VARIATION IN SOIL WATER AND SOIL AIR CONTENTS ASSOCIATED WITH A VEGETATION-SOIL SEQUENCE IN THE TARARUA MOUNTAINS, NEW ZEALAND

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SUMMARY: This paper describes part of a study of vegetation/soil system dynamics in which close relationships were demonstrated between structural change of the forest, with associated changes in composition, and changes in organic matter and soil physical properties, particularly the quantities of water and air in non-capillary pores. Because of these results an analysis was made of the quantities of water and air in the same soils under field conditions to test their correspondence with the vegetation pattern and known physical properties.

INTRODUCTION

The area of study is the ridge system running west of Mt Maymorn (851m) (grid reference 705549) at the southern extremity of the Tararua Ranges, Wellington. The major environmental features of the area may be summarised as follows:—

(1) There is no modification of the vegetation/soil system by direct human activities.

(2) Modification of both the structure and composition of the vegetation/soil system by browsing animals has been severe and is continuing.

(3) Precipitation is considerable (3000mm per annum) with mild to cool summers and cool to cold winters. The moisture and temperature conditions are modified topographically by many strong to gale force winds, particularly from the north-west, and frequent cloud and fog. Snow is infrequent, and drought is non-existent.

(4) The topography is an extensive ridge system with shallow, gentle, meandering streams separated by broad flat interfluves.

(5) The stratigraphic sequence comprises redeposited soil-forming lœss over occasional soliflual deposits, rare lignitic siltstones and massive greywacke. Considerable truncation occurred during the late Pleistocene.

(6) Soils are generally shallow (15-35cm) silt loam gley podzols, humic gley podzols and peaty gley podzols in the yellow brown earth group (Gibbs 1959).

(7) The vegetation is silver beech forest. The surrounding small areas of woodland, scrub and fern/sedgeland are aligned to the prevailing north-west wind and normal to the ridge trend.

The General Systems Theory concept of steady-state (Bertalanffy 1950, Nikiforoff 1959) defining a state of dynamic equilibrium in biological and pedological systems is applied to the close canopied silver beech forest//gley podzol system. Structural and compositional changes beyond the steady-state (i.e. becoming unstable) include decreasing stature of the vegetation, increasing numbers of non-forest plant species and wetter, less ærated and more organic soils. These changes are termed 'post steady-state' (Park 1972); they do not necessarily follow one another in simple linear sequences because topographic factors complicate the relationship. Post steady-state changes involve a progression from close-canopied silver beech forest//gley podzol to fern/sedge-

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land//humic gley podzols. There would appear to be some re-attainment of steady-state in the fern/sedgeland//humic gley podzol, but under the current stresses of turf-browsing, trampling and high water tables, the whole vegetation/soil system is, at this stage, very susceptible to removal down to basement rock.

All field evidence suggests the post steady-state changes are indicative of gradual internal processes rather than catastrophic stresses. It is assumed

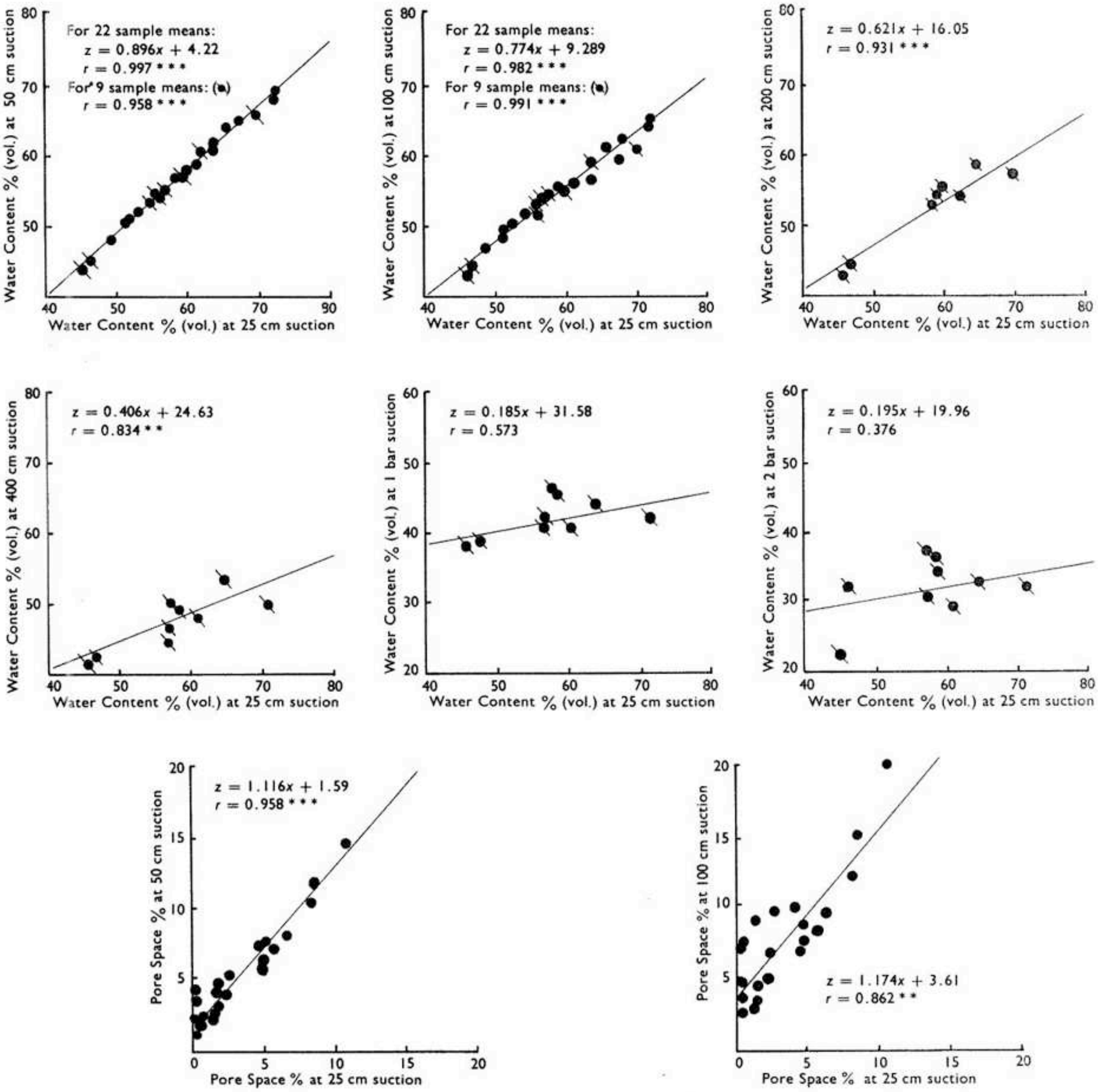

FIGURE 1. *Relationships between water contents and air-filled pore contents at low moisture tensions for the range of soils in the study area.*

that at some stage prior to the initiation of widespread, post steady-state change, intact steady-state forest and scrub occupied all sites with the soil less than 35cm deep. The present distribution of steady-state vegetation coincides with the distribution of soils less than 25cm deep. Structural instability in the vegetation due to a combination of extremely low nutrient levels (Mr P. L. Searle pers. comm.), drainage impedence and poor æration is at a minimum on these soils.

Most changes in soil organic matter and soil physical properties have a significantly curvilinear distribution in relation to a linear gradient of decreasing vegetation space (Park 1971). The quantitative maxima or minima of these curvilinear distributions are associated with the vegetation of most variable physiognomy, i.e. where remnants of growth of trees of the original forest still remain. The organic matter and physical parameters for eight stands in a vegetation/soil sequence (Sequence 1 in Fig. 3) are summarised in Table 1. Table 2 is a summary of the same parameters for a peaty gley podzol (see Fig. 2).

Highly significant linear relationships have been demonstrated between the quantity of organic matter and most soil physical properties. As well as being important in the initial development of a soil under cool, super-humid conditions (Crocker and Dickson 1957) the gradual accretion of organic matter to the mineral soil is a major pedological post steady-state process associated with decreasing soil bulk densities and specific gravities and increases in shrinkage between saturation and oven dry weight, total porosity, soil depth, water contents and the amount of air-filled non-capillary soil pores (Table 1). The linear relationships between the various soil physical properties, particularly between the water contents and the air-filled non-capillary pores contents (Fig. 1), are also highly significant. Most changes in soil moisture retention and the distribution of air-filled pores occurring as a result

TABLE 1. *Summary of Organic Matter and Physical Parameters for the 5-10cm depth of Eight Soils in a Vegetation/soil Sequence Commencing at Steady-state (Stand No. 1).*

Stand No.	1	2	3	4	5	6	7	8
Vegetation	Close canopied forest	open forest	shrub/fern sedgeland	shrub/fern sedgeland	shrub/fern sedgeland	shrub/fern sedgeland	fern/sedge/ mossland	sedge/ mossland
Soil	gley podzol	humic gley podzol	humic gley podzol	humic gley podzol	humic gley podzol	humic gley podzol	humic gley podzol	humic gley podzol
Organic carbon*	4.0	6.9	7.7	7.0	7.2	8.3	4.3	5.6
Total Nitrogen*	0.09	0.13	0.16	0.18	0.22	0.21	0.20	0.20
C/N ratio	43.9	53.5	48.3	39.0	33.3	40.2	21.8	28.4
Bulk density (g/cc)	1.18	1.02	0.92	0.84	0.63	0.79	0.83	0.80
Total porosity*	47.5	58.9	62.9	64.3	72.1	66.4	61.5	64.9
Shrinkage*†	8.4	10.9	17.7	23.0	37.7	28.4	27.2	23.7
Specific gravity	2.35	2.50	2.48	2.37	2.25	2.39	2.41	2.29
WC pores 120μdia.*	46.2	54.2	60.5	57.9	72.0	62.2	57.3	62.9
WC pores 60μdia.*	44.9	53.3	58.7	56.5	68.6	59.4	55.3	61.2
WC pores 30μdia.*	43.4	51.9	56.2	55.2	65.4	56.6	53.3	60.1
APC pores 120μdia.*	1.5	4.8	2.4	6.4	0.1	4.2	8.1	2.1
APC pores 60μdia.*	2.6	5.6	4.3	7.8	3.5	7.0	10.2	3.6
APC pores 30μdia.*	4.1	7.0	6.9	9.1	6.7	9.8	12.2	9.8
Soil depth (cm)	23.7	29.2	18.3	30.8	24.3	31.1	31.6	34.2
Litter depth (cm)	14.1	6.2	8.4	5.9	5.7	4.4	0.2	0.01

WC = water content
APC = air-filled pore content
* = % of soil volume
† = saturation to oven-dry

of structural deterioration of the vegetation take place in the non-capillary pores, i.e. when the soils are above field capacity. At all moisture tensions the volumetric water content and the amount of air-filled pores of a post steady-state soil are greater than in steady-state soils.

METHODS

Twenty-two soils were replicate-sampled from a representative range of sites using stainless steel coring tubes of 1mm wall thickness, 4.8cm internal diameter and with a bevelled cutting edge. Sampling was in the 5-10cm soil depth. Soil physical properties were determined on samples transferred to liners of 45.3cc volume, and of identical diameter to the coring tube. Three techniques of analysis were used:—

(a) *Porous plate* (Richards 1954): for the low tensions of 25, 50 and 100cm, that drain the non-capillary pores of 120μ, 60μ and 30μ diameter respectively.

(b) *Pressure plate* (Richards 1954, Gradwell 1966, Kohnke 1968): for tensions 200, 400 and 1000cm (1000cm is equivalent to 1 bar), that drain the capillary pores of 15μ, 7.5μ and 3.0μ diameter respectively.

(c) *Pressure membrane* (Richards 1954, Gradwell 1966, 1968): for tensions of 2 bar, 5 bar and 15 bar, that drain the capillary pores of 1.5μ, 0.75μ and 0.3μ diameter respectively.

These analyses provided a set of soil properties defining the quantitative responses of the soils to post steady-state environmental stresses. Since they provided no information on the air/water balance of these wet soils under field conditions, the following records were taken:—

(1) The field water contents and field air-filled pore contents were recorded over a nine month period (August 1968-April 1969), excluding the winter months when the soils are almost continually saturated.

(2) Soil in three sequences representing the major gradients of decreasing vegetation space under different environmental conditions were sampled with coring tubes simultaneously under summer conditions on 17 January 1970. Samples were transferred to liners for weighing and volume calculations using bulk densities. Analysis of these samples sought to establish whether, on one sampling occasion, soils from different sites differed in their degree of drainage (i.e. volume of air-filled pores), held water at the same tension, and exhibited any relationships with known soil physical properties. The tensions prevailing in the field and hence the minimum diameters of air-filled pores were interpolated from the moisture content/tension data from a, b, and c, above.

A separate analysis of shrinkage (Park 1971) when obtaining soil moisture retention data for a range of tensions from saturation to wilting point (15 bar) and oven dry indicated that shrinkage, involving contraction of organic colloids on pore walls, is significant in only the capillary pores. For the non-capillary pores of the soils in this study, a simple relationship can be assumed between pore diameter and tension. The relationship is far from simple in true peats because of the fibrous nature of the organic matter.

RESULTS

Variation in Soil Water and Air-Filled Pore Contents over a Period of Nine Months in Three Soils

Data were obtained from samples from the following vegetation/soil system types:—

(1) steady-state low forest//gley podzol

(2) post steady-state fern/sedgeland//humic gley podzol

(3) post steady-state tree/shrubland//peaty gley podzol.

Data are plotted in Figure 2 according to soil moisture tension, the percentage of airfilled pores and the minimum diameter of pores that are drained of water at a particular tension. The results show the comparative similarity in the dis-

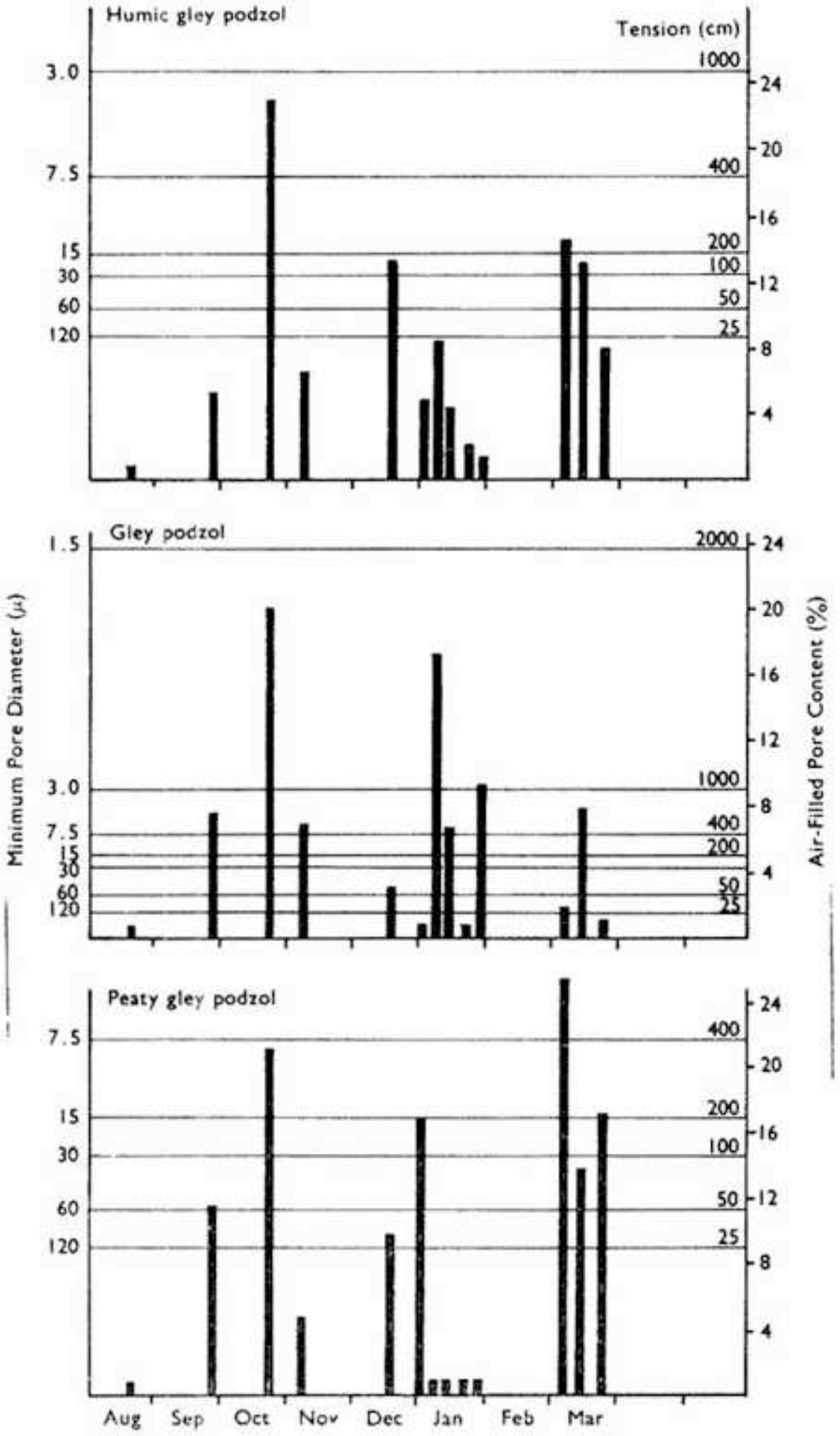

FIGURE 2. *Relationship of air-filled pore contents to pore diameter and moisture tension in three representative soils for thirteen dates in the period August 1968-April 1969.*

TABLE 2. *Organic Matter and Physical Parameters for the 5-10cm depth of a Peaty Gley Podzol (see Fig. 2)*

Organic Carbon*	8.33
Total Nitrogen*	0.20
C/N ratio	42.3
Bulk density (g/cc)	0.70
Total porosity*	69.7
Shrinkage*†	29.9
Specific gravity	2.32
WC of pores 120μ diam.*	60.8
WC of pores 60μ diam.*	58.5
WC of pores 30μ diam.*	55.8
APC of pores 120μ diam.*	8.8
APC of pores 60μ diam.*	11.1
APC of pores 30μ diam.*	14.1
Soil depth (cm)	34.0
Litter depth (cm)	0.2

WC = water content
APC = air-filled pore content
* = % of soil volume
† = saturation to oven-dry

tribution of air-filled pore contents between the three sites for 13 sampling dates. There are considerable discrepancies between the actual air-filled pore contents and the soil moisture tensions. The loose peaty gley podzol is usually wetter and therefore under lower tension than the firmer humic gley podzol in the 5-10cm depth, whilst the very firm humic gley podzol is wetter than the gley podzol under forest. Where the air-filled pore contents of all three soils are similar (for example on 22 October 1968, air-filled pore contents of all soils were high, between 20.4 and 21.6 percent) the tensions at which soil water is held varies greatly. In the peaty gley podzol soil moisture tension was 250cm, in the humic gley podzol 600cm and in the gley podzol as high as 1.7 bar (1700cm). The minimum diameters of air-filled pores on this occasion, the driest encountered during the nine month sampling period, were about 2μ in the gley podzol, 6μ in the humic gley podzol and 11.5μ in the peaty gley podzol. Considering that the summer of 1968-69 in the Wellington district was warmer and drier than in most recent years (Mr J. Finkelstein pers. comm.) it seems that even the driest steady-state soils in this area are rarely subject to moisture tensions greater than 1 bar, where the minimum diameter of air-filled is 3.0μ. Likewise, the post steady-state soils are rarely under tensions greater than 600cm with a minimum air-filled pore diameter of about 6.0μ.

During January 1969 when sampling was most intensive the peaty gley podzol, which occupies a topographic depression, was saturated on each sampling occasion. The distribution of air-filled pore contents at the successive sampling occasions was very similar to the other two soils except that the humic gley podzol was consistently drier in the 5-10cm depth.

After overnight rain of 22mm between the 22 and 23 January, the gley podzol and humic gley podzol were sampled twice, 24 hours apart, to assess changes in the amount of air-filled pores between a forest ridge crest site and a herbaceous upper north-facing slope site respectively. At 0800, after the overnight rain, the 30cm deep humic gley podzol had an air-filled pore content of about 1 percent at 5-10cm depth. The much shallower gley podzol was saturated. However, 24 hours later, the humic gley podzol had become saturated whilst the gley podzol had drained to the extent that soil water was under a tension of approximately 1 bar and the air-filled pore content was almost 9 percent of the soil volume.

Variation in Soil Water and Air-filled Pore Contents in Three Soil Sequences of Soils on the one Sampling Occasion

The field soil water content and air-filled pore content data have been arranged in the same order as the stands in the vegetation structural change sequences (Park 1971) in conjunction with the water contents and air-filled pore contents at known tensions (Fig. 3). The sequences facilitated an understanding of the control of the major environmental factors; direction of slope, angle of slope, prevailing NW wind intensity and soil depth on the vegetation/soil system. Sequences were arranged as follows:—

Sequence 1: Direction of slope, angle of slope and prevailing NW wind intensity all constant. Soil depth varying.
Sequence 2: Direction of slope constant. Other three factors varying.
Sequence 3: All major environmental factors varying.

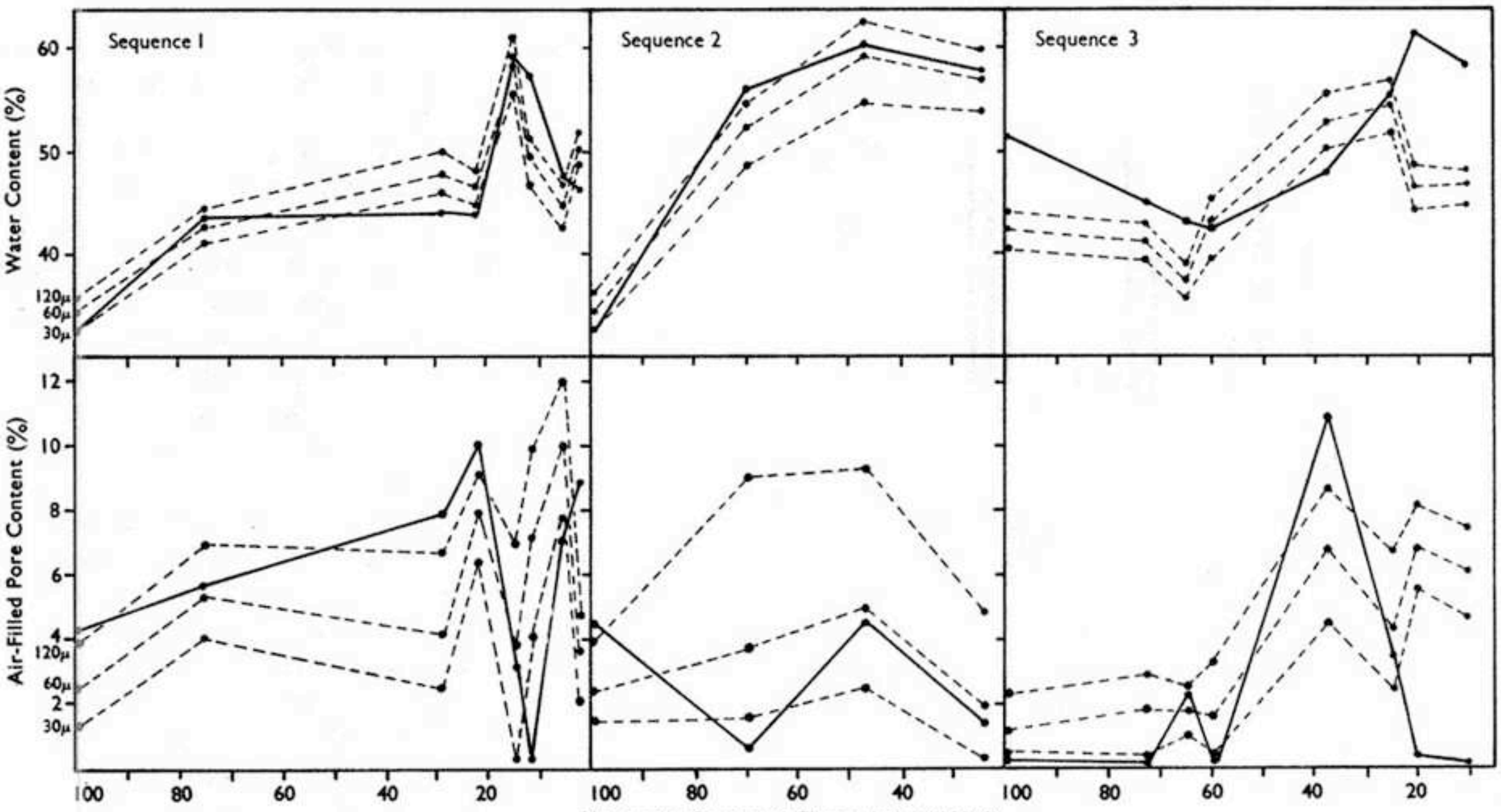

FIGURE 3. *Relationships between field water content (solid lines above) and field air-filled pore content (solid lines below) and known water and air contents (broken lines) at low tensions for three sequences of soils.*

The decreasing quantities along the horizontal axis (Vegetation Structural Change Index) represent the relative proportions of the vegetation space of the steady-state forest remaining in the successive post steady-state stands sampled.

The day of sampling was a 'field capacity day' (Stewart and Adams 1968).

Sequence 1.

The control over topographic position and, to a certain extent, soil depth which are features of this sequence are reflected in a generally close correspondence between field water and air-filled pore contents and contents at defined tensions on a field capacity day. Correspondence is closest in soils nearer the steady state. In most soils in the sequence water contents were at or above field capacity. The minimal diameter of pores cleared of water was about 30μ in steady-state soils, but greater than 60μ in the considerably wetter shrub/fernland and fern/sedgeland soils.

Sequence 2.

Soil water was held at approximately the same tension throughout the sequence, thus the field water and air-filled pore contents varied considerably. The driest soil was the steady-state gley podzol under close-canopied forest which was at field capacity. The three post steady-state soils were all at tensions less than 50cm of water so that the minimum diameter of the air-filled pores was only 60μ.

Sequence 3.

Steady-state soils contained less water on the field capacity day of sampling than post steady-state soils. The wettest soil was under forest in which loss of canopy foliage had just commenced. The characteristically low content of air-filled pores in the post steady-state soils was accentuated by their relatively high water contents. In fact, most soils were at saturation.

DISCUSSION

Observations confirmed the original field premise that overall the soils are very wet throughout the year. Except for the gley podzol under forest, the soils investigated were either saturated or under very low tension during the summer months, rarely draining pores less than 30μ diameter. Soil æration appears to be of significance to plant growth and the vegetation pattern. Correlation of field air-filled pore contents with plant growth is very difficult (Gradwell 1965) as the roots of a single plant, particularly of trees, spread through a considerable vertical and horizontal space in which the air-filled pore content of a soil varies. Of numerous references to the relation between plant growth and soil æration it is perhaps most relevant to quote Gradwell's (1965) work on the Taita clay loam, a moderately weathered and strongly leached yellow-brown earth with some pedogenetic affinities with the soils in this study (Gibbs 1959). Gradwell demonstrated reduced growth of perennial ryegrass (*Lolium perenne*) with increased bulk density if high bulk density (1.10 to 1.25g/cc) was accompanied by low æration. The critical levels of plant growth obtained were considerably lower than levels obtained for plant growth by overseas workers (Grable and Siemer 1968; Kohnke 1968). On the basis of air-filled pore contents computed from bulk density data, Gradwell found that the critical air-filled pore content below which reduced growth occurs is between 4 and 6 percent of soil volume. On the basis of core samples the overall critical level is 7-8 percent; in a firm soil, plant growth requires at least a 6 percent air-filled pore content but in loose very wet soils as little as 1-2 percent may be adequate for plant growth. In the soils discussed in this paper reduced growth in the local plant species by restricted oxygen diffusion is likely at similar air-filled pore contents to those prevailing in the soils sampled by Gradwell. The large rainfall, and the homogeneous texture and shallow profiles of the Maymorn Ridge soils would suggest that some oxygen is undoubtedly available in solution during the frequent periods of saturation or low moisture tension.

The three soils sampled over the nine month period were representative of the range of soils in the Maymorn Ridge area. Except for short periods in summer the air-filled pore contents of these soils were rarely as great as 20 percent of soil volume. On most sampling occasions in fact, the air-filled pores occupied the 0-12 percent range of soil volume where oxygen diffusion and plant growth would be very low. Monthly observations of the soils during the winter months of 1968 and 1969 suggested that all soils were saturated or at very low moisture tension.

In most post steady-state soils, water contents increase to such an extent as to restrict soil æration. Consequently the proportion of air-filled pores dces not show a consistent relationship to pore diameter in a range of stands. The effect of a greater proportion of large pores in the wetter and more organic soils, for example the peaty gley podzol (Fig. 2), is counterbalanced by their near-continuous states of saturation. In this sense the influence of soil water on reducing the amount of available pores is similar to the situation observed by Sheikh and Rutter (1969) in wet heathland soils. They found that even in summer the air-filled pore content of wet organic soils was usually less than the volume of potentially root containing pores.

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