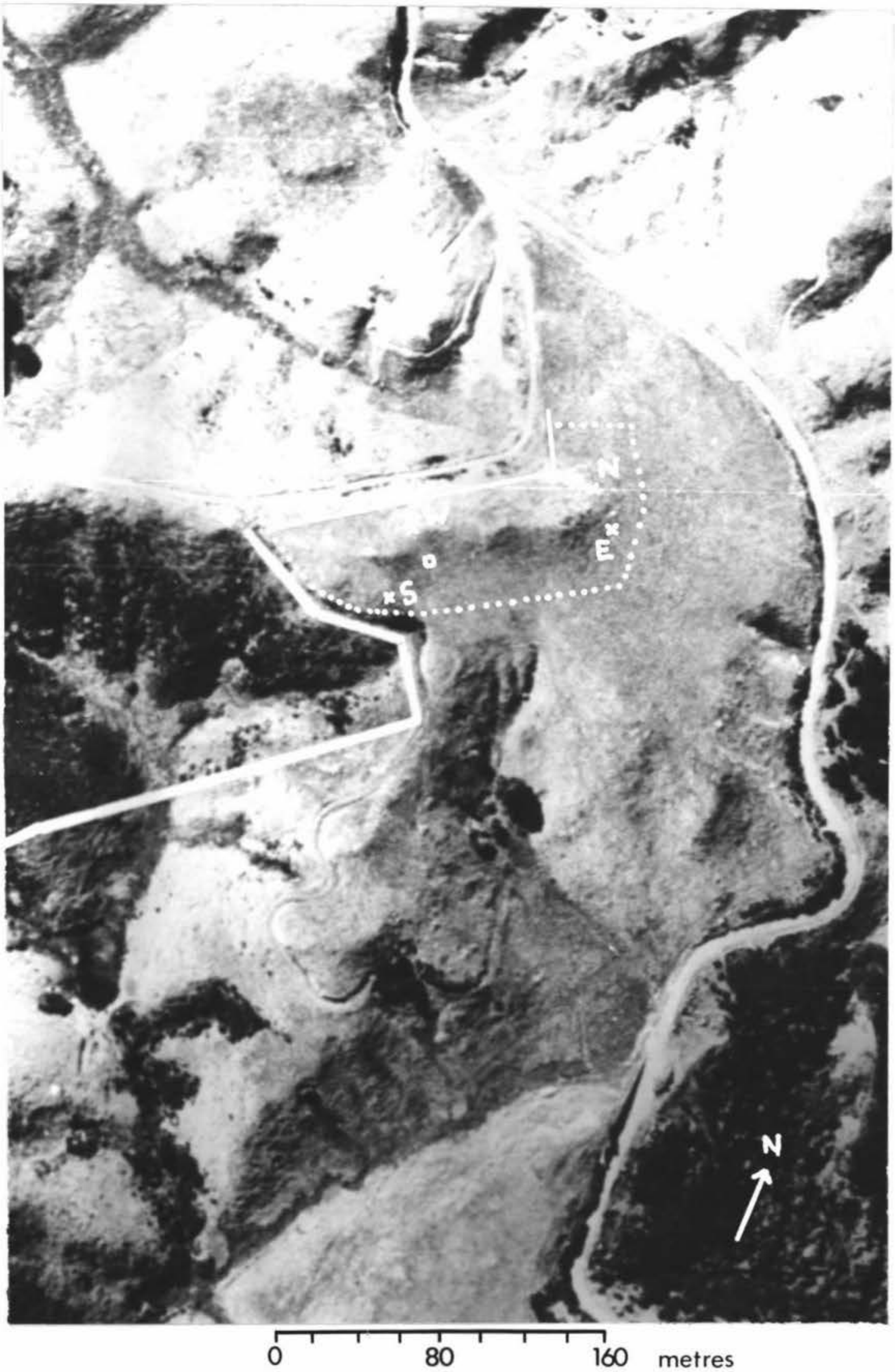


FIGURE II.1 Aerial View of Experimental Area.
(* indicates position of Ballantrae meteorological station; W, N, E, S indicate location of 'microclimate sites'; □ indicates location at which hut was sited).

Measurements were also made, during 1972 and early 1973, of pasture production and botanical composition, of various soil chemical and physical characteristics, and of the amounts of sheep dung deposited at north, south, east and west faces of the hill. It should be noted that soil moisture status and soil temperature have, for ease of consideration, been treated as microclimatic rather than soil factors.

The average slopes of the four aspects were 18°, 13°, 24° and 10° for the north, south, east and west aspects respectively. The north and east values are greater than those of the south and west aspects, due to the presence of a number of steep banks on the former (see Figures II.2, II.3 and II.4). These values were derived by measuring the slope of each aspect at approximately 40 cm. intervals along two transects laid down each face. These transects were randomly selected, and were orientated in an up and downhill direction. The slope measurements for each pair of transects were averaged to give the above figures.

The experimental area was fenced to exclude cattle, but to allow ready access to sheep. No attempt was made to induce differential sheep grazing intensities between the fenced area of approximately 1.2 ha. and the rest of the paddock of approximately 5.8 ha.

(B) EXPERIMENTAL METHODS

1. MICROCLIMATIC FACTORS

1.1 Sunshine Hours, Wind Direction, Relative Humidity, Screen Minimum and Maximum Temperatures and Rainfall.

These climatic variables were recorded daily at 9.00 am. at the adjacent Ballantrae meteorological station. The daily number of sunshine hours was recorded by a Campbell-Stokes sunshine recorder; relative humidity was estimated using wet and dry - bulb thermometers mounted in a Stevenson screen at 1.2m. Screen minimum and maximum temperatures were measured using standard minimum and maximum thermometers, and rainfall using a standard raingauge installed to N.Z. Meteorological Service specifications. Wind direction was estimated by the person reading the meteorological instruments.

1.2 Wind-speed.

Wind-run was measured using one Cassella three-cup W1204/1 anemometer at each aspect. The anemometers were located within 10m. of the respective microclimate sites, and on the downhill side. Each anemometer was mounted on 1.25 cm. (0.5 inch) water pipe, which was braced with wire stays, at a height of 1.2 metres above the ground; the cups were on approximately the

FIGURE II.2 South Aspect 'Microclimate Site'

FIGURE II.3 East Aspect

same level as the adjacent 'microclimate sites'. The height at which the anemometers were mounted was selected as the most suitable for two reasons: firstly, any interference with the instruments by sheep was avoided, and secondly, 1.2 metres is a height at which climatological measurements are often made.

The anemometers, which recorded cumulative miles of wind run, were read at approximately 9.00 am. each Monday and Thursday. Average wind-speeds, in units of kilometers per hour, were derived for each three or four day period from these readings.

1.3. Rainfall.

Rainfall was collected at each aspect by a perspex 'Marquis 1000' raingauge. At approximately 9.00 am. each Monday and Thursday the amount of rainfall for the preceeding period was noted, and the gauges emptied.

The gauges were mounted on wood stakes driven into the ground within 4 m. and on the downhill side of the respective 'microclimate sites'. The gauges were not located immediately alongside the sites, in order to reduce effects on the site microclimates. The collection surfaces were horizontal and 0.3m. vertically above ground level. It was not felt that sufficient data were available on the use of tilted as opposed to horizontal raingauges to warrant a departure from standard climatological practice.

1.4. Soil Moisture Tension

Gypsum blocks were selected as the means of measuring soil moisture status. The available methods of measurement were limited. The possible alternatives were gravimetric moisture sampling, tensiometer or gypsum block installation, or a combination of these. Gravimetric sampling would have necessitated a large number of samples being taken at regular intervals, and the damage caused by repeated sampling on the limited area of each aspect may have been excessive. The method is time consuming, and the measurement obtained is not a direct measure of the amount of moisture available to the plant. Tensiometers operate over a limited range of soil moisture tension and thus would not have been operational for a large portion of the experimental period. Gypsum blocks, although unreliable below approximately 0.7 atmospheres soil moisture tension, do operate throughout the tension range in which water is available to plants; this was considered to be the tension range of most interest. Gypsum blocks measure soil moisture status in terms of moisture tension, and this is directly related to moisture availability. When selecting gypsum blocks for measuring moisture status it was realised that two major problems, namely hysteresis and calibration drift, would be associated with their use.

FIGURE II.4 West [illegible]

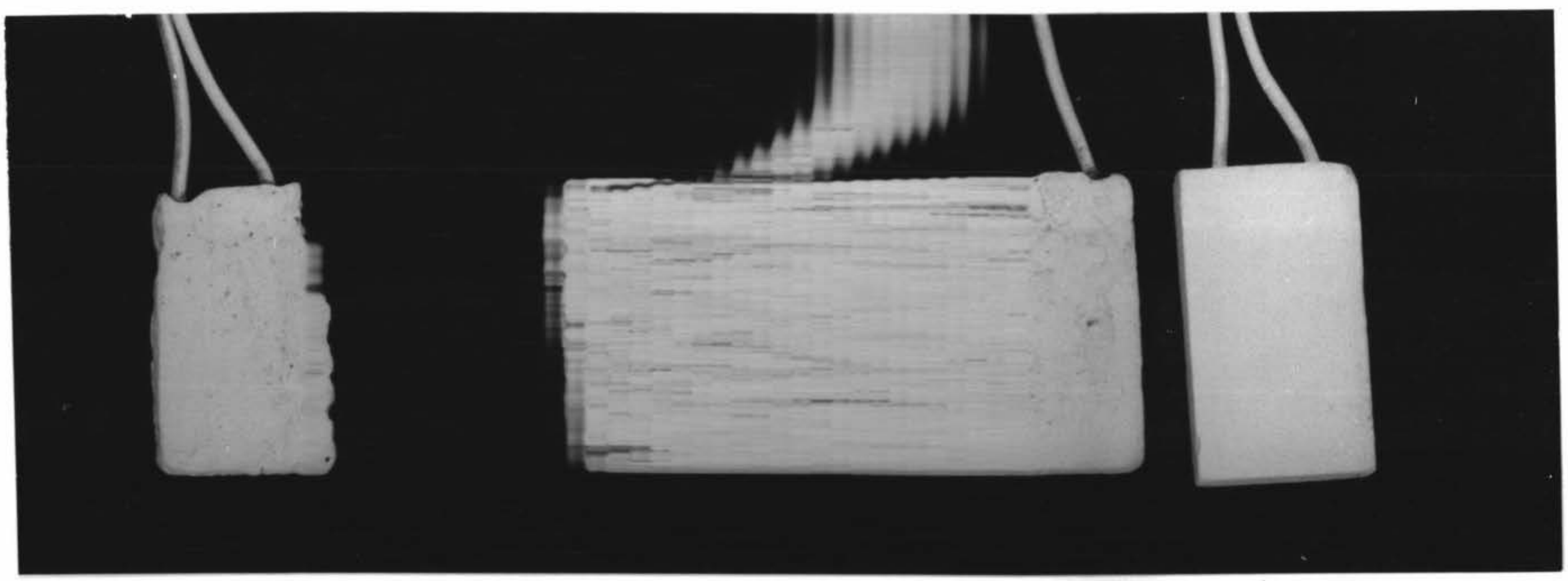


FIGURE II.5 '[illegible] Gypsum Blocks. (Left and centre blocks [illegible]sed during study, right block is unuse[illegible]

The blocks used were rectangular in shape and consisted of two tinned lengths of bared flex set parallel in a matrix of plaster of paris. The units were 1.1 cm. x 6.9 cm. x 3.5 cm. in size, and were the 'F.F.F.' units described by Aitchison et al (1951) (see Figure II.5). Two replicate blocks were buried at 4, 10 and 30 cm. depths (measured perpendicular to the ground surface) in the 'microclimate site' of each aspect. These three depths were selected as giving reasonably full coverage of the rooting zone. Although it would have been desirable, it was not practical to bury the 4 cm. units nearer the soil surface, as damage by sheep hooves may have resulted. The units buried at the 4 cm. depth were orientated parallel to the slope, in depressions excavated in the ground, and the turfs which had been removed were replaced over the blocks. The 10 and 30 cm. units were lowered down holes made by a soil sampler, and the soil cores taken from the holes were carefully replaced. These blocks were orientated perpendicular to the slope of the ground. The leads from the six blocks in each 'microclimate site' were buried in the soil, and the free ends connected to a socket board located at the edge of the site. The electrical resistance of each unit was measured, using a portable meter, at approximately 9.00 am. each Monday and Thursday. The meter was a battery-powered, A.C. operated Wheatstone bridge, with a capacitance balance and a microammeter for visual null-point determination. The instrument was constructed from the circuit diagram for the 'type B' meter described by Aitchison et al (1951); the valves in the circuit were replaced by transistors (Webster, pers. comm.). Two leads with terminal banana plugs were attached to the meter, and these were plugged into the socket boards mentioned above, when reading the resistance of the gypsum blocks.

A nomogram from Aitchison et al (1951) was used to correct the resistance readings to equivalent readings at 20°C, using values from the soil temperature sensors at 4, 10 and 30 cm. as a basis for correction. It was felt that temperature correction of the resistance values was necessary as large seasonal temperature differences existed, and had uncorrected data been analysed a less realistic picture of moisture tension trends would have been obtained.

Aitchison et al (1951) give a curve for the 'F.F.F' blocks for deriving soil pF (i.e. the log of moisture tension in cm. of water) from the log of block resistance readings. However, atmospheres moisture tension was used in preference to pF as the log scale of the latter places greater emphasis on differences at the wet than at the dry end of the curve. This emphasis is particularly evident when data is presented graphically, and the wet end of the curve is the region in which gypsum blocks are relatively inaccurate. The calibration curve presented was checked, using blocks embedded in soil at field capacity and in soil in a pressure membrane. It was found that the curve gave soil moisture tension values which were lower at field capacity (approximately 0.33 atmospheres) and above 6.0 atmospheres, than values which were experimentally determined. Between tensions of 1 and 6 atmospheres the values experimentally determined were similar to those given by the curve. On the basis of these results the top and bottom ends of the curve were redrawn. The pressure apparatus available did not enable soil tensions of greater than 8.3 atmospheres to be obtained. To locate the top end of the calibration curve plants were used to indicate when soil in which gypsum blocks were embedded was at wilting point. The soil moisture tension at this point was assumed to be 15 atmospheres. This was an arbitrary decision as controversy surrounds the problem of defining a specific permanent wilting point (e.g. Rode, 1965). A sweet corn plant was grown in each of three small soil-filled pots, a gypsum block being buried in each pot. The pots were set out in a glasshouse and when the young corn plants wilted during the day they were placed in dark, high-humidity conditions overnight. When the plants failed to recover overnight from this moisture stress, permanent wilting was judged to have occurred and the resistance of each block was recorded.

Prior to burying the blocks in the field a trial run was conducted, using boxes filled with top and subsoil from the experimental area. The blocks were buried in these boxes and the moisture status of both soils was taken from field capacity to a point that was well past wilting point, then back to field capacity, over a period of ten weeks. Periodic measurements were made of gravimetric soil moisture contents and gypsum block resistances. A hysteresis curve was derived from this data. This curve (see Appendix 1.1) serves to illustrate the size of errors which may arise when using a calibration curve derived in the laboratory during the drying phase of a soil, to interpret measurements made in the field during both wetting and drying phases.

Aitchison and Butler (1951) report that where blocks of the same type are considered, differences in block resistance persist in the same order throughout the sensitive range of the units. In order to determine individual block differences, all of the units that were to be used in the field were soaked in water for twenty hours, removed, and following a five minute drip-period, block resistances were measured. The same procedure was followed at the conclusion of the experimental period, to determine whether any calibration drift had occurred. The range of block resistances recorded was 0.64 to 405 kil-ohms and in view of the time involved in correcting all resistance values these corrections were only applied to resistance values of below 1.5 kil-ohms. It was judged that beyond this value use of the corrections would make only a minor contribution to increased accuracy. The calibration check made at the conclusion of the experimental period showed that tension values measured by the blocks had drifted by an average of + 0.4 atmospheres, the range for the individual blocks being + 0.2 to + 0.6 atmospheres. No attempt was made to correct for this drift.

The block resistance data were analysed as follows:

(i) All readings were temperature-corrected.

(ii) Corrections for individual block differences were made.

(iii) Log values of the corrected readings were taken.

(iv) The log values were converted to atmospheres moisture tension, using the calibration curve previously described.

(v) The pairs of tension values for replicate blocks were averaged.

1.5 Soil and Air Temperatures

Air temperatures were measured at 4 cm. and 120 cm. above ground level, and soil temperatures at 4, 10 and 30 cm. depths, at each aspect. During January and February, 1972, measurements were made continuously (once every twelve minutes for any specific sensor) for four consecutive days each week. Throughout this period temperatures were not recorded during the remaining three days of the week. In early March a time clock was obtained and this enabled all sensors to be sampled during a four minute period every hour, for each day of the week.

(a) Temperature sensors.

Diodes were selected as the means of measuring temperature, for a number of reasons:

(i) Diodes are particularly amendable to the automatic recording system which was envisaged.

(ii) They are relatively cheap and robust and have a linear and relatively large response to changes in temperature (approximately 2.3 mA/^{o}C with a 1 mA current flowing).

(iii) Diodes have been successfully used by the Plant Physiology Division (D.S.I.R.) for temperature measurement, and expert advice on their use was available.

Each sensor unit consisted of three diodes; this allowed spatially integrated soil temperature measurements to be made. Following determination of the temperature coefficients of a total of 150 diodes, twenty triplets were selected, the three diodes comprising each group being matched for similar coefficients. Each diode was sealed in a watertight casing to prevent electrical shorts occurring.. The individual diodes of each soil temperature unit were interconnected with one metre lengths of insulated wire; about 7 cm. of wire was used to interconnect the diodes of the air units. The assembled units were calibrated at five points between 0° and 30°C, using the recorder which was to be installed in the field to measure millivolt values. A flask of ice served as a 0°C reference point and a mercury-in-glass thermometer and thermostatically controlled water bath were used to determine the other four points. Radiation shields were devised for the sensors measuring air temperature, in order to reduce errors due to radiative exchange between the sensors and the sun, earth and sky (see Figures II.6 and II.7).

The diodes of the soil units were separately buried within the 'microclimate sites'. The individual diodes were lowered down soil sampler holes and the soil cores which had previously been extracted were carefully replaced. The interconnecting wires and the wires which were connected to the multicore cable (see later) were buried. The 120 cm. air temperature units were mounted over the 'microclimate sites' and the 4 cm. air temperature units approximately one metre to one side. The vegetation under the 4 cm. units was kept clipped to a height of approximately 0.5 to 1.0 cm. throughout the experimental period, to facilitate ventilation of the diodes. Appendix 2.1 gives further details of the preparation and use of the temperature sensors.

(b) Recording equipment

A twelve channel multipoint recorder was used to measure automatically the voltage drop across the sensor units. This recorder was modified by the Electronics section of the Physics and Engineering Department, Massey University, so that a maximum of twenty four channels could be sampled. A constant-current source (Talbot, 1972) was incorporated in the recorder-sensor circuits to enable a 1 mA current to be passed through each sensor as it was sampled by the recorder. An adjustment was also incorporated into the recorder to allow offsetting of the usable millivolt range. Appendix 2.2 provides further details of the recorder modifications.

Multicore cable was used to connect the sensor units to the recorder, which was housed in a small hut sited between the south and west 'microclimate sites' so as to be shielded by the crest of the hill from the prevailing Northwesterly. The multicore cable was buried approximately 10 cm. below the ground surface to reduce any 'noise' which may have been set up in the cable due to the proximity of high voltage power lines which run parallel to the hill, and 11,000 volt lines which crossed the hill

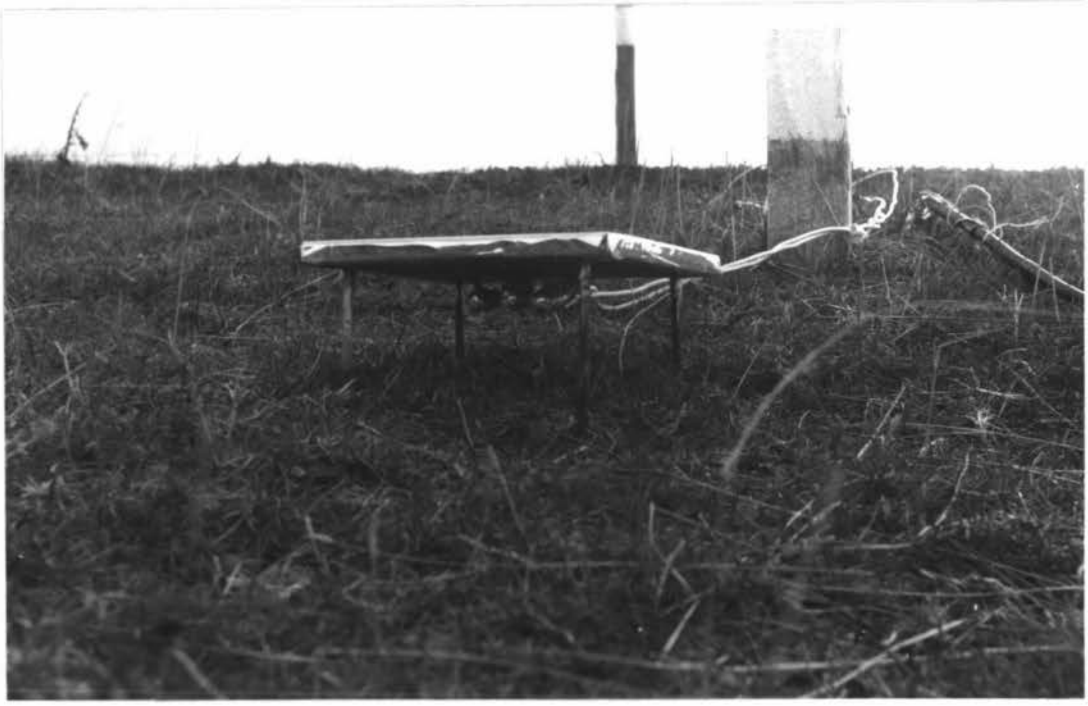


FIGURE II.6 Sensor Unit for 4 cm. Air Temperature Measurements. (The three diodes are suspended beneath the radiation shield).

FIGURE II.7 Sensor Unit for 120 cm. Air Temperature Measurements.

between the west and south 'microclimate sites'. Corrections were derived for each aspect to allow for the effect of the resistance of the multicore cable on the millivolt values recorded. Theoretical considerations and actual measurements in the field formed the basis of the derivation of these corrections. Appendix 2.1 provides further details of the sensor-recorder link up.

The temperature recording system proved satisfactory although a number of minor problems arose. These problems were due in most instances to poor electrical connections in the recorder-diode circuits, and in one instance to an electrical short in the recorder itself. Data recorded during periods of malfunction were not included in the final analysis of temperature differences between aspects.

(c) Recorder chart interpretation

Although twenty four channels were available for use, only twenty were required for temperature measurement. The four remaining channels were connected through an ammeter and standard resistance in series, and a baseline was stamped on the recorder chart due to the voltage drop across each of these four channels. The ammeter enabled a check to be maintained on the magnitude of the current passing through the sensors. As the voltage drop recorded across the sensors was directly proportional to temperature, it was possible to use a linear scale to describe the relationship between chart readings and the equivalent temperatures for each sensor unit. The linear scale was drawn on perspex strips, one for each sensor unit. To convert the chart readings to temperatures, the strips were laid on the recorder chart, initially using the baseline mentioned above as a reference point to locate the strips laterally on the chart. However, it was discovered that the baseline tended to wander, possibly due to ambient temperature fluctuations, and to overcome this problem a line on the recorder chart was used to locate the perspex strips when converting readings to temperatures. Prior to reading the charts a time scale was marked on each. After installation of the time clock, in March, it was possible to pick where each hourly sampling had started as the recorder carriage did not move until four channels had been sampled. This resulted in four superimposed points being marked on the chart. As a check on the accuracy of this method the appropriate time was marked on the recorder chart twice a week, coincident with the reading of the other microclimate instruments. Prior to March, and the installation of the time clock, the time at which the recorder was started was noted and a time scale was obtained using the knowledge that the chart was moving at 300 mm./hour. This was one of the standard chart speeds available on the recorder, and was used throughout the experimental period.

Data from the 4 cm. air and 4 cm. soil sensors was translated from the recorder charts at three-hourly intervals for every day the recorder operated, apart from periods of malfunction of the system. The 120 cm. air temperature sensors were intended to act as an alternative source of air temperature data to the 4 cm. measurements. It was thought that large radiation errors, due to poor ventilation of the radiation shields, might make interpretation of the 4 cm. air temperature data difficult. The possibility of damage to the 4 cm. units by sheep also existed, but this problem did not eventuate. To determine the magnitude of the radiation errors involved, a 4 cm. air temperature sensor and its associated radiation shield were shaded from the sun for several five minute periods on a clear day. The average wind velocity at the time was 28 kph. The air temperatures recorded were on the average 0.7°C higher when the unit was exposed to the sun than when shaded from it. Although the wind speed noted above is quite high, and ventilation of the shield would have been good, it was decided that the radiation errors involved in the 4 cm. air temperature measurements would not in most instances be excessively high, and would not obscure temperature differences between the four aspects. In view of this decision, and because the 4 cm. air temperatures were thought to have far more relevance to plant growth than the 120 cm. air temperatures, the latter information was not extracted from the charts. An additional reason was also implicated in the decision not to extract the 10 and 30 cm. soil temperature data. This was the limited time available for temperature analysis. It was judged that the time expended in extracting the air 120 cm., and soil 10 cm. and 30 cm. data would not be justified by the end results. Preliminary data analysis indicated that the 10 cm. and 30 cm. data would provide little information not given by the 4 cm. soil temperatures. A reasonably full analysis of the 4 cm. soil and 4 cm. air data appeared to be the most sensible use of the time available for this part of the study. The 10 cm. and 30 cm. soil temperature recordings were used only for temperature-correcting the gypsum block resistances recorded, and thus were only utilised for two temperature readings per week.

An accuracy of ± 0.5°C is tentatively placed upon all temperatures recorded. This figure was derived following consideration of a number of possible sources of error. The initial calibration of the individual diode units would have involved an experimental error, and the corrections determined to allow for the resistance of the multicore cable may have introduced a systematic error for each aspect. The actual translation of the temperature readings would also have had associated errors, however these errors would have been random in occurrence and would probably have cancelled themselves where average values of a number of readings were taken.

1.6 Net Radiation

Net radiation was calculated on a per day basis for the north and south 'microclimate sites', for four periods during 1972. These periods encompassed the autumn equinox (13.3 to 5.4.72), the winter solstice (14.6 to 27.6.72), the spring equinox (16.9 to 29.9.72) and the summer solstice (7.12 to 23.12.72).

The first step in the calculation of net radiation was to derive the daily incident radiation on a horizontal surface using:

$R_I = (a + bn/N)\, R_A$ (Slatyer and McIlroy, 1961)

where:

R_I = incident radiation (ly./day)

R_A = extraterrestial radiation (ly./day)

'a' and 'b' = constants.

n = sunshine hours.

N = possible sunshine hours.

'a' and 'b' are given for the four seasons by de Lisle (1966) and the values used were those quoted for Wellington; n was from the Ballantrae meteorological station records and R_A and N from the Smithsonian Meteorological Tables (1958).

The daily R_I thus derived was separated into direct and diffuse components using a curve from Liu and Jordan (1960), which describes the relationship between the daily total and daily diffuse radiation on a horizontal surface. R_I and R_A were required in order to derive this relationship.

The daily direct incident radiation (R (direct)) on a horizontal surface, was modified using tables by Fons et al. (1960), to give an R (direct) figure for North and South-facing surfaces of approximately 25% slope, i.e. the approximate slope of the north (23.0%) and south (26.8%) 'microclimate sites'. It is probable that the figures derived were not for exactly 25% slopes as the modification factors used were an average of those used for 20% and 30% slopes, and for latitudes 38° and 42° South. The relationship between slope and the magnitude of the necessary modification factors, and between latitude and the necessary factors, is unlikely to be linear, and thus the average values used would differ slightly from the actual modification factors for a 25% slope.

A figure for daily net radiation was calculated using the radiation balance:

$R_N = R_I\ (1 - r) - R_B$ (Slatyer and McIlroy, 1961)

where: R_N = daily net radiation on a 25% north or south slope (ly./day)

R_I = the sum of R (direct) and the amount of diffuse radiation previously derived (ly./day)

= the daily incident radiation on a 25% north or south slope

r = the albedo of the surfaces under consideration.

R_B = the daily net back radiation from the surfaces under consideration.

$= \sigma T_a^4\ (0.56 - 0.092\ e_d)\ \ (0.1 + 0.9n/N)$

where:

σT_a^4 = radiant emittance of a black body at temperature T_a ^{o} Kelvin (ly./day).

e_d = air vapour pressure (mb.).

n = sunshine hours.

N = possible sunshine hours.

R_I had already been calculated; r was arbitrarily estimated at 0.25; e_d was calculated from the product of the relative humidity and the dry-bulb saturation vapour pressure, and as such was a 9.00 am. value rather than a mean daily value. The dry-bulb temperature and relative humidity were from the Ballantrae meteorological station records; the dry-bulb saturation vapour pressure, N and σT_a^4 were all taken from the Smithsonian Meteorological Tables (1958). T_a was calculated from:

$T_a = 273 + (T\ max. + T\ min.)\ /2\ (^{o}K)$ where T max. and T min. were maximum and minimum screen temperatures (^{o}C) from the Ballantrae meteorological station records.

A programmable calculator was used extensively throughout the derivation of the daily net radiation values.

1.7 Evapotranspiration

(A) Potential evapotranspiration (PET.).

PET. was calculated on a daily basis, substituting the calculated net radiation (R_N) values from the previous section into a Penman equation. The equation used was:

$PET. = (\Delta/\gamma \cdot H + E_a)\ /\ (\Delta/\gamma + 1)$ (Penman, 1963)

where:

H = the amount of water (mm.) which could be evaporated by R_N.

Δ = the slope of the saturation vapour pressure curve at mean air temperature.

γ = the wet and dry bulb psychrometer equation constant.

$E_a = 0.35\ (0.5 + u/100)\ (e_a - e_d)$, where:

u = wind run (miles/day)

e_a = saturation vapour pressure at mean air temperature (mm.Hg.)

e_d = mean vapour pressure of the air (mm.Hg.)

H was taken as $R_N/59$, Δ was from the Smithsonian Meteorological Tables (1958) and the mean air temperature was taken as the average of the maximum and minimum screen temperatures for that day. γ was taken as 0.63; u was measured at 1.2 m. at each aspect and the values used for the daily PET. calculations were average values for either a three or four day period; e_a was from the Smithsonian Meteorological Tables (1958), and the temperature used to determine this was the 9.00 am. screen temperature rather than the mean air temperature. This was because e_d was a 9.00 am. value and not a mean daily value; e_d was the same as that used in the R_N estimate, although it was necessary to convert the unit of measurement from millibars to mm. of mercury.

A programme was written for PET. calculation, and the above data was run through a programmable calculator.

(B) Actual evapotranspiration (AET.)

Two periods (13.3 to 5.4.72 and 7.12 to 23.12.72) were selected, over which AET. was calculated for the north and south 'microclimate sites'. Soil moisture tension and rainfall data were used as the basis for a water balance:

$AET = P - \Delta W - RO - UD$ where:

ΔW = change in water content of soil.

RO = runoff.

UD = underground drainage.

P = precipitation.

The periods over which AET. was calculated were selected from initial examination of the soil moisture status and rainfall data, in anticipation of RO and UD being small or non-existent. In both the periods selected soil moisture content commenced at approximately field capacity and changed to some lower value during the measurement period. The changes in soil moisture tension recorded by the gypsum blocks at 4, 10 and 30 cm. depths were used as a means of estimating ΔW. Using data for the water characteristics of Judgeford silt loam, which has similar moisture characteristics to the Ngamoka silt loam of the experimental area (Gradwell, pers. comm.), it was possible to estimate from the block data the change in gravimetric water content of the soils at the north and south 'microclimate sites', at depths of 4, 10 and 30 cm.

No differentiation was made between the moisture tension characteristics of the north and south aspect soils, and it is possible that these were different. The bulk density of the soil was determined at the two 'microclimate sites' and three depths (see section 2.2 of this chapter) and the following relationship was used to determine the change in the volumetric water content of the soil at each depth:

$$Vc = (Bd \times Gc) / Wd \qquad \text{(Hillel, 1971)}$$

where:
- Vc = volumetric water content (%)
- Bd = dry bulk density (g/cc.)
- Wd = density of water (1 g/cc.)
- Gc = gravimetric water content (%)

The actual water loss from each site was obtained by adding the rainfall over the period (i.e. P) and the change in soil water content (Δ W). The rainfall values used were taken from the Ballantrae meteorological station records in preference to using the data from the gauges at the north and south 'microclimate sites'. This was in view of doubt existing as to the relationship of the rainfall differences (between aspects) which were recorded, to actual precipitation differences which might have occurred (see Chapter I). The change in soil water content was calculated using Vc and considering the blocks at 4 cm. to represent the soil profile from 0 to 7 cm., the 10 cm. blocks from 7 to 20 cm., and the 30 cm. blocks from 20 to 40 cm. The sum of Δ W and P (i.e. AET.) was expressed in terms of mm. of water per day.

2. SOIL FACTORS

Soil temperature and soil moisture status have been discussed under the heading of microclimatic factors.

2.1 Exchangeable Cations, Available Phosphorus, Total Nitrogen, Organic Carbon, Organic Matter Content, Cation Exchange Capacity, pH and Base Saturation.

(a) Sampling.

All sampling was along randomly selected transects (three on the east, south and west aspects and two on the north aspect) which were orientated in an up and downhill direction. Ninety six cores 2.5 cm. in diameter were taken at each aspect on 30.3.72. The cores were taken to a depth of 7.6 cm. and at approximately 45 cm. intervals along the transects, as indicated by knots on a string. The ninety six cores from each aspect were randomly divided into twelve groups of eight cores each, giving twelve samples per aspect.

(b) Sample Preparation

The samples were air-dried and the vegetative layer was removed (approximately 0.5 cm. depth). The forty eight samples were then ground in a roller grinder to pass through a 2 mm. sieve and a sample of each was fine ground in a mill. These fine ground samples were used for the total nitrogen and organic carbon analyses.

(c) Sample Analysis

The prepared samples were analysed by the Soils Laboratory, Grasslands Division, D.S.I.R. The methods of analysis, which were conventional, are outlined in Appendix 13. Base saturation was taken to be the sum of the exchangeable cations divided by the cation exchange capacity and expressed as a percentage. The organic matter content was taken to be equal to the organic carbon figure multiplied by 1.724 (Taylor and Pohlen, 1962). The pH of soil-water and soil-calcium chloride (0.1M) solutions was measured.

2.2 Bulk Density

Bulk density samples were taken from the north and south 'micro-climate sites' on 20.3.73. Four samples were taken at each of three depths: 0.5 to 8.0 cm., 14.0 to 21.5 cm., and 26.0 to 33.5 cm. The samples were taken with a bulk density sampler, which allowed the extraction of relatively undisturbed cylinders of soil from the profile. These cylindrical samples were encased in an alloy sleeve and the ends of each sample were trimmed flush with the sleeves to give a sample 7.62 cm. long and 7.62 cm. in diameter. The samples were pushed out of their sleeves, dried at 105°C, and weighed. The volume of the cylinders was calculated and the dry bulk density of the samples obtained, using:

$$Bd = W/V \qquad \text{(Hillel, 1971)}$$

where:
Bd = dry bulk density of sample (g./cc.)
W = dry weight of sample (g.)
V = volume of sample (cc.)

2.3 Available Nitrogen

(a) Sampling and incubation

(i) Ambient level of mineral nitrogen

Two soil samplings were made, one on 7.6.72 and the other on 8.10.72. The earlier sampling was timed to fit in with other experimental work, but the latter was carried out when it was judged that the 'spring flush' was imminent. In both cases fifteen cores were taken on each aspect. These were 2.5 cm. in diameter and to a depth of 7.6 cm. Only areas belonging to the microtopographical unit known as slope (Rumball, 1966), and of slope between 5° and 30° were sampled. i.e. paths and banks were not sampled. This sampling limitation was imposed in an effort to obtain results which allowed direct comparison of the nitrogen status of the different aspects.

The fifteen cores were in both instances randomly divided into five samples of three cores each; these were placed in a cool insulated container and taken to the laboratory.

(ii) Rate of mineralisation of nitrogen

On 8.6.72 an additional fifteen cores were randomly taken from each aspect and from within the same areas as described above. These cores were divided into five groups, as before. The vegetative layer on each core was removed and each group of three cores was placed in a 30 cm. length of 3.2 cm. diameter PVC tubing. A rubber stopper was used to plug one end of each tube to prevent throughflow of water, and the leaching which would otherwise have occurred while the tubes were being incubated in the soil. The tubes were buried on the respective aspects at a depth of 4 cm., being orientated up and down the slope with the stopper at the upper end. Four cm. was selected as the depth for incubation as it was the approximate mid-point of the 0 to 7.6 cm. samples. The turf layer was replaced over the tubes when they were buried. On 6.7.72 the tubes wer retrieved and the samples removed, placed in a cool insulated container and transported to the laboratory.

The reason for incubating the cores in the field, rather than carrying out a more conventional laboratory incubation, was that it would have been extremely difficult to represent the field conditions of varying temperature in the laboratory.

On 8.10.72 the same procedure as had been used in the winter incubation was repeated. However, in an attempt to elucidate the factors involved in the different mineralisation rates observed, the total number of tubes was increased to eighty, twenty of these being incubated on each aspect. These twenty were comprised of four groups of five tubes, each group containing soil from a different aspect. i.e. west, north, east and south aspect soils were incubated on each of the aspects. On 20.11.72 the tubes were retrieved and the samples were taken to the laboratory in a cool insulated container.

(b) Laboratory preparation

All samples were stored under refrigeration when not being handled. Each sample was forced by hand through a 3 mm. sieve, and the remaining organic matter and small stones were discarded. 10g. samples were taken from the sieved, wet soil for nitrogen analysis. Aliquots of the wet soil were weighed, dried at 105°C, and reweighed, in order to determine the moisture contents of the samples.

(c) Mineral nitrogen analysis

The 10 g. samples were analysed for mineral nitrogen content by the Soils Laboratory, Grasslands Division (see Appendix 13).

3. ANIMAL FACTOR

3.1 Amounts of Dung Deposition

The amount of sheep dung deposited on unit area of the different aspects was estimated by means of dung collection from previously cleared rectangular plots of known area.

Initial measurements, made using a line transect method and estimating the amount of dung cover on each aspect, were judged to be unreliable due to differential decomposition rates on the different aspects. The clearing of all dung off the plot areas prior to each measurement period was designed to reduce this effect.

The plots were initially 0.3 m. wide, but this was increased to 1 m. for the second and third measurement periods. The length of the plots varied from 16 to 27 m., the long axis being orientated up and down the slope. Two plots were located on each of the east, south and west aspects and one plot on the north aspect. Following selection of the plots, by random means, these were permanently located with corner pegs. Dung deposited on the plots during the periods 21.9 to 23.10.72, 23.10 to 27.11.72 and 27.11 to 21.12.72 was collected, dried at 65°C and weighed. A figure for grams of dung deposited per unit area was derived for each aspect during each of the measurement periods. It would have been desirable to have collected at least one full year's data on dung deposition differences, but this aspect of the study was not part of the original experimental proposal. The idea of examining dunging distribution was conceived on receipt of the results of the analyses conducted on the soil samples taken on 30.3.72. It was decided that, although only a limited analysis could be conducted, some effort should be made to explain the differences in soil fertility which were evident.

4. PASTURE FACTORS

4.1 Botanical Composition and Percentage Bare Ground

(A) Point analysis

Point analysis was selected as the most suitable method of comparing the botanical composition of the pasture on the four aspects. The following reasons were thought important in selecting this method:

(a) The sward under examination is little damaged by point analysis. Methods which involve the collection of herbage samples e.g. tiller and node counts on tiller plugs, and hand separation of herbage samples, damage the sward to a far greater extent than does point analysis. This point was considered relevant for the limited areas of the aspects in this study.
(b) The method allows rapid composition analysis and, if adequate points are taken, is accurate.
(c) The type of measurement which would be made using point analysis was considered adequate for the comparative purposes of this study.

A 'first-hit' technique was used, as opposed to an 'all-hits' technique (Brown, 1954). This decision was governed by the results of preliminary point analyses conducted using both techniques. The results obtained using the 'all hits' method obviously yielded more information on the structure of the vegetation being examined than did the 'first-hit' method. However, this had to be balanced against the decreased accuracy involved due to the rearrangement of the vertical and horizontal structure of the sward as the pins were lowered and the species hit were identified. The 'all-hits' method also proved far more time-consuming than the 'first-hit' method.

The apparatus used was that described by Rumball (1966). This consisted of a rigid frame with adjustable legs and three spring-loaded rods 7.6 cm. apart. A terminal needle 5 cm. long was fitted to each rod. The rods were orientated at right angles to the ground surface when sampling.

It was considered that, due to the small-scale pattern of the pasture being sampled, each point taken was biologically independant of the other two points in the frame. This, however, may not have been the case in some instances, e.g. where mats of Yorkshire Fog had established in damp hollows on the east aspect the pattern of the pasture was such that each point was probably not independant. This is further discussed in section (C) 3.1 of this chapter.

Two measures of pasture structure were derived from the data :
(i) Botanical composition, which was expressed as 'percentage sward composition'. For any particular species this was the number of times that species was hit, expressed as a percentage of the total number of points at which some component of the sward was hit.
(ii) Percentage bare ground, which was calculated as the number of points at which bare ground was hit, expressed as a percentage of the total number of points.

Goodall (1952) reports that cover estimates are inflated by increasing the diameter of the needles used in point analysis. This would in turn result in a decrease in the percentage bare ground values recorded. In an attempt to avoid this phenomenon, which is due to the needle diameters being larger than a theoretical point, an attempt was made to record only those species hit by the very point of the needle. The finite size of the needles would have had little or no effect on the percentage sward composition values derived (Goodall, 1952).

Approximately 500 points were taken at each sampling of an aspect. This number was decided upon by drawing curves which related the number of times a species was hit to the number of points taken, for two species (browntop and hawkbit) on two different aspects. The sample sizes at which the fluctuations in the curves drawn had decreased to a reasonable level were noted (Kershaw, 1964) and were considered in conjunction with data from Rumball (1966), who decided that 300 to 500 points per community type were adequate (using an 'all hits' method), and Brown's (1954) discussion of point analysis in her review of pasture measurement techniques. The curves described above were constructed during the autumn point analysis.

Point analysis measurements were made on all four aspects during the periods 2.5 to 8.5.72 (Autumn), 3.8 to 7.8.72 (Winter), 15.11 to 27.11.72 (Spring) and 31.1 to 13.2.73 (Summer). A stratified random sampling technique was used, the transects along which soil cores had previously been taken (see section 2.1) having been permanently pegged, and the 500 points per aspect were sampled along these transects.

(B) Dry weight analysis

Dry weight analyses of botanical composition were carried out following each pasture production harvest. The herbage from each of the twelve large cages on areas of 5^{o} to 30^{o} slope (three per aspect; see section 4.2) was subsampled and these subsamples were hand-separated into the component species. The separated species were dried at 65^{o}C, weighed, and the botanical composition of each sample was calculated on the basis of the contribution of the component species to the total dry weight of the sample. The three botanical composition estimates for each aspect were averaged. The dry weight compositions so derived were used as a standard measure of botanical composition with which the 'first-hit' point analysis results could be compared.

4.2 Pasture Production

Pasture production measurements were made over four periods in 1972. These periods were 16.1 to 4.4.72 (Summer/Autumn), 4.4. to 28.8.72 (Autumn/Winter), 28.8 to 9.11.72 (Spring), and 13.11 to 30.12.72 (Spring/Summer). Production was measured by a 'trim' method (Radcliffe et al, 1968). The areas on which production was to be measured were trimmed to a standard height at the start of each measurement period and cages were placed over these areas to protect the regrowth from sheep. At the end of the period the cages were removed and a known area was harvested to the original trimmed height. The cages were resited at the end of each measurement period and in no instance was the same area used in two different production periods. The herbage from each harvested area was weighed and subsampled for dry matter percentage determination. The application of these dry matter percentages to the green weights of each sample yielded figures for dry matter production per unit area. Division by the number of days in each production period gave productivity values. Trimming and harvesting were accomplished with the aid of an electric handpiece, powered initially by a portable generator and later by a twelve-volt car battery operating through a DC./AC. invertor. The trimming and harvesting cuts for the first production period were to a height of approximately 0.5 cm.; this is a similar height to that used by Radcliffe (1971). The trimming and harvesting cuts to this height appeared to be very severe and in some cases, especially where a mat existed below the green vegetative layer, almost all photosynthetic plant parts were removed. It was judged that this treatment did not resemble the somewhat laxer grazing regime being practised at the time, and for the following three measurement periods the trimming and harvesting cuts were raised to approximately 1.5 cm. above ground level. An even cutting height was achieved by attaching a skid beneath the handpiece. Where the conditions at harvesting were conducive to herbage loss by wind blow, a portable tripod weighing tent was erected to shield the area being cut.

The number of measurements made at each aspect varied. On the west and south aspects three large (120 cm. x 150 cm. x 45 cm. high) and four small (30 cm. x 30 cm. x 30 cm.) cages were located. The same number of small cages were used on the north and east aspects, but the number of large cages was increased to four for the second, third and fourth measurement periods. The three large cages on the west and south aspects, and three of the four on the north and east aspects, were randomly sited on areas excluding 'stock paths' and having slopes of between 5^{o} and 30^{o}.

These were the same areas from which the mineral nitrogen core samples discussed earlier in this chapter (section 2.3) were taken. At the start of the observational period doubt existed as to the number of cages necessary to derive production data which would show statistically significant differences between aspects. Ideally, the number of cages used would have been greater, however the total area of each aspect on which cages could be placed was limited in size and the number decided upon represented a compromise between statistical and practical considerations. These three cages were placed on areas of a specific slope class as a means of reducing the variability of the data obtained and of obtaining data which could be relatively easily interpreted.

The topographical variation of the north and east aspects was more pronounced than that of the west and south aspects, and the fourth large cage on the former was placed on areas which also excluded 'stock paths' but which exceeded 30° in slope. It was intended that the data from these steeper areas be used to indicate the magnitude of production differences between slope classes, although it was realised that these differences would not prove statistically significant due to the lack of replication on the steeper slope class.

The four small cages were randomly sited on each aspect. These cages were intended to provide an additional source of production data should the information from the large cages be insufficient to show production differences between aspects.

The large cages had angle-iron frames and were covered in lightweight chicken netting of approximately 6 cm. mesh. The small cages were constructed of wire netting of approximately 5 cm. square mesh and were, in effect, 30 cm. cubes with one open face (see Figures II.2, II.4). One metre square areas were harvested from under the large cages, and 25 cm. square areas from under the small cages.

The length of each production period was governed by the amount of herbage which accumulated in the cages, and the necessity for fitting the growth periods into the twelve month measurement period.

Slope was measured using a simple device designed and constructed for the purpose. (see Figure II.8). The device was also used for all other slope measurements made throughout the study. The slope reading obtained was influenced by wind but shielding of the face of the device allowed satisfactory measurements to be made.

(C) STATISTICAL METHODS

The results of all statistical analyses are summarised in Chapter III, or in the appropriate appendices.

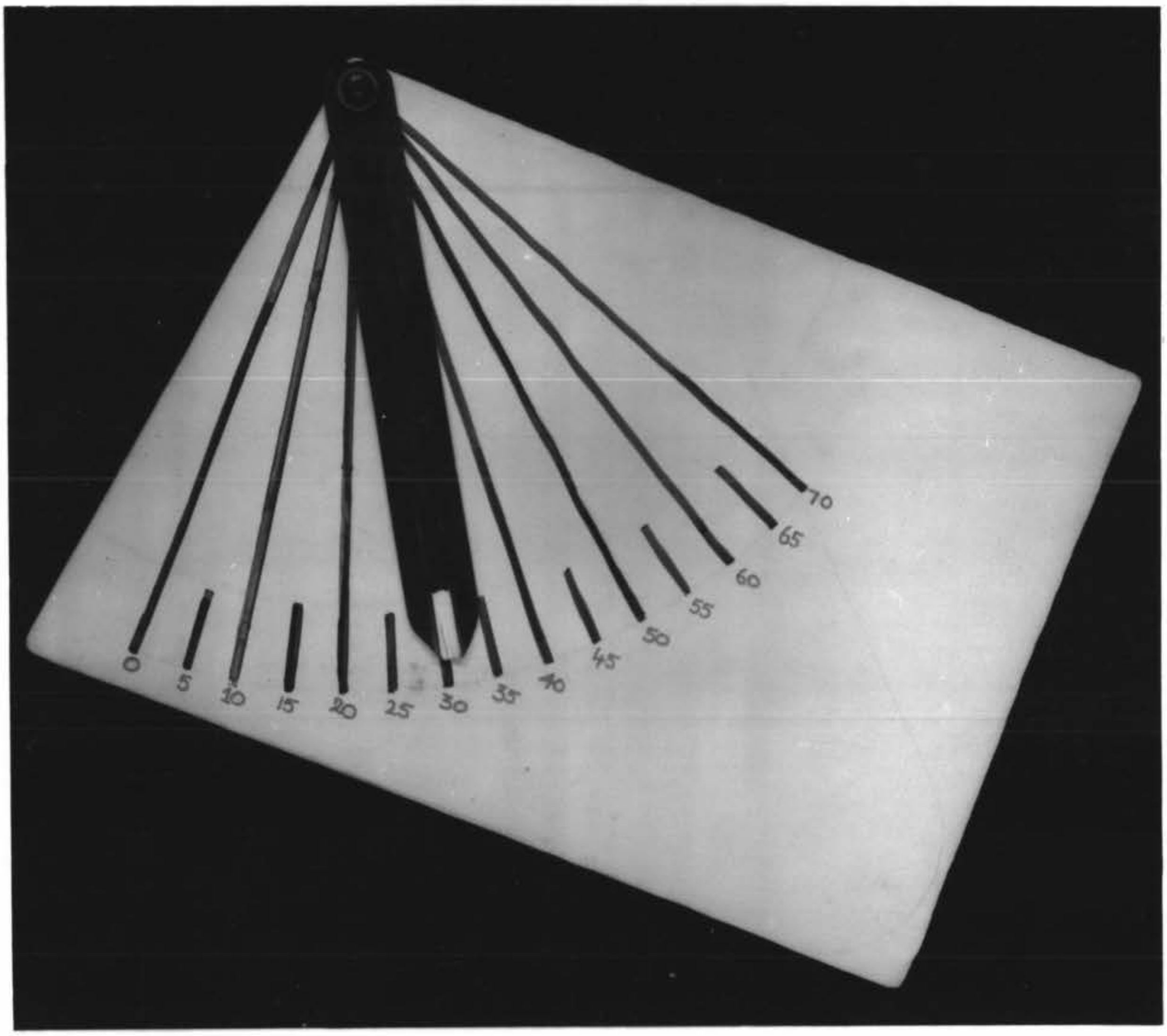


FIGURE II.8 Device used for Measuring Slope.

1. Microclimatic and Animal Factors

The microclimate and dung deposition data recorded were not statistically analysed. This was for two reasons:

(i) Much of the data recorded did not involve sufficient replication to enable satisfactory statistical analysis. This is to be expected in a descriptive study of the type described herein.

(ii) It was judged that graphical or tabular presentation adequately expressed the differences noted.

2. Soil Factors

2.1 Exchangeable Cations, Available Phosphorus, Total Nitrogen, Organic Carbon, Cation Exchange Capacity, pH and Base Saturation.

Single factor analyses of variance were conducted on the data obtained from the above soil analyses. The base saturation data, which were expressed as percentage values, were arcsin transformed prior to statistical analysis. Duncan's multiple range test (Steel and Torrie, 1960) was used to detect significant differences between the individual aspects.

2.2. Mineral Nitrogen

(A) Winter incubation

Single factor analyses of variance were conducted on the ambient and final mineral nitrogen level data. The mineral nitrogen contents of cores which had obviously been taken from recent urine patches were not included in the statistical analyses. This applied to the results of both the winter and spring incubations, but only involved 3 samples of a total of 140. Duncan's multiple range test was used to test for differences between individual aspects. In an attempt to determine the effect of differential sample moisture content on nitrogen mineralisation, regression coefficients describing the relationship between final moisture content (i.e. at the end of the incubation) and final nitrogen content were calculated. This was accomplished with the aid of a programmable calculator, and the programme used also provided F values denoting the significance of each coefficient. Final moisture content was used as a matter of necessity rather than choice. Due to the nature of the data recorded it was not possible to relate both initial and final moisture contents to the mineral nitrogen contents of the samples. It would also have been preferable to use net mineralised nitrogen rather than final nitrogen values, but again this was precluded by the nature of the data available.

(B) Spring incubation

A single factor analysis of variance was used to test for the existence of significant differences in ambient mineral nitrogen level between aspects.

Duncan's multiple range test was applied to determine the significance of differences between the individual aspects.

An analysis of covariance (ANCOVA) was attempted, using the final moisture and mineral nitrogen contents of the incubated cores as the independant and dependant variables respectively, in an attempt to statistically correct for any effects of differential moisture content on nitrogen mineralisation. The application of a test for homogeneity of treatment regressions (Steel and Torrie, 1960) showed the regressions, in fact, to be non-homogeneous, thus precluding the possibility of correcting for differential moisture content effects by this method. Parts of the ANCOVA are presented as two factor analyses of variance of final moisture and mineral nitrogen content.

Regression coefficients for final moisture and mineral nitrogen content were calculated as for the winter incubation data. A two-way analysis of variance of the net mineralisation (final minus ambient level) means confirmed the results of the analysis of variance of final mineral nitrogen content mentioned above, i.e. incubation aspect effects were non-significant, and on the basis of these results mean values for net nitrogen mineralisation during the incubation were calculated for each of the source aspects, incubation aspect effects being ignored. Significant differences between these mean values were determined using Duncan's multiple range test.

An analysis of variance was used to test for differences in the total nitrogen status of the samples used for ambient mineral nitrogen level determination in the Spring. Individual aspect differences were determined using Duncan's multiple range test.

3. Pasture Factors

3.1 Botanical Composition and Percentage Bare Gound.

Binomial confidence limits (Snedecor and Cochrane, 1967) were used to test for differences in botanical composition and percentage bare ground between aspects. Greig-Smith (1964) notes that where frames of points are used, as was the case in this study, it is not possible to use binomial theory as a basis for the prediction of variances and these must be calculated from the data recorded. The reason given is that the variances obtained using frames of points are greater than those obtained using the same number of random points. This was tested for some of the data recorded at Ballantrae. One hundred concurrent points were taken from each of the three transects sampled on the east and south aspects. The fractional occurrence of browntop and catsear in each of these transects, and the mean fractional occurrence for each aspect, were calculated. The appropriate variances were derived by two alternative methods:

(i) Based on binomial theory:

$npq = \text{var.}$

where: n = no. of observations (300).

p = recorded mean fractional occurrence for each aspect.

$q = 1 - p$

(ii) Based on normal theory:

$(x - \bar{x})^2/n-1 = \text{var.}$

where: n = no. of transects (3).

x = recorded fractional occurrence for each transect.

$\bar{x}$ = recorded mean fractional occurrence for each aspect.

In all cases the second method gave similar, or lower, variance values than those predicted by binomial theory (see Appendix 11). This is the opposite result to that noted by Greig-Smith (1964) and may be due to the systematic arrangement of the points along each transect. Greig-Smith (1964) states that there is no way of estimating the variance of a single set of systematic samples. For this reason binomial confidence limits were used as a basis for detecting differences between aspects, although it was realised that due to the relatively low variance of each set of data this would tend to give conservative estimates of the significance of the differences tested.

3.2 Production

Initial inspection of the raw production data (for 1 metre square samples on 5° to 30° slopes) suggested the existence of non-homogeneous treatment variances. The production data were converted to equivalent productivity values in order to eliminate differential growth period lengths, and the non-homogeneity of variance was confirmed using a chi-square test (Steel and Torrie, 1960). A log (x + 1) transformation was applied and the data retested for non-homogeneity, a negative result being obtained. A chi-square test for normality of data (Steel and Torrie, 1960) indicated that the transformed data were normally distributed. A two-way fixed-factor (aspect and growth period) analysis of variance (Remington and Schork, 1970) was used to detect the existence of significant treatment effects. Duncan's multiple range test was used to indicate significant differences in productivity between aspects.

The significance of production differences between slope classes, and between sets of measurements using different sized herbage samples, was determined using t-tests.

CHAPTER III RESULTS

1. MICROCLIMATIC FACTORS

1.1. Wind-Speed

The results of the wind-speed measurements, made for three and four day periods during 1972, are given in Figures III.1 and III.2. During most of the year the average wind-speed on the north aspect was greatest, followed by that on the west, east and south aspects respectively. The difference between the two latter was, in most instances, small.

1.2. Wind Direction

Table III.1 shows the number of days each month for which specific wind directions were recorded. The daily 9.00 am. estimates from which the summary was compiled are given in Appendix 3. The wind directions recorded most often were NW and West, 65% of the observations made being for winds from this quarter. The other quarter from which wind was often recorded was East - SE (23% of all observations), while winds from the North - NE and South - SW were only infrequently experienced.

1.3. Rainfall

Figure III.3 presents the distribution of rainfall throughout 1972. Each group of four bars represents the rainfall record for a three or four day measurement period. Table III.2 gives the total rainfall recorded on each of the four aspects over the experimental period. Where a record for one or more gauges was not obtained, as occurred at four of the measurement periods, the measured rainfalls from the other gauges have not been included in the respective totals.

1.4. Net Radiation Estimates

Average daily net radiation estimates, for the north and south 'microclimate sites' during four selected periods, are given in Table III.3. The daily estimates used to derive these average figures are presented in Appendix 4. The net radiation values for the periods encompassing the autumn and spring equinoxes and the winter solstice are greater for the north than for the south site. However, the value for the period over the summer solstice is less for the north than for the south site. The estimate for the south 'microclimate site' during the Winter is negative.

1.5. Evapotranspiration

(A) Potential Evapotranspiration (PET.)

Average PET. values for the same four periods as mentioned

FIGURE III·1

AVERAGE WIND SPEED JANUARY — JUNE

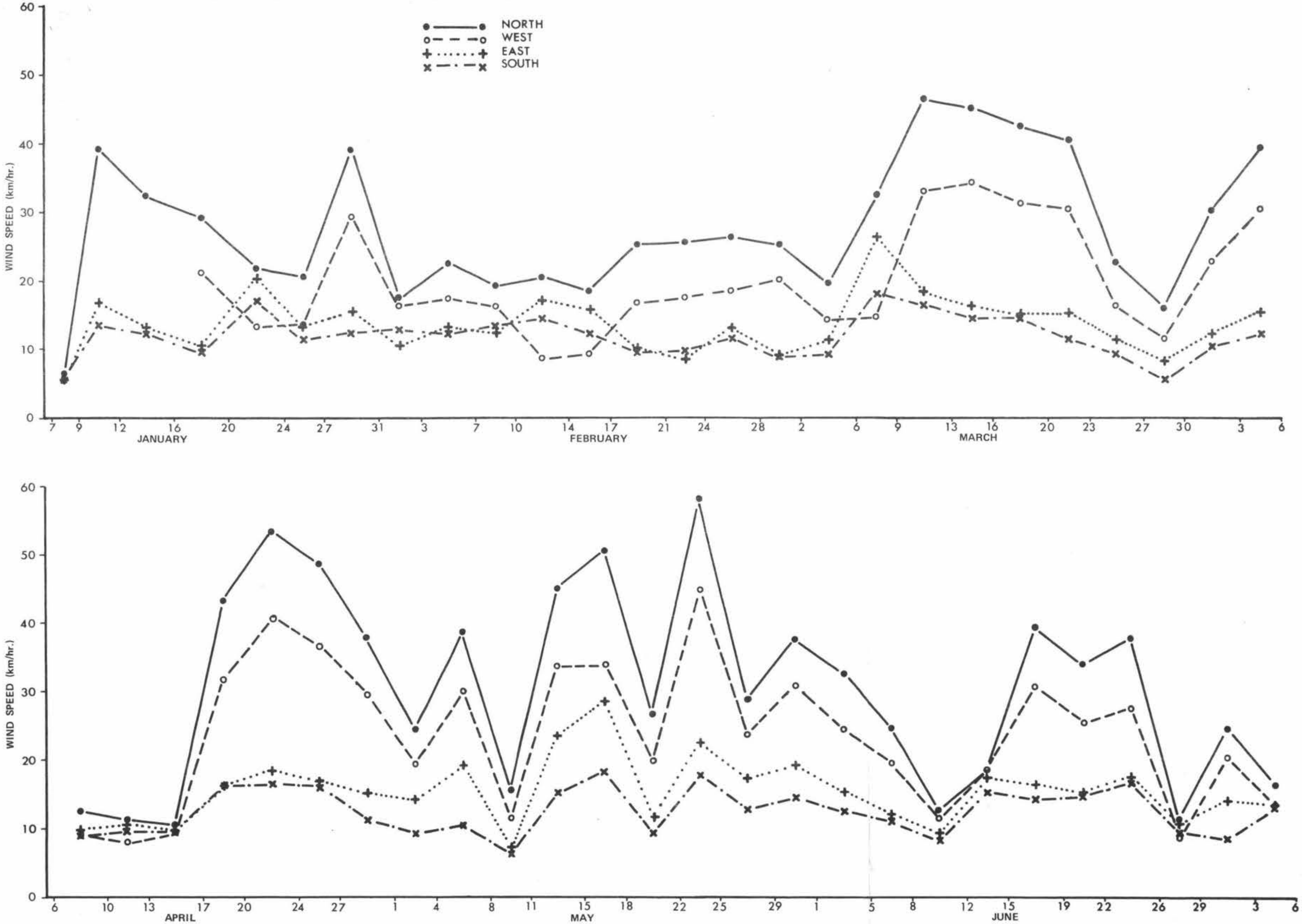


FIGURE III · 2

AVERAGE WIND SPEED

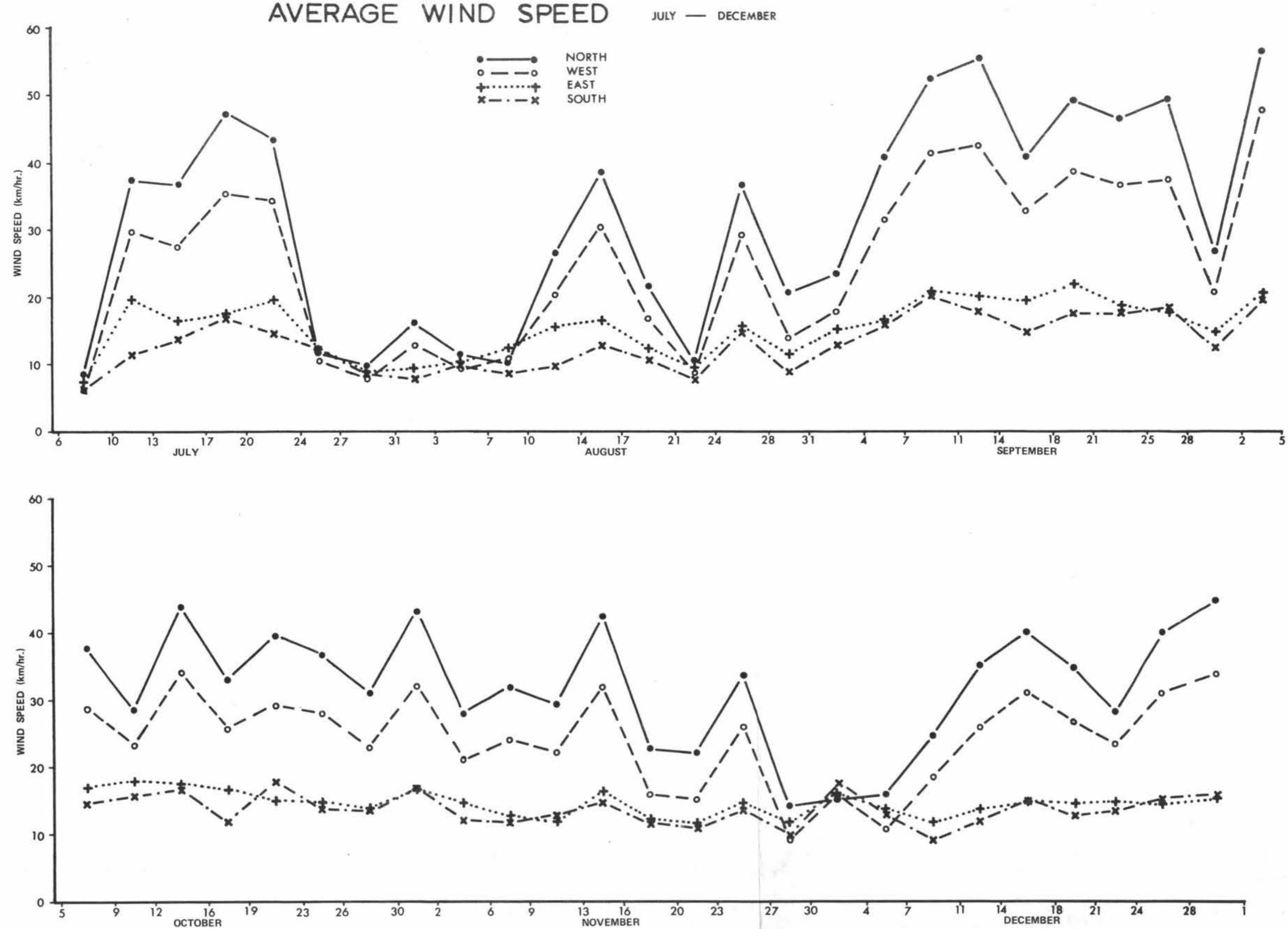


TABLE III.1 Wind Direction Summary for 1972. (number of days wind direction recorded)

	WIND DIRECTION								
	N	NE	E	SE	S	SW	W	NW	CALM
JAN.	1	1	4	2	0	0	7	16	0
FEB.	1	1	5	4	3	0	5	8	1
MAR.	0	3	6	0	0	0	6	15	1
APR.	0	1	2	5	0	1	6	13	2
MAY	0	1	3	3	0	0	3	19	2
JUN.	0	1	3	5	0	0	9	7	4
JUL.	1	1	7	4	0	0	7	8	2
AUG.	1	2	6	6	0	1	4	11	0
SEP.	2	0	1	2	1	2	2	20	0
OCT.	1	0	4	0	2	1	7	16	0
NOV.	2	0	5	2	1	0	11	9	0
DEC.	2	0	2	2	2	0	6	17	0

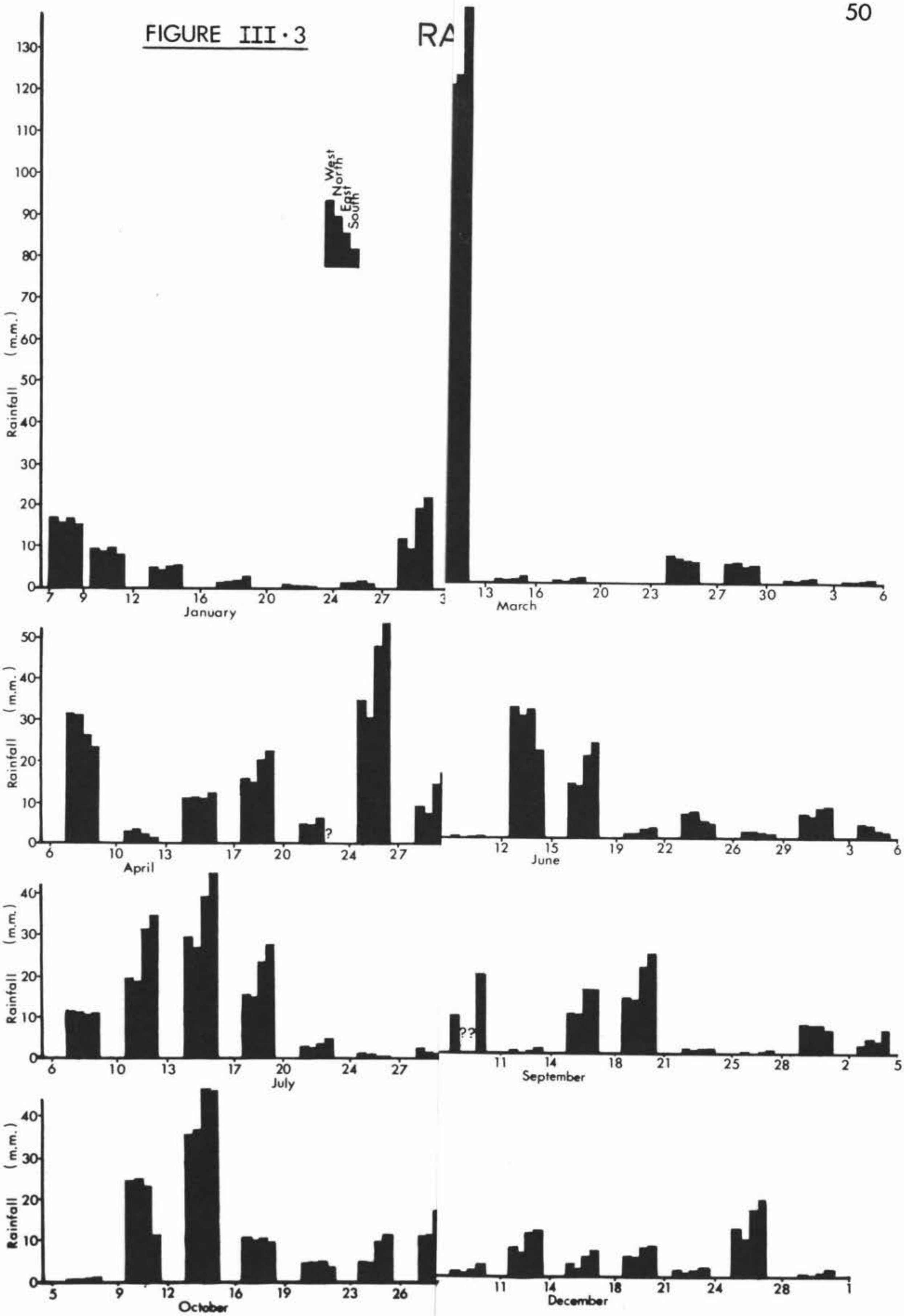
TABLE III.2 Rainfall Total for Each Aspect (mm.)

Aspect	West	North	East	South
Rainfall	862.6	807.9	964.7	1008.6

TABLE III.3 Net Radiation (ly./day) and Evapotranspiration (mm./day) Estimates for North and South 'Microclimate Sites'

	Period:		13.3 to 5.4.72	14.6 to 27.6.72	16.9 to 29.9.72	7.12. to 23.12.72
Net Radiation	North (N)		158.7	27.9	149.5	254.2
	South (S)		109.0	-27.9	109.6	279.2
	Ratio N/S (%)		146		136	91
Evapo-transpiration	North	PET.	3.22	1.03	3.07	3.52
		AET.	1.69			3.84
	South	PET.	1.57	0.30	1.55	2.60
		AET.	0.66			2.45

FIGURE III · 3 RA



above (section 1.4) are given in Table III.3. The daily PET. values used to derive these averages are presented in Appendix 4. During all four periods considered, PET., as calculated, was greater at the north than at the south 'microclimate site'.

(B) Actual Evapotranspiration (AET.)

Table III.3 compares the PET. values mentioned above and the AET. values derived for the autumn and spring periods. The summer values for AET. are similar to those for PET., however the autumn values are approximately 60% smaller than those for PET. For both periods the AET. value for the north site is substantially greater than that for the south site. The bulk density values used in the derivation of AET. are given in Appendix 12.

1.6 Soil Moisture Tension

Figures III.4, III.5 and III.6 present curves for soil moisture tension at 4 and 10 cm. depths on the various aspects. Tension values of 0 atmospheres have been plotted as 0.1 atmospheres to facilitate presentation of the data. The moisture tension values obtained for the 30 cm. depth are given in Appendix 1.2.

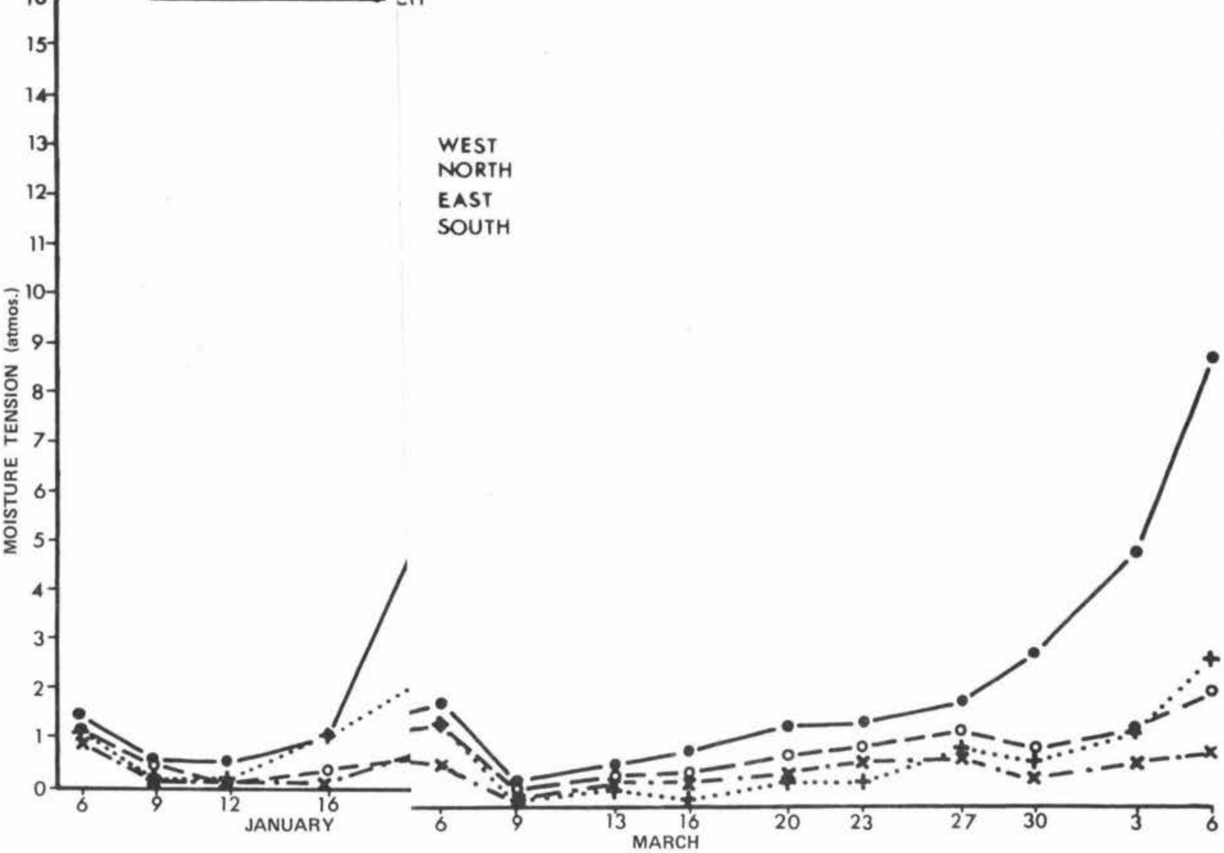
During the period mid-May to early September, moisture tension appears to have been at, or near, field capacity at all depths, on all aspects. During most of the remaining two portions of the year pronounced contrasts existed between aspects. The north aspect was almost invariably the driest aspect, and during dry periods following rain, soil moisture tension increased far more rapidly on the north than on the other aspects. Throughout much of the year the east and west aspects were similar in terms of soil moisture tension, although large differences existed between the two at times. In general the tensions recorded for the east and west aspects were intermediate between those recorded for the 'dry' north and the damper south aspect.

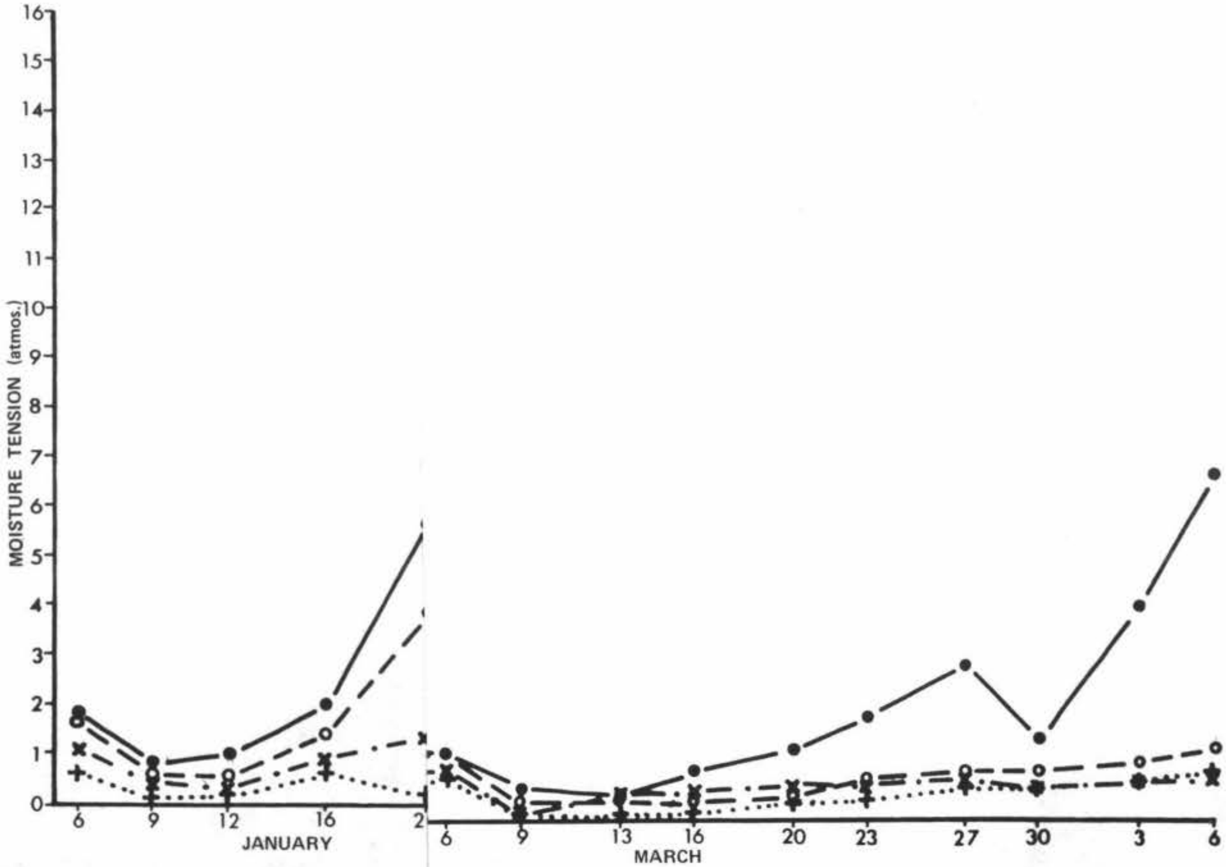
1.7. Temperature

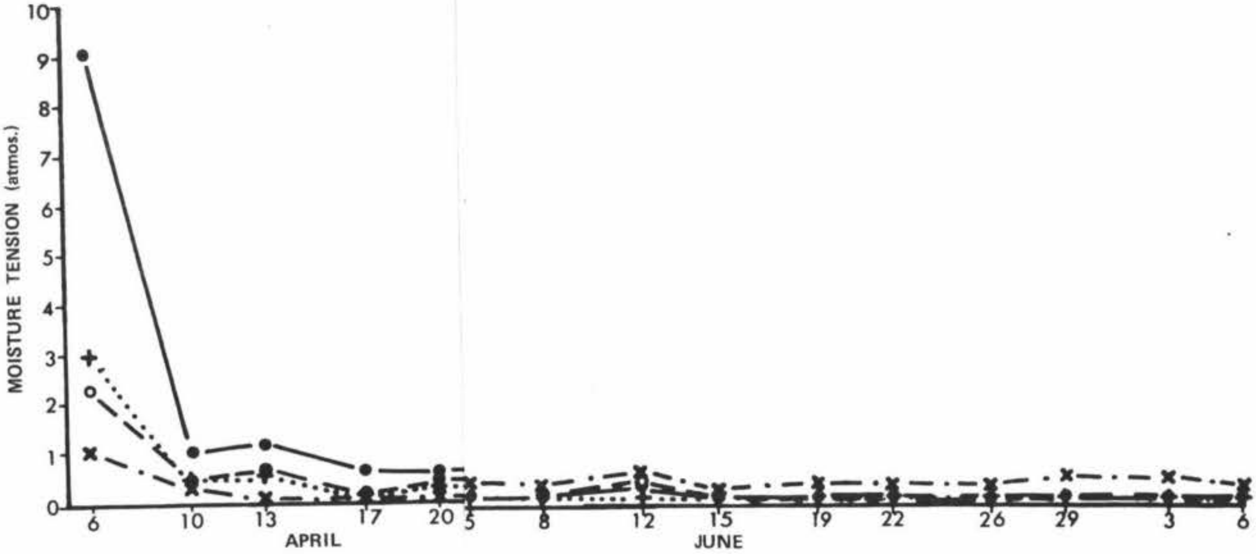
Figures III.7 and III.8 present the annual course of the 4 cm. air and soil temperatures measured at the respective 'microclimate sites'. These curves were derived from data, presented in Appendix 5, which give the average monthly temperature at each of eight three-hourly points throughout the day, for each month of the year. An error of $\pm$ 0.5°C. is placed on each of the curves in Figures III.7 and III.8 (see Chapter II, section 1.5).

The average air temperature curves for the four aspects are similar, the only notable exception being the curve for the north aspect, which dips sharply during February.

FIGURE III·4


CH
WEST
NORTH
EAST
SOUTH
MOISTURE TENSION (atmos.)
JANUARY
MARCH


MOISTURE TENSION (atmos.)
JANUARY
MARCH


MOISTURE TENSION (atmos.)
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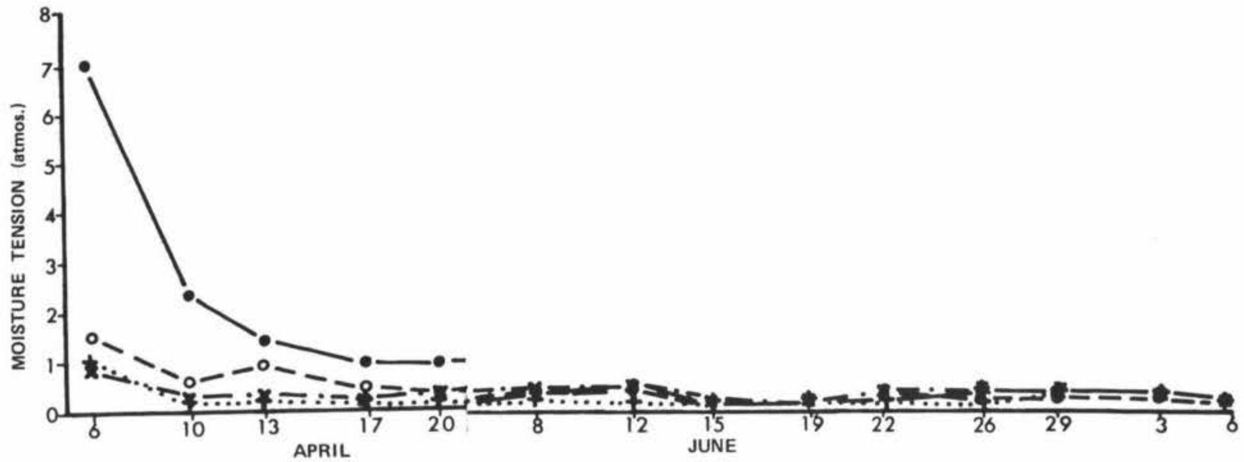
JUNE


MOISTURE TENSION (atmos.)
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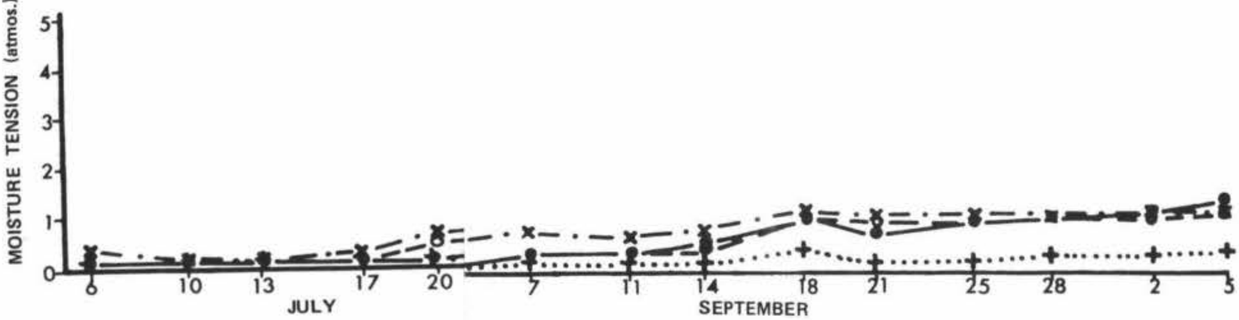
JUNE


MOISTURE TENSION (atmos.)
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2
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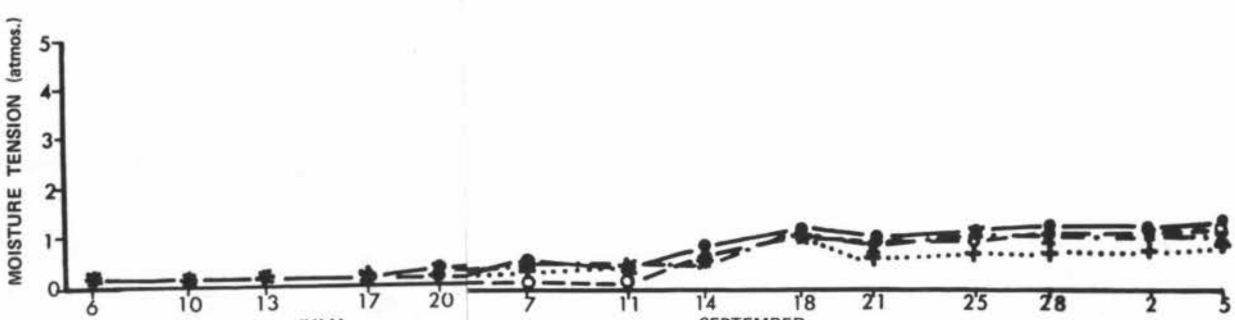
SEPTEMBER


MOISTURE TENSION (atmos.)
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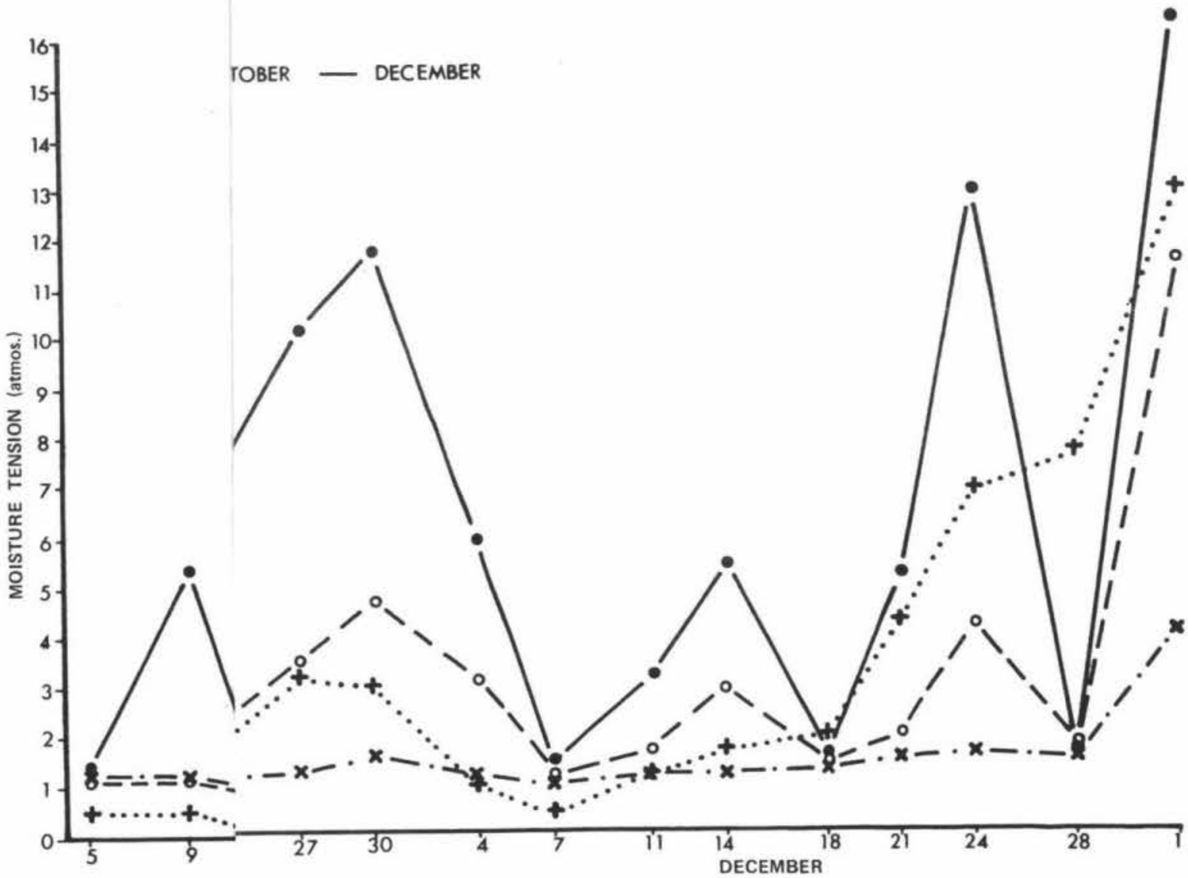
SEPTEMBER


TOBER — DECEMBER
MOISTURE TENSION (atmos.)
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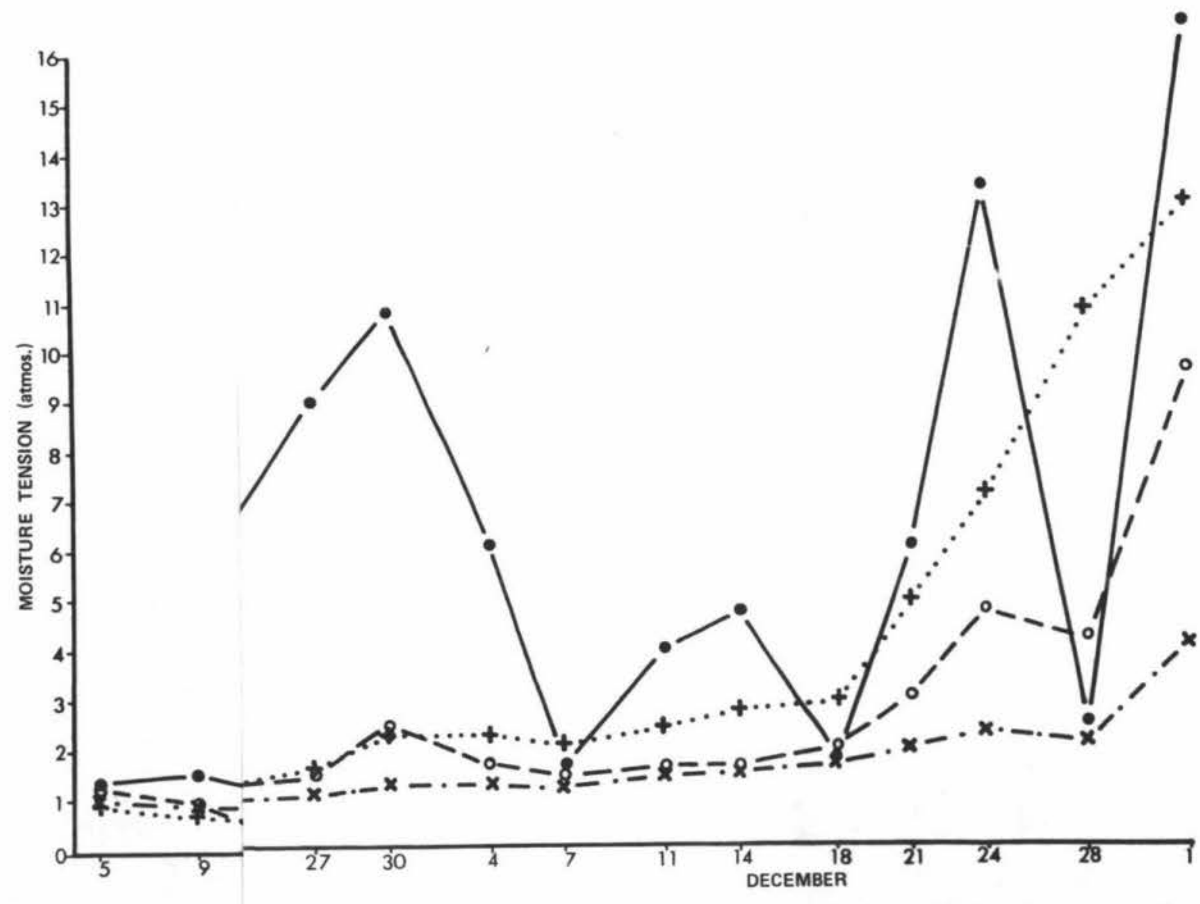
24
28
1
DECEMBER


MOISTURE TENSION (atmos.)
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28
1
DECEMBER

FIGURE III.7

ANNUAL COURSE OF 4 c.m. AIR TEMPERATURE

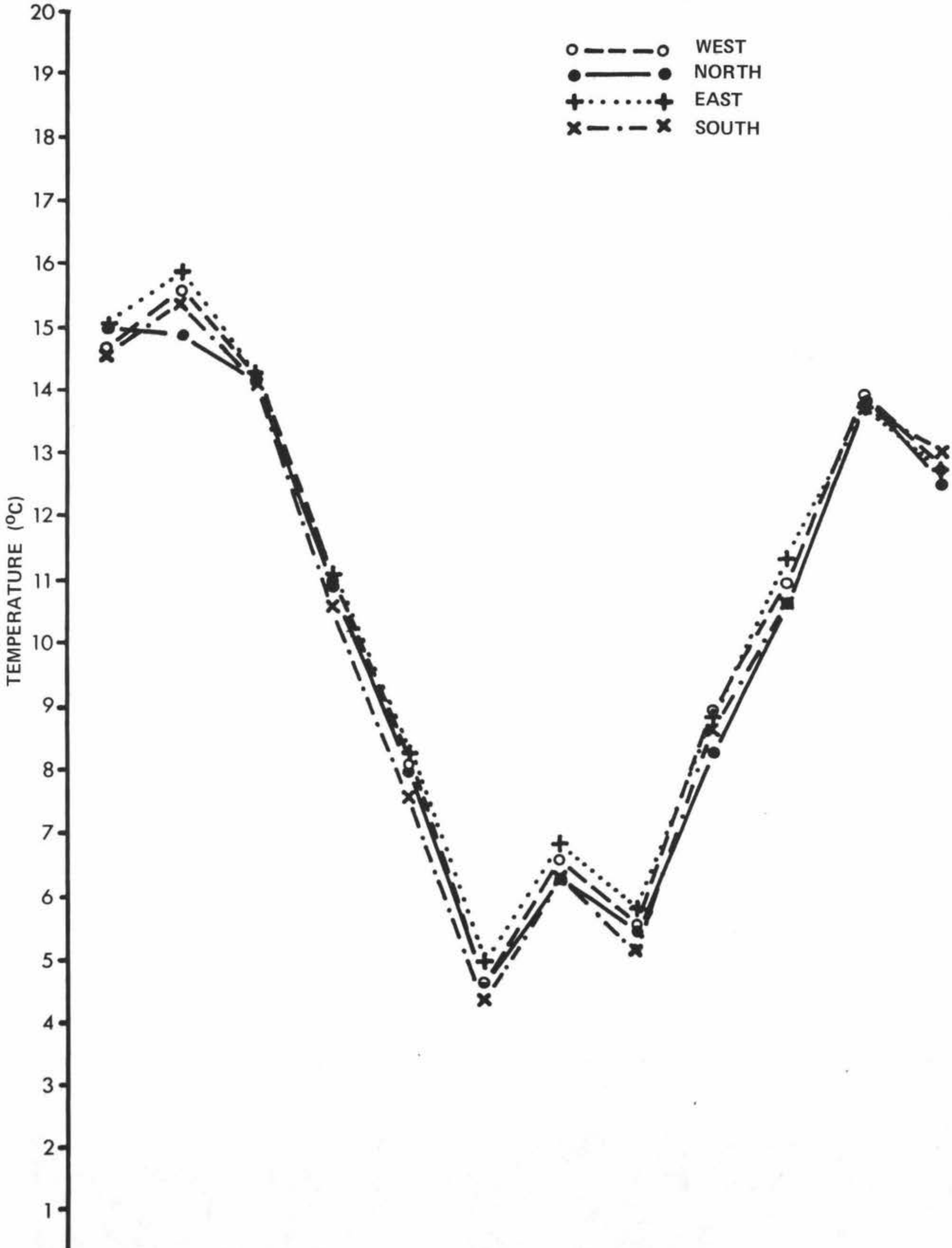
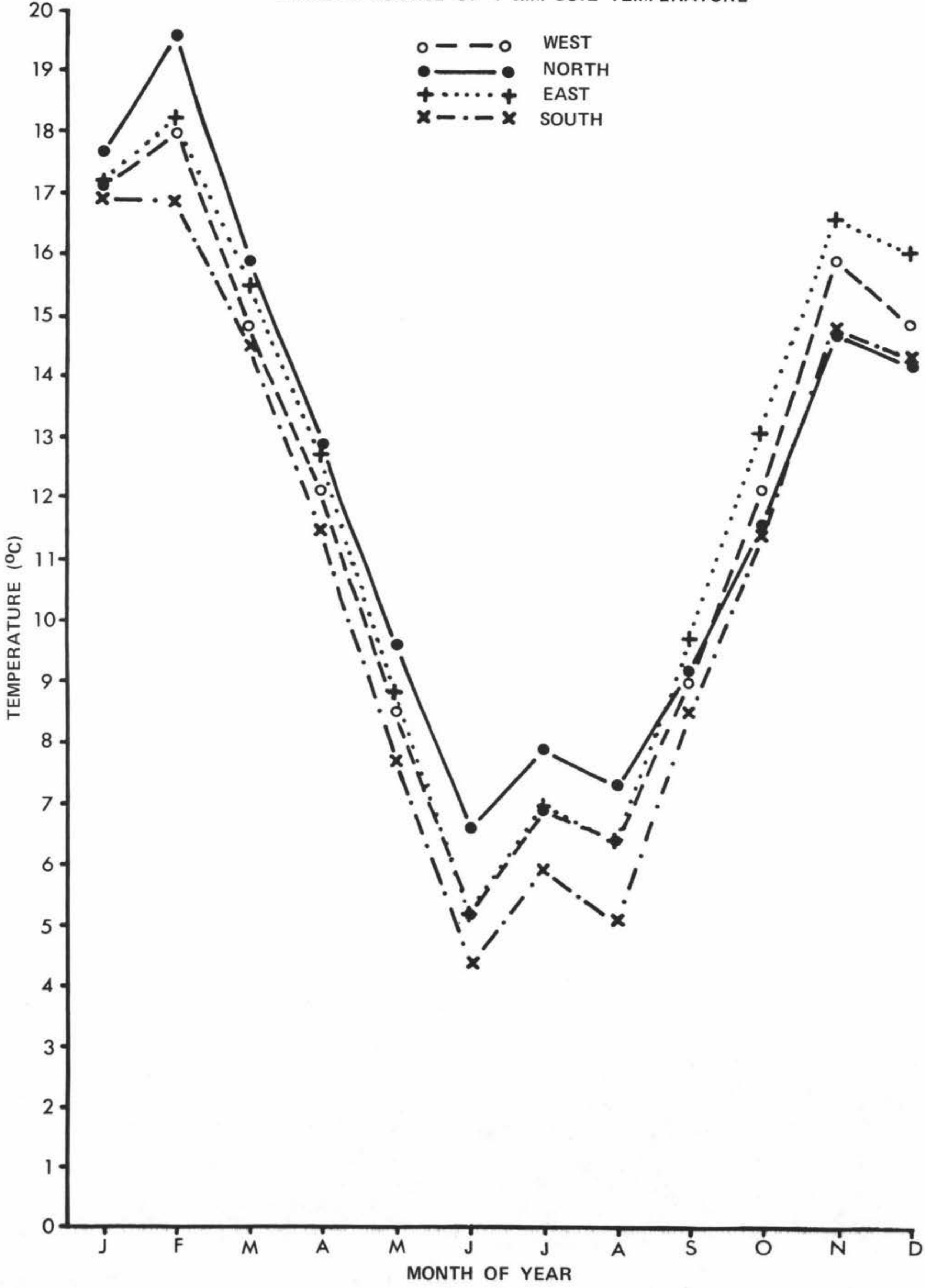


FIGURE III.8

ANNUAL COURSE OF 4 c.m. SOIL TEMPERATURE



During the months January to August the north aspect soil temperature was the warmest, and that of the south aspect the coolest. This effect was most pronounced in February and during the Winter. The soil temperatures on the east and west aspects were similar, and intermediate between those on the north and south aspects, during the above period. However, during the Spring and early Summer (September to December) the soil temperature of the north aspect 'dropped' to that of the south aspect, and the east aspect soil temperature 'rose', to make it the warmest face during this period.

2. SOIL FACTORS

2.1. Exchangeable Cations, Available Phosphorus, Total Nitrogen, Organic Carbon, Organic Matter Content, Cation Exchange Capacity, pH and Base Saturation.

The results of the chemical analyses of the soil samples taken on 30.3.72 are given in Table III.4. All values are means for twelve samples; those means encompassed by a bar are not statistically different at the 5% level, as determined by Duncan's multiple range test. Taylor and Pohlen (1962) give a table of ratings, from low to very high, for the results of chemical analyses of soil. On this basis the exchangeable calcium and magnesium levels are medium, the potassium levels medium to high, and the sodium levels low. The cation exchange capacity values are rated as medium and the base saturation values as low. The available phosphorus figures (if converted to mg.%) are medium for the east and north, and low for the south and west aspects. The total nitrogen, organic carbon and organic matter content values are rated as medium, and the pH values as low.

Table III.4 ranks the aspects according to the results of the chemical analyses. The pH values for the four aspects are similar, although the west aspect appears to have a slightly lower pH than the other aspects. The remainder of the results rank the east aspect highest, followed by the north, and south and west aspects respectively, with the exception of the base saturation and exchangeable sodium results.

2.2 Available Nitrogen

(a) Ambient level of mineral nitrogen.

Table III.5 gives the average ambient level of mineral nitrogen in soil samples taken from areas of 5^{o} to 30^{o} slope on 7.6.72 and 8.10.72. Each value is the mean for five samples, and those values encompassed by a bar are not significantly different at the 5% level, as determined by Duncan's multiple range test. The ambient mineral nitrogen level for the east face was greater, at both samplings, than the levels for the south, north and west faces.

TABLE III.4 Results of Chemical Analyses of Soil Samples Taken 30.3.72

pH (soil-water solution)	E	5.23	S	5.23	N	5.19	W	5.13
pH (soil -0.1 M $CaCl_2$ solution)	S	4.70	N	4.63	E	4.60	W	4.52
Organic carbon (%)	E	7.57	N	6.62	W	5.98	S	5.29
Total nitrogen (%)	E	0.52	N	0.39	S	0.35	W	0.31
Organic matter content (%)	E	13.1	N	11.4	W	10.3	S	9.10
Available phosphorus (ppm.)	E	11.8	N	11.5	W	7.30	S	5.70
Exchangeable calcium (m.eq.%)	E	6.95	N	5.46	S	5.21	W	4.09
Exch. magnesium (m.eq.%)	E	2.52	N	2.16	S	1.53	W	1.21
Exch. potassium (m.eq.%)	E	1.42	N	1.31	S	0.77	W	0.75
Exch. sodium (m.eq. %)	N	0.25	E	0.22	S	0.20	W	0.17
Cation exchange capacity (m.eq.%)	E	23.5	N	21.9	W	18.5	S	18.0
Base saturation (%)	E	43.4	S	40.9	N	40.3	W	35.2

(b) Mineralisation during incubation

Table III.6 presents values for the net amount of nitrogen mineralised during the winter and spring incubations. These values were obtained by subtracting the ambient levels of Table III.5 from the means of the final levels given in Appendix 6.3.

During the winter incubation the net amount of mineral nitrogen formed was much greater on the east than on the other three aspects. A two-factor (source and incubation aspects) analysis of variance, conducted on the net nitrogen mineralisation means of Table III.6, for the spring incubation results, showed a significant source aspect effect. This analysis is summarised in Table III.7. A more sensitive analysis of variance, using the final mineral nitrogen contents of the samples in the spring incubation, confirmed this result (see Appendix 6.1). On the basis of these results, mean values for net mineralisation during the spring incubation were derived for each source aspect. These means, and differences at the 5% level as determined using Duncan's multiple range test, are given in Table III.8. The east aspect value was significantly greater than that for the south aspect, this in turn being greater than those for the north and west aspects.

The relationship between final moisture content (independant variable) and final nitrogen content (dependant variable), during both winter and spring incubations, is expressed by the various regression coefficients given in Table III.9. The individual coefficients for each group of incubated cores, and the individual within source and within incubation aspect coefficients, are given in Appendix 6.2. The moisture content and mineral nitrogen content data from which these regressions were calculated are presented in Appendix 6.3.

Values for the moisture contents of the samples used in the ambient and final mineral nitrogen determinations are given, for both incubation periods, in Table III.10. Each value is the mean for five samples. A two-way analysis of variance of the final moisture contents of the cores used in the spring incubation is summarised in Table III.11. Source aspect effects are highly significant and incubation aspect effects significant.

Total nitrogen values for the soil samples used in the ambient mineral nitrogen analysis at the start of the spring incubation, are given in Table III.12. Each value is the mean for five samples, and values encompassed by a bar are not significantly different at the 5% level, as determined using Duncan's multiple range test. The east aspect soils contained significantly higher levels of total nitrogen than the other soils.

TABLE III.5 Ambient Mineral Nitrogen Levels (ppm., dry soil)

7. 6.72	E	16.8	S	13.2	N	12.0	W	9.8
8.10.72	E	19.1	S	11.5	W	11.1	N	9.4

TABLE III.6 Net Nitrogen Mineralisation during Incubation (ppm., dry soil)

Incubation aspect	Source aspect				
	Winter (7.6 to 6.7.72)	Spring (8.10 to 20.11.72)			
		West	North	East	South
West	2.8	50.2	48.9	105.3	47.4
North	2.4	15.5	33.4	88.8	84.0
East	21.4	5.2	9.5	69.8	55.4
South	0.3	37.4	29.3	42.2	24.1

TABLE III.7 Analysis of Variance of Net Mineralisation Means for Spring Incubation

Source of Variation	M.S	d.f.	F and value required	
Incubation aspect	878.08	3	2.29 ns	3.86
Source aspect	2107.66	3	5.51 *	3.86
Error	382.66	9		

TABLE III.8 Net Nitrogen Mineralisation for Source Aspects during Spring Incubation (ppm., dry soil)

Aspect	East	South	North	West
Nitrogen	76.5	52.7	30.3	27.1

TABLE III.9 Coefficients for Regression of Final Mineral Nitrogen Content on Final Moisture Content

Regression	Winter	Spring
Overall	+ 0.82**	+ 1.01 ns.
Within group	0.00 ns.	- 1.74 ns.
Within source aspect	* n.a.	- 0.16 ns. to - 2.54 ns.
Within incubation aspect	n.a.	+ 0.05 ns. to + 3.23 ns.

* n.a. = not applicable

TABLE III.10 Moisture Contents of Soil Cores used for Mineral Nitrogen Determinations (g./100g. dry soil)

	Winter		Spring Incubation				
	ambient	final	ambient	final moisture content			
				Incubation Aspect			
				West	North	East	South
West	45.7	44.8	38.3	36.5	37.4	36.1	39.0
North	41.9	41.7	26.8	32.0	30.7	28.0	30.5
East	52.5	61.6	44.6	44.7	42.1	43.8	44.0
South	53.1	51.6	49.5	50.2	44.3	44.5	50.8

TABLE III.11 Analysis of Variance of Final Moisture Contents of Soil Samples Incubated during the Spring

Source of variation	d.f.	MS	F
Incubation aspect	3	53.43	2.92*
Source aspect	3	1175.52	64.24**
Interaction	9	15.75	0.86 ns.
Error	61	18.30	
Total	79		

Table III.13 expresses values, calculated from the 4 cm. soil temperature data, for centigrade hours above 5°C. The north aspect value is greatest during the winter incubation, the east aspect value during the spring incubation.

3. ANIMAL FACTOR

Table III.14 gives values for the amount of dung collected from plots on each aspect. Values for the amount of dung collected per 10m^2 were higher on the east and south than on the west and north aspects. This applied for each of the three measurements made.

4. PASTURE FACTORS

4.1 Comparison of Point Analysis and Dry Weight Analysis

Table III.15 compares results obtained using the point analysis and dry weight analysis methods of botanical composition determination. The dry weight figures are means for three samples. In all cases (i.e. at all seasons and on all aspects) point analysis gave values for the grass component of the sward which were lower than those given by dry weight analysis. The comparison of flatweed values indicates the converse, as does the comparison of clover values, with one exception. A list of the values obtained for the individual species is given in Appendix 7.3.

4.2 Comparison of Botanical Composition and Percentage Bare Ground between Aspects.

Table III.16 compares the botanical composition of the swards at the various aspects, as determined by point analysis. Only values for the more abundant species are given. A full list of all species encountered, and their recorded abundance, is given in Appendix 7.3. Those values encompassed by a bar are not significantly different at the 1% level, as determined using binomial confidence limits.

Some species did not show any distribution pattern with respect to changing aspect e.g. sweet vernal, cocksfoot (*Dactylis glomerata*), browntop and white clover (*Trifolium repens*). Other species showed a distinct pattern; Yorkshire fog and perennial ryegrass comprised a greater proportion of the sward on the east than on the other aspects, while danthonia was most abundant on the north aspect and nertera (*Nertera setulosa*) on the west and south aspects. A number of species showed indistinct distribution patterns, and in some cases these patterns were evident only at certain times of the year. Ribgrass (*Plantago lanceolata*) tended to be most abundant on the north aspect for the autumn, winter and

TABLE III.12 Total Nitrogen Values for Soil Cores used in Spring Ambient Level Determinations (% dry soil)

Aspect	East	South	North	West
Nitrogen	0.464	0.391	0.383	0.375

TABLE III.13 Centigrade Hours above 5°C at 4 cm. in Soil, for Winter and Spring Incubations

Aspect	West	North	East	South
Winter incubation	327.6	1083.6	352.8	25.2
Spring incubation	9133.2	8436.6	10203.9	8462.4

TABLE III.14 Dung Deposition at North, South, East and West Aspects (gm. dry dung/$10m^2$)

Period	West	North	East	South
21.9 to 23.10.72	12.9	5.8	85.9	99.1
23.10 to 27.11.72	8.4	5.3	47.5	46.8
27.11 to 21.12.72	31.9	9.5	62.3	73.6

TABLE III.15 Comparison of Botanical Composition as determined by Point Analysis (PA.) and Dry Weight (DW.) Analysis (% values)

		Autumn		Winter		Spring		Summer	
		1.5. to 9.5.72	4.4.72	4.8. to 10.8.72	23.8.72	15.11. to 27.11.72	9.11.72	31.1. to 13.2.73	30.12.72
		PA	DW	PA	DW	PA	DW	PA	DW
WEST	grasses	59.0	68.3	58.7	89.5	55.4	85.2	47.7	66.6
	clovers	4.7	6.0	4.6	1.6	11.8	4.7	7.0	2.7
	flatweeds	29.7	26.2	20.2	2.0	29.0	9.5	31.7	29.0
NORTH	grasses	66.1	75.7	72.5	90.6	66.9	92.8	61.9	83.7
	clovers	2.8	1.4	2.6	0.3	6.3	1.8	2.9	1.3
	flatweeds	24.5	22.5	16.5	2.7	24.8	6.7	22.4	15.0
EAST	grasses	73.8	83.2	76.4	98.2	73.4	93.1	64.2	97.5
	clovers	4.7	2.8	1.6	0.9	4.4	0.7	5.4	4.1
	flatweeds	19.6	13.1	14.6	0.6	18.9	5.6	23.1	19.9
SOUTH	grasses	62.5	70.0	52.3	86.8	57.2	74.8	57.0	79.9
	clovers	5.5	5.0	1.9	1.0	5.5	4.3	5.1	3.3
	flatweeds	25.0	22.0	20.0	4.7	26.8	13.6	28.3	20.0

TABLE III.16 Botanical Composit). Those values encompassed by a bar are not sig

	Autumn			ng	Summer			
Sweet Vernal	N 11.7	W 9.4	S	N 11.0	W 10.1	S 9.0	E 7.7	N 5.5
Browntop	W 36.7	N 34.4	S	E 25.9	N 28.6	S 24.4	E 24.2	W 22.0
Cocksfoot	N 0.8	S 0.8	W	S 0.2	W 1.2	N 0.7	S 0.6	E 0.0
Crested dogstail	E 10.0	S 8.5	W	N 3.0	S 8.4	E 4.2	N 4.0	W 3.7
Yorkshire fog	E 13.2	S 9.3	W	N 1.5	E 14.2	S 7.8	W 4.9	N 1.5
Perennial rye.	E 9.5	S 1.3	N	W 0.2	E 9.2	S 2.8	N 1.1	W 0.9
Danthonia	N 13.3	E 4.5	W	S 1.3	N 18.3	W 4.3	E 2.7	S 0.6
Chewings fescue				E 0.2	S 3.4	N 1.1	E 0.8	W 0.6
Chickweed	N 1.4	E 1.2	S	S 0.0	E 3.1	N 0.0	W 0.0	S 0.0
Moss	S 7.3	W 6.4	N	N 1.5	W 17.4	N 12.1	S 8.4	E 6.5
Catsear	W 17.2	N 11.1	S	E 10.9	W 16.8	E 13.1	S 12.3	N 11.7
Hawksbeard	W 2.7	E 2.7	S	N 0.3	W 0.9	N 0.4	E 0.0	S 0.0
Hawkbit	E 7.5	N 6.1	S	E 2.3	S 6.4	N 6.2	E 5.0	W 3.0
Ribgrass	N 4.2	S 2.6		W 0.7	W 4.6	S 3.4	N 2.2	E 1.5
Nertera	W 4.2	S 1.6		E 0.0	S 4.2	W 4.0	N 0.4	E 0.5
White clover	S 4.9	E 4.7		E 3.9	W 7.0	E 5.4	S 4.8	N 2.9
Suckling clover	0.0	0.0		E 0.5	0.0	0.0	0.0	0.0
Bare ground	N 25.0	S 19.6		E 12.2	E 48.2	N 44.5	W 33.3	S 27.4

spring point analyses. Moss tended to be most prevalent on the south and west aspects, although the only clearcut result indicating this is that of the winter point analysis, and the results of the summer analysis do not wholly bear this out. Chickweed (Cerastium glomeratum) was most abundant on the east aspect in the Spring and Summer, and suckling clover (Trifolium dubium), which is an annual, on the west aspect during the Spring. Catsear (Hypochaeris radicata) appears to have been most commonly encountered on the west aspect, and crested dogstail (Cynosurus cristatus) on the east and south aspects.

No consistent differences in percentage bare ground were evident, although the north aspect tended to have higher bare ground values than the other aspects.

4.3 Production Differences

Rates of pasture production for the four aspects are shown in Table III.17. The figures presented are derived from measurements made on areas of 5° to 30° slope, and protected by large cages. During the summer/autumn period the swards at the east and south aspects grew at significantly faster rates (as determined by Duncan's multiple range test) than those on the north and west aspects. During all three remaining periods productivity values for the east aspect were significantly greater than those for the other three aspects, the latter having similar growth rates (see Figures III.9, III.10, III.11, III.12 for autumn/winter period). The raw production data,and the analysis of variance of the log $(x + 1)$ transformed productivity data,are given in Appendices 7.1 and 7.2.

Table III.18 compares production estimates made using 25 cm. square and 100 cm. square herbage samples. The asterisks denote significant differences at the 5% level, as determined using t-tests. The values for the 25 cm. square samples are means for two to four quadrats, and for the larger samples for three quadrats in each case. The raw data, from which the means in Table III.18 were derived, is given in Appendix 7.4. One significant difference was detected at each of the production cuts, with the exception of the first.

Table III.19 compares production on two slope classes. The data presented is that for production estimates using the four large cages on the east and north aspects. The value for the steeper slope class is derived from one sample only, as opposed to three samples for the more gentle slopes; t-tests on the data failed to indicate any significant differences. In all cases, however, the figures presented show a lower production from the steeper slope class.

TABLE III.17 Productivity on Slopes of 5° to 30° (kg.DM./ha./day)

PERIOD	WEST	NORTH	EAST	SOUTH	Significance at 5% level
16.1 to 4.4.72 Summer/Autumn	8.5	5.3	19.7	14.4	E, S > W,N
4.4. to 23.8.72 Autumn/Winter	2.2	2.7	13.4	2.6	E > N,S,W
23.8 to 9.11.72 Spring	11.5	11.4	51.2	15.6	E > S,W,N
13.11 to 30.12.72 Spring/Summer	22.6	22.9	46.8	19.7	E > N,W,S

TABLE III.18 Comparison of Production Estimates using 25 cm^2 Herbage Samples (small cages) and 1 m^2 Herbage Samples (large cages) (kg.DM./ha.)

GROWTH PERIOD	WEST		NORTH		EAST		SOUTH	
	small cages 25 cm^2 samples	large cages 1 m^2 samples	small cages 25 cm^2 samples	large cages 1 m^2 samples	small cages 25 cm^2 samples	large cages 1 m^2 samples	small cages 25 cm^2 samples	large cages 1 m^2 samples
16.1 to 4.4.72	572	674	504	421	1080	1555	1205	1138
4.4 to 23.8.72	996 *	315	485	374		1884	448	365
23.8 to 9.11.72	708	911	1112 *	902		4046	1939	1229
13.11 to 30.12.72	862	1059	1073	1076	1403 *	2198	762	925
TOTALS	3138	2959	3174	2771		9683	4354	3637

* = significant difference at 5% level

FIGURE III.9 East Aspect: Herbage Production
4.4 to 28.8.72

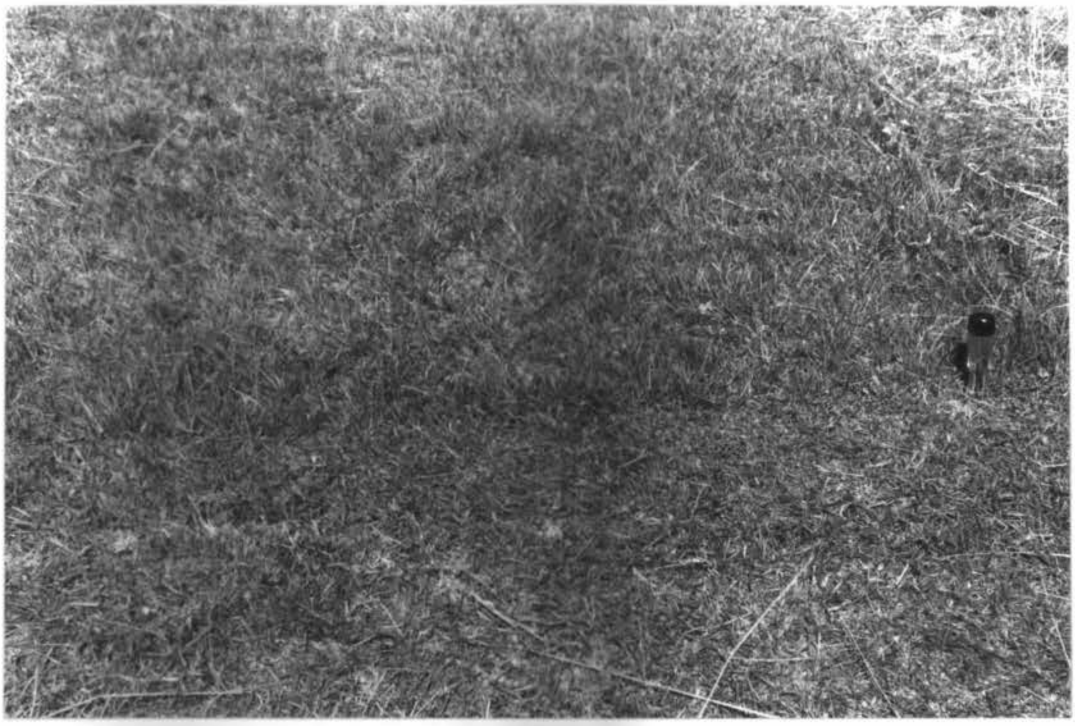


FIGURE III.10 North Aspect: Herbage Production
4.4 to 28.8.72

FIGURE III.11 South Aspect: Herbage Production
4.4 to 28.8.72

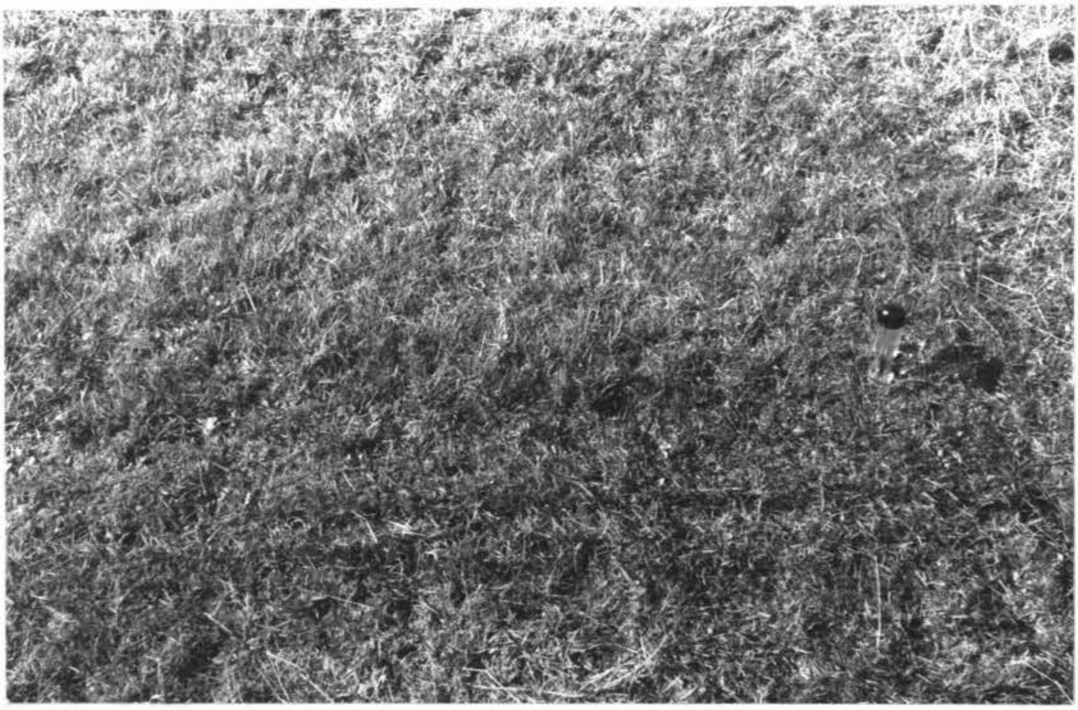


FIGURE III.12 West Aspect: Herbage Production
4.4 to 28.8.72

TABLE III.19 Comparison of Production Estimates made for Two Slope Classes (kg. DM./ha.).

	Slope Class:	>50< 30^{o}	> 30^{o}
NORTH	4.4 to 23.8.72	374	294
	23.8. to 9.11.72	902	855
	13.11 to 30.12.72	1076	805
EAST	4.4 to 23.8.72	1884	581
	23.8 to 9.11.72	4046	1026
	13.11 to 30.12.72	2198	1010

CHAPTER IV DISCUSSION

1. Microclimatic Factors

1.1 Wind-Speed and Direction

Comparison of the daily estimates of wind direction in Appendix 3 and the average wind-speeds presented in Figures III.1 and III.2, illustrates the close relationship between wind direction and the wind-speed on the various aspects. The west and north aspects, especially the latter, were the most exposed aspects during 1972. This was due to the prevailing West - NW wind. The anemometer on the north aspect consistently logged more miles of wind-run than the west aspect anemometer, even during periods of westerly weather. This was probably due to the gully which runs almost due West toward the north aspect and which tends to funnel wind onto this slope. (see Figures I.1 and II.1). The west aspect was sheltered, to a degree, by a large stand of macrocarpa trees which was situated approximately 225 m. to the West (see Figure I.1). Implications of the higher wind-speeds on the north and west aspects include effects on the energy balance existing at each aspect, hence on temperature and soil moisture status, effects on animal behaviour, and physical battering effects on plants, especially erect species.

1.2. Rainfall

A comparison of Figure III.3 and the daily wind direction data in Appendix 3 shows that in general the windward gauge collected less rain than the leeward gauge. In some instances differences of up to 100% occurred between aspects. The annual totals of Table III.2 show that the total rainfall recorded on the south aspect was greatest, followed by the rainfall on the east, west and north aspects respectively. From geometrical considerations, if the angle at which rain fell was the same for all aspects, the leeward aspects would receive less rainfall per unit surface area (as opposed to map area) than the windward aspects. However, the gauges at Ballantrae were set up with horizontally disposed collecting surfaces, and would thus record rainfall on a map area basis. As noted by Geiger (1965), the angle at which rain falls varies with aspect and this complicates interpretation. A further complicating factor is the existence of wind-speed effects on the amount of rainfall collected by raingauges, as noted by Rodda (1966), Green (1970) and Jackson and Aldridge (1972). In view of uncertainty as to the existence and magnitude of actual rainfall differences between aspects, it can only be concluded that differences in rain-gauge catch occurred, and that actual rainfall differences may or may not have occurred.

1.3 Net Radiation and Evapotranspiration

The net radiation (R_N) values in Table III.3, although based on meteorological data, were calculated using an empirical equation, and are thus subject to possible large errors. The seasonal radiation pattern arising from the calculated R_N values is similar to that described by Bryam and Jemison (1943), Gates (1965) and Jackson (1967). This pattern involves large differences in R_N between North and South-facing slopes during the Winter, and relatively small differences during the Summer. The similarity of the R_N values for the north and south aspects, when near the summer solstice, is related to two phenomena: firstly, the sun rises South of East and sets South of West during the Summer, and secondly the sun has a large angular altitude at this time of the year. According to the calculations made for the two aspects at Ballantrae, the average daily R_N on the south 'microclimate site' actually exceeded that on the north 'microclimate site' during the period encompassing the summer solstice. Gates (1965) mentions that this may occur, however, it is possible that the relatively crude modification factors applied to net radiation for a horizontal surface, to derive values for north and south slopes, were in error.

Both potential and actual evapotranspiration (PET. and AET.) estimates indicate that the rate of evapotranspiration (ET.) on the north face was greater than that on the south face during the four periods considered. The PET. value for the south slope in June is positive, despite the R_N value being negative. The energy required for the evaporation of water would, in this case, be provided by advective transfer of sensible heat from the air (Jackson, 1967). The PET. values given by Jackson (1967) for Taita, for the months of March, June, September and December, are similar in magnitude to those calculated for the north and south slopes at Ballantrae. However, the relative magnitudes of the values for the opposing aspects differ. Jackson did not consider differential wind-speed effects and although these might have been small at Taita, they were large at Ballantrae and had a considerable effect on the magnitude of the PET. values calculated. This is illustrated by the PET. estimates for the December period, where the average R_N value used for the south slope was greater than that for the north slope, yet the PET. value derived was smaller.

The calculated PET. and AET. values are approximately equal for December, yet different by a factor of two in March-April. The concept of ET., as developed by Penman (1956), suggests that differences in AET. and PET. are due to the occurrence of soil moisture stress. The calculated ET. data would thus suggest that soil moisture tensions during March-April were considerably greater than in December, and the latter would be near field capacity. This, however, was not the case, and the differences in PET. and AET. which are apparent can not be explained on this basis. Differences of the magnitude of those shown in Table III.3 could easily have arisen due to incorrect assumptions made in the R_N, PET. and AET. calculations, all of which were partially or wholly based on empirical formulae (see Chapter II for details).

1.4. Soil Moisture Status

The 'dry' north face and the relatively damp south face provided the greatest contrasts in soil moisture status. This pattern is one which, with correction to the appropriate hemisphere, is much reported in the literature. As noted in section 1.2 of this chapter, it was not possible to determine the magnitude of rainfall differences which may have existed between aspects, and thus it is not possible to examine the relationship between soil moisture tension and rainfall differences. However, the evapotranspiration (ET.) values calculated give an indication as to the main reason for the differences in moisture status between the various aspects. The rapid rate at which the north aspect dried out following rain appears to have been due to high ET. rates. Variation in soil moisture tension was extreme on the north aspect and relatively small on the south aspect. Variation in the depth to which the soil profile dried out was also noticeable, e.g. on the north face the moisture tension at 30 cm. reached 15 atmospheres, while on the south face the moisture tension at 30 cm. did not rise above 1.4 atmospheres throughout the experimental period (see Appendix 1.2.).

The moisture tensions recorded on the east and west aspects tended to be intermediate between those recorded for the north and south aspects. This would probably have been a function of the intermediate wind-speed and radiation regimes experienced by these two aspects. Large differences in moisture tension between the east and west faces did arise, but these differences did not show any noticeable pattern, nor any correlation with wind speed, despite the consistently higher wind-speed on the west aspect. The compass bearing of the west aspect 'microclimate site' was closer to true North than that of the east aspect site (see Introduction to Chapter II), and this would have resulted in higher radiation inputs to the west than to the east site. Again, soil moisture records do not reflect this differences between the two aspects. The possibility of a higher rainfall on the east aspect further complicates the issue. Temperature differences between the west and east aspects may have tended to counteract the possible different rates of ET. due to the different wind speeds and radiation inputs at the two aspects. However, even if this was the case in the September to December period, it would not have applied for the rest of the year, as soil temperatures on the two aspects were similar. A detailed energy balance study would be necessary to determine the reasons for the observed differences in soil moisture tension between the east and west aspects.

During the winter months little difference in soil moisture tension was recorded between aspects. This is to be expected in view of the low ET. rates and relatively high rainfall at this time of the year.

As mentioned in Chapter II, the gypsum blocks were individually calibrated before and after use, a small calibration drift in the intervening period being evident. This drift was particularly noticeable for the south aspect 30 cm. blocks during September and October (see Appendix 1.2).

1.5 Temperature

Air temperature, soil temperature and evapotranspiration are interrelated, and when considering reasons for temperature differences between aspects these factors can not be considered independently. Variations in one will inevitably result in variations in one, or both, of the others, the whole concept being one of an energy balance, as discussed in the Introduction to this thesis. The temperature curves in Appendix 8 illustrate this point. The relative positions and shapes of these diurnal curves demonstrate the effect of wind on the air and soil temperatures of the various aspects. The north and west aspect air and soil temperatures were noticeably lower, in relation to the south and east temperatures, when a NW wind was blowing on 22.12.72, than on 7.12.72 when a southerly wind was blowing. The number of sunshine hours were similar on these two days, being 10.8 and 10.2 hours respectively. Net Radiation (R_N) is dissipated by transfers of sensible heat to the air and soil, and of latent heat during evaporation. The proportion of R_N utilised for evaporation on the windward slopes was probably larger than that on the leeward slopes, thus leading to lower sensible heat transfers and lowered air and soil temperatures.

The average air temperature curves derived for the four aspects examined are similar (see Figure III.7). The one exception is the low temperature of the north aspect during February. This coincides with a particularly high soil temperature, and the two may be associated.

The partitioning of energy mentioned above, and its effect on temperature, is complicated by the fact that as soil moisture content decreases, the specific heat of the soil decreases. Thus a dry soil changes temperature more readily than a wet soil. The soil temperature curves of Figure III.8 show temperature differences similar to those described in much of the literature reviewed. During the months of January to August the north aspect was the warmest, the south coolest and the east and west intermediate. This is as might be expected in view of the R_N regimes experienced by the various aspects and the resultant differences in energy available for sensible heat transfer to the soil. The pattern of soil temperature variation with aspect for the period September to December is more complex. According to the R_N estimates made, the amount of radiation received by the south slope during December was greater than that received by the north slope; the 'descent' of the north aspect temperature to join that of the south aspect is probably related to these relative R_N values. For the particular slopes involved, however, the south aspect soil temperature could be expected to have been higher than that of the north aspect, during December, due to the lower wind-speed experienced by the former. Possibly the specific heat of the south aspect soil was higher due to a higher soil moisture content, and this could have counteracted the effect of lower wind-speeds. The high soil temperature of the east aspect during the September to December period is difficult to explain. The soil moisture tension data recorded do not suggest a lower specific heat of the east aspect soil, at least for the months of September to November, thus the net heat flux to the soil must have been higher on the east than on any of the other aspects. This could have involved either a greater radiational input, or a lower rate of heat loss from the soil. The former is unlikely to have occurred, according to values for incoming radiation from Geiger (1965), and examination of the air temperature, soil moisture and wind-speed data recorded does not suggest the occurrence of the latter.

2. Soil Factors and the Animal Factor

According to the soil analyses conducted, the south and west aspects had greater nutritional limitations to plant growth than the north and east aspects. Possible reasons for this include:

(i) Nutrient transfer by grazing animals.

(ii) Differential action of soil forming factors at the various aspects.

Both of these may have been involved in the formation of the differences in nutrient levels which were detected. The relatively high soil test results for the east aspect relate well to the estimates of dung deposition for the four aspects, and suggest the existence of a nutrient transfer, via excreta, to the east aspect. However, the 'high' test results for the north aspect, and relatively low results for the south aspect, do not agree with the dung deposition estimates. According to Hilder (1966), urine is distributed in much the same way as dung, at least where sheep are concerned. Thus, according to the dunging data obtained, most of the urine and dung voided by sheep grazing the experimental area was deposited on the east and south aspects. This data was collected over the relatively short period of three months, but does indicate what might reasonably be assumed; for a large proportion of the year the north and west aspects might have been described as inhospitable in comparison to the more sheltered east and south faces, (north, northwest or west winds were recorded on 243 days of the year) and grazing animals might be expected to favour these latter areas. However, it is possible that during periods of easterly or southerly weather the grazing animals would intensively graze, and dung and urinate, on the west and north aspects; such behaviour was not observed during the three month observational period (although there was a tendency for this to occur on the west aspect during the third measurement period), and even if it did occur, would not explain the differences in nutrient levels between the west and north aspects. It is probably that some factor other than nutrient transfer is also involved. The relatively high temperatures, large diurnal soil temperature range (see Appendix 5) and greater soil moisture variation of the north aspect soils, coupled with the possibility of lower rainfall, may have been implicated in the relatively high nutrient levels determined for this aspect. The mode of action involved would be one of higher weathering and lower leaching rates on the north than on the west and south aspects. Ambient mineral nitrogen levels were highest on the east face, at both winter and spring samplings. Although these levels give an indication of the mineral nitrogen status of the soil at each aspect, the figures represent an equilibrium between nitrogen mineralisation and mineral nitrogen 'losses' (e.g. due to plant uptake and leaching) from the soil. The net amount of nitrogen mineralised during incubation indicates the potential of the soil as a mineral nitrogen source, and thus gives a clearer picture of nitrogen availability for plant uptake than does an ambient level measurement. In practice, the net mineralisation values were found to follow a similar pattern to the ambient levels determined, i.e. values for the east aspect were much larger than those for the other three aspects.

The enlarged incubation experiment during the Spring indicated that incubation effects were statistically non-significant, and that source effects were significant, with respect to rate of nitrogen mineralisation. The total nitrogen values of Table III.12 relate well to the respective amounts of mineral nitrogen formed during the spring incubation (Table III.8) and this indicates that during this period the amount of substrate available for microbial activity was a limiting factor to nitrogen mineralisation. This also appears to have been the case for the winter incubation data (Table III.6), although the relationship for this period was not as good.

The observed temperature differences between aspects do not relate well to the different nitrogen mineralisation rates observed during the winter and spring incubations. This statement is based on the results of temperature measurements made at the 'microclimate sites' of each aspect. The soil cores were actually incubated at numerous different sites on each aspect and, during the spring incubation in particular, the turf which was replaced over the incubation tubes changed colour and was distinguishable from the surrounding pasture. The result may have been an effect on the temperature regime of the tubes and may have made the relationship between the temperatures recorded and those experienced by the incubated cores a tenuous one.

Attempts to remove the possible effects of differential moisture content during the spring incubation, on nitrogen mineralisation, were not successful. Statistical analysis showed that source aspect effects were significant at the 1% level, and incubation aspect effects at the 5% level, with respect to their influence on final moisture content. This suggests that any moisture content effects on mineralisation could be a function of both source and incubation aspect, with perhaps the former being most important. However, the regression coefficients of Table III.9 are non-significant in all cases except one. This would indicate that differential moisture content had little effect on nitrogen mineralisation and that moisture content was not a limiting factor during the incubation periods. The positive overall regression for the winter incubation, rather than indicating a causal relationship between soil moisture content and net mineralisation, is probably due to a treatment effect. The within-group regression, which ignores treatment effects, is not significant. As an example, the east aspect soil cores, which yielded high mineralisation rates, may have had high field capacity moisture contents due to high organic matter contents. This does not imply that a causal relationship existed between soil moisture content and the high mineralisation rates for the east aspect soils.

3. Pasture Factors

3.1. Botanical Composition and Percentage Bare Ground.

The 'first-hit' point analysis technique used underestimated the proportions of erect and narrow-leaved species, and overestimated the contribution of prostate and broad-leaved species, when compared with dry weight analysis. The 'first-hit' technique is biased toward the recording of tall as opposed to prostrate species, however, a general bias appears to operate in favour of the latter. This would be due to the fact that cover measurements in general tend to overestimate the contribution of broad-leaved species. Rumball (1966), in comparing an 'all-hits' technique and dry weight analysis, found a similar relationship to that noted here. The comparisons of dry-weight and point analysis for the autumn and summer periods should be treated with caution, especially the latter. This is because of the length of time which elapsed between the two types of measurement, and the consequent possibility of botanical composition change between the two. During the four-week period between the summer dry-weight and point analyses, drought conditions established and these may have had a considerable effect on botanical composition.

The differences in botanical composition (as measured by point analysis) which are evident from the data collected, appear to be due to two main factors: soil nutritional status and soil moisture status. It is unlikely that the magnitude of the differences in soil temperature which were detected would directly account for the large differences in botanical composition recorded. Some of the species which had distinct distribution patterns may be regarded as 'indicator species'. Soil fertility 'requirement' and soil moisture 'requirement' tables are given by Levy (1970) for a number of grasses and clovers. According to these tables perennial ryegrass requires moderately low to extremely high fertility, and moderately dry to wet soils, to maintain dominance in a sward, i.e. under these conditions ryegrass competes strongly. Yorkshire Fog will compete strongly under conditions of low to high fertility and average to very high soil moisture. Notodanthonia bianularis (which probably has similar tolerance limits to the other danthonias present at Ballantrae) requires moderately low to very low fertility, and dry to average soil moisture conditions, to compete strongly. If the above requirements are compared with the relative soil fertility and moisture levels of the various aspects, as defined by the measurements made over the experimental period, a relationship between these two variables and pasture composition is apparent. It seems that the reasons for the high proportions of ryegrass and Yorkshire fog on the east aspect were, relatively speaking, the high level of soil fertility (especially with respect to nitrogen status) and adequate moisture status of the aspect. The frequent moisture stress occurring on the north aspect is probably the reason for the high proportion of danthonia in the sward of that aspect. Nertera appears to be most successful under the low fertility conditions of the west and south aspects. Levy (1970) records suckling clover as 'requiring' conditions of very low to moderately low fertility, and dry to average moisture conditions, for dominance to occur. These 'requirements' are best met by the west aspect, where suckling clover was most abundant. Moss tended to be most abundant on the low fertility west and south aspects, especially the latter, during the Autumn, Winter and Spring, and on the west aspect during the Summer. The increase in the proportions of moss recorded between the autumn and winter point analyses, decrease between the winter and spring analyses, and increase between the spring and summer analyses, are probably, in part, a function of the differing amounts of vegetational cover present at the successive analyses. An increase in cover would result in a decrease in the recorded moss values, and a decrease in cover the converse. Thus the actual amount of moss present could remain static while the proportion recorded by 'first hit' point analysis varied according to changes in cover. The changes in the proportions of moss recorded vary directly with the changes in percentage bare ground recorded, with the exception of the value for the south aspect during the Summer. The reason for this lack of change is uncertain in view of the pronounced change in percentage bare ground. The small amount of white clover present in the swards may be due to the overall low phosphate status of the soils and the resultant strong competition between clovers and grasses. The low pH status of the soils may also be implicated here.

The species which were present in reasonably large amounts, yet did not show any differential distribution, i.e. browntop and sweet vernal, presumably have wide soil fertility and moisture tolerance limits. To try and explain the indistinct distribution patterns of several of the species which were reasonably abundant, e.g. crested dogstail, catsear, ribgrass and hawkbit, would be mainly conjecture in the absence of more precise information on their distribution and ecology.

The differences in botanical composition recorded for the north and south faces at Ballantrae do not agree very well with the differences shown by Suckling (1959) for sunny and shady slopes at Te Awa. Suckling's data show an opposite distribution to that recorded at Ballantrae for moss and ryegrass and a similar distribution for danthonia, Yorkshire fog and percentage bare ground. The differing overall botanical compositions of the pastures at Ballantrae and Te Awa probably explain in part the lack of similarity between the two sets of results. The different point analysis techniques used, 'first-hit' in one instance, and 'all hits' in the other, may also have been implicated. Rumball (1966) reports similar patterns to those found at Ballantrae, with respect to the distribution of annual clovers, danthonia and ryegrass on sunny and shady faces.

3.2 Production Differences.

Production data from areas of 5^{o} to 30^{o} slope, excluding 'stock paths', was used as the basis for comparing pasture production on the four aspects. The data were converted to rate of production (productivity) values, to eliminate differential growth period lengths. The large variability of the data reduced the sensitivity of the multiple range test used and this may have reduced the number of significant differences detected.

The dominant factors influencing pasture productivity appear to have been the rate of soil nitrogen mineralisation, soil moisture status, and possibly available phosphorous status. Air temperature would have had no effect as little difference in the average air temperature of the various aspects was detected. Soil temperature may have been implicated, as differences were found to exist between aspects, but if an effect on pasture productivity did occur this was not revealed by the data. Possibily the effects due to soil fertility and moisture differences were so large as to mask any effects due to differential soil temperatures.

During the first growth-period (i.e. Summer/Autumn), when the rates of pasture production on the south and east aspects were significantly greater than those on the west and north aspects, soil moisture status was probably a limiting factor on at least the north aspect. Available phosphorus levels would not have been limiting at this time, as evidenced by the relatively high productivity and low phosphorus status of the south aspect. No data on mineral nitrogen status are available for this period.

Throughout the second growth-period (Autumn/Winter) the rate of nitrogen mineralisation was probably the factor limiting pasture production. The large differences in productivity between the east and the other aspects, and the similarity of the three latter, indicate that none of the other environmental differences measured could account for the differences in pasture production which were recorded. This is illustrated by the situation existing on the north aspect: the levels of available cations were probably non-limiting (Jackman, pers. comm.), nor was soil moisture, which was near field capacity. The north aspect was warmer in terms of soil temperature than the east, west and south aspects and had a higher available phosphorus status than the west and south aspects, yet produced approximately the same amount of herbage as the two latter. During the third growth-period (Spring) mineral nitrogen status may also have been an important limiting factor, although the difference in net mineralisation between the east and south aspects does not seem large enough to explain the differences in productivity which were recorded. Possibly low phosphorus levels limited production on the west and south aspects but this does not explain the low productivity of the north aspect over this period. Available nitrogen may have been a limiting factor during the fourth growth-period (Spring/Summer), but data are not available to confirm this. The similar rates of production on the north, south and west aspects tend to discount the possibility of a phosphorus or soil moisture limitation.

The total production figure for the east aspect during the experimental period (346 days), was 9683 kg.DM./ha. (see Table III.18). The magnitude of this figure is surprising in view of the low available phosphorus level (Jackman, pers. comm.). It should be remembered that the phosphorus figure quoted in Table III.4 is for the entire aspect, while the production figure is for 5^{o} to 30^{o} slopes only. The available phosphorus levels on these latter areas may have been higher than on the rest of the aspect, due to higher stock concentration and excretal return. It should also be noted that in New Zealand the results of soil chemical analyses are generally correlated with the growth of swards containing substantial proportions of clovers. In fact, what may be ranked as a low phosphorus test on this basis, may be quite adequate for high levels of production by grass and weed swards. This is especially the case where browntop, which is reported to compete strongly for phosphorus (Jackman and Mouat, 1970), comprises a large proportion of the sward under consideration.

Large differences existed, in some instances, between production estimates made using two different sizes of herbage samples. For this reason, and also because satisfactory statistical analysis was possible using data from the 1 metre square samples alone, the data from the 25 cm. square samples were not used in the final determination of production differences between aspects. The differences obtained using different sample sizes were probably due to the fact that where small samples are taken a small area - circumference ratio exists, thus making harvesting techniques prone to large errors.

The comparison of production on two slope classes, using large cages and 1 metre square herbage samples, indicates that large differences in production can occur between areas of different slope. The data obtained were not comprehensive enough to allow the detection of statistically significant differences, however, examination of the data shows that production was lower in all cases on the steeper slope class.

4. General Discussion and Practical Implications of Study.

Dung (and probably urine) distribution on the experimental area appeared to be influenced by the direction of the prevailing wind. This prevailing West/Northwesterly also modified the microclimate of each aspect. Differences in evapotranspiration (ET.) rate were due, in varying degrees, to the relative radiational inputs and wind-speeds at the different aspects. ET. rate had a large effect on soil moisture tension and on soil temperature. Had a smaller time-scale been used (say one week) for average temperature calculation, differences in average air temperature might have been detected.

Nitrogen mineralisation rate, which was one of the main factors limiting pasture productivity, appears to have been dependant upon the amount of substrate available for microbial activity. For the area examined, soil total nitrogen status was a good indicator of mineral nitrogen status; where clovers comprised a greater proportion of the sward this relationship might not hold. Soil moisture status was the other factor which was a major limitation to pasture productivity. The measured differences in productivity between aspects did not appear to be directly attributable to temperature differences. Had steeper slopes been examined, the temperature differences recorded might have been greater, and might then have had a significant effect on differences in productivity between aspects, as is suggested by Suckling (1959, 1964, 1966). Species distribution patterns appear to have been closely related to soil nutritional and moisture status gradients.

To summarise, the measured differences (in pasture botanical composition and productivity) between aspects can be attributed to the different microclimates existing on the various aspects. Important consequences of these different microclimates appear to have been:

(i) Different soil nutrient levels on the various aspects, arising through (a) nutrient transfer between aspects by grazing animals, and (b) differential action of the climatic factor during soil formation.

(ii) Different soil moisture levels on the various aspects, operating through differential ET. rates and leading to different degrees of moisture stress, especially during the summer/autumn period.

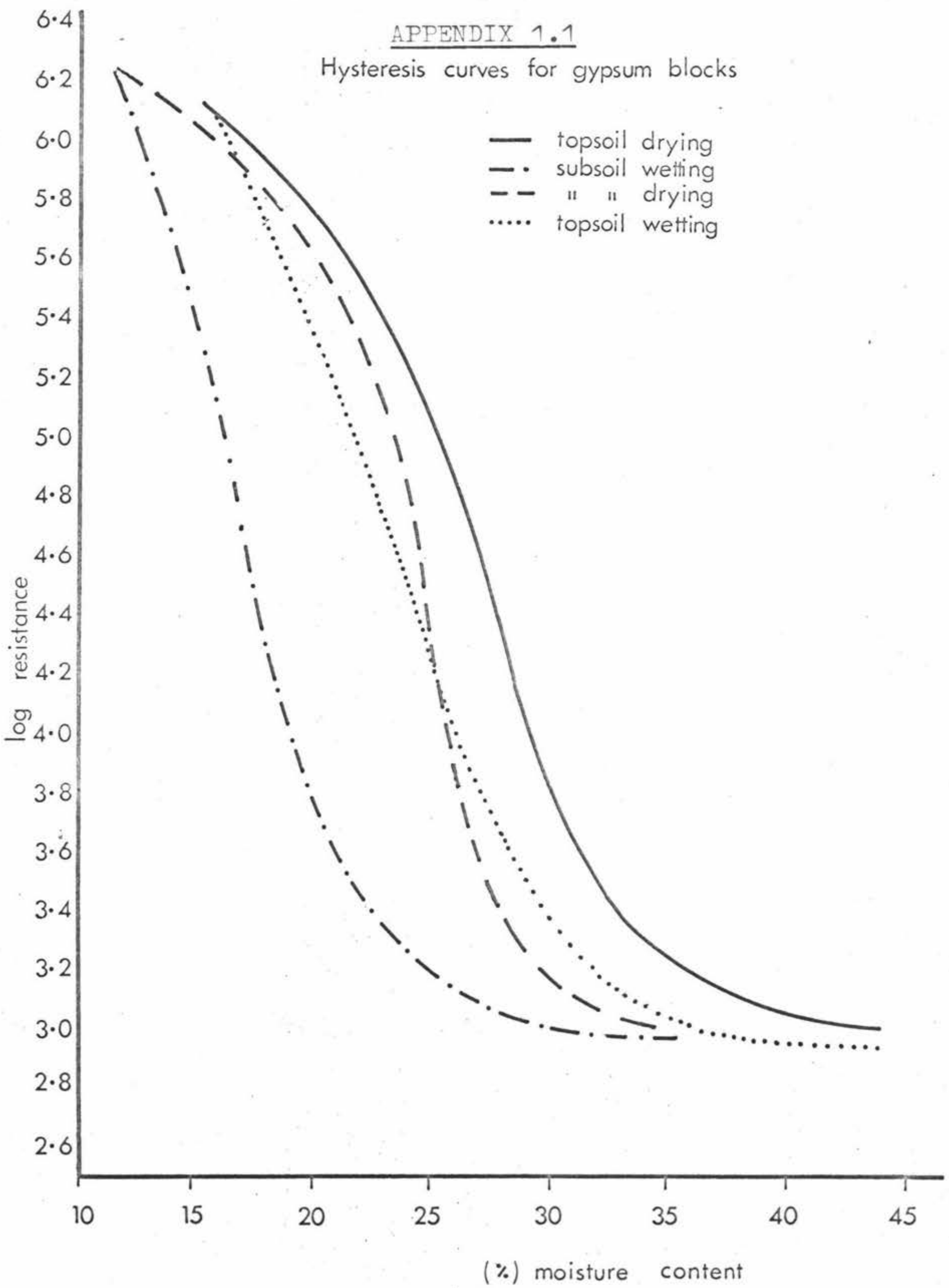
The derivation of satisfactory sampling techniques remains one of the largest problems encountered in hill country research.

As mentioned in Chapter I with regard to temperature records, caution should be used when extrapolating from the specific to the general situation, especially where the former is defined by measurements made over a relatively short period of time. However, a number of broad practical implications arise from this study. As suggested by Suckling (1966), hill country should, where practicable, be fenced with regard to aspect, to facilitate grazing management. In some areas this is not feasible, as variation is of such small-scale as to preclude subdivision on this basis. Where large-scale variation due to aspect exists, fertiliser could be spread at varying rates as indicated by soil nutrient status determinations. However, this would necessitate intensive soil testing, and would not be feasible in many instances due to the problems created by attempting differential topdressing by air. Where hill country has been fenced with aspect differences in mind, and initial fertiliser applications have been made, nutrient transfer by stock will be reduced, or halted, and fertility variation between aspects should decrease.

As mentioned above, two major limitations to productivity were determined for the pasture under examination. Additional limitations would exist where improvements were contemplated; these would include the low clover content of the pasture, which relates to the nitrogen limitation to productivity which was detected, and the low available phosphorus status, which is probably a major limitation to clover growth. Liming would probably be necessary to allow clovers to express themselves under the more favourable conditions existing where phosphatic fertiliser was used. The traditional set-stocked sheep and cattle management used on much hill country may also prove to be a major limitation to increasing sward clover contents, the effect being one of preferential defoliation of clover plants.

Of the two major limitations to productivity which were detected, soil moisture limitations can not practically be remedied. However, subdivision according to magnitude of seasonal moisture stress would help avoid over-grazing of drier areas during the Summer and Autumn. As mentioned above, soil fertility differences between aspects may decline as overall fertility levels are increased. This may mean that temperature differences between aspects will become more important, especially during the Winter, with respect to differences in productivity.

The current trend for hill country seed mixtures appears to be toward a simpler mixture than has been used in the past, comprising ryegrass, white clover, and sometimes cocksfoot, red clover or subterranean clover. Variability exists in hill country pastures, on a wide range of scales, as evidenced by Rumball's (1966) study, the present study, and Madden's (1940) bulletin on the grasslands of the North Island. This variability in pasture botanical composition and productivity would indicate that numerous and diverse habitats are present in most hill country situations; it is possible that, in recognition of the existence of these diverse habitats, other species, such as Lotus pedunculatus, browntop and Yorkshire fog, could profitably be included in mixtures, especially when, and if, improved ecotypes of these species are available at reasonable prices. It may be that the set-stocked grazing regime practised on much hill country will not allow full expression of the variety of species such a mixture would contain, but where different management systems were practised a botanically complex, but highly productive, pasture might eventuate.


APPENDIX 1.1
Hysteresis curves for gypsum blocks
topsoil drying
subsoil wetting
" " drying
topsoil wetting
log resistance
6·4
6·2
6·0
5·8
5·6
5·4
5·2
5·0
4·8
4·6
4·4
4·2
4·0
3·8
3·6
3·4
3·2
3·0
2·8
2·6
10
15
20
25
30
35
40
45
(%) moisture content

APPENDIX 1.2 Soil Moisture Tension at 30 cm. (atmospheres)

Date	W	N	E	S
6.1	0.7	1.7	0.2	0.1
9	0.2	1.1	0.0	0.0
12	0.3	1.2	0.0	0:0
16	0.9	2.2	0.0	0.0
20	1.1	5.9	2.7	0.0
24	2.6	11.7	0:8	0.1
27	8.2	12.9	1.4	0.4
31	1.1	1.5	0.7	0.2
3.2	1.6	3.5	1.3	0.5
7	5.7	11.6	3.2	1.0
10	1.4	1.6	0.7	0.6
14	3.5	7.0	1.8	1.1
17	7.8	12.1	5.3	1.4
21	1.0	1.0	0.3	0.3
24	0.7	0.5	0.0	0.0
28	0.9	1.1	0.0	0.0
2.3	0.9	1.4	0.1	0.0
6	0.9	1.9	0.3	0.0
9	0.4	0.9	0.0	0.0
13	0.1	0.7	0.0	0.0
16	0.3	0.8	0.1	0.0
20	0.5	1.1	0.0	0.0
23	0.6	1.3	0.1	0.0
27	0.7	1.5	0.1	0.0
30	0.8	1.5	0.2	0.0
3.4	0.9	1.7	0.0	0.0
6	0.9	2.2	0.3	0.0
10	0.3	1.8	0.1	0.0
13	0.6	1.9	0.1	0.0
17	0.6	1.2	0.1	0.0
20	0.6	1.0	0.1	0.0
24	0.6	1.0	0.0	0.3
27	0.3	0.5	0.0	0.0
1.5	0.9	0.5	0.0	0.0
4	0.5	0.6	0.0	0.0
8	0.9	0.7	0.0	0.0

Date	W	N	E	S
11.5	0.6	0.6	0.0	0.0
15	0.0	0.3	0.0	0.0
18	0.0	0.5	0.0	0.0
22	0.1	0.6	0.0	0.0
25	0.0	0.3	0.0	0.0
29	0.3	1.0	0.0	0.0
1.6	0.3	0.6	0.0	0.0
5	0.5	0.6	0.0	0.0
8	0.6	0.7	0.0	0.0
12	0.6	0.7	0.1	0.1
15	0.1	0.4	0.0	0.0
19	0.1	0.5	0.0	0.0
22	0.4	0.7	0.0	0.1
26	0.5	0.7	0.0	0.1
29	0.5	0.7	0.0	0.1
3.7	0.5	0.8	0.1	0.1
6	0.3	0.8	0.1	0.1
10	0.1	0.6	0.1	0.0
13	0.0	0.0	0.0	0.0
17	0.0	0.3	0.0	0.0
20	0.1	0.7	0.0	0.0
24	0.0	0.5	0.0	0.1
27	0.0	0.6	0.0	0.2
31	0.1	0.8	0.0	0.3
3.8	0.1	1.1	0.1	0.4
7	0.1	0.8	0.1	0.5
10	0.1	0.8	0.1	0.3
14	0.1	0.6	0.0	0.2
17	0.0	0.4	0.0	0.0
21	0.0	0.8	0.0	0.1
24	0.0	0.8	0.0	0.2
28	0.0	0.6	0.0	0.0
31	0.0	0.6	0.0	0.0
4.9	0.0	0.7	0.0	0.1
7	0.0	0.8	0.0	0.3
11	0.0	0.8	0.0	0.2

Date	W	N	E	S
14.9	0.1	0.8	0.0	0.5
18	0.1	0.8	0.0	0.5
21	0.8	1.1	0.8	0.9
25	0.8	1.2	0.8	0.9
28	0.9	1.2	0.8	1.0
2.10	0.9	1.2	0.8	1.1
5	0.9	1.3	0.9	1.1
9	0.8	1.3	0.8	1.0
12	0.8	1.3	0.9	1.0
16	0.3	0.7	0.4	0.5
19	0.7	1.1	0.1	0.6
23	0.7	1.2	0.6	0.8
26	0.8	1.2	0.6	0.8
30	0.7	1.2	0.6	0.8
2.11	0.8	1.3	0.7	0.9
6	0.8	1.3	0.7	0.9
9	0.9	1.3	0.7	0.9
13	0.9	1.3	0.7	1.0
16	1.0	1.2	0.7	1.0
20	1.0	1.4	0.8	1.0
23	1.1	1.6	0.8	1.0
27	1.0	2.4	0.9	1.0
30	1.0	3.6	0.9	1.0
4.12	1.1	3.7	0.9	1.0
7	1.1	1.7	0.9	1.1
11	1.2	3.3	0.9	1.1
14	1.4	1.6	1.0	1.1
18	1.6	1.6	1.1	1.1
21	2.1	3.7	1.3	1.1
24	3.0	6.8	1.6	1.1
28	1.4	4.5	2.8	1.1
1.1	3.3	15.5	6.5	1.1

APPENDIX 2.1 Further details of preparation and use of temperature sensors.

(a) Diodes: RCA type 1N 2326 germanium temperature-compensating diodes were used. The diodes of each triplet were interconnected and a length of plastic tube (about 2.5 cm.) was pushed over each diode. The open ends were sealed with an epoxy-resin glue, thus giving waterproof units.

(b) Radiation shields: These were constructed for each of the air temperature units. The shields were basically 15 cm. squares of 0.85 cm. plywood (see Figures II.7 and II.8). The diodes were arranged in a parallel fashion, about 1 cm. apart, below the shield; aluminium wiring-clips were used to hold the diodes in place. The 120 cm. units had 2 cm. strips of plywood projecting downwards on two parallel sides of the shield. The shields were orientated so that these strips shaded the diodes from the early morning and late afternoon sun. Each shield was covered in reflective aluminium-mylar sheeting; the individual diodes of each unit were also coated with aluminium-mylar, to reduce radiative exchange between the ground and the sensors. The 120 cm. units were suspended in the air by means of 2 cm. square lengths of wood which were screwed to the back of the shields. These supports were in turn attached to standards driven into the ground at the edge of the 'micro-climate sites'. The 4 cm. units were constructed with a 10 cm. nail projecting downwards at each corner, and the shields sat on these legs; the legs were pushed several centimeters into the soil to prevent the units being blown away.

(c) Multicore cable: Two sizes of cable were used, containing 7 pairs and 15 pairs of cores respectively.

15 pair: 10lb PEUT cable NZPO SL. No. 0 364

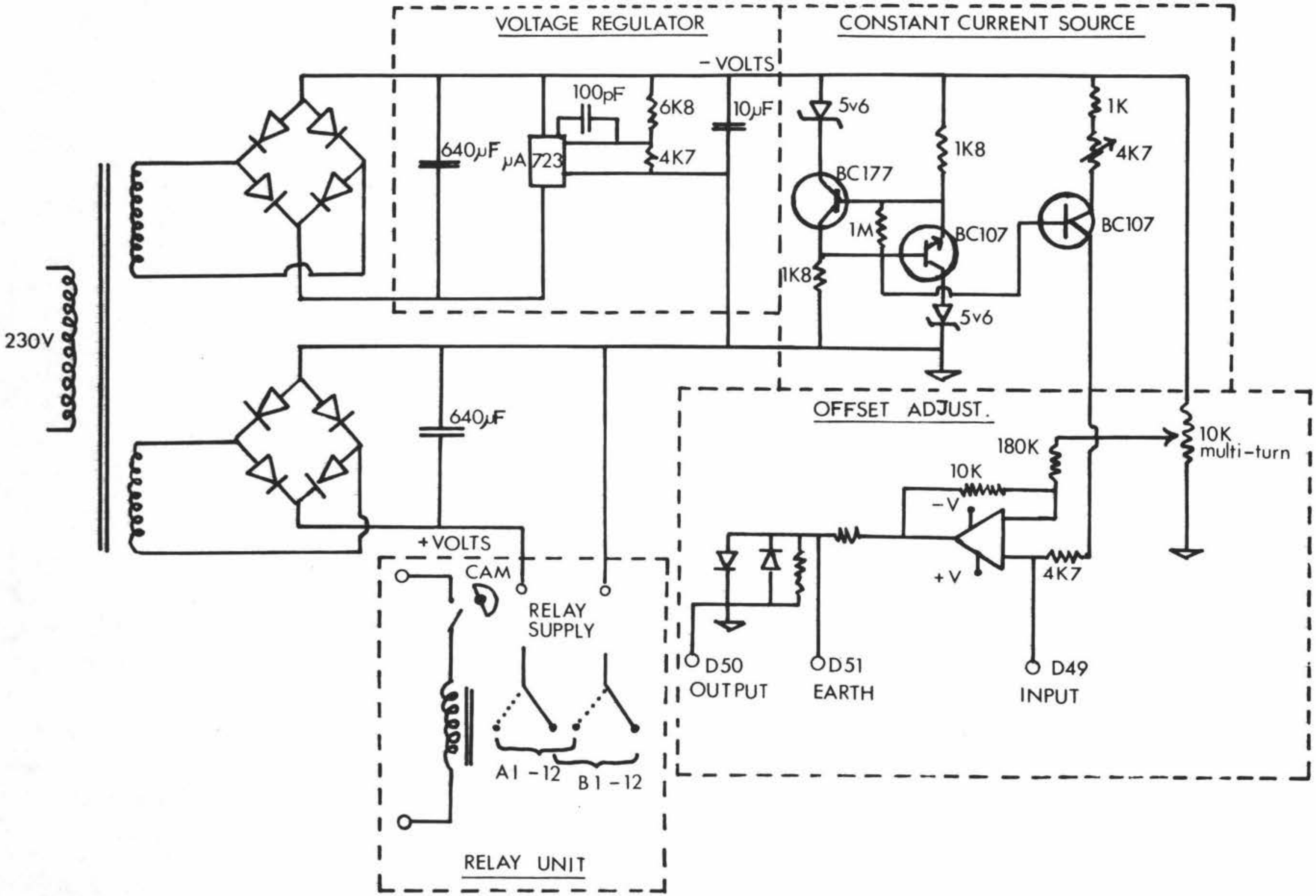
7 pair: 10lb PEUT cable NZPO SL. No. 0 345

The 15 pair cable was used for the north and east 'microclimate sites', being connected to 7 pair cables from each site at the NE end of the hill. 7 pair cable was used for the west and south 'microclimate sites'. The multicore cable was connected (7 pair to 15 pair, and cable to sensors) by plastic screw-type connector strips. Difficulty was encountered in obtaining satisfactory electrical contact at times. The corrections which were applied to the temperature readings for each aspect, to allow for the resistance of the multicore cable, were derived theoretically by calculating the electrical resistance of the length of cable used for each aspect (using the manufacturer's specifications) and also practically, using an ice flask and water bath in the field.

APPENDIX 2.2 Recorder modifications

The recorder used was a Philips PR 3210 A/00 12 channel multipoint recorder. The accompanying circuit diagram describes the modifications made to this recorder. The offset adjust allowed the use of the full width of the recorder chart over the mV range of the sensors, and gave an absolute range of 250 mV. This offset had a fine adjustment, in the form of a multi-turn rheostat, which allowed the range to be shifted either way. The constant-current source required a constant voltage input and this was achieved by use of the voltage regulator shown in the circuit diagram. The recorder was converted to enable the use of 24 rather than 12 channels, by way of a relay box which was set up externally to the recorder. Six relays (one for every two channels) were used to switch from one bank of 12 channels to the other bank, and back again. (A1 - 12 and B1 - 12 on the circuit diagram). A cam on a shaft in the recorder, operating a microswitch, was used to activate the relays at the appropriate time.

RECORDER MODIFICATIONS



APPENDIX 2.2 (contd.)
Circuit diagram for modifications

APPENDIX 3 Daily estimates of wind direction during 1972.
9.00 am. estimates (Ballantrae meteorological records).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	NW	W	NW	NW	E	W	N	NW	W	NW	NW	SE
2	NW	S	NW	NW	CA	NW	NW	W	SE	NW	NW	S
3	NW	S	E	NW	NW	E	NW	NW	NW	NW	NW	SE
4	NW	NW	E	NW	NW	E	E	SE	S	W	E	NW
5	NW	W	NW	NW	SE	NW	E	NE	NW	NW	E	E
6	NW	S	NE	NW	NW	SE	SE	SE	NW	N	NW	E
7	NW	E	NE	CA	SE	W	SE	E	NW	NW	W	S
8	W	N	E	SE	NW	W	E	E	NW	E	NW	NW
9	NW	SE	NE	SE	CA	W	E	E	NW	E	W	NW
10	NW	SE	CA	E	NE	W	NW	N	NW	S	SE	NW
11	NW	NW	W	NE	NW	CA	NW	NW	NW	NW	N	W
12	E	E	W	SE	NW	NW	NW	NE	NW	NW	NW	NW
13	NW	E	W	E	W	SE	NW	NW	W	NW	W	NW
14	NW	NE	NW	SE	E	SE	W	NW	N	NW	W	NW
15	W	E	NW	SE	E	W	W	NW	NW	W	W	NW
16	N	E	NW	CA	NW	NW	CA	NW	NW	S	NW	NW
17	NW	SE	NW	W	NW	NW	W	NW	SE	NW	W	N
18	NW	W	NW	SW	NW	NW		SW	NW	E	E	NW
19	W	NW	W	W	NW	W	W	NW	NW	NW	NW	W
20	W		NW	NW	W	W	NW	SE	NW	E	N	W
21	E	CA	NW	W	NW	W	NW	NW	SW	NW	W	W
22	NE	W	NW	NW	NW	NW	W	SE	SW	W	W	NW
23	SE	NW	NW	NW	NW	W	W	E	NW	NW	NW	NW
24	E	NW	W	W	NW	NE	SE	NW	NW	NW	SE	N
25	W	SE	E	NW	W	CA	E	W	NW	W	W	NW
26	E	NW	NW	NW	NW	E	E	W	NW	W	W	NW
27	SE	NW	E	NW	NW	SE	E	SE	NW	SW	W	NW
28	NW	NW	E	NW	SE	SE	CA	SE	NW	NW	E	NW
29	NW	W	NW	W	NW	CA	SE	E	N	NW	S	W
30	W		W	W	NW	CA	NE	E	E	W	E	W
31	W		NW		NW		W	W		W		NW

CA = Calm

APPENDIX 4 Daily R_N (ly./day) and PET. (mm./day) estimates, derived for four periods during 1972, for the north and south 'microclimates sites'

Date	R_N N	R_N S	PET N	PET S
13.3	170.4	150.6	3.29	1.79
14	193.4	152.9	4.48	2.18
15	183.6	146.6	3.59	1.85
16	117.6	111.4	2.83	1.55
17	151.6	136.0	3.39	1.86
18	183.6	132.1	5.31	2.47
19	217.5	110.7	5.18	2.20
20	174.6	107.6	4.93	2.00
21	153.5	112.8	3.80	1.70
22	186.1	115.4	4.19	1.79
23	222.8	114.9	3.88	1.93
24	180.5	122.7	3.05	1.72
25	100.6	91.3	0.78	0.66
26	115.9	102.2	2.15	1.37
27	231.1	124.9	1.72	0.92
28	174.3	115.2	1.31	0.85
29	172.8	95.5	2.74	1.38
30	103.4	88.6	2.95	1.55
31	96.5	84.5	2.24	1.23
1.4	94.8	82.9	1.97	1.11
2	160.4	79.2	3.05	1.35
3	132.6	82.4	2.84	1.25
4	169.9	71.3	4.43	1.67
5	121.9	85.0	3.15	1.41
14.6	35.0	23.6	0.31	0.23
15	24.3	-35.0	1.71	0.47
16	26.8	-86.0	1.35	0.06
17	33.4	-2.2	0.80	0.25
18	26.9	3.1	0.64	0.22
19	26.8	-88.7	1.37	0.16
20	23.4	-161.7	2.24	0.19
21	32.7	13.9	1.29	0.63
22	32.7	-61.8	1.07	0.09
23	31.4	19.8	1.21	0.62
24	31.4	20.3	0.75	0.39

Date	R_N N	R_N S	PET N	PET S
25.6	33.0	21.7	0.53	0.29
26	23.6	-5.4	0.49	0.30
27	9.2	-52.1	0.68	0.29
16.9	170.3	116.2	3.24	1.62
17	106.9	98.4	1.74	1.03
18	159.8	111.1	4.07	1.87
19	108.7	97.8	2.56	1.34
20	141.4	109.6	2.52	1.31
21	122.9	102.2	3.06	1.55
22	223.5	84.2	4.42	1.78
23	99.9	91.8	2.57	1.35
24	219.4	104.5	4.59	1.98
25	168.5	128.8	2.17	1.24
26	149.0	114.1	4.39	2.13
27	160.3	136.3	4.08	2.09
28	120.0	112.2	2.34	1.51
29	142.8	127.3	1.23	0.95
7.12	300.8	346.6	3.79	3.11
8	194.3	201.8	1.89	1.63
9	251.7	269.6	1.82	1.85
10	284.3	317.3	4.20	3.33
11	269.0	294.7	3.44	2.63
12	196.2	203.7	2.86	1.99
13	231.9	247.3	3.37	2.39
14	284.5	327.0	5.33	3.44
15	302.5	345.8	3.86	2.98
16	222.0	233.0	3.82	2.48
17	249.6	266.4	2.25	2.08
18	271.9	298.3	5.30	3.43
19	248.9	272.5	4.39	2.79
20	216.2	227.5	2.76	1.96
21	180.2	185.7	2.53	1.77
22	313.3	364.0	4.20	3.22
23	303.5	345.3	4.06	3.19

APPENDIX 5 Monthly average diurnal temperatures (^{o}C)

(A) Air 4 cm.

Aspect	Month	2400 0800	0300	0600	0900	1200	1500	1800	2100	Range	Av.
		(Hour of day)									
W	Jan.	11.5	10.4	10.6	16.3	19.8	20.4	16.7	12.0	10.0	14.7
N		11.4	10.3	11.0	16.5	21.0	21.3	16.1	12.1	11.0	15.0
E		11.7	10.7	12.3	17.6	20.3	20.0	15.1	12.3	9.6	15.0
S		11.5	10.5	11.9	16.7	18.9	19.5	15.5	12.1	9.0	14.6
W	Feb.	11.9	10.7	10.9	16.0	21.7	22.6	18.1	12.9	11.9	15.6
N		10.9	9.9	10.2	15.8	21.2	21.5	17.2	12.1	11.6	14.9
E		12.2	11.4	11.9	17.8	22.2	22.2	16.3	13.1	10.8	15.9
S		12.3	10.7	11.2	15.9	20.6	21.2	17.5	13.4	10.5	15.4
W	Mar.	12.4	12.2	12.0	14.7	17.7	17.7	14.9	12.8	5.7	14.3
N		12.3	12.1	11.9	14.9	17.6	17.7	14.3	12.8	5.8	14.2
E		12.4	12.2	12.1	15.5	17.9	17.4	14.1	12.9	5.8	14.3
S		12.2	12.0	11.8	15.1	17.7	17.5	14.0	12.4	4.9	14.1
W	Apr.	9.5	9.1	8.7	11.1	14.2	14.0	11.3	10.1	5.5	11.0
N		9.2	8.9	8.5	11.3	14.5	14.1	10.9	9.6	6.0	10.9
E		9.4	9.2	8.9	11.8	14.4	13.6	11.1	9.0	5.5	11.1
S		9.2	9.0	8.6	10.4	13.7	13.3	11.0	9.8	5.1	10.6
W	May	7.0	7.0	6.7	8.2	10.8	10.4	7.7	7.1	4.1	8.1
N		6.9	6.7	6.7	8.1	10.8	10.3	7.6	7.0	4.1	8.0
E		7.3	7.1	7.0	8.7	11.0	9.8	7.7	7.4	4.0	8.3
S		6.6	6.5	6.6	7.9	10.2	9.5	7.0	6.8	3.8	7.6
W	Jun.	3.7	3.2	2.9	4.5	7.6	7.6	4.3	3.8	4.7	4.7
N		3.7	3.1	3.0	4.6	7.8	7.4	4.2	3.9	4.8	4.7
E		4.1	3.7	3.2	5.3	8.1	6.8	4.7	4.4	4.9	5.0
S		3.8	3.2	3.0	4.6	7.0	5.2	4.6	3.8	4.0	4.4
W	Jul.	5.5	5.3	5.3	6.3	8.9	9.2	6.7	5.9	3.9	6.6
N		5.2	4.9	4.8	6.2	9.0	8.9	6.2	5.4	3.2	6.3
E		5.9	5.6	5.5	6.9	9.4	8.8	6.9	6.1	3.9	6.9
S		5.3	5.1	5.1	6.1	8.4	8.4	6.4	5.7	3.3	6.3
W	Aug.	4.0	3.5	3.4	5.6	8.9	9.2	5.5	4.6	5.8	5.6
N		3.7	3.4	3.2	5.8	9.0	8.8	5.3	4.5	5.8	5.5
E		4.2	3.7	3.7	6.7	9.3	8.8	5.7	4.9	5.6	5.9
S		3.6	3.2	3.1	5.5	8.2	8.2	5.3	4.4	5.1	5.2
W	Sep.	7.6	7.5	7.4	9.4	11.5	11.7	8.9	8.0	4.3	9.0
N		7.0	6.9	6.8	8.8	10.7	10.6	8.1	7.3	3.9	8.3
E		7.5	7.4	7.3	9.8	11.6	11.0	8.7	7.8	4.3	8.9
S		7.1	7.1	6.9	9.8	11.5	10.9	8.4	7.5	4.6	8.7
W	Oct.	9.7	9.1	9.0	11.4	14.0	13.4	11.3	10.0	5.0	11.0
N		9.5	9.0	8.8	11.0	13.4	12.7	11.1	9.7	4.6	10.7
E		9.7	9.1	9.2	14.5	14.0	13.3	11.1	9.9	4.9	11.4
S		9.3	8.8	8.9	11.9	13.4	13.2	10.8	9.6	4.6	10.7

APPENDIX 5 (contd.)

Aspect	Month	2400 0000	0300	0600	0900	(Hour of day) 1200	1500	1800	2100	Range	Av.
W N E S	Nov.	11.7 11.8 11.7 11.4	11.6 11.8 11.4 11.0	11.4 11.6 11.5 11.3	14.1 14.0 14.4 14.6	17.1 16.7 17.3 17.4	17.8 17.1 17.1 17.4	15.9 15.5 14.8 14.9	12.4 12.3 12.4 12.1	6.4 5.5 5.9 6.4	14.0 13.9 13.8 13.8
W N E S	Dec.	10.4 10.4 10.5 10.0	10.1 9.9 10.0 9.7	10.6 10.6 11.2 11.5	14.2 14.2 14.7 15.4	16.8 16.7 16.9 18.0	16.3 16.0 15.7 16.5	13.5 12.7 12.7 13.0	10.8 10.6 10.8 10.4	6.7 6.8 6.9 8.3	12.8 12.6 12.8 13.1

(B) Soil 4 cm.

W N E S	Jan.	15.5 15.6 15.2 15.7	14.7 14.9 14.7 15.1	14.3 14.4 14.5 14.8	15.6 16.2 17.6 16.4	19.3 20.1 19.9 18.9	21.1 22.6 21.0 19.4	19.4 19.9 18.6 18.3	16.7 17.0 16.2 16.6	5.8 8.2 6.5 4.6	17.1 17.7 17.2 16.9
W N E S	Feb.	16.2 17.0 16.8 15.8	15.2 15.9 14.7 15.0	14.6 15.2 14.3 14.5	15.9 17.2 17.9 16.0	20.6 23.4 22.9 18.9	22.9 26.2 23.0 19.8	20.8 22.7 19.3 18.6	17.7 18.8 17.4 16.8	8.3 11.0 8.7 5.3	18.0 19.6 18.2 16.9
W N E S	Mar.	13.9 14.5 14.3 14.1	13.4 14.0 13.8 13.3	13.0 13.7 13.4 13.0	13.7 14.8 15.0 13.8	16.1 18.0 18.0 15.7	17.4 19.3 18.3 16.4	16.1 17.3 16.4 15.5	14.6 15.3 14.9 14.3	4.4 5.6 4.9 3.4	14.8 15.9 15.5 14.5
W N E S	Apr.	11.3 11.8 11.7 11.0	11.1 11.5 11.4 10.8	10.7 11.1 11.2 10.6	10.9 11.7 11.9 10.8	13.1 14.7 14.6 12.3	14.3 15.7 14.8 12.8	13.1 14.0 13.3 12.2	11.9 12.6 12.3 11.5	3.6 4.6 3.6 2.2	12.1 12.9 12.7 11.5
W N E S	May	7.9 8.8 8.0 7.3	7.9 8.7 8.0 7.3	7.5 8.4 7.7 7.2	7.7 8.6 8.2 7.3	9.3 10.9 10.3 8.3	10.2 11.8 10.3 8.7	9.0 10.4 9.2 8.0	8.2 9.3 8.4 7.5	2.7 3.4 2.6 1.5	8.5 9.6 8.8 7.7
W N E S	Jun.	4.8 5.9 4.6 4.2	4.5 5.6 4.3 4.1	4.2 5.2 4.0 3.9	4.3 5.5 4.4 3.9	5.9 7.7 6.6 4.8	7.0 8.8 7.0 5.4	6.0 7.4 5.7 4.8	5.1 6.4 5.0 4.4	2.8 3.6 3.0 1.5	5.2 6.6 5.2 4.4
W N E S	Jul.	6.4 7.2 6.3 5.4	6.1 6.9 6.0 5.4	5.9 6.7 6.0 5.2	5.9 6.9 6.1 5.3	7.4 9.0 8.2 6.5	8.5 10.0 8.7 7.1	7.7 8.8 7.6 6.4	6.9 7.8 6.9 5.9	2.6 3.3 2.4 1.9	6.9 7.9 7.0 5.9
W N E S	Aug.	5.7 6.3 5.4 4.6	5.1 5.7 4.7 4.1	4.9 5.3 4.4 3.8	4.9 5.8 5.4 4.1	7.3 8.9 8.6 6.0	9.0 10.4 9.1 6.9	7.8 8.6 7.4 6.0	6.4 7.2 6.2 5.2	4.1 5.1 4.7 3.1	6.4 7.3 6.4 5.1

APPENDIX 5 (contd.)

Aspect	Month	2400 0000	0300	0600	0900	1200	1500	1800	2100	Range	Av.
		(Hour of day)									
W	Sep.	8.4	8.0	7.7	8.1	10.0	11.0	10.0	9.0	3.3	9.0
N		8.1	7.9	7.7	8.6	10.7	11.4	10.1	9.0	3.7	9.2
E		8.5	8.0	7.8	9.2	11.9	12.1	10.4	9.3	4.3	9.7
S		7.7	7.3	7.2	8.1	9.8	10.1	9.2	8.4	2.9	8.5
W	Oct.	11.4	10.9	10.5	11.1	13.3	14.3	13.3	12.0	3.8	12.1
N		10.6	10.0	9.7	10.9	13.5	14.1	12.6	11.2	4.4	11.6
E		12.0	11.3	10.9	12.6	15.6	15.6	14.0	12.8	4.7	13.1
S		10.7	10.1	9.7	10.9	12.9	13.4	12.5	11.3	3.7	11.4
W	Nov.	15.2	14.3	13.8	14.2	17.2	18.2	17.8	16.1	4.4	15.9
N		13.5	13.0	12.7	13.6	16.1	17.7	16.5	14.4	5.0	14.7
E		15.6	14.7	14.3	15.7	18.6	18.9	18.3	16.6	4.6	16.6
S		14.1	13.4	13.0	13.9	15.9	16.9	16.4	15.0	3.9	14.8
W	Dec.	13.7	13.0	12.6	13.8	16.5	17.8	16.4	14.7	5.2	14.8
N		12.8	12.1	12.0	13.6	16.5	17.4	15.5	13.6	5.4	14.2
E		14.0	13.2	13.0	16.2	19.5	19.6	17.2	15.2	6.6	16.0
S		13.3	12.7	12.5	13.8	16.1	16.5	15.4	14.2	4.0	14.3

APPENDIX 6.1 Analysis of variance of final mineral nitrogen content of soil samples incubated during the Spring

Source of variation	d.f.	M.S.	F.
Incubation aspect	3	3237.83	2.73 ns
Source aspect	3	10325.43	8.71 **
Interaction	9	1788.69	1.51 ns
Error	61	1185.78	
Total	78		

APPENDIX 6.2 Regression coefficients expressing relationship between final moisture content and final mineral nitrogen content, for winter and spring incubations.

(1) WINTER INCUBATION

West	North	East	South
- 1.30 ns	+ 0.26 ns	- 0.07 ns	+ 0.42 ns

(2) SPRING INCUBATION

		Source Aspect			
		West	North	East	South
Incubation aspect	W	- 1.83 ns	- 3.55 ns	- 5.67 ns	+ 9.72 ns
	N	+ 7.99 ns	- 2.64 ns	+ 0.95 ns	- 0.80 ns
	E	- 4.73 ns	- 1.90 ns	- 4.85 ns	- 3.02 ns
	S	+ 1.28 ns	- 0.76 ns	+ 0.39 ns	+ 0.33 ns

	West	North	East	South
Within source aspects	- 0.16 ns	- 1.67 ns	- 1.55 ns	- 2.54 ns
Within incubation aspects	+ 0.40 ns	+ 3.23 ns	+ 1.56 ns	+ 0.05 ns

APPENDIX 6.3 Mineral nitrogen (N) and moisture contents (MC) of incubated cores at end of spring incubation. (ppm. and g/100g dry soil)

INCUBATION ASPECT	SOURCE ASPECT: WEST		NORTH		EAST		SOUTH	
	MC	N	MC	N	MC	N	MC	N
WEST	33.9	75.2	27.9	100.6	41.0	153.9	51.8	125.5
	40.5	30.5	24.5	67.9	47.1	78.2	51.1	33.6
	41.6	83.8	34.2	42.4	49.3	84.0	46.8	-29.5
	31.9	98.5	29.5	65.6	47.7	73.2	50.2	80.4
	34.6	18.6	41.8	23.4	48.2	192.7	51.1	24.7
NORTH	37.2	395.9*	29.0	44.2	41.6	41.6	46.9	118.7
	38.3	35.8	31.1	38.2	47.3	158.8	49.3	84.5
	37.7	26.6	29.9	82.4	48.8	71.5	41.0	95.8
	13.9*	35.5	29.4	18.5	35.7	46.0	43.9	55.6
	36.4	19.6	34.1	30.9	37.2	173.3	40.3	112.3
EAST	33.3	39.6	26.6	29.7	39.7	69.7	50.8	49.6
	36.6	25.3	33.0	24.5	37.6	180.2	41.8	30.7
	37.2	14.8	26.6	23.9	55.8	52.4	42.5	101.2
	37.6	22.3	28.2	16.4	41.6	110.8	46.6	80.9
	35.9	19.5	25.6	48.7	44.1	31.2	40.9	110.1
SOUTH	39.3	113.1	28.5	42.0	48.4	60.5	50.8	33.5
	36.2	32.5	29.5	50.6	48.2	49.7	48.8	25.8
	36.1	29.1	35.7	38.3	41.2	77.0	60.8	41.2
	38.5	31.0	30.0	27.9	38.1	39.0	45.4	32.2
	45.1	38.6	28.7	45.4	44.3	42.4	48.4	55.2

Mineral nitrogen (N) and moisture contents (MC) of incubated cores at end of winter incubation (ppm. and g/100 g soil)

WEST		NORTH		EAST		SOUTH	
MC	N	MC	N	MC	N	MC	N
49.1	8.5	39.1	10.5	72.8	39.7	51.2	21.9
42.4	21.0	35.9	11.7	70.3	33.8	59.2	13.9
45.0	11.1	42.9	22.8	58.7	29.5	46.1	9.6
43.4	10.6	48.8	12.7	49.7	33.2	48.9	6.8
44.1	12.0	46.9*	62.3*	56.3	54.9	52.3	15.5

* = omitted in analysis

APPENDIX 6.4 Analyses of variance of winter and spring ambient level data, winter final level data, and total nitrogen data for spring incubation.

.	d.f.	M.S.	F
(1) Winter ambient level			
between aspects	3	37.53	10.6**
within aspects	15	3.54	
total	18		
(2) Spring ambient level			
between aspects	3	92.68	4.0*
within aspects	16	23.33	
total	19		
(3) Winter final level			
between aspects	3	754.56	15.6**
within aspects	15	48.39	
total	18		
(4) Spring total N level			
between aspects	3	0.008367	9.2**
within aspects	16	0.000913	
total	19		

APPENDIX 7.1 Production on 5^{o} to 30^{o} slopes, measured using 1 m^2 herbage samples (kg. DM./ha.)

	West	North	East	South
16.1 to 4.4.72 (79 days)	1040 546 436	456 515 293	1046 2138 1480	896 1716 803
4.4 to 23.8.72 (141 days)	318 284 344	455 363 303	1114 2645 1893	338 309 448
23.8 to 9.11.72 (79 days)	722 912 1100	640 1069 997	3200 3407 5530	1964 872 850
13.11 to 30.12.72 (47 days)	1018 1064 1097	1521 781 928	2784 2101 1709	760 622 1393

APPENDIX 7.2 Analysis of variance of log (x + 1) transformed productivity data.

Source of variation	d.f.	MS	F
Periods	3	59.0380	75.97^{**}
Aspects	3	30.7186	39.53^{**}
Interaction	9	1.7342	2.23 ns
Error	32	0.7771	
Total	47		

APPENDIX 7.3 Results of point analyses (2.5 to 8.5.72) and dry weight analyses (4.4.72) (% botanical composition)

	WEST		NORTH		EAST		SOUTH	
	PA	DW	PA	DW	PA	DW	PA	DW
Sweet Vernal	9.4	10.7	11.7	8.1	6.0	6.1	9.1	8.2
Browntop	36.7	38.4	34.4	43.0	30.1	45.7	33.2	48.6
Cocksfoot	0.7	1.1	0.8	0.8	0.5	1.8	0.8	0.6
Crested dogstail	6.4	7.1	2.8	1.5	10.0	7.3	8.5	6.1
Yorkshire fog	3.9	1.0	1.7	0.3	13.2	8.8	9.3	4.4
Perennial ryegrass	0.7	4.2	0.8	0.1	9.5	10.3	1.3	2.0
Danthonia	1.2	5.8	13.3	21.9	4.5	3.2	0.3	0.1
Poa spp.	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
Bidibid	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0
Daisy	0.2	0.3	0.0	0.4	0.5	0.1	1.6	0.3
Centella spp.	0.5	0.4	0.3	0.0	0.0	0.0	1.3	0.6
Marsh thistle	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Hawksbeard	2.7	1.6	0.8	0.2	2.7	1.2	2.3	2.1
Chickweed	0.0	0.6	1.4	0.1	1.2	1.1	0.0	0.0
Dichondra repens	0.2	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Cudweed	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.3
Hydrocotyle moschata	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Catsear	17.2	13.1	11.1	7.7	6.7	4.0	9.6	10.1
Purging flax	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Hawkbit	3.2	7.0	6.1	2.7	7.5	4.3	5.4	4.7
Nertera	4.2	0.8	0.3	0.1	0.0	0.0	1.6	0.3
Ribgrass	1.5	1.4	4.2	11.5	1.0	2.1	2.6	2.7
Selfheal	0.0	0.8	0.3	0.0	0.0	0.1	0.0	0.7
Sheep sorrel	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0
Moss	6.4	0.6	3.6	0.5	1.7	0.9	7.3	1.6
Dandelion	0.0	0.2	0.0	0.0	0.0	0.3	0.3	0.5
Red clover	0.0	0.2	0.0	0.0	0.0	0.0	0.3	0.2
White clover	4.7	5.7	2.8	1.4	4.7	2.8	4.8	4.4
Striated clover	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.4
Subterranean clover	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Bare ground	15.4		25.0		16.2		19.6	

APPENDIX 7.3 (contd.) Results of point analyses (3.8 to 7.8.72) and dry weight analyses (28.8.72) (% botanical composition)

	WEST		NORTH		EAST		SOUTH	
	PA	DW	PA	DW	PA	DW	PA	DW
Sweet vernal	10.9	12.8	9.5	8.6	10.1	6.7	6.2	9.9
Browntop	30.5	50.5	35.8	45.6	28.3	48.0	26.1	56.2
Cocksfoot	0.0	1.2	0.9	0.0	1.1	0.0	0.0	0.3
Crested dogstail	6.9	10.7	5.8	2.8	7.1	10.1	9.4	9.8
Yorkshire fog	6.6	1.5	1.7	0.1	13.1	13.2	6.0	1.3
Perennial ryegrass	0.0	2.4	2.6	0.6	7.1	16.0	1.4	4.2
Danthonia	3.0	8.2	14.7	22.3	6.0	0.8	2.4	1.8
Poa spp.	0.5	0.1	0.6	0.2	3.3	2.7	0.2	0.1
Bidibid	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0
Daisy	0.3	0.0	0.3	0.0	0.8	0.0	1.2	0.0
Marsh thistle	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7
Hawksbeard	2.8	0.5	2.3	0.3	4.6	0.1	4.8	1.4
Chickweed	0.0	0.1	0.0	1.0	1.1	0.2	0.5	0.0
Cudweed	0.0	0.0	0.3	0.7	0.0	0.0	0.0	0.1
Hydrocotyle moschata	0.0	0.0	0.3	0.0	0.0	0.0	0.2	0.0
Catsear	10.2	0.4	6.4	0.7	4.6	0.2	7.4	2.3
Hawkbit	2.5	0.4	4.3	0.1	2.7	0.1	2.2	0.7
Nertera	3.3	0.2	0.3	0.0	0.3	0.0	2.4	0.1
Ribgrass	0.5	0.4	2.3	0.6	0.5	0.0	0.5	0.0
Selfheal	0.3	0.0	0.3	0.0	0.0	0.0	0.5	0.2
Moss	16.8	2.4	7.5	3.7	7.4	0.5	23.0	3.1
Dandelion	0.3	0.0	0.3	0.0	0.0	0.0	0.5	0.0
Red clover	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
White clover	4.6	1.6	2.3	0.3	1.6	0.9	1.9	1.0
Chewings fescue	0.3	2.1	0.9	10.4	0.3	0.7	2.6	3.2
Lotus major	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Woodrush	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Bare ground	19.9		29.7		25.4		24.9	

APPENDIX 7.3 (contd.) Results of point analyses (15.11 to 27.11.72) and dry weight analyses (9.11.72) (% botanical composition)

	WEST		NORTH		EAST		SOUTH	
	PA	DW	PA	DW	PA	DW	PA	DW
Sweet vernal	12.9	24.0	11.0	27.1	11.1	16.9	11.4	15.5
Browntop	27.3	40.9	29.8	38.2	25.9	29.0	28.6	39.8
Cocksfoot	0.9	0.2	1.3	0.0	0.9	1.5	0.2	0.7
Crested dogstail	4.6	6.1	3.0	0.9	7.9	9.1	5.5	5.9
Yorkshire fog	3.5	2.5	1.5	0.4	13.7	12.6	5.3	2.6
Perennial ryegrass	0.2	3.7	1.0	0.1	8.1	16.9	1.3	2.4
Danthonia	4.4	4.2	16.5	21.5	3.0	0.1	1.3	3.3
Poa spp.	0.9	1.2	1.0	0.8	2.6	6.9	1.8	0.8
Daisy	0.5	0.7	0.0	0.0	0.2	0.1	1.3	2.1
<u>Centella</u> spp.	0.5	0.1	0.8	0.2	0.0	0.0	0.7	0.0
Marsh thistle	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0
Hawksbeard	1.9	0.5	0.3	0.3	1.4	0.2	0.4	0.4
Chickweed	0.0	0.0	0.0	1.3	1.6	1.4	0.0	0.0
<u>Dichondra repens</u>	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Cudweed	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Catsear	18.7	6.4	12.5	1.4	10.9	3.2	14.1	6.5
Hawkbit	3.5	0.8	3.5	0.8	2.3	0.3	5.3	4.1
Nertera	2.8	0.2	0.3	0.1	0.0	0.0	2.4	0.1
Ribgrass	0.7	0.5	6.5	1.0	2.3	0.5	1.5	0.8
Selfheal	0.2	0.2	0.8	0.0	0.0	0.0	0.4	1.6
Moss	4.3	0.6	1.5	0.5	1.9	0.1	8.4	2.6
Dandelion	0.2	0.0	0.0	0.0	0.2	0.0	0.7	0.0
Red clover	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
White clover	6.5	3.9	5.5	0.3	3.9	0.7	4.0	3.6
Striated clover	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Chewings fescue	0.7	2.4	1.8	3.9	0.2	0.1	1.8	3.7
Lotus major	0.0	0.0	0.3	0.0	0.0	0.0	0.2	1.6
Ragwort	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Californian thistle	0.0	0.0	0.2	0.0	0.0	0.0	0.9	0.0
Scotch thistle	0.0	0.0	0.3	0.0	0.2	0.0	0.0	0.0
Suckling clover	5.1	0.1	0.8	1.6	0.5	0.0	1.5	1.3
Fern	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Bare ground	17.5		18.9		12.2		13.3	

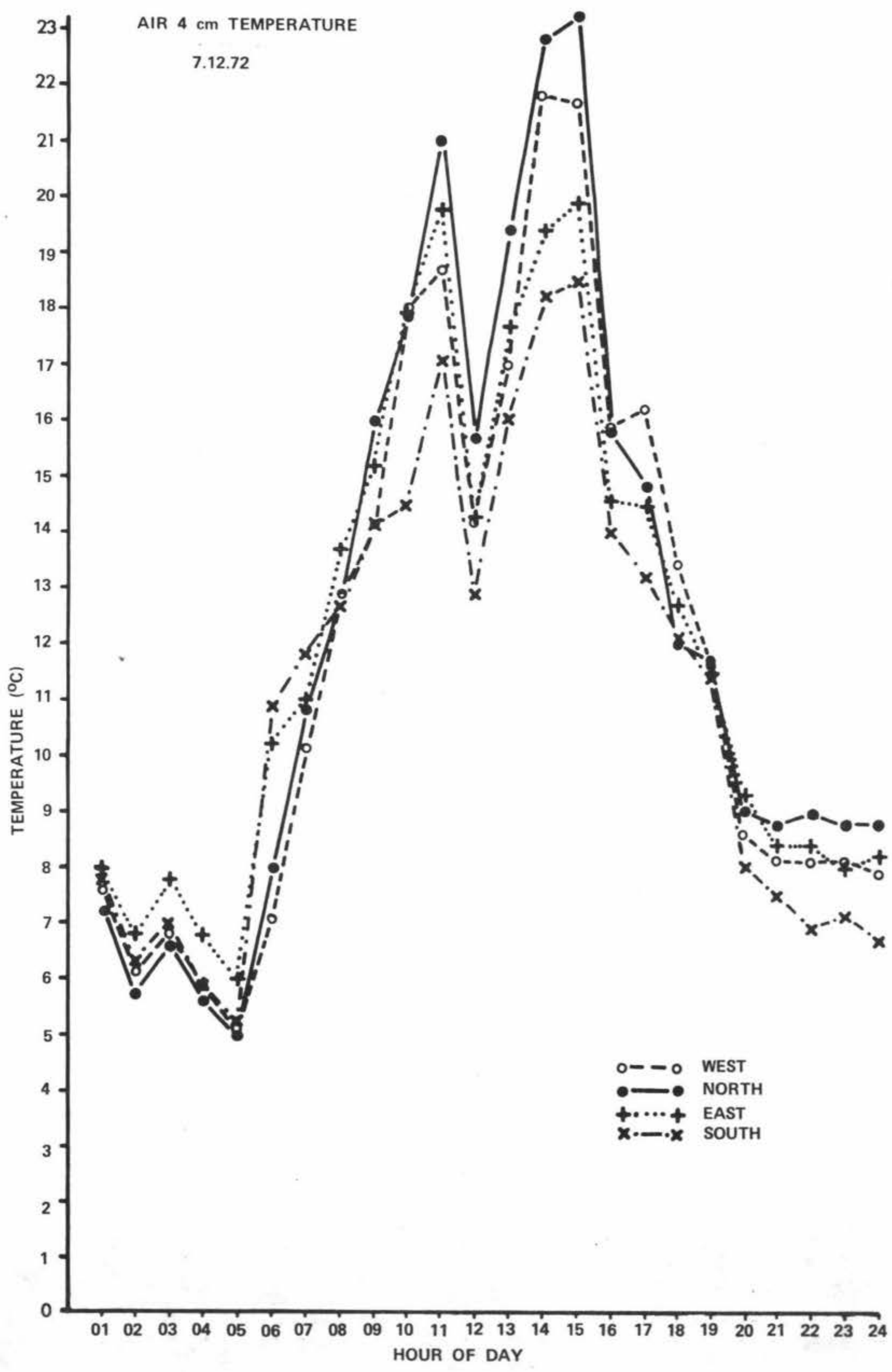
APPENDIX 7.3 (contd.) Results of point analyses (31.1 to 13.2.73) and dry weight analyses (30.12.72) (% botanical composition)

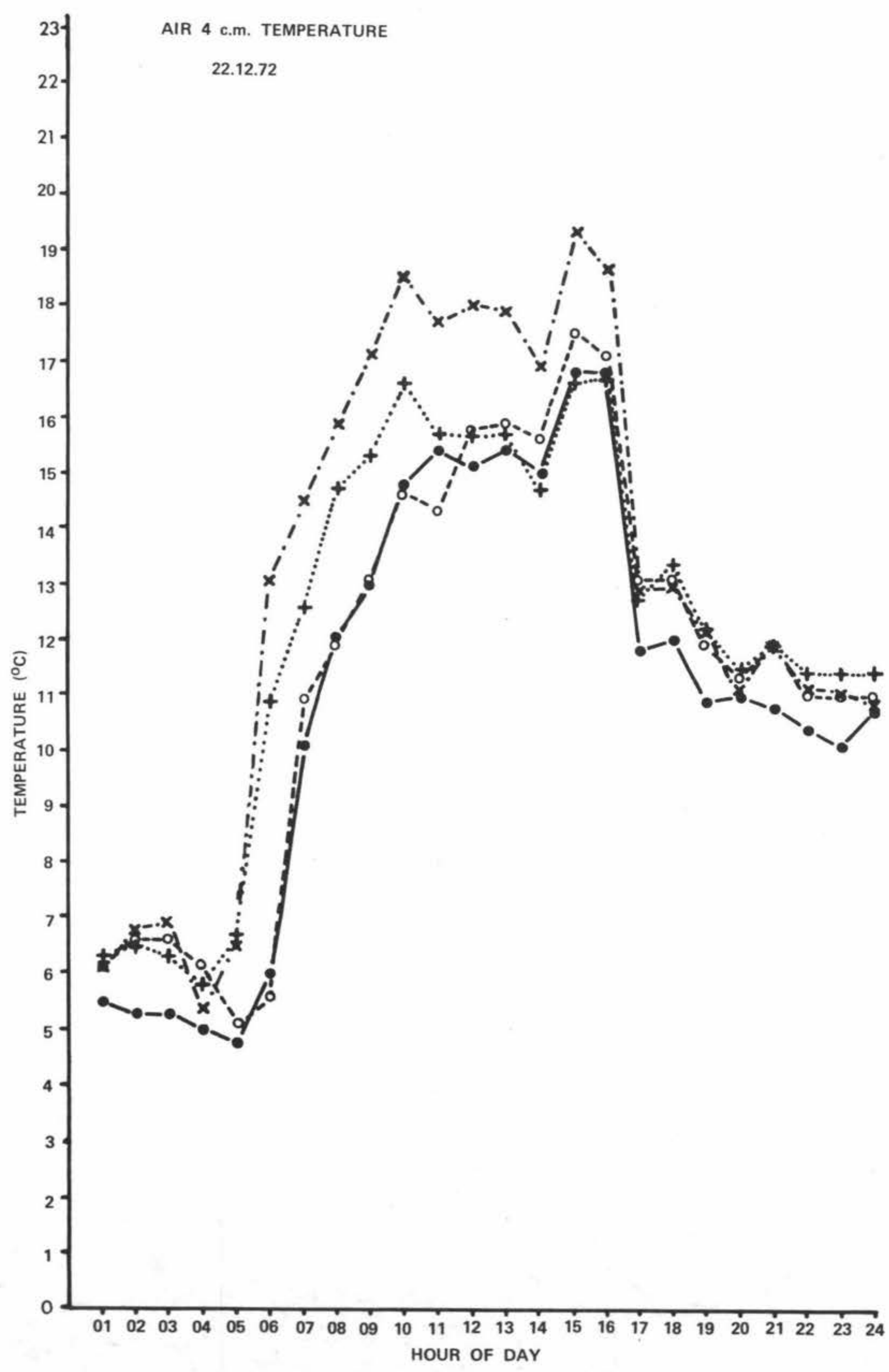
	WEST		NORTH		EAST		SOUTH	
	PA	DW	PA	DW	PA	DW	PA	DW
Sweet vernal	10.1	4.8	5.5	14.5	7.7	4.3	9.0	5.8
Browntop	22.0	37.1	28.6	30.4	24.2	20.8	24.4	39.0
Cocksfoot	1.2	0.0	0.7	0.0	0.0	0.1	0.6	3.4
Crested dogstail	3.7	7.6	4.0	5.8	4.2	18.0	8.4	8.7
Yorkshire fog	4.9	1.6	1.5	1.7	14.2	11.5	7.8	1.6
Perennial ryegrass	0.9	0.7	1.1	0.9	9.2	19.1	2.8	2.0
Danthonia	4.3	13.3	18.3	27.3	2.7	0.5	0.6	10.6
Poa spp.	0.0	0.4	1.1	0.3	1.2	0.4	0.0	0.6
Bidibid	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Daisy	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1
Centella spp.	1.2	0.0	0.4	0.0	0.0	0.0	1.7	0.0
Marsh thistle	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Hawksbeard	0.9	0.0	0.4	0.0	0.0	0.4	0.0	0.0
Chickweed	0.0	0.2	0.0	0.0	3.1	0.1	0.0	0.1
Dichondra repens	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Yarrow	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Catsear	16.8	21.1	11.7	5.8	13.1	4.3	12.3	11.8
Hawkbit	3.0	5.7	6.2	8.8	5.0	14.4	5.4	4.6
Nertera	4.0	0.1	0.4	0.0	0.4	0.0	4.2	0.3
Ribgrass	4.6	0.0	2.2	0.5	1.5	1.1	3.4	1.9
Selfheal	0.9	1.0	0.7	0.0	0.0	0.0	0.3	0.8
Moss	17.4	0.5	12.1	0.0	6.5	0.0	8.4	0.9
Dandelion	0.3	1.0	0.0	0.0	0.0	0.0	0.0	0.7
Red clover	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
White clover	7.0	0.8	2.9	1.3	5.4	4.1	4.8	1.5
Striated clover	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Chewings fescue	0.6	1.8	1.1	2.7	0.8	1.1	3.4	8.2
Suckling clover	0.0	1.5	0.0	0.0	0.0	0.0	0.0	4.7
Californian thistle	0.0	0.0	0.0	0.0	0.8	0.0	0.8	0.0
Fern	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Ragwort	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bare ground	33.3		44.5		48.2		27.4	

APPENDIX 7.4 Production on 5° to 30° slopes, measured using 25 cm^2 herbage samples (kg. DM./ha.)

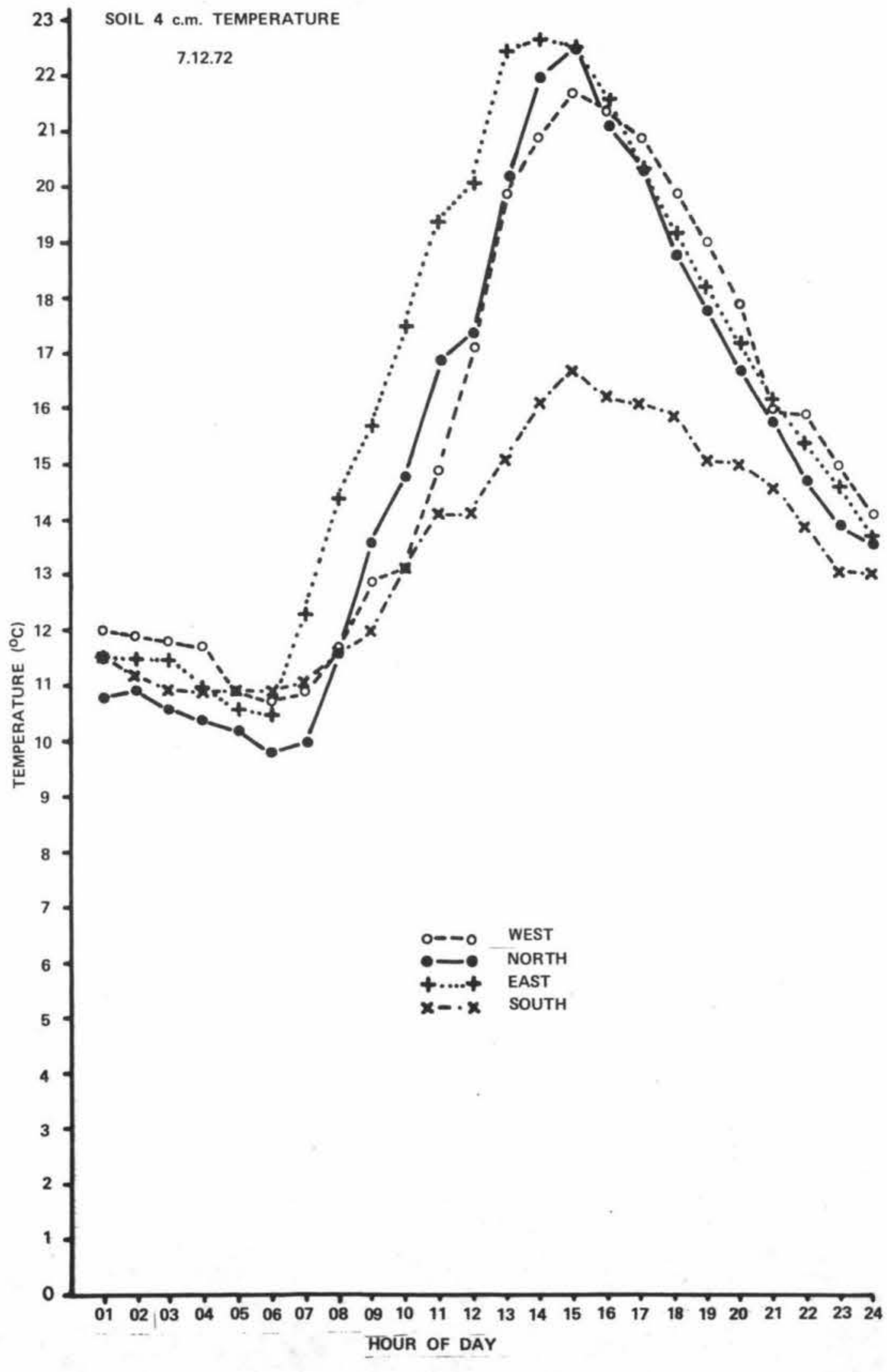
	WEST	NORTH	EAST	SOUTH
16.1 to 4.4.72	480 480 464 864	480 528	624 1536	1312 1456 848
4.4 to 23.8.72	464 1275 1179 1065	688 320 448	2704	624 272
23.8 to 9.11.72	432 864 1024 512	1280 928 1029 1200		1088 1328 3400
13.11 to 30.12.72	990 1000 930 528	880 1265	704 1530 1970	640 1030 705 672

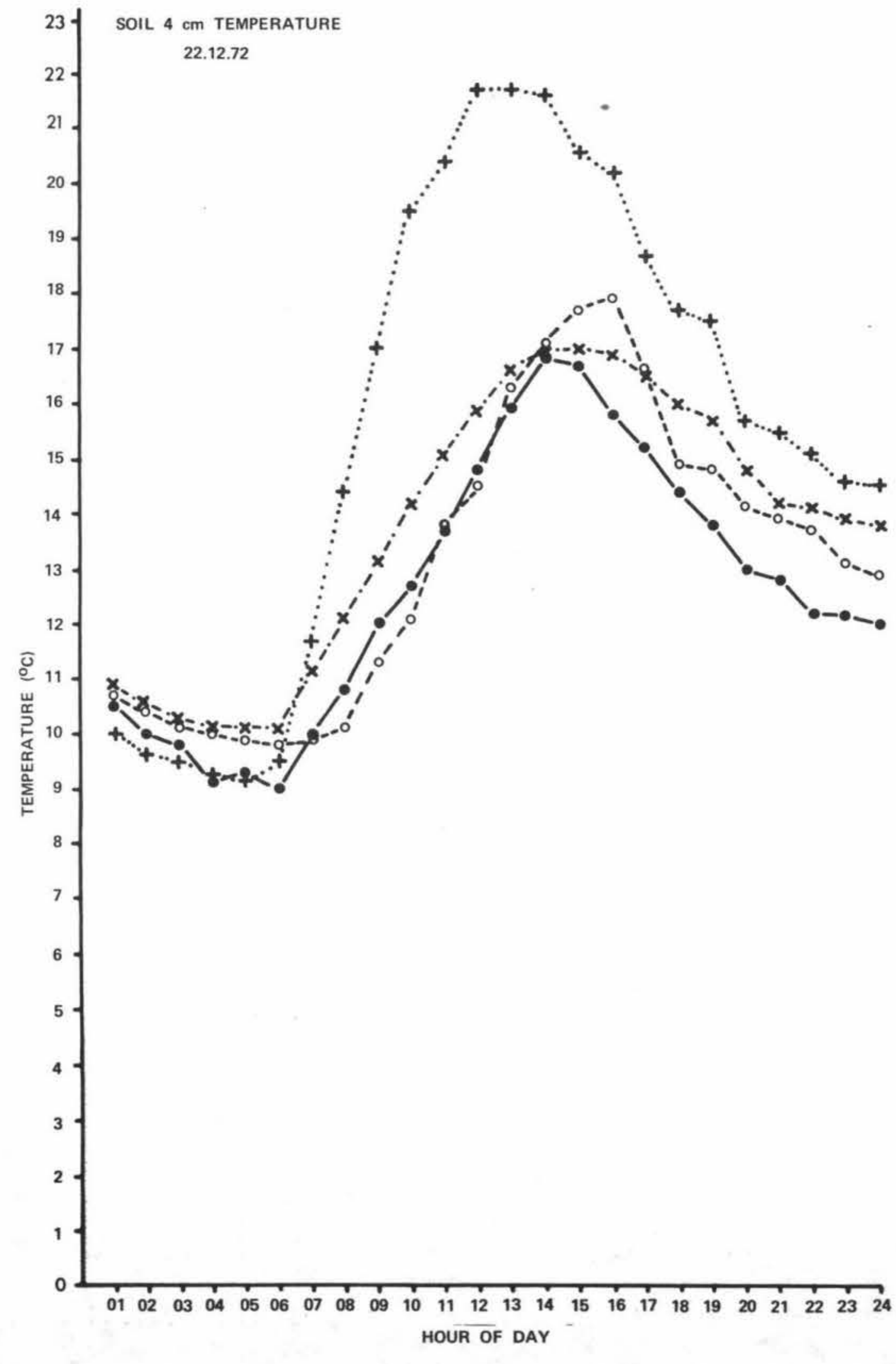
APPENDIX 8


AIR 4 cm TEMPERATURE
7.12.72
TEMPERATURE (°C)
HOUR OF DAY
WEST
NORTH
EAST
SOUTH


AIR 4 c.m. TEMPERATURE
22.12.72
TEMPERATURE (°C)
HOUR OF DAY

APPENDIX 8 contd





APPENDIX 9 Analyses of variance of soil test results for samples taken 30.3.72

In all analyses d.f. for mean squares between aspects = 3 within aspects = 44, total = 47.
The base saturation data was arcsin transformed prior to analysis.

	M.S. between aspects	M.S. within aspects	F value and significance
pH (H_2O)	0.0184	0.0027	6.82 *
pH (0.1 M $CaCl_2$)	0.0592	0.0087	6.80 *
Organic carbon	11.2517	0.1575	71.44 **
Total nitrogen	0.0958	0.000734	136.86 **
Available phosphorus	395.905	7.731	51.21 **
Exchangeable K	1.4696	0.0146	100.66 **
Exchangeable Ca	17.5533	0.1807	97.14 **
Exchangeable Mg	4.2645	0.0325	131.22 **
Exchangeable Na	0.0113	0.000207	54.59 **
Cation exchange cap.	85.44	0.64	129.50 **
Base saturation	143.48	2.22	64.63 **

APPENDIX 10 Species encountered during point analyses and herbage dissections.

Common name	Botanical name
Sweet vernal	Anthoxanthum odoratum
Browntop	Agrostis tenuis
Cocksfoot	Dactylis glomerata
Crested dogstail	Cynosurus cristatus
Yorkshire fog	Holcus lanatus
Perennial ryegrass	Lolium perenne
Danthonia	Notodanthonia spp.
Poa spp.	Poa trivialis, P. pratense, P. annua.
Chewings fescue	Festuca rubra var. commutata
White clover	Trifolium repens
Red clover	T. pratense
Subterranean clover	T. subterraneum
Striated clover	T. striatum
Suckling clover	T. dubium
Lotus major	Lotus pedunculatus
Bidibid	Acaena anserinifolia
Daisy	Bellis perennis
Centella spp.	Centella spp.
Hawksbeard	Crepis capillaris
Chickweed (mouse-eared)	Cerastium glomeratum
Dichondra repens	Dichondra repens
Cudweed	Gnaphalium luteo-album
Hydrocotyle moschata	Hydrocotyle moschata
Catsear	Hypochaeris radiata
Purging flax	Linum catharticum
Hawkbit	Leontodon taraxacoides
Nertera	Nertera setulosa
Ribgrass	Plantago lanceolata
Selfheal	Prunella vulgaris
Sheep's sorrel	Rumex acetosella
Dandelion	Taraxacum officinale
Marsh thistle	Circium palustre
Californian thistle	C. arvense
Scotch thistle	C. vulgare
Ragwort	Senecio jacobaea
Woodrush	Luzula sp.
Fern	Pteridium esculentum
Yarrow	Achillea millefolium
Moss	Thuidium sp., Dicranum sp., Campylopus introflexus, Hypnum or Drepanocladus spp., Bryum sp.

APPENDIX 11 Comparison of variances calculated using binomial and normal theory.

Variance calculated by:	var = npq	var = $\sum(x - \bar{x})^2 / n - 1$
South aspect:		
browntop	59.6	16.3
catsear	35.4	17.3
East aspect:		
browntop	60.9	58.3
catsear	26.2	0.7

APPENDIX 12 Bulk density values determined from samples taken on 20.3.73 (g./cc.)

depth:	0.5 to 8.0 cm.	14.0 to 21.5 cm.	26.0 to 33.5 cm.
South aspect:	0.89	1.09	1.16
	0.90	1.12	1.16
	0.91	1.07	1.14
	0.86	1.11	1.19
average	0.89	1.10	1.16
North aspect:	0.77	1.01	1.10
	0.84	1.08	1.18
	0.82	1.05	1.10
	0.81	1.08	1.14
average	0.81	1.06	1.13

APPENDIX 13 Methods of soil analysis

Cation Exchange Capacity (CEC)

Subsamples of the 2 mm. soil samples were leached with NH_4Ac, and the CEC of each determined following steam distillation.

Exchangeable K, Na, Ca and Mg.

The extract solutions from the CEC column were tested on the auto-analyser (AA). for K, Na, Ca and Mg.

Organic C

Subsamples of the fine-ground soil were treated with CrO_3 and H_2SO_4; sediment was removed by centrifugation and reduced chromium was measured colormetrically on the A.A.

Total N

Subsamples of the fine ground soil were digested (Kjeldahl procedure), diluted in water and cleaned by centrifugation. The N contents of the solutions thus obtained were determined colorimetrically on the AA.

pH

10 gm. soil subsamples (2 mm.) were mixed with 25 ml. of H_2O, and with 25 ml. 0.1 M $CaCl_2$. These suspensions were allowed to stand for 2 hours, then were tested with a pH meter.

Available P (Truog method)

Subsamples of 2 mm. soil were extracted with dilute H_2SO4; the extract solutions were cleaned by centrifugation and tested colormetrically on the AA.

Exchangeable NH_4-N and NO_3-N

Samples of 3 mm. wet soil were extracted with 2N KC1 and the NH_4-N and NO_3-N content of the extract solutions were determined colormetrically on the AA. To obtain values in terms of dry soil, the following formula was applied.

$$\text{ppm.N} = \left(\frac{100 + (Z - X)}{X}\right) Y$$

where Z = gm. wet soil used

Y = ppm. N in extract

X = gm. dry soil in wet soil sample (obtained using the moisture factor derived for each sample)

The NH_4-N and NO_3-N values thus obtained were added to give the mineral N content of dry soil samples.

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