# PROCEEDINGS OF THE
# NORTH OF ENGLAND
# SOILS DISCUSSION GROUP

Number 14

Meeting at Reaseheath Cheshire 1977

## SOIL PROBLEMS OF THE CHESHIRE PLAIN

# NORTH OF ENGLAND SOILS DISCUSSION GROUP

## 1977-78

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Institute of Terrestrial Ecology
Bangor.

Hon. Secretary/Treasurer:-

P.J.A. HOWARD
Institute of Terrestrial Ecology
Merlewood Research Station
Grange-over-Sands
Cumbria LA11 6JU

Hon. Editor:-

M.J. ALEXANDER
Department of Geography
Durham University
South Road
Durham City DH1 3LE

Committee:-

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Soil Survey of England & Wales
Bishop Burton.

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Soil Survey of England and Wales
Harrogate.

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ADAS
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The Discussion Group holds an Annual Meeting in September, this includes a field excursion and a paper reading session with discussions. Each meeting is devoted to a specific topic which largely determines the locality to be visited. This meeting is reported in the Proceedings of the Group.

Members of the Group receive the Proceedings free of charge. Application for membership should be addressed to the Hon. Secretary/ Treasurer. Annual Subscription £1.50.

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## FARMING IN CHESHIRE

by

A. Finn

(Divisional Agricultural Officer)

Cheshire is principally a county of family farms. It is regarded as one of the finest counties for dairying, as local expertise in dairy husbandry and grassland management has been passed down over many generations. We have about 5,000 viable agricultural holdings totalling 170,000 ha. More than 11,800 people are employed in agriculture and of these 5,500 have some direct involvement in a farming business. Farm sale prices and rents are relatively high but with good husbandry our productivity is high too. Cheshire is a county of intensive farming and intensive industrial endeavour. 343 parishes averaging only 500 ha. each.

The land is mostly attractive pasture with tidy, hedge-bordered lanes and with sufficient trees and woodland to please the eye. The farming north of the River Mersey, which came into Cheshire with local Government re-organisation, includes some of the best agricultural land in the country. Vegetable growing is particularly important on some of these "moss" soils north of the Mersey.

Cheshire is part of the most important dairying area in Britain and there is strong emphasis on milk production. The county carries 141,000 dairy cows, mostly in herds of about 80-100, while beef cows only amount to about 1,000 head. Cheshire's 2,242 registered milk producers sell over 636 million litres of milk each year - this is the equivalent of nearly 2.2 million litres of milk each day.

The most common and popular breed of cattle is the black and white British Friesian which is ideally suited to Cheshire's heavier soils and quick growing pastures. The Canadian Holstein Friesian is also becoming popular in the county and several herds have been established by farmers who lost their British strain in the foot-and-mouth epidemic of 1967/68. There are also a few specialised herds of Ayrshire and Channel Island breeds. As Cheshire farming depends largely on grassland farming, grass is treated as a crop. Cheshire farmers have achieved impressive stocking rates, with one cow to the acre on many farms.

A wide variety of grassland management techniques are practiced. Most of them are intensive and we have some farms that have been 'zero grazing' grassland for over 10 years. A recent more interesting grazing system is called 'set stocking' in which the cows graze one set area for the whole summer. In winter much of the rationing is based on self feed or easy feed silage.

Grass conserved as silage plays a very important part in winter feeding. On many farms grass is providing enough food for maintenance and about a quarter of the milk production over the year. Cow health and milk quality still justify the feeding of some hay and some excellent barn dried hay is produced on a few farms. Two North Cheshire farmers produce grass for artificial drying on a large scale and the end product is sold as a concentrate feed for dairy cows.

Over 80% of the land area of Cheshire is down to grass over half of which is permanent pasture. Most leys are sown with a mixture of grasses but not usually clover. Intensive management has encouraged the sowing of single species of ryegrass leys and the use of mineral fertiliser is

relatively heavy.

There is a wide contrast in the types of farm buildings in the county, most of the old buildings are sound and can be adapted for modern farming. In the last 6 years about 30% of the holdings have taken advantage of the Farm Capital Grant Scheme.

Most commonly seen new buildings on farms are cubicle houses for cows and bunker silos. Cow cubicles are usually large low buildings with cow cubicles on each side of a central passage for feeding. Sometimes these buildings are linked to ground silos to facilitate winter feeding. Many bunker silos have the walls made of railway sleepers. In winter the silage is vertically "grazed" by cows eating their way into the silage with the rate of consumption controlled by an electric fence.

Tower silos are an increasingly common feature of the Cheshire landscape but are not yet generally accepted as the main system for silage. Although more efficient than bunkers they are costly and require expensive machinery to operate. There has been substantial capital investment in sophisticated feeding and slurry disposal systems - but the most recent advance has been in modern milking parlours and dairy equipment. The choice of milking system varies according to the size of the herd. Nearly 60% of the herds are still housed in cowsheds but the herringbone (and abreast parlour) system are steadily gaining in popularity. Several farms have introduced the new rotary type milking parlour. Only about 200 farms still send away milk in churns. Milk is now usually taken from the cow direct into refrigerated tanks to await daily collection by bulk milk tanker. The milking machine is now taken off the cow automatically (ACRs). Although most of the Cheshire Cheese is now made in creameries there are still 12 farms producing farmhouse cheese.

There are about 115,000 pigs in Cheshire but few farms specialise solely in pig production. There are a few large pig breeding and pedigree herds but generally pigs are part of a mixed enterprise farm. The quality of bacon produced on Cheshire farms is very high.

The county is reported to have 39,000 breeding ewes and a total sheep population of about 81,000. Although the numbers have increased slightly in recent years, I must confess in going about the county one rarely sees sheep. Many advisers feel that Cheshire pastures would carry more clover and require less nitrogen if the sheep population was to increase.

Cheshire farming has been described as 'black and white on green' - in other words Friesian cows grazing green grass. It comes as a surprise to most Cheshire folk when told that only about 52% of our holdings do in fact produce milk. We have in Cheshire some heavy soils and most of these are in milk production but we also have some very light soils scattered throughout the county. There is a considerable amount of boulder clay which gives some pretty heavy land which due to its flatness is very difficult to cultivate. It is best drained and left in grass. The light land is under intensive arable or horticultural production. It is interesting to note that the area under total horticultural crops increased by about 4% last year. We have 28 ha. under glass most of which is heated for crops like tomatoes and chrysanthemums. There is also nearly 2 ha. of land under plastic structures. Forage Maize is a new crop for winter feeding livestock and grows well on the lightest soils.

The vast majority of the cereal hectarage is barley but in a favourable autumn the wheat hectarage sown increases considerably. Potatoes are a very important crop in parts of the north of the county; over 4,000 ha. of potatoes are grown of which 1,000 ha. are earlies. Early potatoes are an important feature of farming on the lightest soils, particularly in the Frodsham and Kelsall areas. In recent years there has been a considerable

TABLE 1

## COMPARISONS OF FINAL AGRICULTURAL RETURNS (hectares or numbers)

| | 1975 | CHESHIRE 1976 | % Change |
|---|---|---|---|
| Wheat | 2566 | 3343 | + 30.3% |
| Barley | 25461 | 24231 | - 4.8% |
| Oats | 1535 | 1340 | - 12.7% |
| Mixed Corn | 855 | 445 | - 48 % |
| Total Cereal | 30440 | 29377 | - 3.5% |
| Maize for silage | 320 | 380 | + 18.8% |
| E. Potatoes | 965 | 1078 | + 11.7% |
| M.C. Potatoes | 2913 | 3235 | + 11.1% |
| Total Potatoes | 3879 | 4313 | + 11.2% |
| Oil Seed rape | 7 | 26 | +271.4% |
| Sugar Beet (not S. feed) | 30 | 31 | + 3.7% |
| Beans (for S. feed) | 56 | 46 | - 17.9% |
| Turnips, swedes and fodder beet (for S. feed) | 417 | 387 | - 7.2% |
| Mangolds | 49 | 49 | - |
| Kale (for S. feed) | 560 | 546 | - 2.5% |
| Small fruit (not under orch. trees) | 183 | 197 | + 7.7% |
| Hardy nursery stock | 250 | 256 | + 2.4% |
| Area under glasshouses | 26 | 26 | - |
| Total horticulture | 1498 | 1557 | + 3.9% |
| Bare fallow | 378 | 435 | + 15.1% |
| Tillage | 38127 | 37503 | - 1.6% |
| Clover, sainfoin etc. | 33942 | 34751 | + 2.4% |
| Total arable land | 72137 | 72539 | + 0.6% |
| P. Grass | 91536 | 91606 | + 0.1% |
| Total of crops and grass | 163665 | 163965 | + 0.2% |
| Rough grazings | 7698 | 7152 | - 7.1% |
| Total area | 174494 | 174117 | - 0.2% |
| Total Dairy herd | 140428 | 141370 | + 0.7% |
| Total Beef herd | 11440 | 9913 | - 13.3% |
| Total all other cattle and calves | 124465 | 117657 | - 5.5% |
| Total cattle and calves | 299823 | 293499 | - 2.1% |
| Total breeding pig herds | 10476 | 11642 | + 11.1% |
| Total pigs | 110146 | 115883 | + 5.2% |
| Total breeding ewes | 38703 | 38837 | + 0.3% |
| Total sheep and lambs | 80761 | 81384 | + 0.8% |
| Total poultry | 2342785 | 2381139 | + 1.6% |
| Male workers | 4853 | 4398 | + 0.9% |
| Female workers | 1504 | 1427 | - 5.1% |
| Total workers | 6357 | 6325 | - 0.5% |
| Total farmers, managers and workers | 11612 | 11794 | + 1.6% |

(Source ADAS Cheshire/Staffordshire)

hectarage of record potatoes grown under contract for the crisping trade in Manchester. This area has declined this season with a greater proportion of early varieties grown.

## CLIMATE AND GEOGRAPHY

Much of the county is under 121 m contour and some under 60 m. To the east beyond Macclesfield we have what might be described as an upland area rising to something over 305 m. As you will expect this range of elevation has an effect on the rainfall. Across the plain the rainfall on a ten year average is about 750mm but it does rise in excess of 1,000 mm beyond Macclesfield in the east. Some of the driest parts of the country are around Chester in the west and in the Wirral. Here the rainfall is frequently well below 762 mm annually. This rainfall is well spread throughout the summer months e.g. since May to date (September) most of Cheshire has had 152 mm rainfall. This encourages relatively high humidity and ideal conditions for growing grass. The problem is to utilise this grass efficiently and economically.

Soil temperatures in excess of $5.5^{o}C$ allows a growing season from about late March until mid or late November i.e. a growing season of about 240 days.

## FARM STRUCTURE

The distribution of the four main farming types found in Cheshire as shown in Figure 1. The area to the west, south and north east is mainly dairying, towards mid-Cheshire there is an increase in arable though dairying remains very important. To the east we have upland farming beyond Macclesfield and the new part of Cheshire in the North could be described as arable farming with some horticulture and there are three other areas so marked.
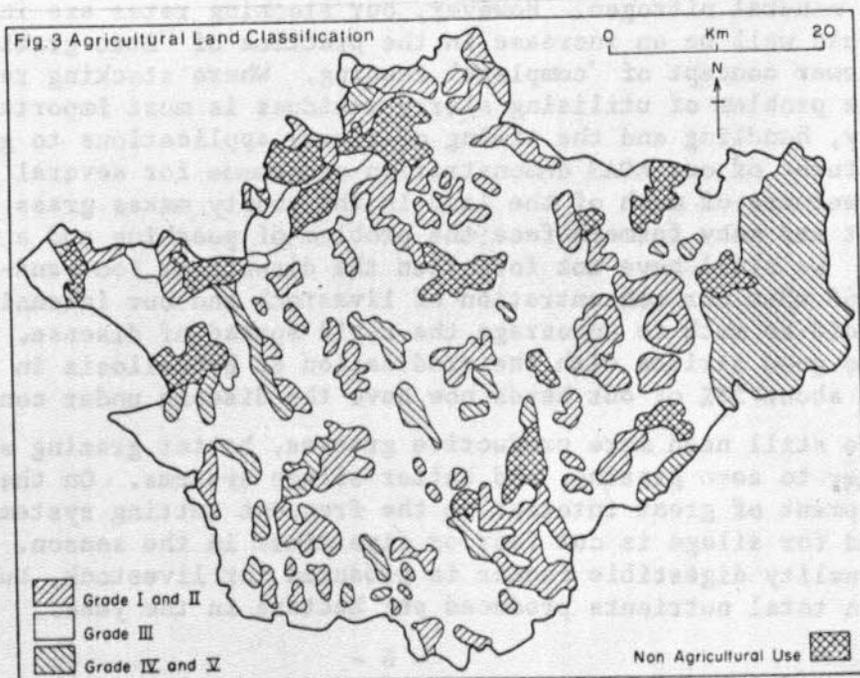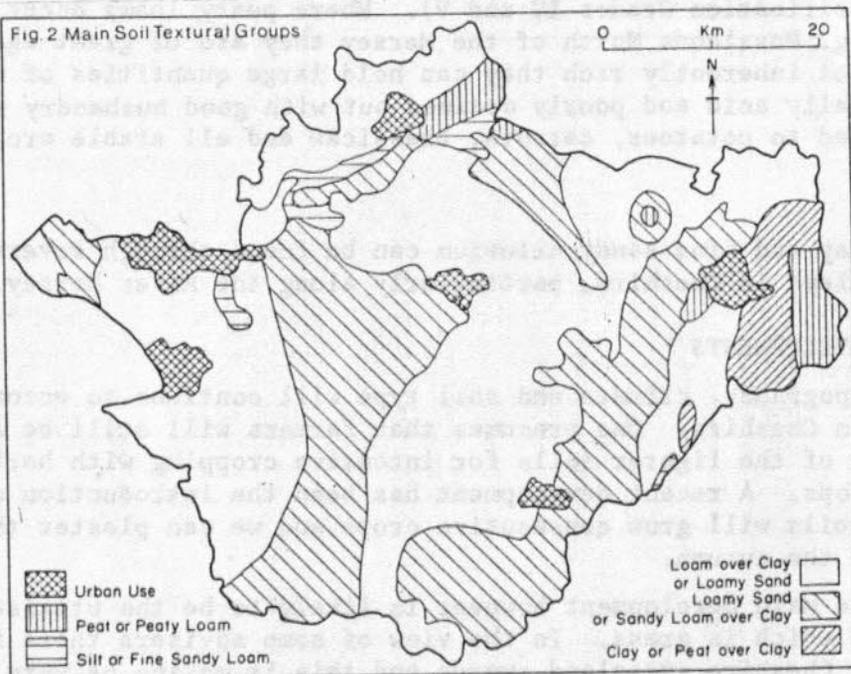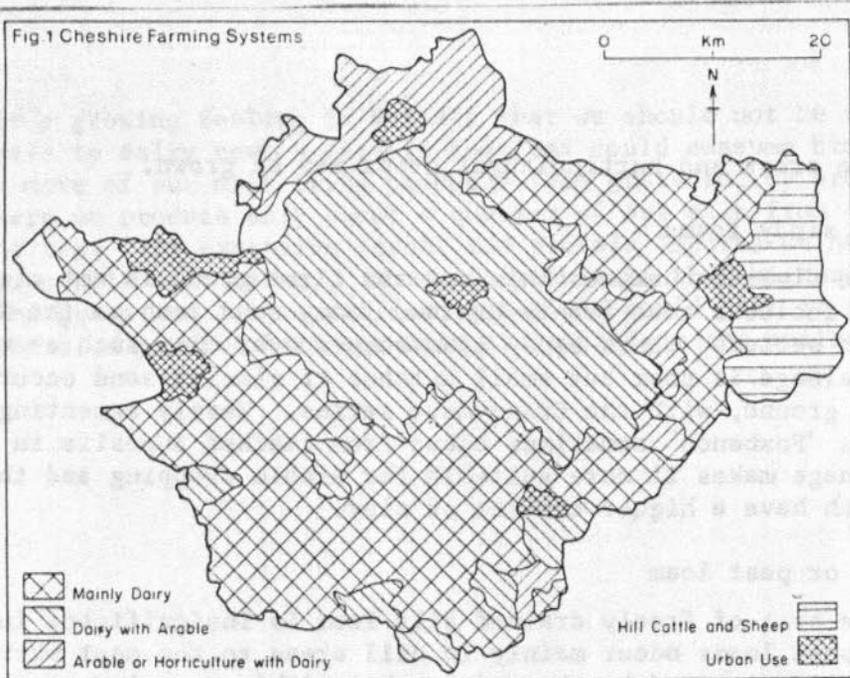
If one divides the number of dairy herds into size categories 65% of the herds are still under 80 cows. Nonetheless there are some very large herds. In 1965 there was one herd of over 150 cows, 10 years later that number has increased to 70 herds and we now have 30 herds of over 200 cows.

## SOILS OF CHESHIRE

The Cheshire Plain is surrounded by 3 hill areas. To the West the Welsh hills consist mainly of Ordovician and Silurian rocks and these extend into parts of Shropshire and Herefordshire. To the North East the Pennines are wholly composed of Carboniferous grits, shales and limestones. This area merges into the North Staffordshire hills consisting of the Coal measures and Triassic sandstone. The soils in Cheshire are characterised by the considerable variation within a small area. The Cheshire Plain, a lowland area of about 3,108 sq.km., is floored by Keuper and Upper Coal Measure Marls and by soft sandstones of the Bunter formation. However, almost everywhere these formations are masked by a thick mantle of glacial drift. Sands and gravel can also be found overlying the boulder clay in glacial outwash deposits. Where this occurs horticultural crops and in particular soft fruit for the "Pick-your-own" market has occurred. From an agricultural standpoint we can divide the soils of Cheshire on a textural basis. (The textural variation of soils on Cheshire is shown in Figure 2, and the agricultural land classification of the county is shown in Figure 3).:-

### Loamy and loamy sands

In mid and west Cheshire soils are mainly loamy in texture. Where these occur over clay subsoil, such as with the Salop or Cottam series drainage is poor and grass is the predominant crop. Where loamy sand occurs such as with the Newport series derived from middle sands, drainage is good

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Fig.1 Cheshire Farming Systems

0    Km    20

N

Mainly Dairy

Dairy with Arable

Arable or Horticulture with Dairy

Hill Cattle and Sheep

Urban Use

Fig. 2 Main Soil Textural Groups

0    Km    20

N

Urban Use

Peat or Peaty Loam

Silt or Fine Sandy Loam

Loam over Clay
or Loamy Sand

Loamy Sand
or Sandy Loam over Clay

Clay or Peat over Clay

Fig. 3 Agricultural Land Classification

0    Km    20

N

Grade I and II

Grade III

Grade IV and V

Non Agricultural Use

and arable crops and horticultural crops may be grown.

## Sands and sandy loams

The division between this and the first group is not clearly defined. This area includes some freely drained loamy sand such as the Newport and Bridgnorth series. Where sandy loam occurs over clay such as with the Wem series drainage is poor but small patches of glacial sand occur, particularly on rising ground, with the Crannymore series. Weakly cementing pans known locally as 'Foxbench' sometimes occur from leached deposits in these sands. Good drainage makes it more suitable for arable cropping and the surrounding areas which have a higher content of clay.

## Silt clay or peat loam

The area of freely drained silt loam is insignificant in Cheshire. Clay and peat loams occur mainly in hill areas to the east where the method of farming is dictated by the topography. (This area is mainly agricultural land classification Grades IV and V). Where peaty loams occur on lower ground e.g. Mosslands North of the Mersey they are of great agricultural value. Not inherently rich they can hold large quantities of nutrients. They are naturally acid and poorly drained but with good husbandry form valuable land suited to potatoes, carrots, brassicae and all arable crops.

## Alluvium

Clay and fine sandy alluvium can be found through several of the river valleys in Cheshire, particularly along the River Mersey.

## FUTURE DEVELOPMENTS

Topography, climate and soil type will continue to encourage dairy farming in Cheshire. One presumes that farmers will still be able to take advantage of the lighter soils for intensive cropping with horticulture and arable crops. A recent development has been the introduction of forage maize. Lighter soils will grow consecutive crops and we can plaster the soils with slurry in the autumn.

The main development however is likely to be the utilisation of our main crop which is grass. In the view of some advisers there is insufficient clover in Cheshire grassland swards and this is making us very dependent on imported mineral nitrogen. However, our stocking rates are intensive and there could well be an increase in the practice of 'Zero grazing', encouraged by the newer concept of 'complete' feeding. Where stocking rates are so heavy the problem of utilising slurry residues is most important. Storage of slurry, handling and the timing of slurry applications to grassland have been features of our ADAS demonstration programme for several years. The general wetness of much of the land in the county makes grass utilisation difficult and many farmers face the problem of poaching and a long winter of feeding. We still have not forgotten the disastrous Foot-and-Mouth outbreak of 1967/68 when our concentration of livestock and our intensive stocking systems did so much to encourage the rapid spread of disease. Recently we have made good strides with the eradication of Brucellosis in the county herd and about 58% of our herds now have the disease under control or eradicated.

We still need more productive grasses, better grazing systems, probably going over to zero grazing, and better silage systems. On the latter point a development of great interest is the frequent cutting system where grassland earmarked for silage is cut four or five times in the season. In this way higher quality digestible fodder is produced for livestock, but there could be a drop in total nutrients produced per hectare in the year.

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There is a growing feeling in Britain that we should not be feeding expensive cereals to dairy cows - cereals that man could consume himself. I foresee much more of our milk being produced from grass and by products. In Cheshire where we produce only about a quarter of our milk from our grass and most of the rest from expensive cereal and protein imports we have a long way to go towards self sufficiency. Some of us believe that higher yielding forage crops and grass and better utilised grassland could make it possible in the next few years to produce half our milk at least from the soils of Cheshire.

AN INTRODUCTION TO THE PHYSICAL BACKGROUND AND SOILS OF CHESHIRE

by

R.R. Furness

(Soil Survey of England and Wales, Bishop Barton)

INTRODUCTION

Cheshire, a county extending from the Welsh Borderlands to the Peak District Pennines and into the outer suburbs of Manchester and Liverpool, is often looked upon as one of the more desirable parts of north-west England. Although the image is of leafy countryside, dairy cattle and pleasant market towns it is also an industrial county containing important sections of the engineering, chemical and textile industries.

The county, drained by the river Dee in the west and by the Weaver and its tributaries which flow into the Mersey estuary, is divided into 4 physical regions (see Figure 1). These are the Pennines, the Plain, the Mid-Cheshire Ridge and the Wirral Peninsula. In each of these, geology, climate and relief differ in relative importance, resulting in different soil and vegetation patterns.

GEOLOGICAL BACKGROUND AND SOIL PARENT MATERIALS

Much of Cheshire lies within a broad north-east to south-west trending basin of Permian and Triassic rocks extending from Lancashire to Shropshire. Older Carboniferous rocks occur at great depth beneath the Triassic strata, but are exposed only in the Pennines east of the Red Rock Fault where the Millstone Grit series forms the folded western limb of the Pennine anticline. Solid strata are rarely seen on the plain, most of which is covered by thick Pleistocene and Recent deposits. Extensive outcrops of the underlying red Triassic rocks occur only on the Mid-Cheshire Ridge (Fig. 2). Elsewhere, exposures of solid rock are restricted to isolated low hills where red sandstone or Keuper Marl protrude through the surrounding glacial deposits, and to occasional stream sections. Although the soils of the plain are thus almost entirely formed in drift, the predominant reddish colour suggests that much of the finer material is locally derived.

During the Pleistocene age, Cheshire was covered by ice sheets and a complex series of tills and glaciofluvial sands was laid down to give the subdivision shown in Table 1. The idea of two distinct glaciations, represented by a lower and upper boulder clay separated by the Middle Sands and succeeded by a further period of sand deposition, is now thought to be an over-simplification. Evans and Arthurton, quoted by Mitchell et al (1973) suggest that almost the whole succession, including some of the Middle Sands and Lower Boulder Clay, belongs to the late Devensian glaciation. This sequence, termed the Stockport Formation by Worsley (1967), is summarized in Table 1. The succession is difficult to follow as lenses of till often occur within the Middle Sands. Where these locally form the top of the sequence they can easily be mistaken for the Upper Boulder Clay. Similarly sand lenses occur within the till in many places.

Although the succession is one of the present problems of Pleistocene stratigraphy, the geological age of the sands and clays has no direct bearing on soil formation. As soil parent materials, the glacial deposits can be grouped and described under the broad headings of tills, Head deposits and glaciofluvial sands (Fig. 2). River terraces, although strictly a separate deposit, merge with many of the late glacial and post-glacial sands. They form a similar parent material to the glaciofluvial sands and so are grouped with them.
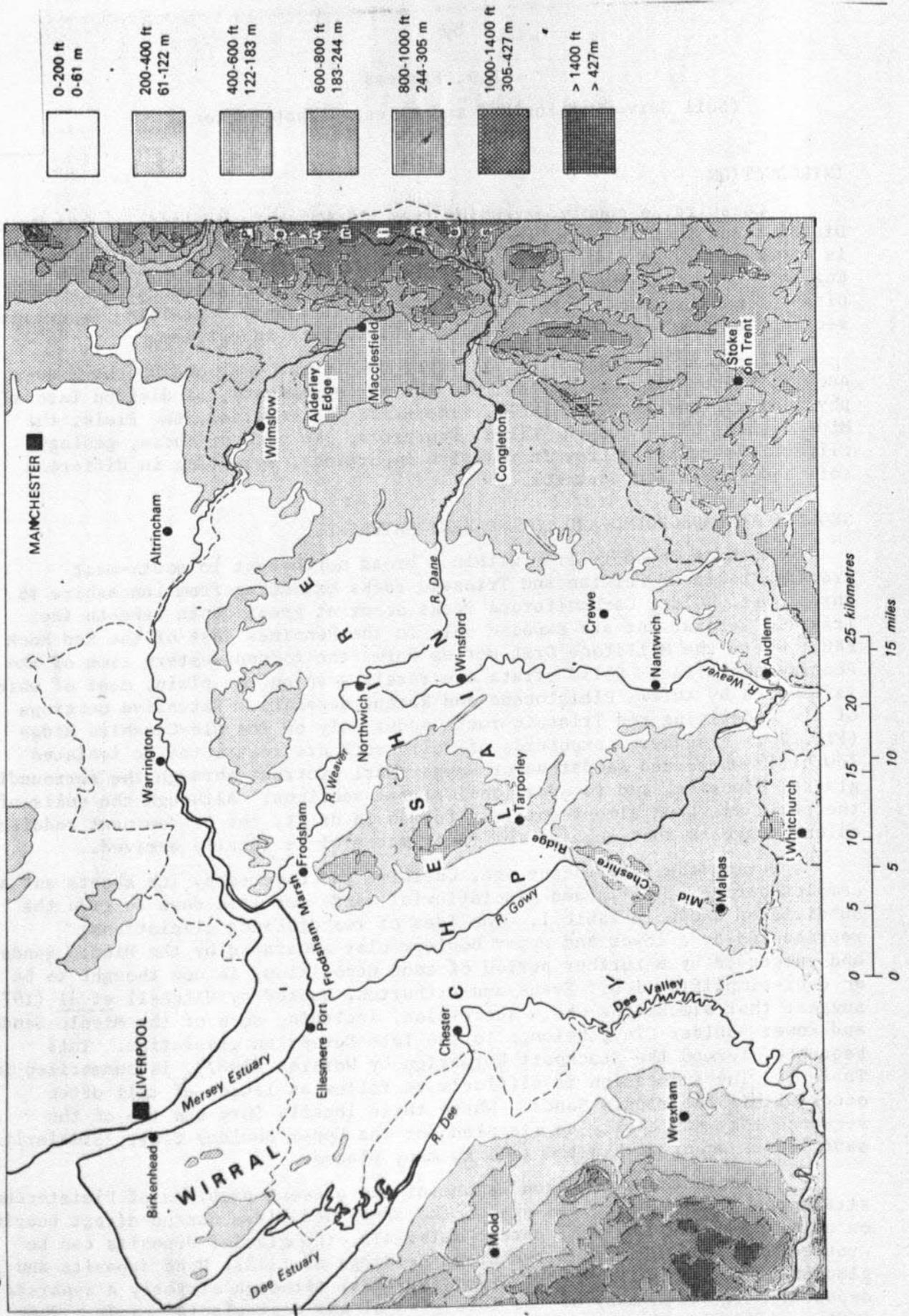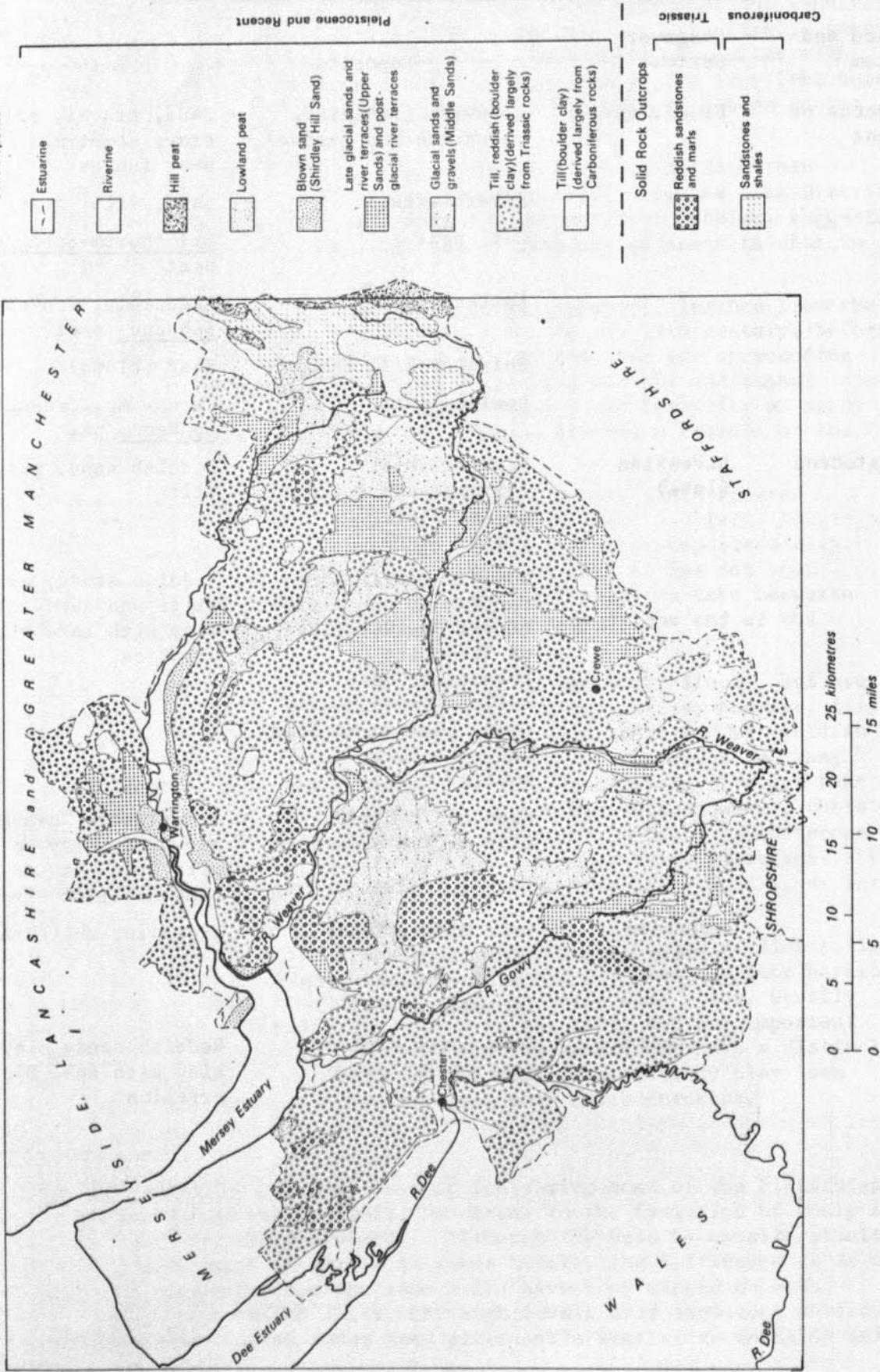
# Fig.1 PHYSICAL REGIONS OF CHESHIRE



Legend:
- 0-200 ft / 0-61 m
- 200-400 ft / 61-122 m
- 400-600 ft / 122-183 m
- 600-800 ft / 183-244 m
- 800-1000 ft / 244-305 m
- 1000-1400 ft / 305-427 m
- > 1400 ft / > 427m

MANCHESTER
LIVERPOOL

Birkenhead
WIRRAL
Dee Estuary
Mersey Estuary
Ellesmere Port
Frodsham Marsh
Frodsham
Warrington
Altrincham
Wilmslow
Alderley Edge
Macclesfield

Mold
R. Dee
Chester
Dee Valley
Wrexham

R. Gowy
Cheshire Ridge
Mid.
Malpas
Whitchurch

C H E S H I R E    P L A I N

R. Weaver
Tarporley
Northwich
Winsford
R. Dane
Congleton
Stoke on Trent

R. Weaver
Crewe
Nantwich
Audlem

0   5   10   15   20   25 kilometres
0   5   10   15 miles

# Fig. 2 THE GEOLOGY OF CHESHIRE

**Drift Deposits**

Pleistocene and Recent

| | |
|---|---|
| \ | Estuarine |
| | Riverine |
| ▧ | Hill peat |
| | Lowland peat |
| | Blown sand (Shirdley Hill Sand) |
| | Late glacial sands and river terraces (Upper Sands) and post-glacial river terraces |
| | Glacial sands and gravels (Middle Sands) |
| | Till, reddish (boulder clay) (derived largely from Triassic rocks) |
| | Till (boulder clay) (derived largely from Carboniferous rocks) |

**Solid Rock Outcrops**

Carboniferous    Triassic

| | |
|---|---|
| ▨ | Reddish sandstones and marls |
| | Sandstones and shales |

MERSEYSIDE

LANCASHIRE and GREATER MANCHESTER

Mersey Estuary

Dee Estuary

R. Dee

R. Gowy

Weaver

Warrington

Chester

Crewe

WALES

SHROPSHIRE

STAFFORDSHIRE

R. Weaver

R. Dee

0    5    10    15    20    25 kilometres

0    5    10    15 miles

## TABLE 1

### GEOLOGICAL SUCCESSION OF THE DRIFT DEPOSITS

| Period and System | Stage or Series | Deposits | Lithology |
|---|---|---|---|
| Holocene or Recent | Flandrian | Alluvium (riverine, estuarine and marine) | Sand, gravel, silt and clay, sometimes with peat lenses |
| | | River terrace | Sand, silt, gravel |
| | | Hill peat | *Eriophorum*-*Sphagnum* peat |
| | | Lowland peat | Reedswamp, fen-carr and *Sphagnum* peat |
| | | Shirdley Hill Sand | Sand (blown) |
| | | Lowland peat | Reedswamp, fen-carr and *Sphagnum* peat |
| Pleistocene | Devensian (late) | Fluvioglacial terraces and deltas of the plain (Upper Sand) | Reddish sand, gravel and silt |
| | | Boulder clay/sand complex of the plain (Upper Boulder Clay or Stockport Formation, but includes some Middle Sands (Gawsworth Sand) and some Lower Boulder Clay) | Reddish sands, gravels, silts and sandy clay to clay with Lake District erratics |
| | | Head and Boulder Clay of the Pennines | Brown sands, gravels and sandy clay to clay with Pennines and Lake District erratics |
| | Devensian (middle and early) | Some Middle Sands, (Congleton and Chelford Sands with included peats) | Brown and white sand |
| | Wolstonian | Some Lower Boulder Clay of the plain | Reddish sandy clay to clay with Lake District erratics |

# 1) Tills

Tills and associated glaciolacustrine clays are one of the most important soil-forming materials in Cheshire. Much of the plain is formed entirely on them and they also extend on to the lower slopes of the Pennines. On the plain they are a reddish brown clay, clay loam or, more rarely, sandy clay loam derived largely from the underlying Keuper Marl, but often with beds and lenses of yellow and red sand. The thickness varies from less than 1 m where it feathers out on to the Mid-Cheshire Ridge to 72 m near Hooton in the Wirral.

Erratics are common, and in places abundant enough to form thin stony horizons in the till. The stones are nearly all from the Lake District and southern Scotland, but there are also occasional flint pebbles, suggesting the presence of chalk in the Irish Sea basin, probably adjacent to that in Northern Ireland.

Soft concentrations of secondary calcium carbonate, leached from the horizons above, are common at a depth of 1-2 m. In the 19th century, before cheap lime was available this was dug out and spread over the surrounding fields to reduce acidity. This practice of marling had the additional benefit of increasing the moisture-holding capacity and fertility of sandy soils. The resulting marl pits with their ponds are now a feature of the Cheshire landscape.

In some parts of the county, particularly in the south between Middlewich, Crewe and Audlem, and east of the Dee, there are large tracts of reddish brown sometimes finely laminated, obviously water-deposited clay. The physical properties of this material indicate that it has not been compressed by ice, suggesting that it is connected with the Lake Lapworth system which covered much of Lancashire and Cheshire at the end of the Pleistocene.

In the Pennines, till occurs generally on the lower slopes, but usually merges into Head at higher levels. In one or two localities, however, till continues to a height of over 300 m. Its age is uncertain and it could in part belong to an earlier glaciation. The greyish brown colour and many Carboniferous pebbles indicate that much is locally derived, although Lake District erratics also occur. At the foot of the Pennines, however, there is a transitional zone of interbedded till derived from both Carboniferous and Triassic rocks. It is difficult to separate these tills satisfactorily, since isolated pockets of reddish till occur well into the Pennines, as far east as the Glossop district.

The tills and glaciolacustrine clays of the plain give reddish soils which are mainly fine textured with a clay loam or sandy clay loam surface horizon over a clay or clay loam. Coarse loamy surface soils also occur, usually where there is a thin glaciofluvial wash over the till, but are important only locally. In the Pennines the Carboniferous sandstones have a distinct effect on the tills, which are stony and of clay loam or sandy clay loam texture. Clayey till is restricted to areas near shale outcrops.

# 2) Head Deposits

The high Pennines remained free of ice during most of the Pleistocene but were weathered severely by frost, resulting in the formation of shaly and, particularly, sandstone Head deposits. Although the Head is usually stonier than the till, into which it merges at lower levels, the difference as Jowett (1914) noted is not marked and the same soils have been mapped on both deposits. The only exception is at very high levels over sandstone outcrops where extremely stony coarse sandy Head gives soils similar to those on solid sandstone.

## 3) Glaciofluvial Sands and Terrace Deposits

The sands represent periods of glacial retreat during which water flowed from the melting ice sheets and deposited sand over the preceeding till. They occur at several levels in the succession and merge, at the top, into Recent river terrace deposits. Sand deposits are scattered across the plain, with large areas around Delamere Forest, to the southeast of Crewe and Nantwich, and in a broad eastern belt from Macclesfield southwards to the Staffordshire border near Alsager. As soil-forming materials glaciofluvial and terrace sands are second in importance to the tills.

The succession is extremely complex and although deposits such as the Gawsworth, Congleton and Chelford sands are distinct in their own districts, correlation across the county is uncertain. The Chelford Sand, a white deposit with a radiocarbon age, from included peat, of about 57000 years B.P. (Evans et al 1968), is considered to be the oldest and passes upwards into the brown Congleton Sand. Both deposits are important sources of industrial sand. The Gawsworth Sand is thought to be the same general age as the Middle Sands of Delamere Forest, which have been dated at about 28000 years B.P. (Boulton and Worsley 1965). The heavy mineralogy of the Congleton and Chelford Sands points to a derivation from the Millstone Grit. The sands also thin out westwards, away from the Pennines, suggesting that they are an outwash deposit laid down during periods of glacial melting. In the west and south many of the later sand deposits form terminal moraines. These are associated by Poole and Whiteman (1966) with the overflow channels through the Mid-Cheshire Ridge into the Lake Lapworth system which drained southwards into the river Severn.

The late glacial sands merge into river terrace sands which occur at various levels beside the Dee, Weaver, Dane, Bollin and Mersey rivers. The lithology of the deposits is similar to that of the glacial sands although pebbles and gravel lenses are more common.

The Shirdley Hill Sand is a windblown deposit formed by redistribution of the terrace sands around the Mersey and along the northern edge of the county. Glacial and terrace sands give easily worked, sandy or coarse loamy, but sometimes rather infertile soils. Although there is no consistent difference in soils formed on the various sand deposits there is a general relationship. Freely drained soils tend to be rather more common on the Middle Sands, mainly because this deposit commonly forms sloping or hummocky relief. Podzols and ground-water gley soils tend to be rather more common on the flatter late-glacial sands which are often thin and over till at a shallow depth, but again this is not a reliable guide. Terrace sands, however, are usually gleyed. Soils on the Shirdley Hill Sand are often podzolised and/or gleyed.

## 4) Alluvium

Riverine alluvium occurs on the floodplains of most streams and rivers and in some enclosed hollows where it is often associated with peat. In the lower reaches of the Dee and Mersey it passes into estuarine alluvium which has been sorted and deposited under tidal conditions and is often calcareous.

Riverine alluvium deposits, wide enough to affect the farming pattern, occur only on the larger rivers such as the Dane, Weaver, Bollin and Mersey. The material is sandy or coarse loamy on the river banks where there is often an indistinct levee, but becomes progressively finer away from the channel, with clayey and fine loamy sediments being deposited along the edges of the floodplain furthest from the river. Along smaller streams particle-size usually reflects that of the glacial deposits within their catchment. The alluvium

in enclosed hollows is usually clay or silty clay. The thickness varies considerably and on the Weaver, a fairly typical Cheshire river, ranges from 1.5 - 6.0 m. Riverbank exposures commonly show, 2.0 - 2.4 m of loamy sand or sandy loam, sometimes with faint laminations at depth, but this passes laterally into silty clay or clay with distance from the river. A feature of the Weaver exposures is the absence of stones and gravel seams, although a boring by the County Council near Nantwich showed peat and gravel at 3 m.

River alluvium is important as a soil-parent material in the Dee valley near Farndon and along parts of the Weaver and Dane valleys, but soils are mainly clayey or fine loamy and poorly drained, although some smaller patches of better drained sandy or coarse loamy soil occur along the river banks.

Estuarine alluvium occurs in the Dee estuary below Chester, most of which has been reclaimed for agriculture only within the last 150 years. A large tract of salt marsh still remains west of Burton Point. The reclaimed land extends up to the 7.6 m contour, represented by a low cliff line which was cut when the sea-level rose at the end of the Pleistocene. The alluvium, which is at least 15 m thick near Shotton Steelworks, consists of a pale brown calcareous fine sand with darker silty lenses and laminae. Small scattered patches of silty clay loam also occur and can form the topsoil above sand which had been deposited earlier.

In the Mersey estuary, Frodsham marshes form an extensive area transitional between true estuarine and river conditions. Some fine sandy sediments are similar to those in the Dee estuary while other deposits of clay and clay over peat have more in common with the deposits in the lower reaches of the river valleys.

5) Peat

Hill peat covers much of the Pennine plateau where it is an important soil-forming material. It is very uniform and consists mainly of the remains of cotton-grass (Eriophorum spp.) and Sphagnum moss which have accumulated under the cold wet conditions. The thickness averages 1.5 m over much of the plateau but reaches 3 m in depressions.

Lowland peat is scattered in hollows across the plain but is important only in the north around Warrington, where raised mosses also occur. Some hollows are glacial features such as kettle holes, while others may result from natural salt subsidence. The peats are of varying ages and pollen analyses suggest the presence of Zone I deposits onwards (Birks 1965), indicating that the oldest peats are of late Devensian (Late-Glacial) rather than Flandrian (Post-Glacial) age.

Raised mosses develop from basin peat deposits under the influence of excessive rainfall and consist almost entirely of Sphagnum and cotton-grass.

The lowland peats are important soil-forming materials only in the north, where they form valuable arable land when adequately drained.

CLIMATE

Climatic factors, particularly rainfall and temperature, have an important effect on soil formation. In the Pennines high rainfall, an orographic feature, is accompanied by low temperatures and high humidity and, consequently, slow rates of evaporation. This gives wet, poorly drained soils, even on steep slopes, and, at high altitudes, the formation of peat. On the plain where rainfall is less, higher temperatures and lower humidity result in greater evapotranspiration and so rain has much less effect than in the Pennines. Soils thus tend to be much drier, and wet conditions are restricted .

mainly to gently sloping and enclosed land on relatively impermeable materials.

Average annual rainfall figures show that the driest districts are in the west and south, in the rain shadow of the Welsh uplands. The average rainfall of 775 mm at Nantwich is typical of the southern part of the plain, while 850 mm at Earlestown is average for the north. In the east, however, rainfall rises rapidly with altitude from 922 mm at a height of 152 m near Macclesfield to over 1,000 mm in the Pennines around Buxton. Rainfall in most places is fairly evenly distributed throughout the year, but with spring tending to be the driest season and late summer and early autumn the wettest. August and October are the two wettest months over the whole county except on the Pennine boundary near Buxton, where January is the wettest.

Temperatures are controlled mainly by altitude, mean annual temperatures ranging from almost $10^{\circ}$C on the plain to $7.8^{\circ}$C at Buxton. In the lowlands the greatest temperature ranges tend to occur in the south where there is little maritime influence. The range on the Pennines is similar to that over much of the plain but is within much lower limits.

Frost is more common in south Cheshire, where keen radiation frosts can occur, and in the Pennines, where low temperatures accompanied by strong winds and snow often give very severe winters.

The mean monthly temperatures indicate that the growing season, taken arbitrarily as the period then this temperature exceeds $5.5^{\circ}$C, extends from March to November over much of the plain, but only from April to October in the Pennines.

Sunshine records show that the Wirral is the sunniest area and the Pennines the cloudiest. Wind is an important factor affecting evaporation, particularly if accompanied by strong sunlight; for example, in the Wirral frequent strong winds and long hours of sunshine have a noticeable effect on soil moisture régimes. Wind has far less drying effect in the Pennines where there is much less sun, and gales are often accompanied by rain or low cloud.
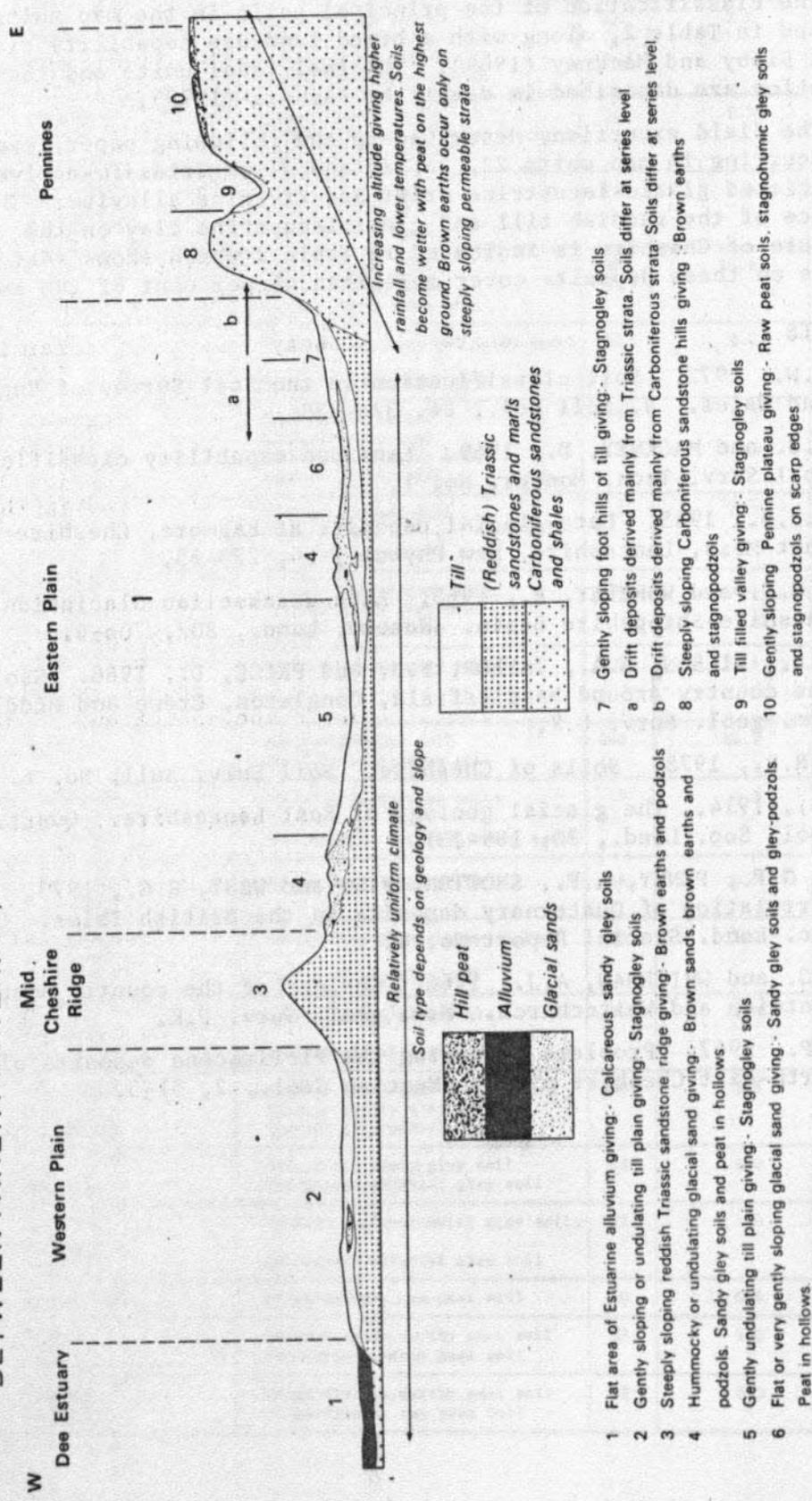
Potential transpiration is important in the summer months. Over most of the plain there is an excess of evaporation over rainfall from April to July or August. This progressively reduces the soil moisture content to give an average maximum potential soil water deficit of over 100 mm. As a result, drought conditions occur at some time in most years. In the eastern foothills and the Pennines, however, evapotranspiration exceeds rainfall only in the middle of summer and the average maximum potential soil water deficit is much lower. These conditions are reflected in soil profiles which, on similar parent material and under the same topographical conditions, are much wetter and more strongly gleyed than on the plain.

THE SOILS

The effect of climate, geology and relief on the distribution of soils in Cheshire is illustrated diagramatically in Figure 3. On the plain and Mid-Cheshire Ridge differences in altitude are not great enough to affect climate, and soil type depends largely on variations in geology and slope. In the Pennines however, increasing altitude gives higher rainfall and lower temperatures. Soils become progressively wetter, with peat on the highest ground. Brown earths occur only on steeply sloping permeable strata.

Using the classification of Avery (1973), the soils have been grouped into 20 map units containing soils which occur together consistently, with

# Fig.3 DIAGRAMMATIC SECTION ACROSS CHESHIRE SHOWING RELATIONSHIP BETWEEN PARENT MATERIAL, TOPOGRAPHY AND SOILS

W — Dee Estuary — Western Plain — Mid Cheshire Ridge — Eastern Plain — Pennines — E

Increasing altitude giving higher rainfall and lower temperatures. Soils become wetter with peat on the highest ground. Brown earths occur only on steeply sloping permeable strata

Relatively uniform climate

Soil type depends on geology and slope

**Parent material:**
- Till
- (Reddish) Triassic sandstones and marls
- Carboniferous sandstones and shales
- Hill peat
- Alluvium
- Glacial sands

1 Flat area of Estuarine alluvium giving:- Calcareous sandy gley soils

2 Gently sloping or undulating till plain giving:- Stagnogley soils

3 Steeply sloping reddish Triassic sandstone ridge giving:- Brown earths and podzols

4 Hummocky or undulating glacial sand giving:- Brown sands, brown earths and podzols. Sandy gley soils and peat in hollows.

5 Gently undulating till plain giving:- Stagnogley soils

6 Flat or very gently sloping glacial sand giving:- Sandy gley soils and gley-podzols. Peat in hollows.

7 Gently sloping foot hills of till giving:- Stagnogley soils

a Drift deposits derived mainly from Triassic strata. Soils differ at series level

b Drift deposits derived mainly from Carboniferous strata. Soils differ at series level

8 Steeply sloping Carboniferous sandstone hills giving:- Brown earths and stagnopodzols

9 Till filled valley giving:- Stagnogley soils

10 Gently sloping Pennine plateau giving:- Raw peat soils. stagnohumic gley soils and stagnopodzols on scarp edges

characteristic relief features and climate. The units are numbered nationally and contain, with one exception, two or more soil series which recur in more or less similar proportions and in a pattern distinct enough to affect farming.

The classification of the principal soils in the map units is summarised in Table 2, along with a broad land use capability classification based on Bibby and Mackney (1969). The individual units and their distribution are described in detail by Furness (1978).

The field excursion, described in the following paper, examined soils occurring in map units 22, 26, 27 and 31 on Triassic-derived till and associated glacio-lacustrine drift and riverine alluvium. The importance of the reddish till and glaciolacustrine clay on the agriculture of Cheshire is indicated in Table 2 which shows that the 3 map units on these deposits cover more than 46 per cent of the county.

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Table 2.    Cheshire - Soil Map Units Principal Soil Series, Extent and Land Capability

| Map unit (Numbered nationally) | Principal Soil series in order of importance | Soil subgroup | km$^2$ | % of county | Land capability classification |
|---|---|---|---|---|---|
| 18 | Rivington<br>Withnell<br>Swindon Bank<br>Heapey | Typical brown earth<br>Typical brown podzolic soil<br>Typical brown earth<br>Stagnogleyic brown earth | 63 | 2.7 | 3g - 5c |
| 19 | Bromsgrove<br>Hodnet<br>Wick | Typical brown earth<br>Stagnogleyic argillic brown earth<br>Typical brown earth | 35 | 1.5 | 2s |
| 20 | Bridgnorth<br>Bromsgrove<br>Delamere | Typical brown sand<br>Typical brown earth<br>Humo-ferric podzol | 65 | 2.8 | 2a - 5gs |
| 21 | Newport<br>Wick<br>Blackwood | Typical brown sand<br>Typical brown earth<br>Typical sandy gley soil | 294 | 12.6 | 2s - 3s |
| 22 | Salwick<br>Flint<br>Salop | Stagnogleyic argillic brown earth<br><br>Argillic stagnogley soil | 63 | 2.7 | 3ws |
| 23 | Crannymoor<br>Newport<br>Blackwood<br>Reaseheath | Humo-ferric podzol<br>Typical brown sand<br>Typical sandy gley soil<br>Typical gley-podzol | 77 | 3.3 | 2s - 3ws |
| 24 | Belmont<br>Revidge<br>Anglezarke | Ironpan stagnopodzol<br>Humic ranker<br>Humo-ferric podzol | 7 | 0.2 | 6gs |
| 25 | Rufford<br>Blackwood<br>Reaseheath | Argillic stagnogley soil<br>Typical sandy gley soil<br>Typical gley-podzol | 54 | 2.3 | 3ws |
| 26 | Salop<br>Clifton<br>Rufford | Argillic stagnogley soils | 770 | 33.1 | 3ws |
| 27 | Crewe<br>Salop | Pelo-stagnogley soil<br>Argillic stagnogley soil | 240 | 10.3 | 3ws - 4ws |
| 28 | Brockhurst<br>Salop<br>Worcester | Argillic stagnogley soils<br><br>Stagnogleyic argillic brown earth | 19 | 0.8 | 3ws |
| 29 | Brickfield<br>Hallsworth | Cambic stagnogley soils | 16 | 0.7 | 3ws - 4ws |
| 30 | Wilcocks<br>Roddlesworth<br>Un-named | Cambic stagnohumic gley soils<br><br>Typical humic gley soil | 40 | 1.7 | 5ws |
| 31 | Compton<br>Midelney<br>Un-named | Pelo-alluvial gley soils<br><br>Typical alluvial gley soil | 54 | 2.3 | 4ws |
| 32 | Blackwood<br>Quorndon<br>Reaseheath | Typical sandy gley soil<br>Typical cambic gley soil<br>Typical gley-podzol | 200 | 8.6 | 2s - 3ws |
| 33 | Dee<br>Hesketh | Calcareous sandy gley soil<br>Calcareous alluvial gley soil | 23 | 1.0 | 2sc - 3w |
| 34 | Un-named<br>Un-named<br>Hesketh | Typical humic-alluvial gley soils<br><br>Calcareous alluvial gley soil | 23 | 1.0 | 3ws - 4w |
| 35 | Winter Hill | Oligo-fibrous raw peat soil | 10 | 0.4 | 6wc |
| 36 | Ridley<br>Altcar | Oligo-fibrous earthy peat soil<br>Eu-fibrous earthy peat soil | 23 | 1.0 | 1-6w |
| 37 | Westhay<br>Longmoss | Oligo-fibrous earthy peat soil<br>Oligo-fibrous raw peat soil | 8 | 0.3 | 2s - 5ws |

REPORT ON THE FIELD MEETING IN SOUTH AND WEST CHESHIRE

by

R.R. Furness and S.J. King

(Soil Survey of England and Wales, Bishop Barton)

The excursion visited the southern part of the plain (Fig. 1), the largest and agriculturally the most important of the Cheshire regions (Furness 1978). It is a district of drift soils varying from those on fine loamy and clayey reddish tills, glaciolacustrine clays and alluvium to those on coarse glaciofluvial sands and gravels. The emphasis of the excursion however, was on the fine loamy and clayey soils and their management for intensive livestock farming.

The morning was spent examining soils formed on reddish glaciolacustrine drift and river alluvium, all of which are difficult to drain due to their large clay content and flat low-lying situation. A sequence of four profiles, starting in an undrained, unimproved area and ending in intensively drained and well managed land, were seen. The afternoon was devoted to soils on reddish till (King 1977). These are the most widespread in the county and a series of fine loamy and fine loamy over clayey profiles ranging from strongly to slightly gleyed were seen.

PROFILE NO. 1 WARMINGHAM SERIES

This is a clayey argillic stagnohumic gley soil on reddish stoneless glaciolacustrine drift. In south Cheshire the series has been mapped only in the district immediately north of Crewe. It has also been recorded in South Yorkshire (Hartnup 1977).

The black peaty or humose stoneless clay loam or clay Ahg horizon distinguishes the series from the greyish brown surface horizon of the associated Crewe series. The grey colours of the strongly gleyed Bg or Eg horizon extend in places to a depth of 50 cm and contrast sharply with the black topsoil. The gleying is usually much more marked than in the Crewe series. Below about 50 cm gleying becomes gradually less intense, the BCg horizon being a stoneless prismatic structured reddish brown or occasionally brown clay with grey structure faces and small white concretions of secondary calcium carbonate.

When suitably drained these are good grassland soils, but effective gravity drainage is often difficult due to very low gradients and the height of the surrounding ground. The land use capability class in 4ws.

Although this low-lying area known as Warmingham Moss, may have been covered extensively by peat in the past, it is unlikely that there was ever any great thickness as the poor drainage would tend to preserve any peat present. It is more likely to have always been a wet area with patches of peat within soils with a generally humose topsoil similar to the present situation.
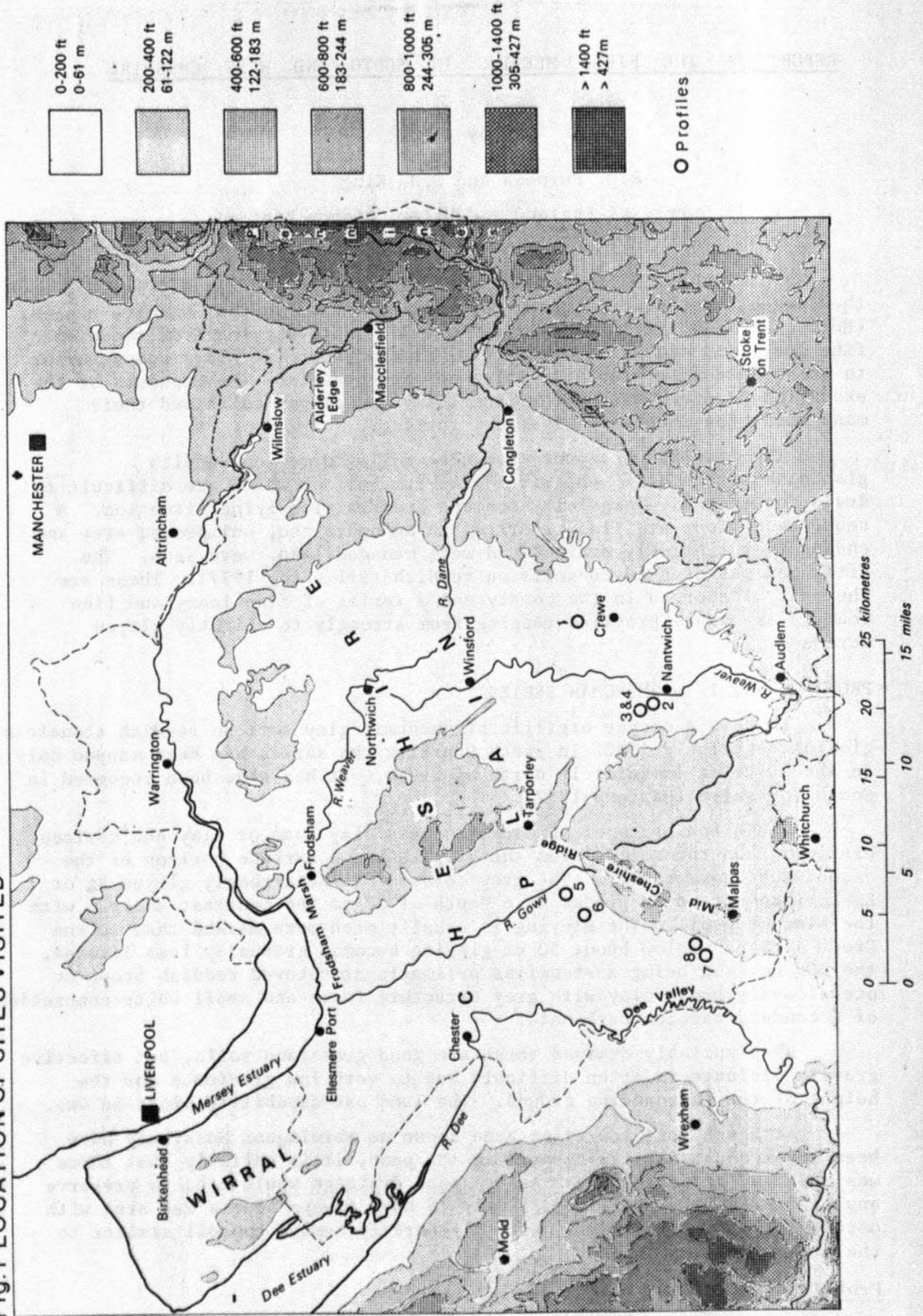
Profile description

Grid reference:    SJ 65/9785.

Soil subgroup:    Argillic-stagnohumic gley soil.

Lithology:    Humose over clayey, glaciolacustrine drift.

# Fig.1 LOCATION OF SITES VISITED



Legend:

- 0-200 ft / 0-61 m
- 200-400 ft / 61-122 m
- 400-600 ft / 122-183 m
- 600-800 ft / 183-244 m
- 800-1000 ft / 244-305 m
- 1000-1400 ft / 305-427 m
- >1400 ft / >427m
- ○ Profiles

Locality: 45 m west of railway footbridge, Coppenhall.

Elevation: 52 m O.D.

Slope and aspect: Level.

Land use: Permanent grassland.

Horizons:
cm

Ahg

0-20
Very dark brown (10 YR 2/2) stoneless very friable peaty clay loam; weak medium subangular blocky and granular; extremely abundant fine fibrous roots; occasional earthworms; merging even boundary.

ABg

20-30
Very dark grey (10 YR 3/1) stoneless slightly humose clay with common faint fine very dark greyish brown to dark yellowish brown (10 YR 3/2 to 3/4) mottles along root channels; strong medium prismatic;common fine fibrous and a few small fleshy roots; rare earthworms; narrow irregular boundary.

Bg

30-51
Grey (5 Y 5/1) stoneless clay loam with common or many distinct medium dark yellowish brown (10 YR 4/4) mottles; strong coarse prismatic; common fine fibrous roots; merging even boundary.

BCg

51-102
Brown (10 YR 4/3) stoneless clay with some sandy clay pockets; many distinct grey (10 YR 5/1) mottles on structure faces and old root channels; strong coarse prismatic; rare fine fibrous and very small woody roots.

Analyses

| Horizon | Ahg | ABg | Bg | BCg |
|---|---|---|---|---|
| Depth (cm) | 0-20 | 20-30 | 30-51 | 51-102 |
| (200 μm-2mm % | 25 | 1 | 1 | 1 |
| Sand ( 60-200 μm % | 11 | 5 | 28 | 24 |
| Silt 2-60 μm % | 29 | 27 | 32 | 33 |
| Clay <2 μm % | 35 | 67 | 39 | 42 |
| Loss on ignition % | 64.2 | 12.6 | 5.2 | 5.4 |
| pH in water (1:2.5) | 4.7 | 5.1 | 5.5 | 6.2 |
| pH in 0.01M CaCl$_2$ (1:2.5) | 4.1 | 4.5 | 4.9 | 5.7 |
| C % | 32.7 | 3.7 | 0.8 | - |
| N % | 1.73 | 0.30 | - | - |
| C/N % | 19 | 12 | - | - |
| C.E.C. (me/100 g) | 100.7 | 37.8 | 17.5 | 19.7 |

## PROFILE NO. 2 MIDELNEY SERIES

This is a clayey pelo-alluvial gley soil over earthy peat, on interbedded river alluvium and peat (Findlay 1965). In Cheshire this soil is common on back swamps along the larger rivers such as the Dee, Weaver and Dane, where thin peat has formed under very wet conditions and been preserved by later accumulations of clayey alluvium. The series is also common in enclosed hollows and depressions where alluvium is associated with thick peat deposits, often as a peripheral zone around the peat.

The surface horizon of mottled dark grey or dark greyish brown silty clay loam, sometimes clay loam, is followed by a Bg horizon of brown strongly mottled stoneless clay. The 2Cg horizon of peat or peaty loam, usually at a depth of 50-70 cm, is the main distinguishing feature and separates the series from the otherwise similar Compton series. Where peat occurs only in lenses it is followed by a 3Cg horizon of dark grey clay loam, but in many profiles peat continues to a considerable depth. Although the clay is derived from red till this colour is less common than in the Compton series, due to stronger gleying associated with the peaty horizons. The Midelney series is a naturally fertile but acid soil which, although very wet in the winter months, is drought-resistant and gives high yields of grass if fertilized and limed. The risk of flooding and fine texture prevent arable cropping. These factors downgrade the unit to land use capability class 4ws.

### Profile description

Grid reference: SJ 65/5240

Soil subgroup: Pelo-alluvial gley soil.

Lithology: Clayey over earthy peaty, riverine alluvium.

Locality: 640 m NNE of Beam Bridge, Nantwich.

Elevation: 35 m O.D.

Slope and aspect: Level, backswamp depression.

Land use: Permanent grass.

Horizons:
cm

Ahg
0-20

Very dark greyish brown (10 YR 3/2) friable stoneless clay loam, moderate medium to coarse subangular blocky structure breaking to medium granular; fine and medium fissures common; moderate organic matter content; abundant fine fibrous roots; a few earthworms; narrow even boundary.

Bg
20-69

Brown to dark brown (7.5 YR 4/4) stoneless firm clay; fine distinct dark grey (5 YR 4/1) mottles common on root channels; some dark grey (5 YR 4/1) structure faces, particularly towards the base of the horizon; strong coarse prismatic structure; fine pores common along old root channels; a few fine fissures between structure faces; fine roots common; some charcoal fragments near base of horizon; earthworms rare; merging undulating boundary.

| | | | | |
|---|---|---|---|---|
| 2Cg | Very dark greyish brown (10 YR 3/2) pseudo-fibrous humified | | | |
| 69-84 | peat and silty clay; some recognizable remains of reeds and | | | |
| | wood; moderate thick platy structure; merging even boundary. | | | |
| 3Cg | Very dark grey (10 YR 3/1) slightly humose stoneless clay | | | |
| 84+ | loam with numerous pseudo-fibrous fragments and lenses of | | | |
| | peat; moderately developed medium to coarse blocky structure. | | | |

Analyses

| Horizon | Ahg | Bg | 2Cg | 3Cg |
|---|---|---|---|---|
| Depth (cm) | 0-20 | 20-69 | 69-84 | 84+ |
| Sand( (200 µm - 2 mm. % | 23 | 5 | 7 | 2 |
| (60-200 µm % | 20 | 6 | 7 | 25 |
| Silt 2-60 µm % | 32 | 42 | 45 | 47 |
| Clay <2 µm % | 25 | 47 | 41 | 26 |
| Loss on ignition % | 4.3 | 8.5 | 40.2 | 9.5 |
| Organic carbon % | - | - | 19.9 | 3.3 |
| Nitrogen % | - | - | 1.30 | 0.24 |
| C/N % | - | - | 15 | 14 |
| pH in water (1:2.5) | 6.4 | 6.5 | 4.2 | 5.7 |
| pH in 0.01M CaCl$_2$ (1:2.5) | 6.0 | 5.9 | 4.1 | 5.6 |
| C.E.C.  (me/100 g) | 23.6 | 30.4 | 71.6 | 23.5 |

Dip-well water levels. To assess the duration of wetness in the soil and its relationship to rainfall and profile morphology, water levels in eight different soils on the Cheshire College of Agriculture farm, chosen to represent soils common throughout the plain, were monitored for three years. The methods used were similar to those of Thomasson and Robson (1967). Three 10 cm diameter holes were bored in each representative soil to depths of 30, 60 and 110 cm to correspond approximately to the topsoil, subsoil and parent material. Rainfall and depth of water from the surface of each well were recorded at weekly intervals through the year from November 1970 to November 1973.

Site No. 2 has no artificial drainage and the profile is waterlogged within 30 cm of the surface for much of the year (Fig.2A). Only in summer is there any significant fall in the 30 cm well, with a tendency for the lowest levels to occur in August and September, although this could well be due to the particular rainfall distribution in the three recording years. Heavy rainfall is quickly reflected in the 30 and 60 cm wells, indicating a distinct surface water effect with water being held in the clayey horizons above the peat. Levels in the 110 cm well, however, are very uniform, apart from the first seven months of recording in 1970-71 when water movement into and out of the well could have been disturbed by the insertion techniques. Levels in this well appear to be controlled by water-table movements which reflect seasonal rather than weekly rainfall.

The records show that this soil is in wetness class V (Hodgson 1976) and confirm that the gley colours in this profile are a reliable indication of soil drainage.
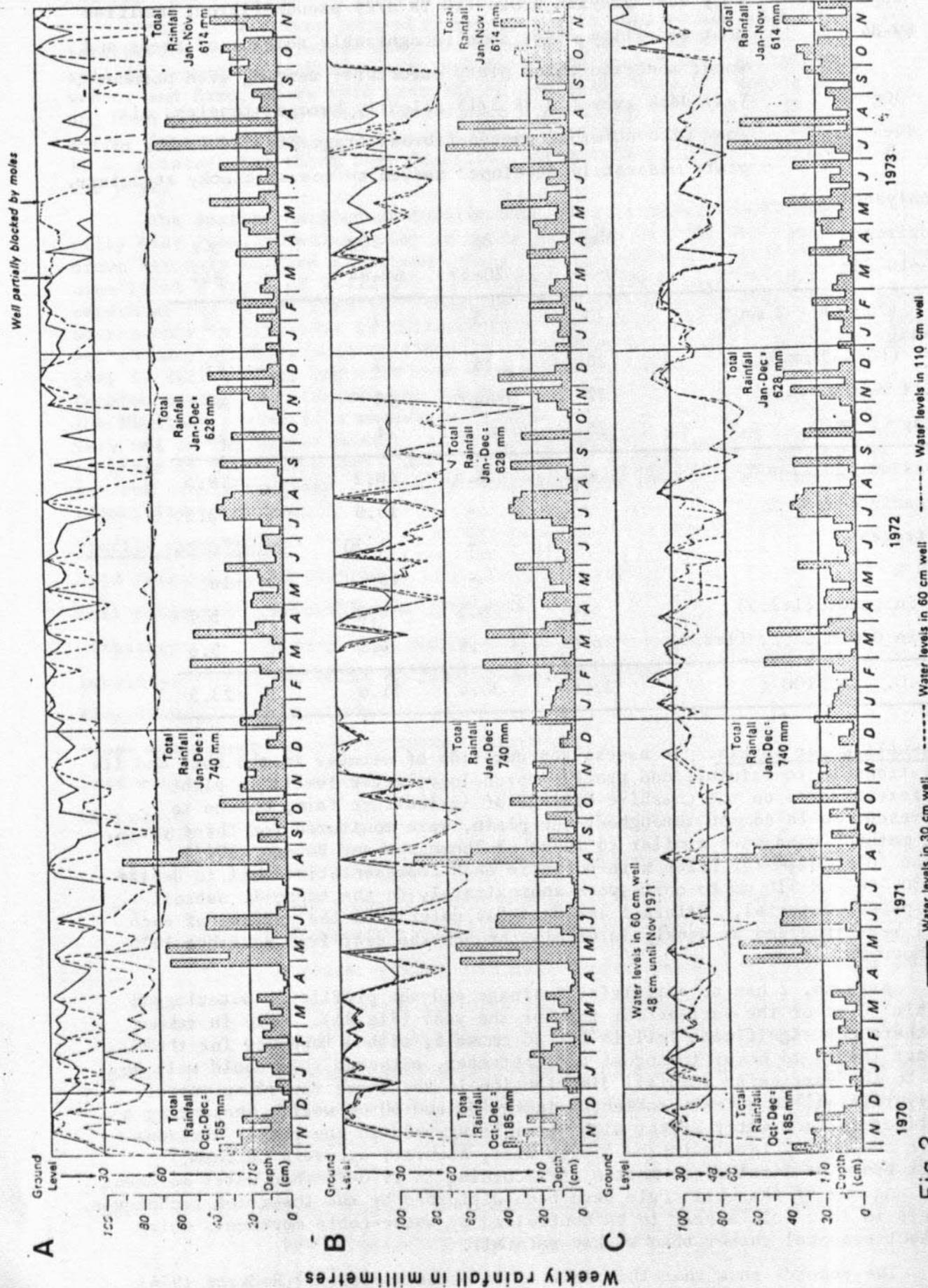
Fig. 2

A Water levels in relation to rainfall in Profile 2 (Midelney Series)  B Water levels in relation to rainfall in Profile 3 (Crewe Series)  C Water levels in relation to rainfall in Profile 4 (Crewe Series), with artificial drainage Series), without adequate drainage

——— Water levels in 30 cm well    ------ Water levels in 60 cm well    —·—·— Water levels in 110 cm well

PROFILES  NO.  3  and  NO. 4  CREWE  SERIES

These profiles in adjoining fields show that strongly developed gley colours are not, however, necessarily a good indication of present soil drainage.  The Crewe series is a clayey pelo-stagnogley soil on reddish stoneless glaciolacustrine drift.  The profile is similar in colour to the Salop series (Profile No. 6), but has a much larger clay content and is stoneless throughout.  Gleying is also more strongly developed and the series is perhaps best regarded as a finer, wetter and stoneless equivalent of the Salop series.  The Crewe series has also been described in Shropshire and Staffordshire (Jones 1975).

The Ag horizon is a stoneless dark greyish brown clay, above a grey stoneless clay Eg horizon.  The latter is the zone of maximum waterlogging and usually occurs 20-30 cm below the surface.  Below, gleying becomes gradually less intense, the Btg and BCg horizons being grey, mottled reddish grey and reddish brown, stoneless clay or sometimes silty clay.  The BCg horizon below is a stoneless prismatic structured reddish brown clay with small nodules and concretions of secondary calcium carbonate.  The salient features are the distinct grey Eg horizon and the absence of stones.  The absence of a black humose or peaty A horizon separates Crewe soils from the associated argillic stagnohumic gley soils of the Warmingham series.

Crewe soils are naturally very fertile and with suitable drainage are capable of good yields of grass.  Phosphate may be lacking but is easily added in fertilizers which release it slowly over many years.  The parent material is calcareous but surface horizons can become acidic enough to need occasional light dressings of lime.  Land use capability class varies from 3-4 ws depending on drainage and site.

Profile description

Grid reference:      SJ 65/4946

Soil subgroup:        Pelo-stagnogley soil.

Lithology:            Clayey, glaciolacustrine drift.

Locality:             0.7 km NE of Reaseheath Hall.

Elevation:            38 m O.D.

Slope and aspect:     $2^{\circ}$ E.

Land use:             Permanent grassland.

This profile, in an inadequately drained field was not described, but was included in the excursion so that the degree of gleying could be compared with that of profile No. 4 in the extensively drained field nearby.

Profile description

Grid reference:      SJ 65/5346.

Soil subgroup:        Pelo-stagnogley soil.

Lithology:            Clayey, glaciolacustrine drift.

Locality:             0.8 km NE of Reaseheath Hall,

Elevation:            38 m O.D.

Slope and aspect:     Level.

Land use:             Ley used for paddock grazing.

Horizons:
cm

| | |
|---|---|
| Apg<br>0-15 | Dark greyish brown (10 YR 4/2) stoneless clay, faint fine rusty mottling common; moderately developed medium subangular blocky and medium granular structure; firm; a few fine vertical fissures; moderate organic matter with abundant fine roots and some earthworms; sharp undulating boundary. |
| Ag<br>15-20 | Brown to dark brown (10 YR 4/3) stoneless clay with many distinct fine to medium strong brown (7.5 YR 5/8) mottles; moderate medium angular blocky structure; firm; a few large vertical fissures containing material washed in from the overlying horizon; moderate organic matter; fine roots common; a few earthworms; narrow even boundary. |
| Bg/Eg<br>20-31 | Grey (5 Y 5/1) stoneless clay; common distinct and prominent fine to medium strong brown (7.5 YR 5/8) mottles; medium angular to prismatic structure; a few medium vertical fissures; a few fine roots and earthworms; merging irregular boundary. |
| Btg<br>31-51 | Brown to dark brown (7.5 YR 4/2) stoneless clay with distinct grey to light grey (5 Y 6/1) and strong brown (7.5 YR 5/8) mottles on structure faces and old root channels; strong coarse prismatic structures; firm or very firm; a few fine roots often following faces; old fine root channels abundant often giving broken peds a finely pored appearance; a few earthworms; merging irregular boundary. |
| BCg<br>51-71 | Dark reddish grey (5YR 4/2) stoneless clay with distinct grey (5 Y 5/1) mottling mainly on structure faces and old root channels; strong coarse prismatic structure; firm; rare fine roots; common old root channels; rare earthworms; merging irregular boundary. |
| BCgk<br>71 + | Dark reddish brown (5 YR 3/3) slightly calcareous stoneless clay with large prominent grey (N5) mottles on structure faces; strong coarse prismatic structure; very firm; very rare fine roots; calcium carbonate common occurring as a white (10 YR 8/1) dendritic pattern and as very small concretions. |

Analyses

| Horizon | Apg | Ag | Bg/Eg | Btg | BCg | BCgk |
|---|---|---|---|---|---|---|
| Depth (cm) | 0-15 | 15-20 | 20-31 | 31-51 | 51-71 | 71+ |
| Sand (200 µm-2 mm % | 11 | 8 | 2 | | | 1 |
| (60-200µm % | 12 | 11 | 5 | 1 | 1 | 1 |
| Silt 2-60 µm % | 34 | 35 | 37 | 24 | 31 | 33 |
| Clay < 2 µm % | 43 | 46 | 56 | 75 | 68 | 65 |
| $CaCO_3$ equivalent % | 0.5 | nil | nil | nil | nil | 9.9 |
| Loss on ignition % | 11.0 | 7.7 | 6.2 | 6.7 | 7.1 | 7.7 |
| Organic carbon % | 3.8 | - | - | - | - | - |
| pH in water (1:2.5) | 6.9 | 7.1 | 7.0 | 7.4 | 7.7 | 8.2 |
| pH in 0.01M $CaCl_2$ (1:2.5) | 6.6 | 6.6 | 6.5 | 6.9 | 7.2 | 7.6 |
| C.E.C. (me/100 g) | 27.4 | - | 20.6 | 23.4 | - | - |

Dip-well water levels. The levels in Profile 3 (Fig.2B), in permanent pasture with little or no artificial drainage, show that in most years the soil is waterlogged to the surface throughout the winter, and even in summer during wet spells. Levels in the 30-, 60- and 110 cm wells are almost identical when water is within 30 cm of the surface except for a slight tendency for levels to rise more quickly and be held for longer in the 30 cm well, perhaps indicating slight compaction within the surface horizon. Low evaporation in winter means that the soil remains waterlogged to the surface, even during rain-free periods, whereas levels fluctuate to a much greater extent and are closely related to individual falls of rain during the summer. The records indicate that this profile falls within wetness class V. Profile No. 4 (Fig. ) is in a reseeded pasture, tile drained at 11 yard intervals and, although in lower lying ground than profile 3, the beneficial effects of underdrainage are immediately seen. Waterlogging within 30 cm of the surface is much less common and is restricted almost entirely to the winter months, when it is severe only during prolonged wet periods. Unlike the undrained profile which is quickly saturated even by isolated heavy rainfall, fluctuations in this profile are less evident and occur mainly below the 30 cm level. Water levels in the 110 cm well occasionally rise above those in the 30- and 50 wells. This anomalous situation could be due to the well being further away from a drain. The effect of tile drainage is to improve the profile from wetness class V to IV. This will reduce poaching and allow the grazing season to be extended into October and early November, when undrained profiles are badly waterlogged. Although both profiles show marked gleying, with strongly developed grey and yellow mottling, the tile-drained profile is more strongly gleyed, indicating that before drainage this profile was the wetter of the two.

Physical properties - (the terms used below are defined in the Appendix). Physical measurements on profile No. 4 adjoining the dip-wells in the tile-drained field show a moderately high available water capacity in the well-structured surface horizon but a low level in subsurface horizons where there is more clay. Retained water capacity is high throughout the profile, as would be expected in a clay soil with fine pores and air capacity moderately low and very low in the BCg horizon. Similar results were obtained from another profile (SJ 75/1935) and confirm that, although the Crewe series has a high water content, much subsoil water is held at high suctions and is not

accessible to plants. Conversion of the available water to millimetres of
water shows that in Profile SJ 65/5346 there is little more available water
than in the sandy Newport series. In a normal summer, available water exceeds
the average maximum cumulative soil water deficit. In dry years the underlying
water-table will tend to compensate and prevent severe deficits in the horizons
above. Drought conditions are thus likely to be very rare in this soil.

PROFILE NO. 5 - CLIFTON SERIES

Profile No. 5 is a fine loamy argillic stagnogley soil on reddish till
of Triassic origin. The series covers much of the plain east and west of the
Mid-Cheshire Ridge and is also widespread in Lancashire and Staffordshire.

The A horizon is a moderately structured, mottled dark brown or very
dark greyish brown sandy loam or sandy clay loam. The pale brown mottled
Eg horizon is a slightly stony sandy clay loam. Below is a brown or reddish
brown strongly structured and prominently mottled Btg horizon of clay loam or
sandy clay loam with significantly more clay as evidenced by clay skins or
concentrations of strongly oriented illuvial clay. The Cg horizon below is a
coarse prismatic mottled reddish brown clay loam.

The stone content is usually slight but occasional pockets of gravel
and small stones in the B horizon are of agricultural significance. Similarly,
lenses of sand derived from local Triassic sandstone and glaciofluvial deposits
are common within the till.

The Clifton series is traditionally a grassland soil, mainly in
permanent pasture although on slightly better drained sites reseeding is
practised and arable crops grown. In recent years there has also been a
successful move towards market gardening on Clifton soils which indicates
that with careful management a much wider range of crops could be grown.
Land use capability class 3 ws.

Profile description

Grid reference:       SJ 45/9183.

Soil subgroup:        Argillic stagnogley soils.

Lithology:            Fine loamy, reddish till.

Locality:             450 m NE of Tattenhall Hall, Tattenhall.

Elevation:            38 m O.D.

Slope and aspect:     Level.

Land use:             Permanent grassland.

Horizons:
  cm

  Ap(g)      Dark brown (10 YR 3/3) friable sandy loam with common distinct
  0-18       fine and medium yellowish red (5 YR 5/6) mottles; slightly
             stony with small angular and rounded igneous pebbles; moderate
             medium subangular blocky breaking to fine subangular blocky and
             medium crumb; abundant fine and medium pores and fine fissures;
             moderate intimately mixed organic matter; abundant fine fibrous
             roots; earthworms present; sharp even boundary.

  Eg         Brown (7.5 YR 5/2) and pale brown (10 YR 6/3) friable sandy
  18-30      loam with many distinct fine and medium yellowish red (5 YR 4/6)
             mottles; slightly stony; moderate medium subangular blocky
             breaking to fine subangular blocky and fine crumb; abundant

fine and medium pores and common fine fissures; low intimately mixed organic matter; common fine fibrous roots; merging undulating boundary.

Btg
30-49
Brown (7.5 YR 5/4) friable sandy clay loam with many prominent fine and medium yellowish red (5 YR 5/8) mottles, common distinct, fine, light yellowish brown (10 YR 6/4) and grey (5 Y 6/1) mottles; slightly stony; moderately strong coarse subangular blocky tending towards coarse prismatic; abundant fine and medium pores and fine fissures; few fine fibrous roots; merging even boundary.

BCg
49-90
Dark brown (7.5 YR 4/4) firm to very firm clay loam with many prominent large greenish grey ( 5 GY 6/1) and pale olive (5 Y 6/3) mottles particularly along structure faces; slightly stony; moderately strong coarse prismatic; few fine fibrous roots; few ferrimanganiferous concretions.

Analyses

| Horizon | Ap(g) | Eg | Btg | BCg |
|---|---|---|---|---|
| Depth (cm) | 0-18 | 18-30 | 30-49 | 49-90 |
| Sand (600 μm-2mm % | 1 | 1 | 1 | 1 |
| Sand (200-600 μm % | 28 | 27 | 22 | 13 |
| Sand (60-200 μm % | 27 | 29 | 29 | 24 |
| Silt 2-60 μm % | 25 | 27 | 23 | 32 |
| Clay <2 μm % | 19 | 16 | 25 | 30 |
| $CaCO_3$ equivalent % | - | - | - | nil |
| Organic carbon % | 4.5 | 0.9 | 0.4 | - |
| pH in water (1:2.5) | 5.9 | 6.1 | 6.3 | 6.9 |
| pH in 0.01M $CaCl_2$ (1:2.5) | 5.7 | 5.8 | 5.8 | 6.3 |
| C.E.C. (me/100 g) | 18.1 | 11.2 | 10.0 | 13.9 |
| Pyrophosphate-extractable | | | | |
| Fe % | 0.12 | 0.10 | 0.02 | 0.01 |
| Al % | 0.03 | 0.04 | 0.05 | 0.03 |
| C % | 0.43 | 0.27 | 0.13 | 0.06 |
| Residual dithionite extractable | | | | |
| Fe % | 0.50 | 0.35 | 0.55 | 0.95 |

Physical properties (see Appendix). Available water content is high in the surface horizon due to the organic matter content, decreasing to a moderately low level at depth. The increase in fine particles with depth is expressed in the decreasing air capacity from moderately low to very low. Retained water capacity varies from high in the surface to moderately high in the Cg horizon, but with a moderately low level in the coarser intermediate Eg horizon. Total available water in the profile as a whole, when compared with the average maximum potential cumulative soil moisture deficit, indicate that the Clifton series is unlikely to suffer from drought.

PROFILE NO. 6 - SALOP SERIES

This is a fine loamy over clayey argillic stagnogley soil on reddish Triassic-derived till. First recognised in Shropshire (Crompton and Osmond 1954) the series has since been mapped throughout north-west England, the Midlands, and in Wales.

The A horizon is a dark greyish brown clay loam with a moderately developed medium subangular blocky structure. The strongly mottled brownish grey Eg horizon of clay loam passes into a reddish brown Btg of clay loam or clay, the particle-size class reflecting the amount of translocated clay. This in turn passes into a coarse prismatic reddish brown plastic clay with distinct mottling along structure faces.

Although in favourable seasons excellent arable crops can be produced from soils of the Salop series, they are difficult to manage in continuous cultivation or under a rotation which includes only short-term leys. As a result Salop soils are traditionally grassland soils. Hay feeding and shippon housing are still widespread. Many farms however now conserve grass for silage, have modern livestock buildings, a good standard of grassland management and stocking rates approaching one cow per acre. Intensive stocking induces structural problems however and many farmers feel that zero grazing could reduce the risk of structural damage. Land use capability class 3ws.

Profile description

| | |
|---|---|
| Grid reference: | SJ 45/9174. |
| Soil subgroup: | Argillic stagnogley soil. |
| Lithology: | Fine loamy over clayey; reddish till. |
| Locality: | 250 m E of Woodlake Farm, Tattenhall. |
| Elevation: | 40 m O.D. |
| Slope and aspect: | Level. |
| Land use: | Re-seeded grassland. |

Horizons:
cm

Ap(g)
0-18     Brown (10 YR 4/3) friable clay loam with many faint brown (7.5 YR 4/4) and strong brown (7.5 YR 5/6) mottles; slightly stony with small subangular and rounded igneous pebbles; moderate medium subangular blocky breaking to fine subangular blocky and medium crumb; common fine pores and fissures; moderate intimately mixed organic matter; abundant fine fibrous roots; earthworms present; narrow even boundary.

Eg
18-29     Greyish brown to light brownish grey (2.5 Y 5/2-6/2) firm clay loam with many distinct fine and medium strong brown (7.5 YR 5/6) and very pale brown (10 YR 7/4) mottles; slightly stony; moderate

|          | medium subangular blocky; common fine pores and fissures; common fine fibrous roots; some earthworms; merging even boundary. |
|----------|------------------------------------------------------------------------------------------------------------------------------|
| Btg<br>29-50 | Yellowish brown (10 YR 5/4) and light brownish grey (10 YR 6/2) firm clay loam with common distinct medium and large brownish yellow (10 YR 6/8) and very pale brown (10 YR 7/4) mottles; slightly stony; moderate medium and coarse subangular blocky; common fine pores and fissures; common fine fibrous roots; merging even boundary. |
| BCg<br>50-90 | Dark reddish grey (5 YR 4/2) plastic clay with distinct large and medium grey ( 5 Y 5/1) mottles along structure faces and old root channels; slightly stony; strong coarse prismatic; few fine fibrous roots; few ferrimanganiferous concretions. |

Analyses

| Horizon<br>Depth (cm) | Ap(g)<br>0-18 | Eg<br>18.29 | Btg<br>29-50 | BCg<br>50-90 |
|-----------------------|------|-------|-------|-------|
| Sand (600 µm-2 mm %   | 1    | 4     | 2     | 1     |
| Sand (200-600 µm %    | 19   | 20    | 17    | 12    |
| (60-200 µm %          | 22   | 22    | 21    | 15    |
| Silt 2-60 µm %        | 33   | 34    | 26    | 32    |
| Clay < 2 µm %         | 25   | 20    | 34    | 40    |
| $CaCO_3$ equivalent % | -    | -     | -     | 1     |
| Organic carbon %      | 2.0  | 1.0   | 0.4   | -     |
| pH in water (1:2.5)   | 5.8  | 5.4   | 6.4   | 7.1   |
| pH in 0.01M $CaCl_2$ (1:2.5) | 5.6 | 5.2 | 6.2 | 6.9   |
| C.E.C. (me/100 g)     | 16.8 | 13.7  | 14.7  | 15.2  |

Pyrophosphate-extractable

| | Ap(g) | Eg | Btg | BCg |
|---|------|------|------|------|
| Fe %  | 0.10 | 0.02 | 0.03 | 0.02 |
| Al %  | 0.04 | 0.02 | 0.04 | 0.09 |
| C %   | 0.46 | 0.23 | 0.27 | 0.09 |

Residual dithionite-extractable

| | Ap(g) | Eg | Btg | BCg |
|---|------|------|------|------|
| Fe %  | 0.55 | 0.90 | 1.75 | 1.15 |

Physical properties (see appendix). This profile has much water available at low suctions in the surface horizon due to the large organic content, decreasing markedly in the subsoil. The increase in bulk density down the profile is reflected by air capacity, which decreases to a small volume. The large amount of water retained at 15 bar suction is typical of fine-textured soils and indicates that there are many fine pores. Profile available water exceeds the average maximum potential soil water deficit, and drought will not be a limitation in most years.

# PROFILE NO. 7 - SALWICK SERIES

Profile No. 7 is a fine loamy stagnogleyic argillic brown earth on reddish Triassic-derived till. The soil was first described in Lancashire and later recognised in Cheshire and Staffordshire.

The A horizon is a moderately structured dark brown or dark greyish brown sandy clay loam. The faintly mottled dark brown to brown eluvial Eb horizon, a slightly stony sandy clay loam or sandy loam, passes into a mottled reddish brown clay loam Bt horizon with significantly more clay in the form of clay skins. The Cg horizon below is a coarse prismatic mottled reddish brown clay loam. The till contains an appreciable proportion of sand from local Triassic sandstone and glaciofluvial deposits. This sand often forms lenses or pockets within the till.

Although soils of the Salwick series are well suited to grass and are at present under the traditional Cheshire practice of permanent grass or long ley with barley a secondary enterprise, they are capable of supporting a much wider range of crops. Land use capability class 3ws.

## Profile description

| | |
|---|---|
| Grid reference: | SJ 45/8701 |
| Soil subgroup: | Stagnogleyic argillic brown earth. |
| Lithology: | Fine loamy reddish till. |
| Locality: | 500 m ESE of Dairy Farm, Edge. |
| Elevation: | 79 m O.D. |
| Slope and aspect: | 1°S |
| Land use: | Re-seeded grassland, (short-term ley). |

Horizons:
cm

Ap
0-20
Brown (7.5 YR 4/2) friable sandy loam; few faint fine strong brown (7.5 YR 5/6) mottles; slightly stony with small and medium subangular and rounded igneous pebbles; moderate medium subangular blocky breaking to fine subangular blocky and fine and medium crumb; common fine pores and fissures; moderate intimately mixed organic matter.; abundant fine fibrous roots; earthworms present; narrow even boundary.

Eb(g)
20-47
Light brown (7.5 YR 6/4) friable sandy loam; few faint fine strong brown (7.5 YR 5/6) mottles; slightly stony; moderate medium and coarse subangular blocky; abundant fine and medium pores and common fine fissures; low intimately mixed organic matter; common fine fibrous roots; earthworms present; merging even boundary.

Bt(g)
47-62
Yellowish red (5 YR 5/6) firm sandy clay loam with very pale brown (10 YR 7/4) loamy sand along structure faces; common faint fine and medium strong brown (7.5 YR 5/8) mottles; slightly stony; moderately strong coarse prismatic; abundant fine pores and common fine fissures; few fine fibrous roots; common ferrimanganiferous concretions (5-10 mm); merging even boundary,

BC(g)  Reddish brown (5 YR 4/4) firm sandy clay loam; common
62-90  faint fine strong brown (7.5 YR 5/8) mottles; slightly stony;
moderately strong very coarse prismatic; abundant fine pores
and common fine fissures; rare fine fibrous roots; common
ferrimanganiferous concretions (< 2 mm).

Analyses

| Horizon | | Ap | Eb(g) | Bt(g) | BC(g) |
|---|---|---|---|---|---|
| Depth (cm) | | 0-20 | 20-47 | 47-62 | 62-90 |
| Sand | (600 μm-2 mm % | 2 | 3 | 3 | 2 |
| | (200-600 μm % | 25 | 27 | 26 | 26 |
| | (60-200 μm % | 30 | 28 | 26 | 27 |
| Silt 2-60 μm % | | 28 | 27 | 21 | 21 |
| Clay < 2 μm % | | 15 | 15 | 24 | 24 |
| Loss on ignition % | | 5.4 | 2.8 | 2.8 | 2.4 |
| $CaCO_3$ equivalent % | | - | nil | nil | nil |
| Organic carbon % | | 2.1 | 0.5 | - | - |
| pH in water (1:2.5) | | 6.3 | 6.5 | 7.0 | 6.9 |
| pH in 0.01M $CaCl_2$ (1:2.5) | | 5.8 | 5.9 | 6.2 | 6.2 |

Pyrophosphate-extractable

        Fe %            0.06

        Al %            0.04

Residual dithionite-extractable

        Fe %            0.9

Dithionite-extractable

        Fe %     0.8                         1.5      1.4

## PROFILE NO. 8 - FLINT SERIES

The Flint series is a fine loamy over clayey stagnogleyic argillic
brown earth on reddish Triassic-derived till.

The A horizon is a moderately structured brown sandy clay loam or clay
loam over a slightly mottled Eb horizon of dark greyish brown moderately
structured sandy clay loam. The reddish brown Bt horizon of well structured
clay loam or clay contains illuviated clay as clay skins or intra-ped concretions
of silicate clay. In places the Eb may be mixed within the topsoil by
cultivation and the surface horizon lies directly over the Bt. The Cg horizon
is a reddish brown strongly prismatic clay with distinct mottling along ped
faces.

This is an ideal grassland soil and in southern Cheshire is mainly
under permanent grassland or long ley. Barley is sometimes a secondary crop
and with careful management yields well. Where the series is more extensive
arable crops are becoming more important and are grown in rotation with short-
term leys.

Profile description (N.B. Profile description and analyses do not refer
  to the prepared pit)

Grid reference:         SJ 45/7493.

Soil subgroup:          Stagnohumic argillic brown earth.

Lithology:              Fine loamy over clayey; reddish till.

Locality:               350 m S of Gates-heath Farm, Colborne Bellow.

Elevation:              23 m O.D.

Slope and aspect:       $1^{o}$S.

Land use:               Re-seeded grassland.

Horizons:
  cm

Ap      Brown (7.5 YR 5/4) friable clay loam with few faint fine strong
0-23    brown (7.5 YR 5/8) mottles; slightly stony with small and medium
        subangular blocky breaking to fine subangular blocky and fine and
        medium crumb; abundant fine pores and common fine fissures; moderate
        intimately mixed organic matter;abundant fine fibrous roots; earth-
        worms present; sharp even boundary.

Bt(g)   Reddish brown (5 YR 5/3) firm clay with common faint fine and
23-54   medium light brownish grey (2.5 Y  6/2) and yellowish red
        (5 YR 5/8) mottles; slightly stony; moderate medium subangular
        blocky breaking to fine subangular blocky and medium crumb;
        common fine pores and fissures; low intimately mixed organic
        matter; common fine fibrous roots; merging even boundary.

BCg     Reddish brown (5 YR 4/3) plastic clay with many distinct large
54-90   greenish grey (5 GY 6/1) mottles along structure faces; moderately
        strong medium prismatic; common fine pores and rare fine fissures;
        few fine fibrous roots concentrated along structure faces.

Analyses

| Horizon | | Ap | Bt(g) | BCg |
|---|---|---|---|---|
| Depth (cm) | | 0-23 | 23-54 | 54-90 |
| Sand | (600 μm-2 mm % | 1 | 1 | 2 |
| | (200-600 μm % | 19 | 11 | 8 |
| | (60-200 μm % | 23 | 14 | 13 |
| Silt 2-60 μm % | | 33 | 31 | 35 |
| Clay < 2 μm % | | 24 | 43 | 42 |

| CaCO$_3$ equivalent % | - | nil | 6.0 |
|---|---|---|---|
| Organic carbon % | 1.7 | 0.5 | 0.3 |
| pH in water (1:2.5) | 6.1 | 6.7 | 7.7 |
| pH in 0.01M CaCl$_2$ (1:2.5) | 6.0 | 6.5 | 7.3 |
| C.E.C. (me/100 g) | 16.4 | 17.4 | 12.2 |

Pyrophosphate-extractable

| | Fe % | 0.05 | 0.01 | 0.01 |
|---|---|---|---|---|
| | Al % | 0.03 | 0.04 | 0.02 |
| | C % | 0.24 | 0.13 | 0.09 |

Residual dithionite-extractable

| | Fe % | 1.60 | 2.05 | 1.55 |
|---|---|---|---|---|

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APPENDIX

Definitions of physical properties of the soil

1) Water release characteristics and available water capacity

Core samples, taken in tinned metal sleeves of 22 cm$^3$ volume, were equilibrated at 0.05 and 0.15 bar suction on a sand suction table (Avery and Bascomb 1974). Subsamples from the sand cores were brought to equilibrium at 2.0 and 15 bars suction in a pressure membrane apparatus. Water contents at each suction were first calculated on the basis to oven-dry 105°C soil and then expressed as a percentage of the original soil volume.

The minimum available water capacity of a horizon (Av) is calculated from the difference between the volume of water retained at 0.05 bar suction, and the volume retained at 15 bar suction. This represents the water available to support crop growth after surplus, drainable, water has been removed.

2) Bulk density, air capacity and total pore space

The bulk density of the oven-dry cores and in some cases the particle density was determined. Total pore space was calculated for each horizon using a value of 2.65 cm$^{-3}$, for particle density or, where determined, the actual particle density for the horizon.

The air capacity, defined as the volume of air-filled voids at suction of 0.05 bar is expressed as a percentage of total bulk volume and indicates the relative aeration of soils during winter and spring when the soils are at or near field capacity. It also gives a general indication of the permeability of each horizon. The results of the physical property test are reported on the following scales.

| Retained water capacity (Ov (0.05)) (vol. per cent) | | Bulk density (Db) (g cm$^{-3}$) | |
|---|---|---|---|
| 0-9.9 | VL | < 0.2 | VL |
| 10-19.9 | L | 0.2-0.8 | L |
| 20-29.9 | ML | 0.8-1.3 | Medium |
| 30-39.9 | MH | 1.3-1.8 | H |
| 40-49.9 | H | >1.8 | VH |
| 50+ | VH | | |

Available water (Av)
+ air capacity (C$_a$)

| (vol. per cent) | |
|---|---|
| 0-4.9 | VL |
| 5-9.9 | L |
| 10-14.9 | ML |
| 15-19.9 | MH |
| 20-24.9 | H |
| 25+ | VH |

VL = very low

L  = low

ML = moderately low

MH = moderately high

H = high

VH = very high

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## GRASSLAND PRODUCTION IN RELATION TO SOIL FACTORS

by

J.O. Green

(Grassland Research Institute, Hurley, Berkshire)

One doesn't have to be trained in science to recognise that soils differ in their capacity to nourish crops, or that they differ in their reaction to treading and wheeling, under a given set of weather conditions.

The grass farmer is no less concerned than the arable farmer to ensure that his crop has an adequate supply of mineral nutrients. He is even more concerned, or more constantly so, with physical conditions in the soil, because grass grows almost the year round and he must harvest it continually.

In order to help him, we need to know what factors limit the supply of nutrients to the crop, and to understand the mechanics of soil compaction and poaching. We might be tempted to concentrate on those soil factors a farmer can manipulate by liming, manuring, tillage, drainage, even by warping, marling etc. But it is equally important to have an appreciation of the physical limitations of each soil type so that grassland can be managed in such a way as to avert serious damage to soil structure.

Jones et al (1972) brought soils from 16 diverse sites together for a pot culture experiment. With uniform additions of P, K, Mg, S and N, and with the pots kept at 75 cm water tension, ryegrass produced twice as much dry matter on one soil than on another.

The soil is not merely a source of plant nutrients: it has to be seen as a medium for the uptake of nutrients and, since that is one function of roots, for root development. As such, it has important physical, as well as chemical properties. The soil also serves as a platform for the anchorage of the plants and for the animals and machines that harvest the herbage. Seen from this viewpoint, its physical constitution is important, though our main concern is with the effect of changes in soil structure, occasioned by treading etc., upon the survival and growth of the crop.

Although the inherent physical characteristics of a grassland soil are relevant both to crop growth and to herbage utilisation, I propose to begin by discussing soil factors strictly in relation to crop growth. We need to establish what is required by the crop in the way of soil structure before we can assess the long-term significance of any change in structure that may be brought about by treading.

My own contribution to this discussion can be little more than a string of questions, but I shall at least try to raise some of the more pertinent issues.

The effects and reactions of soil are so conditioned by weather that many of them cannot usefully be discussed without reference to climatic factors. For instance, however well a soil may be endowed with plant nutrients, it can only be fertile if water is available for the uptake of those nutrients and for the biological activity involved in the whole nutritional cycle. As far as grass is concerned, it is important that the topsoil in which most of the soluble nutrients (indigenous or applied) reside, should have a water régime which renders those nutrients available throughout the long growing season of this crop. Rainfall or irrigation is needed to replenish topsoil moisture from time to time, though the interval will vary with the retentivity of the soil. At the same time, the soil needs to be adequately aerated so that roots can grow, giving the plants access to the

less mobile nutrients.

It is generally held that the Cheshire plain is a good area for grass production because there is a good supply of soil moisture. There is some justification for this assumption in that over the greater part of the area there is either a deep soil, or a water table within reach of grass roots: but what is probably most important is that the rainfall is relatively well distributed, and not so high as to cause much waterlogging. It may also be significant that over a large proportion of the area the topsoil is a sandy loam and the subsoil a retentive clay or silty clay.

Although soils differ in their capacity to generate available plant nutrients, and to hold them against leaching forces, these indigenous nutrients are nowadays, and in this region, by no means the sole supply. Moreover, the uptake of nutrients applied to the surface is dependent on adventitious water. In the case of long-term grass, there is limited scope for the distribution of applied nutrients through the soil profile: the least mobile materials, such as lime and phosphates, diffuse extremely slowly following surface application. In so far as the crop needs a continual supply of any such nutrient, frequent wetting of the upper soil must be advantageous. (As an aside, it can be argued that the main function of irrigation in the British climate is to make nutrients available, rather than to meet the crop's basic demand for water, because the greater part of this can be set by roots extracting water from deeper levels, where the concentration of nutrients is normally negligible.)

In searching for a soil factor that is closely correlated with grass yield, I think we are most likely to find one in the amount of plant-available water within the nutrient layer - integrated over the growing season. I will leave the delineation of the nutrient layer to discussion, but I would like to pursue the subject of soil water a little further.

In the course of our grassland surveys we have taken small auger borings to examine the top 30 cm of soil in each field and made assessments of soil texture and drainage status. We commonly find indications of imperfect drainage under swards that are dense, have good botanical composition, and have all the appearance of being productive crops. Only where there is severe gleying within 30 cm of the surface can we be reasonably certain that the most desirable grasses are at a disadvantage in competition with, say, creeping bentgrass; and even there we cannot say with any certainty that the yield of dry matter is depressed.

In the national study of permanent grass farms which is being carried out by the Joint Permanent Pasture Group and ADAS regional staffs, a survey of the grass fields on each farm is coupled with recording of physical inputs and outputs for the farm as a whole. The study began in the West Midland Region, and results for the first year in that region are now available. As in previous surveys, among swards of any given age those on poorly drained land contained a lower proportion of ryegrass and other preferred species (on average) than those on land we classed as imperfectly drained or well drained. However, there was no apparent correlation between the stocking rate or the output of a whole farm and its overall drainage ranking.

It would be unwise to conclude that grass production is not impaired by excessive wetness of the soil; results from the Langabeare experiment showed that yield can be increased by drainage on a very wet site, and it will be accepted that effective drainage will allow the soil temperature to rise more rapidly in spring, thus advancing the growth of grass. But I will suggest that a soil which is imperfectly drained, in the arable or even in the context of grass growth during the short days, may have a greater capacity to produce grass during a dry spell of weather in summer than has a free-draining soil. It is not simply that this summer growth compensates for a

late start; in many livestock enterprises the availability of fresh grass in August is a major determinant of stocking rate and, thereby, of productivity.

On the other hand, grass growth is commonly depressed in summer by lack of moisture and this must occur more frequently on the less retentive soils. Morrison and Jackson (1976) interpret results from the GM series of experiments as evidence that the effect of a shortfall of rain is moderated by a heavy soil.

Grass can only be exploited fully by harvesting successive crops of herbage before they decline in feeding value. Grazing animals or harvesting equipment must have access to the crop when it is ripe. In the process, some damage is done to both the crop and the soil. Some crop may be spoiled, and if stubble tissue is damaged there will also be a temporary reduction in growth. If soil structure deteriorates then, almost by definition, crop growth will suffer; and this effect may persist indefinitely. The wetter the soil at the time, the greater will be the effect upon its structure.

There has been much discussion about poaching of grassland and about the losses and damage it causes, but I would suggest that this is only the conspicuous tip of an iceberg. I suspect that the compaction that occurs within the profile, even when the soil is dry and the turf remains intact, is a cumulative process that might qualify for the term 'insidious'!

What I have in mind here is the compaction of a layer of soil at a level that is, for the most part, beyond the ameliorating influence of frost and less regularly subject to the alternate drying and wetting which alleviates the more superficial effects of poaching. There is little doubt that such compaction curtails root development, though how it operates seems obscure. A plant whose roots fail to penetrate the subsoil is not only deprived of subsoil water; it may also lose an anchorage. If the topsoil itself is very friable, wholesale sod-pulling can occur.

Any compaction that develops, either at or below the surface, to the point at which it impedes drainage will extend the periods during which the soil is susceptible to puddling and/or compaction.

What can the farmer do to prevent this kind of structural deterioration under grass? Perhaps because it occurs when the soil is moist - or downright wet - the first suggestion this question usually evokes is to improve the drainage. I wonder if this should be our first thought. Should it not rather be, to manage the sward so that it affords maximum protection to the soil? In the first place, it should be dense at the base, so as to cushion the soil against the impact of traffic and to spread the load. In this respect, intermittent grazing, by cattle alone, is little better than mowing. Frequent or continuous stocking throughout most of the growing season, housing of cattle while the soil moisture content exceeds the critical level for the particular soil type, and grazing sheep only for the remainder of the season, are all measures that will contribute to the formation of a dense sward. To complete this counsel of perfection I must add that, having produced a productive sward, one should think twice before reseeding land that is susceptible to physical damage. And, of course, drain as well. In a wet climate, and on some of the soils under discussion, belt and braces may be needed to avoid calamity.

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THE SUITABILITY FOR GRASSLAND USE OF THE TRIASSIC DRIFT SOILS
OF THE CHESHIRE PLAIN

by

T.R. Harrod

(Soil Survey of England and Wales, Starcross)

The Land Use Capability Classification of Bibby and Mackney (1969) and the Land Classification Surveys of ADAS (MAFF 1966) have been major developments in the interpretation of soil surveys, offering rational means of assessing land. Both systems consider the potential flexibility of land under farming of moderately high standard where limitations, such as adverse drainage, are effectively dealt with wherever possible. Both use very similar categories (classes in Bibby and Mackney, grades in the ADAS scheme) for land of agricultural potential. Both, however, place emphasis on flexibility and arable cropping, with only the third and lower classes/grades defined as best suited to grass. The experience of classifying as class 3 ground which grassland farmers confidently proclaim as "the best land in England" is one shared by many soil surveyors in grassland country, and bearing in mind that over half of the cropped land of England and Wales is in grass, classification of land suitability specifically for this crop seems worthwhile.

·To this end guidelines have been devised for classifying soil suitability for grassland (Harrod 1978). The purpose of this Paper is to outline the scheme and apply it to the drift soils of the Cheshire plain, several of which are of importance in extent and productive capacity. The scheme adopts the basic assumptions of Bibby and Mackney (1969) and uses information available from soil survey coupled with some climatic data. Four major classes of suitability are recognised in terms of the balance between potential yield, as influenced by soil and climatic conditions, and the trafficability of the land.

It is useful to consider what properties of soil, land and climate encourage the growth of grass and enable the farmer to manage and harvest it as a crop. Primarily the plant requires a balanced supply of nutrients, moisture and air. (In the summer half-year temperatures and light are sufficient to encourage continual growth throughout the lowlands of the British Isles). Soil conditions regulate the supply of moisture and air, while a basic assumption of the scheme (as in that of Bibby and Mackney (1969) is that, on well farmed land, nutrient supplies will be maintained. This supposes, at least in the more productive lowlands, frequent applications of nitrogenous fertilizers, to which, given suitable moisture conditions, grass is very responsive. If optimal growth is achieved, monthly, or more frequent access is necessary, not only to graze or mow the crop but also to apply fertilizers. Consequently frequent movement of animals and machinery is involved, and in dairy farming, the most profitable use of grass, twice daily traffic to milking is necessary. Unless movement is without damage to the sward, either by poaching or through rutting by wheels, there are both short and long term losses in production. Soiled and trampled grass is rejected by animals, while grazing under wet conditions encourages lameness in stock. More permanent degradation of soil structure by compaction makes the soil less suited to rooting, while bare patches in the sward invite colonisation by weeds, and the subsequent deterioration of the pasture. The capability of grassland lies not only in its ability to grow grass but also to physically carry stock and vehicles, a point which becomes increasingly evident as farmers strive for optimal productivity.

Of soil properties influencing grassland suitability, soil moisture régime (Hodgson 1974) is the most important, expressing through dryness subclasses the soil's regulation of moisture supply to the crop, and through wetness class its ability to allow movement over the land following wet weather. In better drained soils (those of low wetness class number in the Soil Survey Field Handbook, Hodgson 1974) available water capacity depends on particle size class, packing density, profile depth and stoniness. These are synthesised with climatic considerations to give dryness subclasses, which offer a good indication of relative droughtiness in soils. Laboratory measurements of available water are being made for an increasing number of soils. In wetter soils with higher wetness class numbers available water capacity can be supplemented by ground water, or is modified by the effects of slower downward drainage.

Soil wetness primarily influences ease of going over ground, but its affect on yield must not be disregarded. Whether or not the soil and sward are damaged when trafficked by animals or machines depends on soil bearing strength. This in turn reflects soil density and water content, both of which relate to properties usually directly observed by the soil surveyor, or to their derivatives. Pertinent direct observations are particle-size class, while retained water capacity (total soil water content at 0.05 bar tension, approximating to field capacity), and permeability (air capacity), can be related to these or obtained by laboratory measurement. While the lower plastic limit offers a useful guide to the strength properties of soil relevant to the study of poaching and related damage, this test is not currently available as part of Survey routine laboratory procedure.

Properties other than soil moisture régime can influence grassland suitability. In hill and upland farming where fertilizers cannot be applied so easily, the natural nutrient balance of the soil becomes more critical. Most minor elements needed by herbage and livestock are in balanced supply in the soil, notable exceptions such as teart (molybdenum-induced hypocupraemia) highlighting the dependence which is often taken for granted. Other soil properties influencing grassland use are similar to those affecting arable farming, but may differ in emphasis. These are particularly important in terms of ease of maintenance, improvement and reseeding of pastures. Whereas for general agricultural purposes land drainage may be feasible, for pasture the likely extent of improvement by drainage will depend on the soil and will determine whether the work is justified. Soil stoniness, shallowness and boulder content can be limiting where interfering with cultivations. While ease of cultivation is broadly related to trafficability and poaching susceptibility, its special requirements (Thomasson 1971, Jones 1975) are of concern when pastures are reseeded by conventional means. Wet land and hill and upland situations require careful timing of cultivation, usually during drier spells in summer.

Climatic influences on the suitability of land for pasture operate both directly, as in the regulation of growing season by temperature and indirectly by more complex interactions with the soil. Only in the Pennines, the Lake District and the Welsh Mountains is it considered (Harrod 1978) that yields are seriously curtailed by low temperatures, the 240 day isopleth of Hogg (1965) providing a useful boundary.

Given adequate temperature, light, moisture and nutrients grass grows vigorously and, by transpiration, rapidly removes water from the soil. It is capable of yielding several crops a year, and unlike annual crops, quickly covers the ground. Consequently, it depends heavily on frequent recharge of soil moisture to ensure continued growth. Intensive grassland management relies on rapid rotation of grazing and regrowth encouraged by nitrogen applied immediately after grazing: uptake of this fertilizer relies on it being

"watered in". The balance during the summer half-year between moisture supply, as rainfall, and depletion by evapotranspiration has been calculated for over 700 stations in the Soil Survey Field Handbook (Hodgson 1974) as Average Potential Cumulative Soil Water Deficit (MD). 100mm MD has been used (Avery et al 1974) in the soil map of England and Wales to separate the humid western and northern land from the dry lowlands.

Climate, where it affects soil wetness, regulates the period over which soils are trafficable and can sensibly carry stock. Another aspect of climate of no little concern to the farmer growing grass is the need for suitable conditions for conservation. While consideration of some environmental influences, such as those regulating ease of haymaking, is beyond the scope of a study of soil suitability for pasture, it should be noted that climatic constraints on husbandry can often be broadly parallelled by soil changes, which are themselves at least partly determined by climate. An example is the broad coincidence of the upper limit of pastoral farming and haymaking with the occurrence of thin peaty surface layers on permeable soils around upland margins.

To provide a rational basis for grassland suitability classification the various contributions of soil and climate, discussed above, are drawn together in the assessment of yield and trafficability/poaching risk categories, (Harrod 1978). The four yield categories (a to d in increasing order of drought susceptibility) are based directly on Field Handbook dryness subclasses, in which 1m profile available water is set against MD, with modification for cool uplands and moist western districts. Trafficability and poaching risk are jointly ranked on a five point scale, since the soil conditions bringing about poaching by hooves are also conducive to damage by vehicles and wheeled machinery. The scale (1-5) is in increasing order of poaching risk and decreasing ease of trafficability. Ordering follows integration of soil properties affecting long term soil strength: profile wetness class, depth of impermeable layer and retained water capacity of the surface horizon within moist or dry climatic zones.

Ideal pasture produces ample grass throughout the summer half year, which can be readily used without prejudicing later crops. Ranking of land by its suitability for pasture expresses the ease with which a balance can be struck between potential production, summarised in yield categories, and the utilisation and encouragement of growth, indicated by trafficability/ poaching risk categories. In the best suited soils this balance is well formed and easily maintained but in the most difficult it is far from ideal. Table 1 shows the integrated categories of yield and trafficability/poaching risk as guidance to the suitability classification (Harrod 1978) detailed below.

Table 1. GRASSLAND SOIL SUITABILITY CLASSES AND YIELD AND TRAFFICABILITY/ POACHING RISK CATEGORIES

| Yield Categories | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| d | C (ii) | C (ii) | C (iii) | C (iii) | C(iii) or (iv)/D |
| c | C (ii) | C (ii) | C (iii) | C (iii) | C(iii) or (iv)/D |
| b | B | B | C (iii) | C (i) | C (i) |
| a | A | A | C (i) | C (i) | C (i) |

Trafficability/Poaching risk category

GRASSLAND SOIL SUITABILITY CLASSES

CLASS A.  SOILS WELL SUITED TO PASTURE - Potential yields are high with
ample growth throughout the season.  The land is readily trafficked,
poaching risk is small and the large stock densities associated with intensive
grassland can be sustained with ease.  These soils are sufficiently resilient
to stand reasonable amounts of winter stocking, particularly by sheep.
Disposal of excess rainfall is rapid and siting is on slopes less than $11^{o}$.
In many districts their high potential as arable land is exploited.

CLASS B.  SOILS SUITED TO PASTURE WITH ONLY MINOR LIMITATIONS -
Restrictions of these soils occur as slight imbalances of potential yield and
trafficability, which are, however, acceptable and enable satisfactory intensive
use.  Large areas of long-established productive grassland come within this
class.  Some soils in drier areas may suffer mild summer drought and limited
autumn growth.  In moister areas problems are of trafficking and winter use
should be confined to dry weather.

CLASS C.  SOILS SUITED TO SEASONAL PASTURE - Here there are serious
limitations of potential yield and/or trafficability.  The balance between
these cannot be sustained throughout the season for a variety of reasons,
rendering the soils unsuited to use as intensive pasture.  Within this class
are several types of soil differently suited for seasonal grass.

(i)  Many traditional pastoral soils have high potential yields but suffer
large poaching risk and difficult trafficability.  While the most suited land
use is pasture such soils will not support large stock densities but can provide
very productive summer pasture.  This land is not usable in winter.

(ii)  Coarse, stony or shallow soils, particularly in dry areas, have low
potential yields but are very trafficable.  Grass growth is largely restricted
to spring and early summer although the land can be stocked during the winter.
Many of these soils are favoured for arable farming.

(iii)  Low potential yield and difficult trafficability are combined in many
traditional pastures in the drier midland, eastern and southern counties.
Here most clayey surface water gley soils and pelosols have available water
capacity far short of the MD.  When moisture conditions favour growth poaching
risk and difficulties of trafficking are considerable.  Winter use is not
advisable.

(iv)  Some upland soils suffer from restricted growing season and have poaching
and trafficability problems due to organic or humose surfaces.  Moderate
summer use is feasible.

(v)  On slopes of $11-25^{o}$ management is difficult.  Vehicular use is very
restricted and the sward poaches more readily than on similar soils on lower
gradients.

CLASS D.  SOILS ILL-SUITED FOR PASTURE - Such land has very small yield
potential and extremely difficult going.  Serious management and improvement
is not feasible.  Included are very wet upland soils, very stony, rocky or raw
soils, very steep land (slopes more than $25^{o}$) and ground often flooded by salt
water.

It can be useful in land management to identify the specific limitations
operating within grassland suitability classes, differentiating these as
suitability categories.  As with Bibby and Mackney (1969) letter notations
are adopted although, apart from gradient and/or soil pattern (code g) emphasis
differs.  Interactions of climate, soils and hydrology operate in various ways.
For present purposes notation 'w' applies where wetness retards full use,
primarily by raised poaching risk and difficulties of trafficability.  Code 's'
indicates that yields can be restricted by an available water capacity small

relative to climatic moisture deficit (MD). Where the growing season shortens to less than 240 days code 'c' is involved. Other climatic restrictions integrated into trafficability and yield categories are dealt with under 'w' or 's'. Such notations are economical of space, and helpful for cartographic purposes. Suitability class and category codes can also be complemented by yield and trafficability ratings, indicating overall potential.

Any consideration of grassland in England and Wales must take into account contrasts between the moist west and the relatively dry east. The one favours pastoral farming, the other arable farming. Avery et al (1974) divided humid western and northern land from the dry lowlands on the basis of the 100mm MD isopleth. Inclusion in the dry lowlands of much of south western England and the Cheshire plain seems unsatisfactory for the present scheme, since both areas are well known for their pastures. While a small MD undoubtably encourages grass growth, westerly maritime areas like Cheshire and the south west benefit from relatively frequent recharges of soil moisture during the summer, slightly earlier spring growth and an autumn flush when moisture deficits are made up well before the end of the growing season. Areas where return to meteorological field capacity precedes the end of the growing season by more than 30 days, coincide well with lowland districts favoured for grass growing. (Harrod 1978 Fig. 1, based on data from MAFF 1971 and Hogg 1965). Therefore, in the present soil suitability scheme the moist zone is extended beyond 100mm MD to include these.

The enhanced grass growth is recognised by soil dryness subclass ratings being raised one unit on conversion to the grassland yield category (b becomes a etc). At the same time moister conditions increase long term poaching risk and reduce trafficability, the use of dry and moist climatic zones in trafficability/poaching risk assessment having been already mentioned.

Guidelines to grassland soil suitability reflect the approach of Bibby and Mackney (1969), consideration being confined to the effects of unmodifiable physical limitations on farming of a moderately high standard. The influence of land drainage in the scheme deserves further discussion. While in coarse ground-water gley soils artificial drainage is very effective, in finer hydromorphic and semi-hydromorphic soils benefits are less easily achieved. Drainage of these commonly requires repeated secondary treatments to aid permeability, although in many soils with surface wetness, bearing strength cannot be raised to a stockable level unless there is evapotranspiration. Areas in which weather and soil moisture conditions only rarely combine to favour successful secondary drainage, may, nevertheless often support relatively low-output grassland farming on small sized holdings. In such circumstances considerations of farm size, as determined by traditions and history of land tenure, can colour judgment of what is a moderately high standard of management. When applying the scheme, therefore, it should not be assumed that effective land drainage has been carried out in the moist lowland and uplands on comparatively unresponsive soils, notably pelosols and clayey and fine loamy surface-water gley soils or stagnogleyic brown soils.

APPLICATION OF THE GRASSLAND SOIL SUITABILITY CLASSIFICATION TO THE TRIASSIC DRIFT SOILS OF CHESHIRE.

Table 2 summarises the basic survey data; wetness classes are those given in the county Bulletin (Furness 1978). Depths to impermeable layers are those most usual in the series and do not refer to specific profiles. Retained water capacity measurements where available (some taken from Jones 1975) form the basis of the classes given, otherwise they were estimated from published profile descriptions using the method of Harrod 1978, Table 2. This data is then used to estimate the poaching/trafficability category as in

Table 2 (following Harrod 1978 Table 4). Similarly available water capacity to 1m is derived either from published measurements or as estimates derived from particle size, packing density and stoniness given in profile descriptions (appendix I of the Soil Survey Field Handbook, Hodgson 1974, in which calculations are modified for wetter soils). MD for the area covered by these soils is taken as about 120mm. From these values the dryness subclass is obtained, which appropriately modified is the basis of grassland yield categories, (Harrod 1978 Table 1).

Table 2. SOME PHYSICAL PROPERTIES OF CHESHIRE SOILS

| Soil Series | Wetness Class* | Depth to Impermeable Layer (cm) | RWC of surface | AWC** | Dryness Subclass* |
|---|---|---|---|---|---|
| Salop | IV (III) | <40 | M <br> M | 147[3] <br> 131[4] | c <br> c |
| Flint | III (III) | 40-80 | M <br> M[4] | 139[3] <br> 101[4] | c <br> c-d |
| Clifton | IV (III) | <40 | M <br> M | 206[3] <br> 145[4] <br> 166[2] <br> 139[2] | a <br> c <br> b <br> c |
| Salwick | III (III) | 40-80 | H <br> H | 157[4] <br> 109[4] <br> 129[1] | b <br> c <br> c |
| Crewe | V (IV) | <40 | H <br> H | 153[4] <br> 150[4] <br> 129[1] | a <br> a <br> a |
| Rufford | V (IV) | 40-80 | M | 151[1] | a |
| Reaseheath | V (III) | >80 | L | 107[1] <br> 140[2] | a (b) <br> a (b) |
| Blackwood | IV (I) | >80 | L | 106[1] <br> 114[2] <br> 123[2] | b (c) <br> b (c) <br> c (c) |
| Newport | I | >80 | M <br> L | 116[4] <br> 100[1] <br> 105[2] | c <br> c-d <br> c-d |
| Crannymoor | I | >80 | L | 118[1] <br> 111[2] | c <br> c |
| Wick | I | >80 | M/L | 89[4] <br> 119[2] <br> 130[2] | c <br> c <br> c |
| Quorndon | IV (II) | >80 | M/H | 164[4] <br> 127[3] | a <br> b |

\* Indicates conditions after drainage

\*\* Raised numbers indicate references
(1) Furness (1971)
(2) Furness and King (1973)
(3) King (1977)
(4) Jones (1975)

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When drawn together, yield and trafficability categories allow estimation of grassland suitability class, (as in Table 5 of Harrod 1978) for twelve Cheshire soil series (Table 3).

Table 3.  GRASSLAND SOIL SUITABILITY CLASSES

| Soil Series | Trafficability and Poaching Risk | Yield | Suitability Class |
|---|---|---|---|
| Salop | 4 | b | C |
| Flint | 3 | b | B |
| Clifton | 4 | b | C |
| Salwick | 4 | b | C |
| Crewe | 5 | a | C |
| Rufford | 5 | a | C |
| Reaseheath* | 3 | a | C |
| Blackwood* | 1 | b | A |
| Newport | 1 | b-c | B |
| Crannymoor | 1 | b | A |
| Wick | 1 | b | A |
| Quorndon* | 2 | a | A |

*After adequate drainage

On the basis of the published profiles used to compile Tables 2 and 3, soils well suited to use as pasture (Class A) are Wick, Crannymoor and, after adequate drainage, Quorndon and Blackwood series. Poaching risk is small and moisture reserves relatively large. Because soil conditions also favour arable cultivation their high potential for grassland is not always realised. Class B, soils suited with minor limitation to pasture, is made up of the Flint, Newport and Reaseheath series, the latter after adequate drainage. Undrained the Blackwood series can be appropriately placed in this class. On the Newport series poaching risk is small and movement easy under almost all weather conditions, susceptibility to drought being the main restriction. As with most free draining soils these are more often used for arable farming. Pasture on Flint, Reaseheath and undrained Blackwood soils is less prone to drought but has a moderate potential for poaching. The remaining soils, including undrained Reaseheath and Quorndon are suited to pasture only seasonally. Potential yields of grass are large but grazing and management without damage is only possible at drier times in the summer half year.

The predominance in the Cheshire landscape of surface water gley soils in reddish drifts (Salop, Clifton, Rufford and Crewe series) is interesting in view of the county's long established reputation as a grassland and dairy farming district. These widespread soils present considerable difficulty to the cattle farmer, particularly in intensive dairying. Given enough fertilizers, grass yields are potentially substantial. However, timing of grazing and mechanised management is almost always difficult. Intensive use of these soils inevitably encourages traffic when they are liable to damage so that much of their potential yield is sacrificed.

The practice, at least since enclosure, of using this strong land for grass production, because of lack of arable potential, and later its development of a reputation as cattle country is mirrored elsewhere, for example in Leicestershire. There, as in Cheshire, the local reputation was founded on carefully regulated summer grazing with modest stock densities. Modern developments in the east Midlands, where summers are drier for longer periods, have favoured extension of arable farming onto the traditional pastures on surface water gley soils. In Cheshire the apparently slightly more favourable location and climate have, coupled with generally high standards of husbandry, maintained the traditional grass land use on these difficult soils, albeit in a more intensive form.

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## EDAPHIC EFFECTS OF POACHING BY CATTLE

by

### D.J. Briggs

(Department of Geography, Sheffield University)

INTRODUCTION

One of the main limitations facing attempts to increase output from grazing land is the problem of poaching or trampling. The problem is most acute under winter grazing régimes, particularly on low lying, poorly drained soils. In wet years, however, damage may equally occur during spring and autumn, and may be far more widespread. Thus, in 1977, active poaching was witnessed during May on clay soils in east Yorkshire, while in their review of agricultural effects on the soil in the late 1960's the Ministry of Agriculture recorded extensive poaching problems in many of the clay vales of England and Wales (MAFF 1970).

Two factors make the problem particularly difficult to cope with. First is the fact that the effect of trampling depend very much upon relatively short term weather conditions. Trampling during even short periods when the soil is wet and plastic may considerably reduce grass growth and cause serious structural damage to the soil (e.g. Campbell 1966). Yet in many instances, especially during the late winter and spring when alternative feedstuffs are not available, it may be impossible to delay releasing animals onto the land; if the soil has not dried sufficiently, damage is inevitable. Given the difficulties in predicting weather patterns and soil conditions, such events are difficult to avoid on many of the heavier, more susceptible soils.

The second problem arises from the fact that trampling and grazing pressures are not evenly distributed. In any field, pressure tends to be concentrated in certain areas - around gates, feed troughs and water troughs, for example. Poaching in these situations is common, even during relatively dry years, when attempts are made to fully exploit the rest of the land.

In many areas, therefore, poaching is inevitable. It brings with it a series of problems. Under extreme conditions it may result in a significant loss of yield, and unless the soil is restored the effect may persist for several years. Under dairying systems, poaching also presents a serious problem of cleanliness. Clearly, therefore, it is important to understand the effects of poaching upon the soil, since from this it may be possible to devise means of amending poached land. The aim of this paper is to examine some of the edaphic consequences of poaching, and briefly to discuss some of the problems of rectification. The data presented are the preliminary results from an investigation of poaching funded by a University of Sheffield research grant.

PROCESSES AND EFFECTS: THEORETICAL CONSIDERATIONS

It is, perhaps, justifiable to define two forms of poaching. When the soil is dry (probably some way below the liquid limit), the effect of trampling is to consolidate the soil, closing up pore spaces, reducing total porosity and increasing bulk density. When the soil is wet, its shear strength is reduced and the pressure applied by the animal causes shearing of the soil. This destroys the natural structure of the soil and may further reduce porosity and increase bulk density. The main effect, however, is to overturn and remould the soil.

Since consolidation of the soil inevitably diminishes the rate of drainage and increases the ability of the soil to retain water, there is

a tendency for it to lead to shearing and remoulding. In many cases, therefore, remoulding is a product of more prolonged or more intensive poaching. It is normally accompanied by severe tearing, bruising and burial of the vegetation and it leads to the creation of a rough, pocketed soil surface. In practical terms it seems likely that the effects of remoulding are considerably more serious than consolidation, for during remoulding, the hooves of the animals may penetrate some way into the soil. Vegetation and organic matter are liable to be buried at some depth, while a compacted layer may form at the base of the sheared layer.

The effects of poaching, are however, more complex and far reaching than this outline suggests. One reason is that, compared to unpoached areas, poached soils frequently occur under higher stocking intensities. To this extent poaching can, in fact, be considered a result of overstocking - albeit localised and temporary. The result is that poached soils experience a greater input of animal residues, in the form of dung and urea. Additionally, reductions in the rate of vegetation growth and in some cases, complete destruction of the vegetation cover, lead to changes in the vegetative uptake and return of soil nutrients. Combined with the indirect effects of compaction, such as changes in the redox potential, these modifications clearly result in complex adjustments to both the organic and chemical processes in the soil.

These changes may be anticipated in a purely qualitative way, but despite the studies by Gradwell (1966, 1968) and Edmond (1962, 1963), too little data is yet available to provide the framework for an adequate quantitative model of soil processes under considerations of poaching. The model presented in Figure 1, therefore, is a first step towards an understanding of these effects. This diagram shows, the dual aspects of poaching - the direct structural consequences of trampling and the more indirect changes due to differences in the rates of nutrient cycling by plants and animals.

Taking first, the effects of trampling upon the soil it is apparent that the initial effects are to reduce plant growth and to cause compaction of the soil. Edmond (1962, 1963), working in New Zealand, found that grass growth was reduced by up to 30% under trampling intensities of 6-9 sheep/ acre (15-22/ha); Campbell (1966) recorded reductions in growth of 15% after a single day's grazing by cows at 60-120/acre (148-296/ha). Under excessive stocking rates it is in fact common for the vegetation to be completely destroyed by trampling, and this effectively short-circuits the plant pathway in the nutrient cycle within the system, leading to diminished inputs of plant residues and of nutrients.

The structural effects of trampling are initially a reduction in soil porosity and an increase in bulk density. Gradwell (1968) recorded an increase in the bulk density of a volcanic soil from 0.79 to 0.88 g cm$^{-3}$ in response to an increase in the stocking intensity from 3.6 to 21.5 sheep/acre (9-53/ha). This change seems to be a result mainly of the loss of macropores, for in the same study Gradwell noted a reduction in the volume of large pores from 13% to 7.1%.
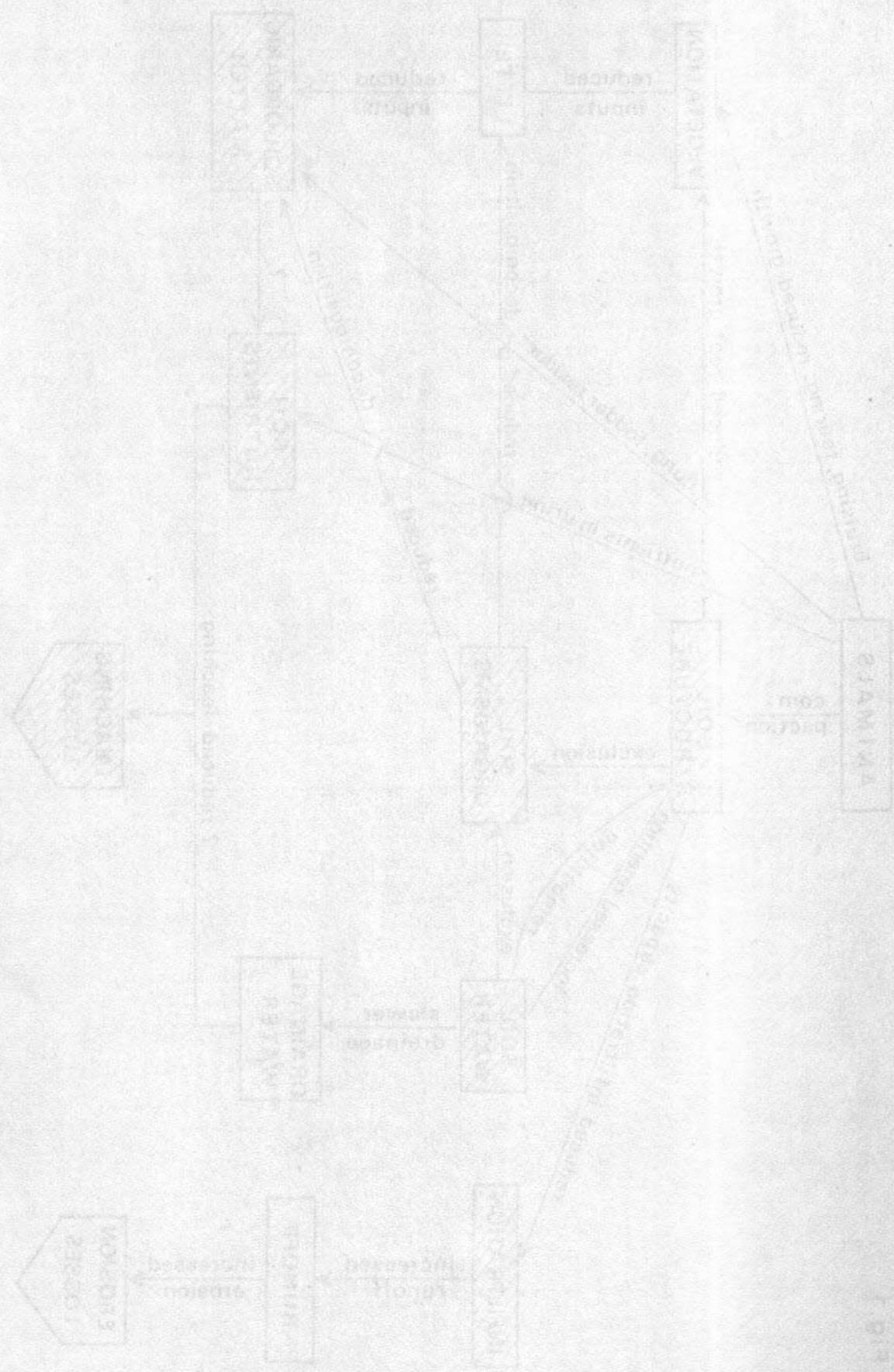
A variety of consequences follow from this compaction of the soil. The infiltration capacity is reduced (see, for example, Chow 1966), and this in turn leads to increased runoff and possibly to erosion. It may mean also that smaller quantities of nutrients are supplied to the soil by rainfall. At the same time, the loss of macropores and corresponding increase in capillary pores reduce the drainage capacity of the soil and may increase its ability to retain water for long periods. The anaerobic conditions which result are liable to lead to reduction of nitrates, sulphates and so on and thus to the creation of more soluble compounds. On the other

Fig.1

VEGETATION

LITTER

SOIL ORGANIC MATTER

reduced inputs

reduced inputs

ANIMALS

SOIL NUTRIENTS

SOIL STRUCTURE

SOIL ORGANISMS

LEACHING LOSSES

SOIL WATER

DRAINAGE WATER

INFILTRATION

RUNOFF

EROSION LOSSES

reduced growth

reduced root growth

bruising, tearing, reduced growth

dung, fodder residues

reduced decomposition

decomposition

?

nutrients in urine

reduced

com-paction

exclusion

exclusion

removing

increased retention

increased infiltration

reduced infiltration capacity

slower drainage

? reduced leaching

increased runoff

increased erosion

A PARTIAL MODEL OF POACHING

hand, the slower drainage rate will tend to diminish leaching losses.

These adjustments to the pressure of trampling are paralleled by the changes in the cycling of nutrients by the animals. In general, due to the diminished grass cover of heavily trampled areas, the uptake of nutrients by grazing is severely reduced. At the same time, however, a transfer of materials from more productive areas tends to be affected through the concentration of dung, urea and fodder residues in the over-stocked area. In this way, there is likely to be an increase in the inputs of nutrients through the animal pathway. The effects upon the soil are, however, rather difficult to predict. In general, it seems that, despite the initial inhibitory effects of urea upon nitrification, nitrate contents may increase (Doak 1952). Similarly, soil contents of potassium (returned mainly in the urine), calcium, magnesium and phosphorus (mainly in dung) are also likely to rise (Davies et al 1962, Floate 1972). This effect is likely to be accentuated by the far slower leaching losses from the compacted soils. However, the decline in the numbers of soil organisms caused by trampling, will tend to slow down the rate of organic decomposition, and for this reason nutrients are liable to be stored for longer in non-available forms. Overall, therefore, although one may expect an increase in the total contents of nutrients in the poached areas, relatively little of this will probably be readily available to plants.

TESTING THE MODEL

In order to test the general framework of the model in Fig. 1, therefore, and in order to quantify some of the responses suggested, it was decided to assess the effects of prolonged overstocking on a number of key soil variables (Table 1).

Table 1.                    SOIL ANALYSIS OF SAMPLE PLOTS

| Property | Depth | Method |
|----------|-------|--------|
| Bulk density | 0-5, 5-10, 10-15 cm | Core method |
| Porosity | " " " | Core method, SG by displacement |
| Pore size distribution | " " " | Suction table and pressure plate |
| Available water capacity | " " " | Suction table and pressure plate |
| Exchangeable K | " " " | By flame photometer on ammonium acetate extract |
| Exchangeable Ca | " " " | By EDTA titration on ammonium acetate extract |
| Exchangeable Mg | " " " | By EDTA titration on ammonium acetate extract |
| Available $NO_3$ | 0-3,3-6,6-9,9-12,12-15cm | Specific ion electrode on $H_2O$ extract |
| Organic carbon | " " " " | Walkley-Black titration |
| Infiltration capacity | - | Cylinder infiltrometer |
| Earthworm numbers | - | Hand sorting |

Accordingly, three plots were set up in a field showing evidence of local overstocking. One plot was located in an area of intense damage, characterised by considerable remoulding of the soil. A second plot was in an area of compaction but not remoulding; in this plot scattered vegetation was still present. A third, control plot was in the lightly-grazed, fully vegetated area. The stocking intensities of the three plots could not be determined exactly, but were in the approximate ratios of 20:4:1 respectively. For convenience the three plots are referred to as heavily, moderately and lightly stocked. The plots were sampled at intervals from the spring of 1977 onwards. Except where otherwise stated the results presented below relate only to the sampling in early May. In each plot, six sites were located on each occasion, and samples taken at depths of 0-5, 5-10 and 10-15 cm for most analyses, but at 3 cm intervals from the surface to 15 cm for nitrate and organic carbon analyses. Assessments of infiltration capacity, leaching losses and earthworm numbers were made separately.

RESULTS

1) Soil structure

Because of the complexity of soil structure, a number of different properties were measured to assess the impact of trampling. These comprised bulk density; porosity, pore size distribution and aggregate stability (Table 1).

On the control plot, bulk densities increased slightly with depth, reflecting probably the reduced effects of roots and organic matter below the upper 5 cm of the profile (Table 2, Fig. 2). A similar pattern was found in the moderately stocked plot, although densities were higher, particularly in the topmost layer (Table 3). In the heavily stocked plot the bulk densities did not change significantly with depth and, in the surface layer, were markedly higher than in both other plots.

In general similar, though less marked patterns were shown by the measures of porosity, a decline in porosity values being evident with depth in the control plot, but no significant change occurring in the heavily stocked area. In the surface layer, porosities were significantly higher in the lightly stocked plot than in either of the other areas, but no significant differences occurred in the lower horizons.

More detail is given to this picture of structural changes by consideration of the pore size distribution of the soils. Minor differences are apparent in the volumes of micropores in the surface layers of the sample plots (Table 3, Figure 2), but the main variations relate to the larger pores. Compared to the control plot, both the moderately and heavily stocked areas have fewer pores in the 0.06-0.009 mm range in the surface layer. Below this layer, the two most lightly stocked areas show no significant difference, but both have more pores within this range than the heavily stocked area. In part, this indicates that in the moderately stocked (consolidated) area compaction is most intense in the uppermost zone of the soil, while in the heavily stocked, remoulded area loss of pore space extends to greater depths.

The picture is more complex, however, for, in the case of the macropores (> 0.06 mm), the only significant difference is between the lightly and moderately stocked plots: markedly more pores of this size occur in the lightly stocked areas. While allowing for the problems of measurement and the possibilities of chance differences, the explanation seems to be partly that, under the heavy stocking regime the burial of undecomposed masses of organic residues produces discrete mats of vegetable matter. In the artificial conditions of laboratory analysis these act as macropores, though it seems likely that their influence in the field is considerably less important. Additionally, inspection of the plots suggested that dessication cracks formed

Table 2        RESULTS OF SOIL ANALYSES OF SAMPLE PLOTS

| | | Bulk Density (g cm⁻³) | Porosity (%) | Exchangeable Ca (mg/100g) | Exchangeable Mg (mg/100g) | Exchangeable K (mg/100g) | Available Water Capacity (%) |
|---|---|---|---|---|---|---|---|
| HEAVILY STOCKED | 0-5cm | 1.44 | 46.1 | 194 | 106 | 94.3 | 15.6 |
| | 5-10cm | 1.37 | 45.2 | 192 | 99 | 80.0 | 10.7 |
| | 10-15cm | 1.33 | 47.2 | 196 | 100 | 74.4 | 14.9 |
| MODERATELY STOCKED | 0-5 cm | 1.25 | 50.2 | 274 | 117 | 38.2 | 14.7 |
| | 5-10cm | 1.31 | 45.0 | 240 | 101 | 21.2 | 14.6 |
| | 10-15cm | 1.35 | 45.5 | 227 | 89 | 17.2 | 14.6 |
| LIGHTLY STOCKED | 0-5 cm | 1.11 | 54.4 | 263 | 125 | 16.4 | 16.7 |
| | 5-10cm | 1.26 | 46.8 | 231 | 119 | 6.4 | 14.4 |
| | 10-15cm | 1.27 | 46.1 | 204 | 105 | 4.1 | 16.2 |

Fig. 2

VOLUME (%)

BULK DENSITY (g cm$^{-3}$)

HEAVILY STOCKED

MODERATELY STOCKED

LIGHTLY STOCKED

DEPTH (cm)

< 0.0002 mm

0.0002- 0.001mm

0.001- 0.009mm

0.008- 0.06mm
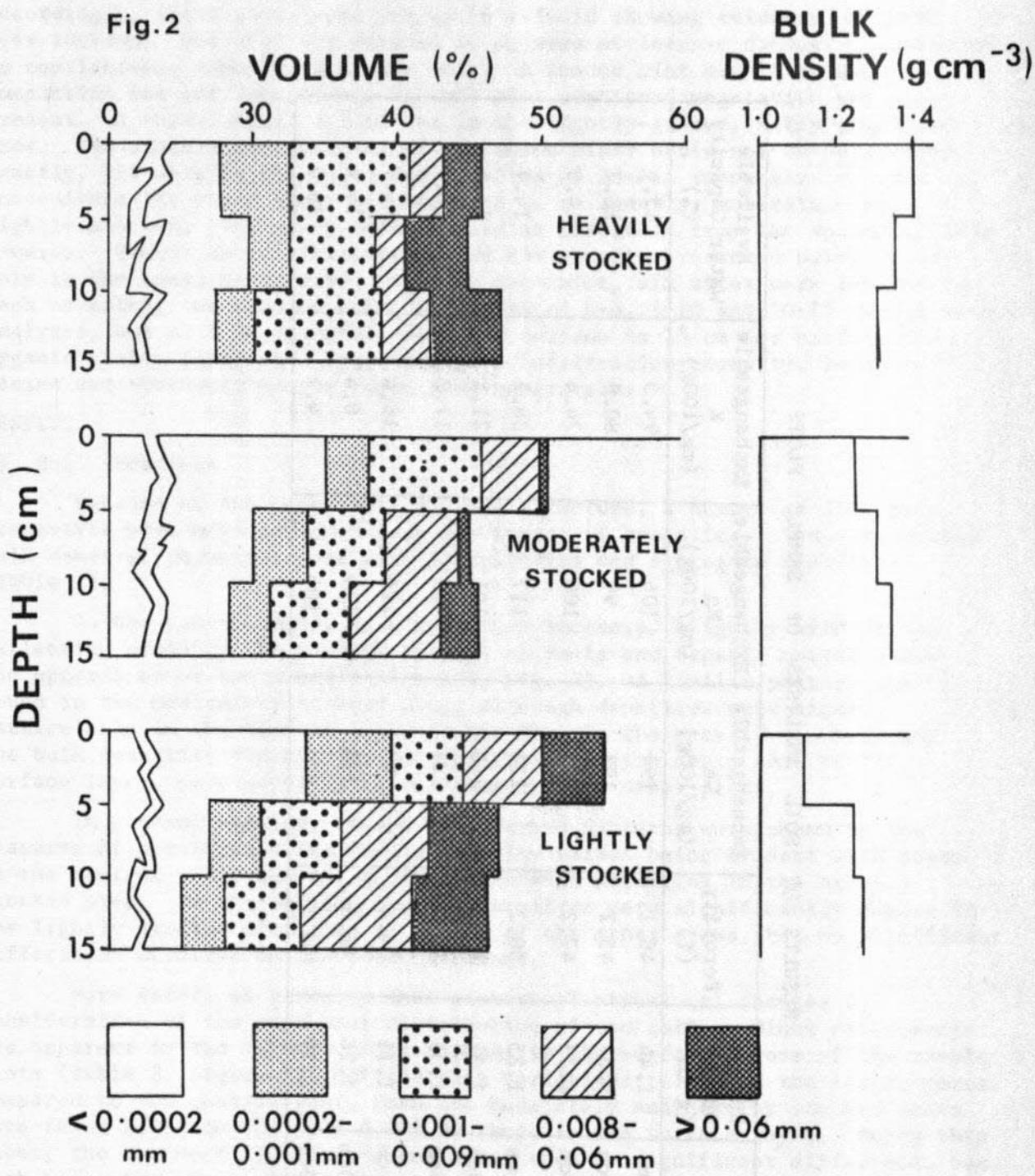
> 0.06 mm

Table 3. SIGNIFICANT DIFFERENCES IN SOIL CONDITIONS UNDER DIFFERENT STOCKING INTENSITIES (5% REJECTION LEVEL FOR STUDENT'S t TEST)

| PROPERTY | DEPTH | | |
|---|---|---|---|
| | 0-5 cm | 5 - 10 cm | 10 - 15 cm |
| BULK DENSITY | H>M>L | | |
| POROSITY | L>M=H | | |
| PORES > 0.06mm | L>M | | |
| PORES 0.009 - 0.06mm | L>M = H | L = M>H | L = M > H |
| PORES 0.001 - 0.009mm | | | |
| PORES 0.0002 - 0.001mm | L>M | | |
| AVAILABLE WATER CAPACITY | | | |
| EXCHANGEABLE Ca | L = M>H | L = M>H | M>L = H |
| EXCHANGEABLE Mg | L>H | | |
| EXCHANGEABLE K | H>M>L | H>M>L | H>M>L |

| PROPERTY | DEPTH | | | | |
|---|---|---|---|---|---|
| | 0 - 3cm | 3 - 6 cm | 6 - 9 cm | 9 - 12cm | 12 - 15 cm |
| ORGANIC CARBON | L = M>H | L = M>H | L = M>H | H>M | |
| NITRATE - NITROGEN | H>M>L | H>M>L | H>M>L | H>M>L | H>M>L |

(note H = heavily stocked; M = moderately stocked; L = highly stocked)

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in the remoulded soil in the heavily stocked plot as it dried. This probably led to the creation of widely spaced macropores in this soil, which were apparently picked up by some of the samples. Consequently, while the expected difference was recorded between the lightly and moderately stocked régimes, no differences could be distinguished in the case of the heavily stocked plot.

Taking the structural properties as a whole, the following general patterns can be discerned:

i. bulk densities increase in the surface layer in response to trampling.

ii. porosities in the surface layer tend to decrease under trampling but less markedly.

iii. trampling leads to a loss of the larger pores, particularly from the surface layer but, to a lesser extent throughout the upper 15 cm under heavy stocking conditions.

iv. the overall effect of remoulding under heavy stocking is to mix and overturn the soil, thus destroying the vertical differences which otherwise exist.

## 2) Hydrological properties

As a result of the changes in porosity and structure, the poached soil also shows differences in its ability to retain and absorb water. Measurements of infiltration capacity reveal a marked reduction in the rate at which rainwater can enter the soil when affected by trampling; infiltration capacities fell from 7.64 cm $hr^{-1}$ on the lightly stocked plot to 0.10 cm $hr^{-1}$ on the moderately stocked plot and practically zero on the heavily stocked area (Table 4).

Table 4 INFILTRATION CAPACITIES AND EARTHWORM NUMBERS
OF SAMPLE PLOTS

| Stocking rate | Infiltration capacity (cm $hr^{-1}$) | Earthworms (no $m^{-2}$) |
|---|---|---|
| Heavily stocked | 0.008 | 0.0 |
| Moderately stocked | 0.103 | 42.5 |
| Lightly stocked | 7.638 | 145.0 |

The total water-holding capacity of the soil similarly falls as the porosity is reduced. However, relatively more is apparently held at higher tensions, and thus the effect upon the available water capacity is not so marked (Tables 2, 3). In general it appears that more moisture is retained in available form in the lightly stocked area than in the moderately or heavily stocked plots; the overall water holding capacities of the top 15 cm are 15.8%, 14.6% and 13.7% respectively. The changes are notably less than those recorded by Gradwell (1968) but this seems to reflect the differences in the soils studied. In this investigation the original available water capacity of the soil is relatively low, for the soil is fine-grained and compact.

## 3) Organic properties

Changes in the organic matter content of the soil appear, in many ways, to be one of the most fundamental effects of poaching. Under light stocking the organic matter content shows an expected decline with depth from an average of about 4.4% at the surface to 2.0% at 12-15 cm. A similar pattern is apparent in the moderately stocked plot, but under heavy stocking the organic content does not change appreciably with depth, averaging 2.1 - 2.5% throughout the profile (Figure 3). In part this reflects the effects of overturning and burial of the soil during remoulding by animal hooves. However, it also represents a considerable loss of organic matter from the top 9 cm (contents are significantly lower than in the other plots throughout this depth). It further seems that this loss of organic matter has a range of indirect effects, for it accounts to some extent for the changes in porosity and bulk density seen in the poached soil. Given the greater inputs of dung into the trampled areas, this loss must represent the effects of the destruction of vegetation.

The soil fauna is similarly influenced by poaching. Earthworm counts showed an average of $145/m^{-2}$ in the lightly stocked plot. By contrast an average of $42.5/m^{-2}$ were recovered from the moderately stocked plot and none from the heavily stocked area (Table 4). Although it is likely that the mesofauna is more severely limited by poaching than the micro-organisms, it nevertheless seems clear that the population of soil organisms is reduced by trampling. Moreover, as Edwards and Heath (1962) convincingly showed, earthworms play a vital role in organic matter decomposition, and their loss alone may have considerable repercussions upon the processes of organic matter decay and nutrient cycling.

## 4) Available nutrients

The chemical effects of poaching are possibly the most complex and unpredictable parts of the whole system, for they depend upon the relative strength of several different interactions. In general, poaching seems to lead to an increase in both nitrate and potassium contents, but a decline in the contents of calcium and magnesium.

The rise in the nitrate content is possibly a reflection of the stimulatory effect which urea has upon nitrification (Doak 1952). However, the reduction in the rate of leaching (see below) may help retain nitrate within the poached soil.

The changes in the cations are particularly interesting. Potassium is a major nutrient constituent of urea, and the increased quantities of exchangeable potassium in the poached soil presumably attest to the higher inputs of urea. In contrast, both calcium and magnesium are input mainly in dung. In this form, especially in the absence of soil fauna, they tend to remain in an unavailable state. Thus, while relatively little calcium and magnesium is taken up by cation exchange, potassium is readily attracted from the urea by the exchange sites or is stored in a soluble state within the soil solution.

## 5) Leaching losses

Measurements of leaching losses were made by artificially leaching two cores from each plot with 125 mm distilled water. Analysis of the leachates showed that the concentration of nutrients was related to the intensity of trampling. However, the yield of drainage water was only 13.2% from the heavily trampled plots, compared with 61.6% from the moderately stocked area and 53.2% from the lightly stocked plot. Thus, the high concentrations from the heavily grazed plot result from the flushing effect of the first few volumes of leachate. The total leaching losses from the

ORGANIC CARBON (%)

DEPTH (cm)

NITRATE-NITROGEN (mg/100g)

DEPTH (cm)

Lightly stocked
Moderately stocked
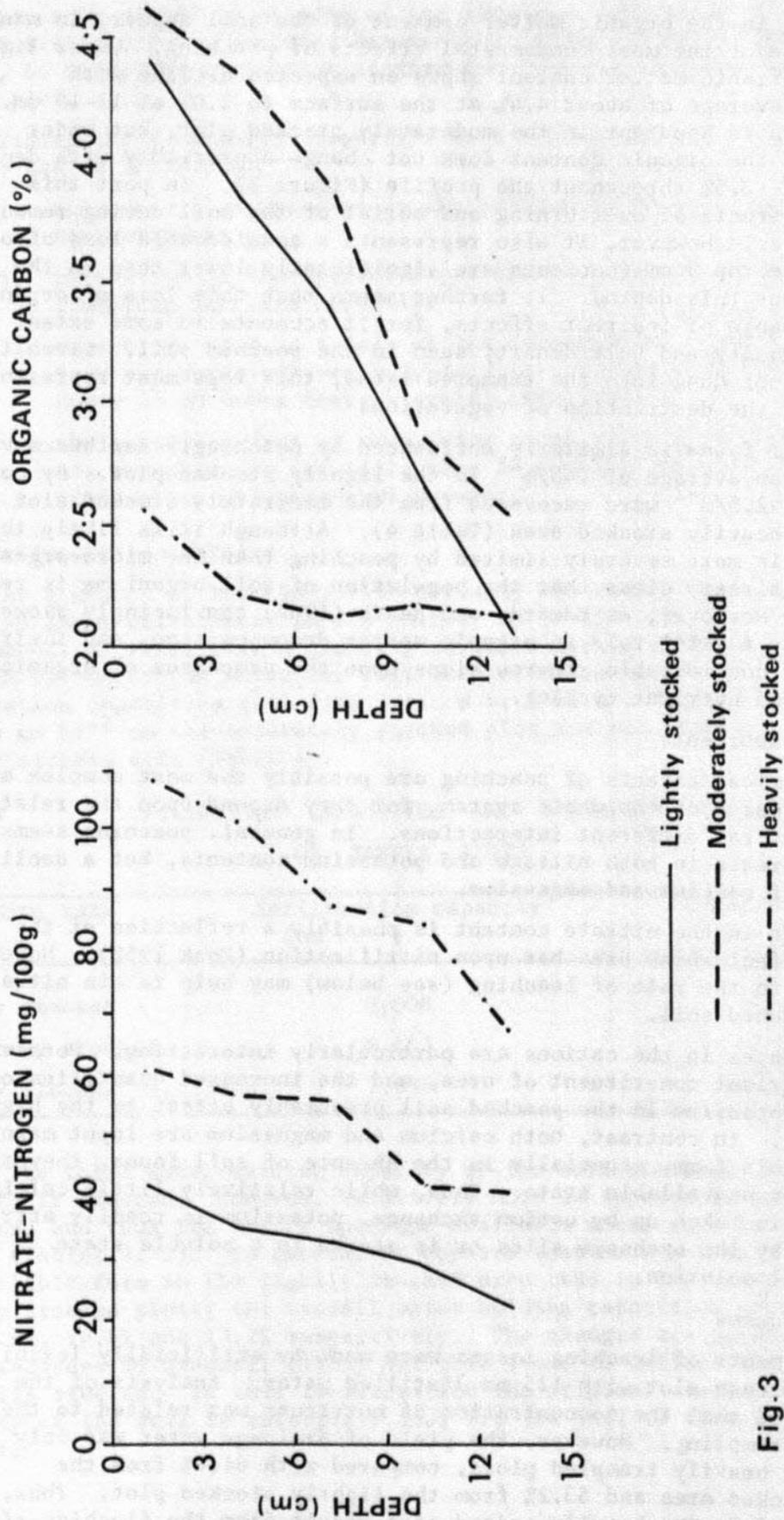Heavily stocked

Fig.3

heavily grazed area are consequently almost negligible, and far less than from the other areas (Table 5).

Table 5.          LEACHING LOSSES FROM SOIL CORES

| Stocking rate | ppm applied water | | | |
|---|---|---|---|---|
| | NO$_3$ | K | Ca | Mg |
| Heavily stocked | 30.3 | 48.2 | 10.1 | 2.5 |
| Moderately stocked | 98.2 | 298.1 | 315.6 | 132.2 |
| Lightly stocked | 55.9 | 69.5 | 181.1 | 239.8 |

DISCUSSION AND CONCLUSIONS

These results generally support the model outlined in Figure 1, and allow a number of 'order-of-magnitude' values to be assigned to the changes which occur under poaching. They also illustrate the way in which the response of the soil depends upon the interaction between the direct effects of trampling and the changes in the inputs and outputs of nutrients and organic residues; in particular, in the balance between the vegetative and animal nutrient cycles.

Several practical considerations also arise. In particular, the fact that poaching affects the chemical status of the soil means that when restoring poached areas adjustments probably need to be made to the nutrient levels by fertilising. In this context it is worth noting that amendment of the soil is likely to stimulate organic decomposition and faunal activity. Thus, although there is an apparent tendency for nitrate contents to increase under poaching, this may well be reversed during recovery of the soil, and nitrogen deficiencies may develop.

A further question of especial significance is the rate at which the effects of poaching are reversed when the trampling pressure is withdrawn. Gradwell (1968) presented data indicating that the bulk density of the surface soil failed to recover completely during the summer months, and the same seems to be true here (Table 6).

Table 6.          BULK DENSITY CHANGES DURING THE SUMMER (g cm$^{-3}$)

| Stocking rate | May | August |
|---|---|---|
| Heavily stocked | 1.44 | 1.34 |
| Moderately stocked | 1.25 | 1.13 |
| Lightly stocked | 1.11 | 1.06 |

One implication of these observations is that recovery of the poached areas is not possible simply by removing the trampling pressure for short periods, for example by excluding animals for the summer, by avoiding trampled gateways, or by moving feed-troughs. Indeed, this latter approach may well lead to the extension of the problem to new areas of the field. Instead, restoration seems to require deep ploughing, fertilizing and reseeding.

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## RESULTS OF SUBSOILING EXPERIMENTS ON THE COTTAM (SALOP) SERIES
## IN NORTH WALES

by

G.R. Davies

(A.D.A.S. Bangor)

INTRODUCTION

Shortly after the writer came to North Wales in 1970, a number of cases of "pulling out" of grass by grazing cattle were investigated in the Maelor district of Clwyd. In that year all instances of that type of problem seemed to occur on soils derived from Triassic Boulder Clay - Salop series and its somewhat better drained variant mapped as the Cottam series in North Wales, Roberts (1958), Ball (1960 and 1963). It was considered that the imperfect and poor drainage on these two soils series could be leading to shallow rooting of the grass which in turn resulted in the "pulling out" of the grass by cattle during dry weather. In order to examine this theory consideration was given as to the possibility of improving the drainage on fields so affected.

Soils of the so called Cottam series contain a very compact mottled zone at 20-30 cms but then pass into red, fissured clay or silty clay. The thickness of the mottled zone varies but the clay is often reached at 40-45 cms and it was considered that if this compact zone could be shattered, improvement of the drainage might result without resort to the installation of tile drains. In his review of subsoiling and its effect on crop yields, Swain (1975) reported that marked responses had been obtained in arable crops such as potatoes and cereals; better root growth below 20 cms had also been obtained. It was therefore decided to carry out subsoiling trials at three sites in the Maelor.

Because at one site in the Maelor a very marked improvement in drainage conditions was obtained with a very obvious increase of grass growth in early spring, it was decided to extend the series of trials to the area of similar soils in the lower Clwyd valley. As reported by several speakers at a joint ADAS/PPG (ARC) 'Symposium on Subsoil Treatments on Grassland' at the National Agricultural Centre on 17 March 1976 (unpublished) yield responses have been very variable and in the main disappointing, especially where measurements were taken at the "silage" or "hay" stage of growth. In the North Wales experiments, where obvious improvements in drainage were obtained, at all the 'wet' sites in fact, grass growth commenced earlier on the treated plots. An attempt was made, therefore, to quantify this increased early growth.

METHOD

In all some eight trials were layed down and at each, two parallel strips, each 8-16 m in width, were subsoiled. The two subsoiled strips were separated by distance at least as wide as the subsoiled area; this was used as a control plot with a second control plot outside one or other of the subsoiled areas. At one or two sites, however, a much greater distance was left between the two subsoiled strips, and then both control plots were sited on this in 'between' zone. In most cases the subsoiled areas extended across the width of the field but leaving a headland at each end. In no case did the subsoiled slits extend into a ditch.

Subsoiling was carried out, using the Department's 'Lely' subsoiler,

to a depth of approximately 45 cms. In all cases a tractor wheel ran on the slit made by the previous run giving a width between slits of 70-75 cms. Soils were dry to a depth of at least 50 cms when the trials were subsoiled and a considerable 'heave' was obtained on all occasions.

Three trials were laid down in the Maelor district in early September, 1970. However, shortly afterwards there was a change in the farming plan at one of the sites and this had to be abandoned. Dip wells were sunk at the other two sites and readings taken for about 18 months. At Hollybush, where yields were also measured, observations ceased in Spring 1972 when the farmer tile and mole drained the field. At Wallingford, no effects had been noted, and, although spasmodic observations were made for a further 18 months, no regular readings were obtained after the Spring of 1972.

A further five trials were started in late September/early October 1972 in the lower Clwyd valley and dip wells were sunk at all five sites in the November. At the St Asaph site no effects were seen and observations ceased when the field was ploughed up in Spring 1974. No consistent effects were noted at Trefnant, either, and this site was abandoned in Spring 1974. Although the Bodelwyddan site, the only one on recently drained land, was giving positive results, it too had to be abandoned in Spring 1975, when part of the experimental area was ploughed up.

Both sites at Waen gave very marked responses and one of the trials is still in being. Unfortunately, so great was the success at Waen, that the farmers (two brothers) commenced an intensive scheme of subsoiling on the farm and, in so doing, "destroyed" the control plots at the other site.

Dip wells were installed, one on each of the treatments by first boring out a vertical hole 75 cms deep and 10 cms in diameter and then inserting in it a piece of plastic drainpipe 7 cms in diameter. The gap between the outside of the pipe and the wall of the hole was then filled with gravel. Covers were placed over the dip wells to prevent damage by, and to, stock in the field. During each winter and spring, the level of water in the holes was measured at approximately monthly intervals.

Because the major effect of improving the drainage of grassland is usually noted in the early growth of spring, cuts were taken at a number of sites to obtain yield data. At Hollybush the cut was taken on 1 June when the rest of the field was mown for silage. At the Clwyd sites, cuts were taken earlier, i.e. when the subsoiled plots appeared to be ready for grazing. Sub-plots at Bodelwyddan in 1974 and at Waen in 1974, 76 and 77 were given an early spring top dressing of nitrogen at 62 kg/ha to study the interaction of subsoiling with nitrogen. In all cases four to six random cuts, each of $9m^2$, were taken from each plot or sub-plot and weighed. The dry matter content of the herbage was determined on sub-samples.

In 1977 the Entomology department of ADAS at Bangor sampled the plots at Waen and estimated the leatherjacket populations on the control and subsoiled plots.

RESULTS

As stated earlier, no marked effects due to subsoiling treatments were seen at three of the sites - Wallingford, St Asaph and Trefnant. It was obvious that at all three sites, fields stayed reasonably dry during the winter and only small scattered pockets of wet soil were seen. The conclusion must be drawn that in spite of the apparent impeded drainage in the profile, reasonably effecting drainage systems had been installed at some time in the past.

Hollybush.

After the subsoiling had been carried out in early September 1970, the

autumn was rather wet and by late November marked differences in the surface condition of the plots became very apparent. On the treated areas no water was lying on the soil surface and the ground was firm to walk on. On the control plots water was standing in pools in places and the soil was very soft to the tread. These very apparent differences did not disappear until mid April, 1971, by which time grass growth on the subsoiled plots was visibly much better than elsewhere in the field. Not only was the grass greener on the two treated areas but also a greater quantity of herbage was available for grazing or mowing. These same visual effects on the load carrying capacity of the soil became apparent again in the autumn of 1971 and stayed visible throughout the winter of 1971/72. The depth of water in the dip wells was read periodically during these two winters and the results confirm the visual effects. (Fig. 1.).

A number of random cuts were obtained from the control and treated plots on 1 June, when the whole field was cut for silage. The very marked differences in growth, which had been very apparent earlier, had by now virtually disappeared. Mean yield of dry matter was 5.9 tonnes/ha on the subsoiled plots and 5.3 on the controls. As the s.e. per plot was 1.04 or 18.5% this difference cannot be considered significant.

Bodelwyddan

This was the only site where subsoiling has been carried out over a relatively recently installed drainage system. During both winters the level of water in the dip wells was consistantly lower in the subsoiled plots than in the controls (Fig. 2). During the first winter, which was relatively dry, the differences were not so marked, and the load bearing capacity was similar on both treatments. No obvious growth differences were seen which was reflected in the yields of dry matter when cut on 5 April, viz: 0.24 and 0.25 tonnes per hectare on the control and subsoiled treatments respectively.

The second winter was somewhat wetter and for a period in the early months of 1974 the dip wells in the control plots were full, or nearly full, whereas on the treated plots the level of water never approached the top. In March sub-plots on each of the main plots received the nitrogen top-dressing and cuts were taken on 23 April when there were very marked differences in growth between the treatments.
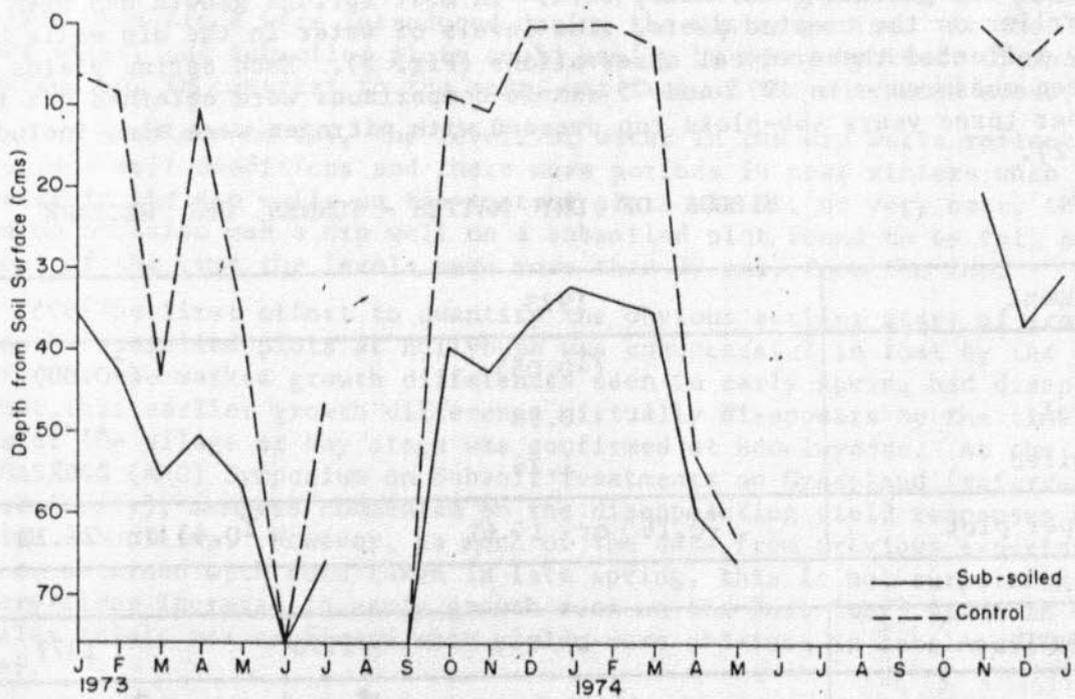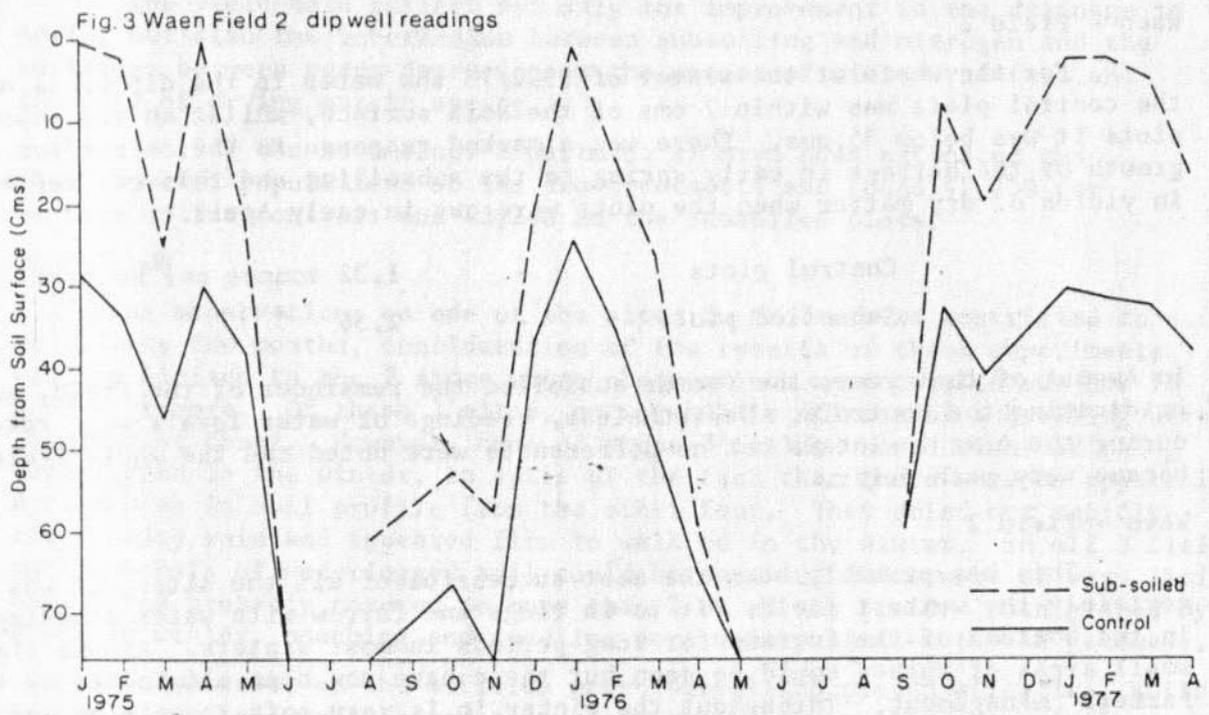
Table 1.        YIELD OF DRY MATTER - TONNES PER HECTARE

| Treatments | No Nitrogen | Plus Nitrogen |
|---|---|---|
| | ($^{+}_{-}0.79$) | |
| Control | 0.56 | 0.84 |
| Subsoiled | 0.98 | 1.34 |
| s.e. per plot | $^{+}_{-}$ 0.22    or | 23.8% |

As can be clearly seen from table 1, the marked visual response to subsoiling was confirmed by the yield data. In addition an interaction effect between nitrogen and subsoiling was also obtained.

As the field was shut up for hay, the opportunity was taken to take random cuts on 26 June from those parts of the main plots which had neither received the nitrogen applied nor been cut in April. A dressing of nitrogen had, by then, been applied by the farmer over all the field. The control plots yielded 4.51 tonnes per hectare dry matter and the subsoiled 4.28 ($^{+}_{-}$ 0.54). By mid season, therefore, the effects due to the subsoiling had

Fig.1 Holly Bush dip well readings



Fig.2 Bodelwyddan dip well readings

Fig. 3 Waen Field 2 dip well readings
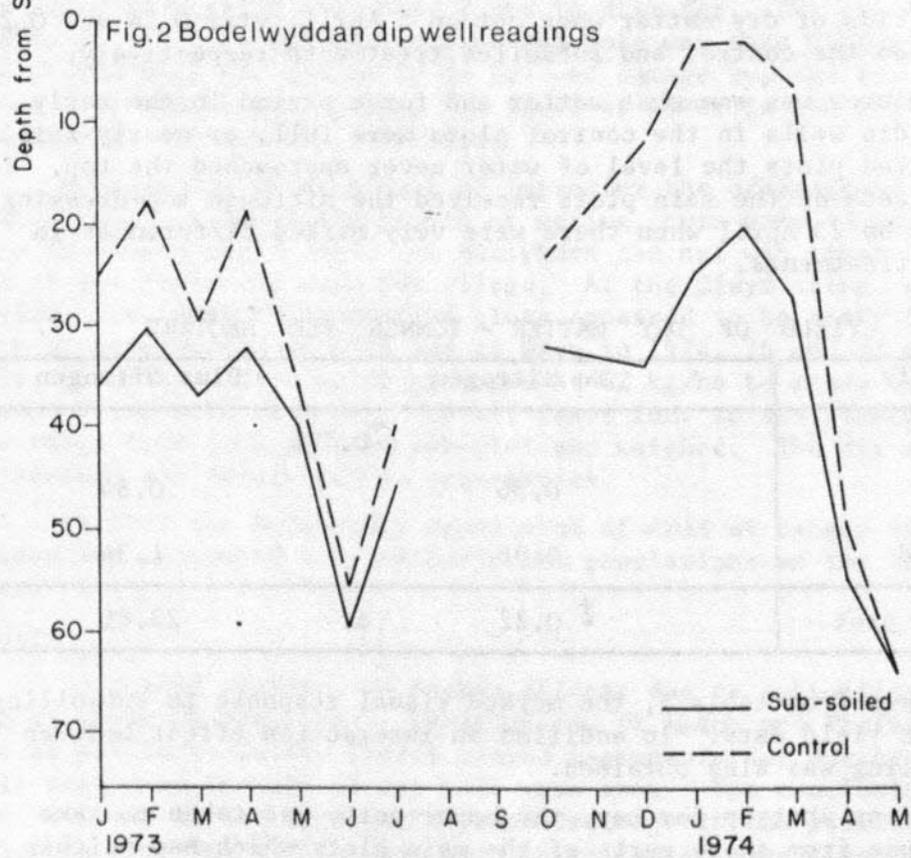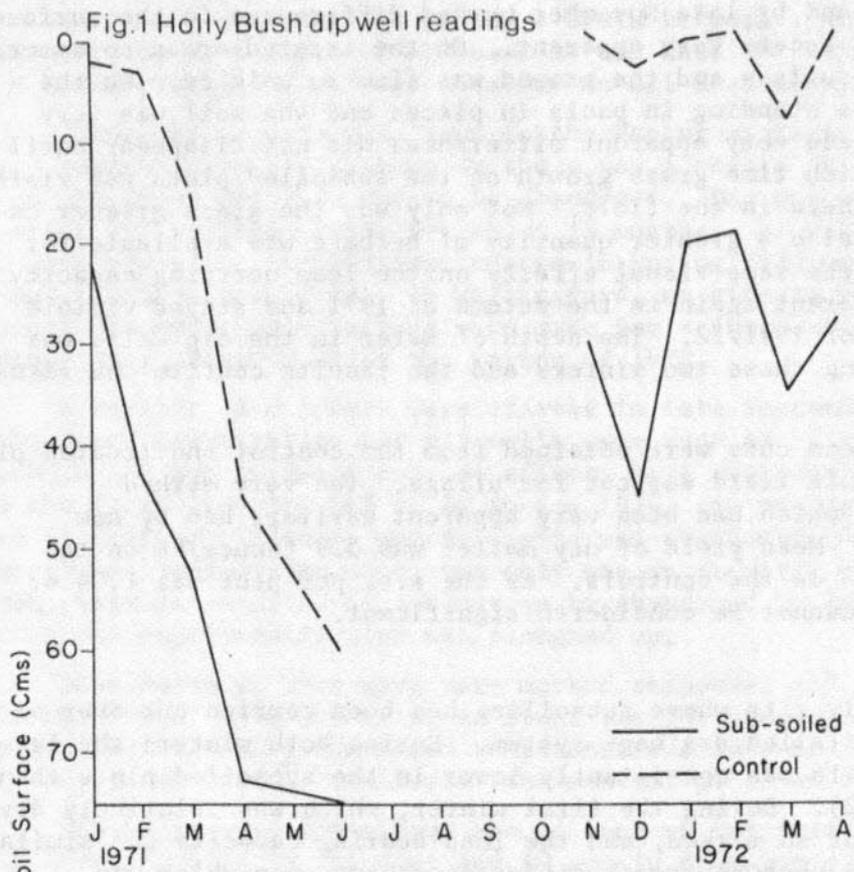
completely vanished.

Waen - Field 1

For the whole of the winter of 1972/73 the water in the dip wells on the control plots was within 7 cms of the soil surface, whilst on the subsoiled plots it was below 35 cms. There was a marked response in the colour and growth of the herbage in early spring to the subsoiling and this was reflected in yields of dry matter when the plots were cut in early April.

| Control plots | - | 1.32 tonnes per hectare |
| Subsoiled plots | - | 2.36 " " " |

In August of that year, the farmer subsoiled the remainder of the field, so eradicating the controls. Nevertheless, readings of water levels were taken during the next 2 winters but no differences were noted and the whole field became very much drier.

Waen - Field 2

This has probably been the most successful of all the sites, it was certainly the wettest field. It is in ridge and furrow with water standing in the bottoms of the furrows for long periods in most winters. At one time small areas of rushes could be seen but these have now been eliminated by the farmers' management. Throughout the winter it is very soft to walk on and is easily poached by stock.

The two subsoiled plots can easily be picked out during the winter in that they are firm to walk on and water only sites in the bottom of the furrows for very short periods after heavy rain. In most springs growth has been very much earlier on the treated plots. The levels of water in the dip wells have clearly reflected these visual observations (Fig. 3). Each spring yields have been measured - in 1973 and 75 simple comparisons were obtained but in the other three years sub-plots top dressed with nitrogen were also included, (Table 2).

Table 2.          YIELDS OF DRY MATTER - TONNES PER HECTARE

| Treatment | 1973 | 1975 |
|---|---|---|
|  | $(\pm 0.05)$ | $(\pm 0.30)$ |
| Control | 0.98 | 1.42 |
| Subsoiled | 1.28 | 2.62 |
| s.e. per plot | $\pm 0.16$ or 14.6% | $\pm 0.43$ or 21.1% |

| Treatment | 1974 | 1976 | 1977 |
|---|---|---|---|
|  | $(\pm 0.04)$ | $(\pm 0.19)$ | $(\pm 0.10)$ |
| Control, No N | 0.34 | 3.74 | 0.63 |
| Control, + N | 0.73 | 4.70 | 0.91 |
| Subsoiled, No N | 0.59 | 4.95 | 0.86 |
| Subsoiled + N | 1.25 | 5.36 | 1.30 |
| s.e. per plot | $\pm 0.12$ or 16.1% | $\pm 0.55$ or 11.7% | $\pm 0.29$ or 31.7% |

The yield data reflect not only the improvement in the drainage in spring but also the interaction between subsoiling and nitrogen and the variation between years depending on the amount of winter rainfall and the rate of drying out in spring.

In 1977 the Entomology Department at Bryn Adda estimated the Leatherjacket populations on the two treatments and found 95,750 per hectare on the controls and 43,240 on the subsoiled plots.

DISCUSSION

As observations on one of the sites in Maelor were restricted to a relatively few months, consideration of the results of these experiments will be limited to the 7 sites where observations were carried out for 18 months or more. Of these 7 sites, no worthwhile effects of subsoiling were obtained at three. However, none of these 3 fields showed signs of being waterlogged in the winter, in spite of the fact that there were no apparent differences in soil profile from the other four. They dried out rapidly after heavy rain and appeared firm to walk on in the winter. In all 3 fields small pockets of waterlogged soil could be seen but these were of very limited extent and probably covered no more than 2-3% of any field. When grazed by stock in winter, poaching and puddling were mainly limited to the gateways.

In contrast on the 4 fields where subsoiling proved effective, soils were more or less waterlogged throughout the winter with ponding in low areas. At Bodelwyddan, which had been tile drained a few years previously, soils were not quite so wet, particularly during the first winter of the trial and this site could be considered intermediate in character between the dry and the very 'wet' fields. In all 4 fields, however, extensive poaching and puddling took place when stock were introduced during the winter period. At the 3 really wet sites, the subsoiled plots could easily be found by their firmness when walked on, in contrast to the soft, wet feel of the untreated areas.

Needless to say, the levels of water in the dip wells reflected the surface soil conditions and there were periods in most winters when the water in the dip wells on the control plots was at, or very near, the surface. On no occasion was a dip well on a subsoiled plot found to be full and for most of the time the levels were more than 30 cms. from the top.

The first effort to quantify the obvious earlier start of grass growth on the subsoiled plots at Hollybush was unsuccessful in that by the beginning of June the marked growth differences seen in early spring had disappeared. That this earlier growth difference virtually disappears by the time the grass is at the silage or hay stage was confirmed at Bodelwyddan. At the Joint ADAS/PPG (ARC) Symposium on Subsoil Treatments on Grassland (referred to previously), members commented on the disappointing yield responses obtained with subsoiling. However, as much of the data from previous experiments has been obtained with cuts taken in late spring, this is not surprising. The very clear increase in early growth seen on the four 'wet' sites in the North Wales trials was confirmed when yields were obtained in late April or early May.

At the Symposium, Hughes (Trials in SW England), Evans (Mid and South Wales) and Farrar and Marks (West Midlands) all referred to a positive interaction between nitrogen and subsoiling. Where differential nitrogen treatments were given in the N. Wales trials a nitrogen/subsoiling interaction was also obtained.

On many occasions, subsoiling has been referred to as "square" moling and that, as a consequence, on sloping fields water will be transported into the lower parts of the field if not intercepted by a drainage system. The seven sites were on level or only slightly sloping fields, and in no case were

the subsoil cuts taken through into a ditch. Close watch was kept, therefore, to see whether water accumulated in the lower parts of the subsoiled plots but in no case was this effect seen.

In choosing the fields for the trials, sites were selected where it would be possible, with the subsoiler available, to run the 'shoe' in the red, fissured clay below the compact zone. A number of farmers in the area have attempted to subsoil fields where these conditions do not exist and where the Salop soil profile is gleyed below the mottled zone. In these cases subsoiling has not been successful and fields have tended to become wetter. In addition water has often ponded to a greater extent in low places.

It is necessary, when considering the overall cost effectiveness of subsoiling, to know how frequently the operation has to be repeated. In this respect, it is very disappointing that continuous observations have been possible at only one site. Here, the treatment has certainly lasted 5 years and it is to be hoped that data can be obtained for a number of years yet. In addition, although comparisons at the other site at Waen cannot be undertaken, it is hoped to observe when the drainage has deteriorated to its former state.

In conclusions it can be said that where fields on the Salop series lie wet in winter and where the depth to the well drained clay is sufficiently small (45 cms) as to allow a tine to be pulled in the red clay, subsoiling can be considered as a relatively cheap alternative system to a more expensive tile/mole system. It can be undertaken, in seasons when soil conditions are suitable, by farmers themselves provided they possess a tractor of sufficient power and traction. A number of farmers in the Clwyd valley are now, in fact, subsoiling suitable fields; essentially these are on beef, or beef and sheep, enterprises. Whether, on more intensive farms, a more permanent drainage system would eventually be required cannot be decided from these trials.

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ACKNOWLEDGMENTS:

THE SAND MINERALOGY OF SOME REDDISH DRIFTS AND ASSOCIATED SOILS
IN CHESHIRE AND CUMBRIA

by

I.N.L. Kilgour

(Soil Survey of England and Wales, Penrith)

## INTRODUCTION

Reddish drifts and associated soils cover quite a large area of Cheshire and to a lesser extent Cumbria. The sand component in these is often considerable. In the sandy drifts, the sand fraction is usually more than 95 per cent of the mineral content, decreasing in the upper horizons although quantities are still large. Even in till, the silt and sand fractions normally comprise over half the mineral content, although when the soil is manipulated the presence of coarser particles is effectively masked by the clay and fine silt.

The mineralogy of the coarser particles can influence the natural fertility of the soil, since many of the elements required by plants are originally released from some of these particles. Tamm (1934, 1937) used the percentage of heavy minerals (base mineral index) as a measure of one of the factors affecting forest yield and showed that the cause of poor forest yield could be found in the mineralogical properties of the sand.

A study was therefore initiated to characterise the mineralogy of the sand fractions of these soils and to determine any significant differences in provenance and mineralogy between the soils of the two counties which may affect classification and use at series level.

## MINERALS PRESENT

To aid identification under microscope, the minerals are first cleaned ultrasonically and then separated in Bromoform which has a specific gravity of 2.9. Those minerals with specific gravities greater than 2.9 therefore sink, and those with less float. Using this method the minerals most commonly found in soils can be split into two fractions listed in Table 1.

Heavy minerals are a very small proportion of the soil or drift, generally less than 1.5% of the grains in any one particle-size fraction. The remaining particles are mostly of quartz, a little orthoclase feldspar, rare plagioclase feldspars and muscovite. However the heavy mineral fraction is responsible for most of the variation in the chemical composition of the sand (Table 1.) Many grains are coated with red iron oxide, which gives the characteristic colour to drifts derived from Triassic rocks.

## ORIGINS OF MINERALS

The minerals in most Cheshire soils and drifts are derived not only from the Triassic rocks but from other sources in the Irish Sea basin or the Lake District, such material being deposited during and after the Last Glacial period. The red colour of the drifts and dominance of quartz in the coarser fractions show that the solid geology has influenced their composition considerably. However, macroscopic examination of glaciofluvial sands and sand fractions from the tills often shows scattered olive-green igneous rock fragments, suggesting other sources, and a varied heavy mineral suite, seen microscopically, also indicates a Palaeozoic provenance for some of the drift.

Table 1.  Minerals commonly occurring in the Fine Sand Fraction (60-250 $\mu$m)
in Soils and Drifts in Cheshire and Chemical Composition of the
Heavy Minerals.

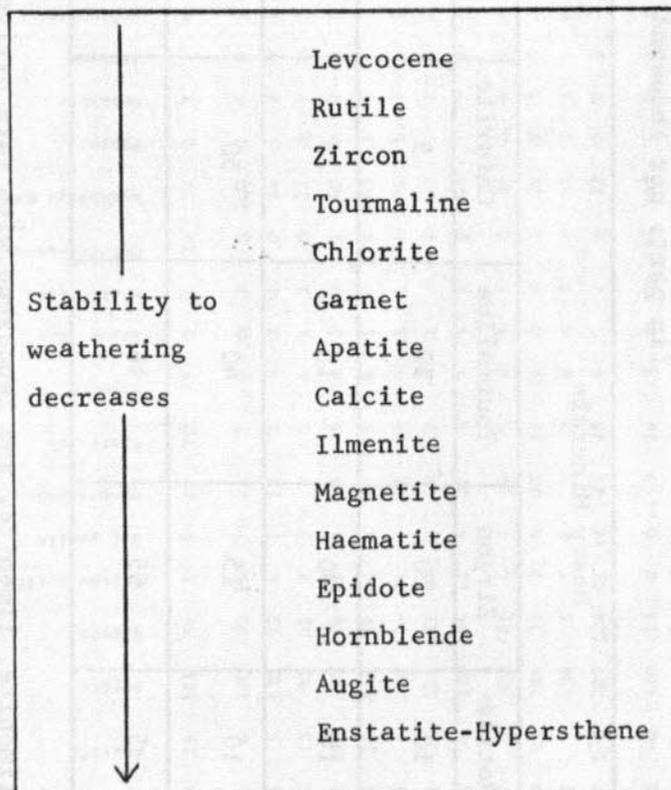| Specific Gravity <2.9 | Specific Gravity >2.9 | Composition |
|---|---|---|
| Quartz | Anatase | $TiO_2$ |
| Orthoclose Feldspar | Andalusite | $Al_2SiO_5$ |
| Plagioclase Feldspar | Apatite | $Ca_5(F,Cl)(PO_4)_3$ |
| Muscovite | Augite | $(Ca,Mg,Fe,Al)_2(Al,Si)_2O_6$ |
| | Calcite-Dolomite | $CaCO_3-CaMg(CO_3)_2$ |
| | Chlorite | $(MgFe'')_{10}Al_2(SiAl)_8O_{20}(OH,F)_{16}$ |
| | Epidote | $Ca_2(Al,Fe)_3(OH)(SiO_4)_3$ |
| | Garnet (Andradite) | $Ca_3Fe_2(SiO_4)_3$ |
| | Haematite | $Fe_2O_3$ |
| | Hornblende | $NaCa_2(MgFe''(SiAl)_8O_{22}(OH,F)_2$ |
| | Hypersthene-Enstatite | $(MgFe'')SiO_3$ |
| | Ilmenite | $FeTiO_3$ |
| | Limonite | Hydrous $Fe_2O_3$ |
| | Magnetite | $Fe_3O_4$ |
| | Monazite | $(Ce, La, Y, Th)PO_4$ |
| | Rutile | $TiO_2$ |
| | Sillimanite | $Al_2SiO_5$ |
| | Sphene | $CaTiSiO_5$ |
| | Staurolite | $FeAl_4Si_2O_{10}(OH)_2$ |
| | Tourmaline | $Na(MgFe'')_3Al_6(BO_3)_3(Si_6O_{18})$ $(OH, F)_4$ |
| | Zircon | $ZrSiO_4$ |

Because of ionic substitution within the silicate framework of certain minerals
the chemical composition can vary.  For example, there are several species of
chlorite, garnet and tourmaline.

Owing to the age of the Triassic sandstone generally only the more resistant minerals (Table 2) still survive.

Table* 2

Stability of Commonly Occurring Minerals

```
                        Levcocene
                        Rutile
                        Zircon
                        Tourmaline
                        Chlorite
Stability to            Garnet
weathering              Apatite
decreases               Calcite
                        Ilmenite
                        Magnetite
                        Haematite
                        Epidote
                        Hornblende
                        Augite
                        Enstatite-Hypersthene
```

\* Table based on Pettijohn's work on mineral stability (1941) and also Smithson (1953). Calcite and Haematite are given approximate positions.

The Triassic Sandstone and its derived soils have few mineral types and quartz is even more common than in some heterogeneous drifts. Although the mineral composition of the Triassic Sandstone differs a little in Cumbria (Table 3) and Cheshire, the most important heavy mineral contents are similar, being mostly the opaque iron and iron-titanium minerals. Only the most resistant transparent heavy minerals such as rutile, zircon and tourmaline, occur to any great extent, while the others, barytes for instance, are rare. Weathered material is always present, and the mineralogy of soils derived from weathered sandstone drifts closely mirrors that of the unweathered rock as would be expected. However the till deposits and much of the glaciofluvial sand in Cheshire (Table 4) contain non-Triassic material, and the heavy mineral composition is more variable.

THE CHESHIRE TILL, GLACIOFLUVIAL SANDS AND ASSOCIATED SOILS

Augite, hornblende, zircon and tourmaline are the commonest transparent minerals in the till. Augite grains are large, either pale green or brown and of fresh appearance, they are subangular or subrounded often with jagged ends and a characteristic etching on the surfaces. Hornblende is less common and the brown variety always rarer than the green. Augite and hornblende are unstable minerals in detrital deposits and the presence of so many large and little weathered grains of augite is unusual, but characteristic of superficial

Table 3  Common Heavy Minerals in the Permo-Triassic Sandstone and Derived Soils in Cumbria
(in parts per thousand)

| Sandstone and Soil Series | Opaques* | Heavy Minerals | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| | | Rutile | Zircon | Tourmaline | Chlorite | Garnet |
| Permian Sandstone (near Penrith, Cumbria) | 880 | 10 | 50 | 20 | 5 | 5 |
| Newport Series (near Penrith, Cumbria) | 890 | 10 | 30 | 15 | 23 | 13 |
| Triassic Sandstone (near Lazonby, Cumbria) | 840 | 10 | 15 | 40 | 50 | 5 |
| Newport Series (near Lazonby, Cumbria) | 810 | 5 | 55 | 96 | 7 | 5 |

*Opaque minerals are magnetite, haematite, limonite, ilmenite, and leucoxene with rare pyrites

Table 4. Mineralogical Composition of Heavy Residues from Fine Fractions (50–250μm) recalculated as parts per thousand of each Heavy Fraction

| Lithology | Soil series and Profile No. | Sample depth (cm) | Haematite & limonite | Magnetite, ilmenite & leucoxene (rare pyrites) | (Total) | Pink Garnet | Colourless Garnet | Green hornblende | Brown hornblende | Chlorite | Tourmaline | Apatite | Augite | Zircon | Yellow rutile | Red rutile | Hyperstene | Enstatite | Epidote | Staurolite | Andalusite | Calcite-dolomite | Weathered material | Sphene | Monazite | Anatase | Collophane | Zoisite | Sillimanite | Additional Minerals |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fine loamy over clay till | Salop SJ 45/8772 | 100 | | | 428 | 2 | 14 | 40 | 19 | 13 | 110 | 55 | 121 | 84 | 8 | 5 | 14 | 10 | 15 | 0 | 2 | 2 | 32 | 2 | 3 | 1 | 6 | 4 | | |
| Loamy reddish till | Clifton SJ 45/8602 | 30 | | | 440 | 3 | 13 | 33 | 12 | 8 | 100 | 6 | 120 | 110 | 13 | 7 | 13 | 5 | 5 | 0 | 3 | 14 | 100 | 2 | 2 | 0 | 2 | 2 | | |
| | | 90 | | | 628 | 4 | 9 | 23 | 17 | 14 | 45 | 7 | 130 | 53 | 4 | 7 | 15 | 5 | 5 | 4 | 1 | 0 | 24 | 4 | 4 | 0 | 2 | 1 | | Siderite |
| | | 120 | | | 662 | 1 | 17 | 30 | 9 | 12 | 66 | 13 | 97 | 45 | 7 | 5 | 5 | 8 | 4 | 1 | 2 | 0 | 21 | 0 | 5 | 0 | 5 | 0 | 1 | |
| | | 180 | | | 418 | 3 | 12 | 37 | 20 | 21 | 93 | 107 | 85 | 70 | 12 | 6 | 24 | 15 | 14 | 0 | 0 | 41 | 40 | 0 | 8 | 1 | 1 | 2 | 1 | |
| | Salwick SJ 45/3701 | 30 | | | 452 | 5 | 13 | 39 | 17 | 15 | 124 | 15 | 122 | 59 | 10 | 7 | 17 | 8 | 6 | 1 | 2 | 0 | 63 | 3 | 5 | 0 | 3 | 3 | 1 | Tremolite-Actinolite |
| | | 90 | | | 454 | 2 | 5 | 38 | 13 | 20 | 99 | 6 | 98 | 114 | 21 | 3 | 17 | 15 | 14 | 0 | 3 | 0 | 51 | 1 | 8 | 1 | 2 | 1 | 2 | Tremolite-Actinolite |
| | | 120 | | | 569 | 1 | 13 | 29 | 10 | 25 | 61 | 37 | 105 | 81 | 17 | 4 | 7 | 17 | 3 | 1 | 1 | 0 | 33 | 1 | 5 | 0 | 0 | 2 | 1 | |
| | | 180 | | | 457 | 2 | 18 | 40 | 10 | 25 | 70 | 49 | 138 | 86 | 11 | 6 | 12 | 7 | 8 | 1 | 1 | 0 | 43 | 2 | 1 | 0 | 2 | 1 | 1 | |
| Sandy drift (Head and glaciofluvial) | Newport SJ 55/3682 | 40 | | | 583 | 4 | 5 | 33 | 14 | 7 | 37 | 37 | 208 | 37 | 4 | 7 | 16 | 3 | 5 | 1 | 0 | 0 | 31 | 2 | 2 | 3 | 0 | 3 | | Tremolite-Actinolite |
| | | 70 | | | 484 | 2 | 5 | 24 | 6 | 5 | 23 | 11 | 289 | 37 | 3 | 4 | 27 | 8 | 11 | 0 | 0 | 0 | 39 | 0 | 0 | 0 | 2 | 1 | | |
| | | 100 | | | 355 | 3 | 5 | 49 | 18 | 0 | 32 | 3 | 434 | 8 | 7 | 6 | 3 | 11 | 5 | 0 | 0 | 10 | 57 | 2 | 0 | 3 | 0 | 2 | 1 | Muscovite |
| | Blackwood SJ 55/3857 | 40 | | | 245 | 6 | 14 | 32 | 9 | 6 | 187 | 176 | 107 | 104 | 21 | 12 | 22 | 28 | 5 | 1 | 1 | 0 | 20 | 0 | 1 | 0 | 3 | 1 | 1 | Tremolite-Actinolite |
| Glaciofluvial sand | Beeston Quarry | 40 | 268 | | 97 | 1 | 9 | 17 | 5 | 8 | 8 | 40 | 110 | 13 | 0 | 4 | 10 | 24 | 5 | 0 | 0 | 290 | 43 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Coarse loamy drift (Head and glaciofluvial) | Wick SJ 45/7703 | 40 | 456 | | 240 | 1 | 14 | 18 | 5 | 7 | 78 | 9 | 77 | 74 | 9 | 8 | 4 | 11 | 11 | 0 | 0 | 0 | 16 | 0 | 5 | 3 | 0 | 0 | 0 | Diopside |
| | | 100 | 366 | | 195 | 0 | 5 | 38 | 7 | 28 | 37 | 18 | 104 | 132 | 5 | 1 | 25 | 13 | 5 | 0 | 0 | 0 | 17 | 1 | 7 | 0 | 1 | 0 | 0 | Muscovite; Kyanite |
| Silty or fine loamy drift | Hodnet SJ 55/3804 | 90 | 27 | | 529 | 0 | 9 | 5 | 28 | 1,356 | 4 | 16 | 4 | 24 | 7 | 2 | 337 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | |
| Coarse loamy drift over clayey reddish till | Rufford SJ 55/3804 | 50 | 42 | | 147 | 1 | 14 | 3 | 2 | 7 | 25 | 61 | 42 | 84 | 20 | 0 | 0 | 234 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 1 | |

deposits in Cheshire. Both minerals are widespread in igneous and metamorphic rocks. Augite occurs especially in intermediate and basic igneous rocks i.e. andesite and basalts, while hornblende occurs in a wide range of igneous rocks and in metamorphic rocks derived from igneous rocks.

Tourmaline, an accessory mineral in the more acid igneous rocks and also in metamorphic rocks and pegmatites, is usually pale yellow to brown and pleochroic. Less commonly, deep brown and other coloured varieties also exist. Like tourmaline, zircon is initially a minor constituent of acid igneous and metamorphic rocks, in which the grains are small and colourless, rarely pink, with many inclusions. Apatite, less resistant than zircon and tourmaline, is always very rounded, small and colourless, originating as a minor constituent in igneous and metamorphic rocks. Chlorite occurs mainly either as a polycrystalline weathering product of ferromagnesian minerals such as augite or hornblende or as pale green rounded flakes which are isotropic under crossed nicols. In the latter form, grains have probably come direct from low-grade metamorphosed igneous and sedimentary rocks which contain much chlorite. Hypersthene is often more abundant than enstatite and andalusite, found in metamorphosed argillaceous rocks, and of general occurrence though only in minor amounts. Rhombs and more rounded grains of calcite-dolomite are present in the till beneath the Clifton and Salwick series and indicate the beginning of the secondary carbonate layer that at one time was used for marl in agriculture.

In the glaciofluvial deposits shape, size and colour of mineral grains resemble those in the tills. However, in the samples analysed there was noticeably more of some minerals. Augite is exceptionally abundant at 100 cm in the Newport profile (SJ 536582) whilst 60% of the heavy minerals in the Rufford soil are composed of enstatite and hypersthene. The Blackwood soil (SJ 538557) has large amounts of tourmaline, apatite, augite and zircon, and the sand in Beeston Quarry is rich in calcareous material. Opaque mineral grains, normally very abundant, are also very scarce in the Rufford soil, (SJ 538504). The Hodnet soil (SJ 435567) is atypical in the samples from Cheshire because it lacks augite and has much colourless chlorite.

COMPARISON OF COMMON HEAVY MINERALS IN THE RED DRIFTS OF CHESHIRE WITH THOSE IN SIMILAR DEPOSITS IN CUMBRIA

The heavy minerals of selected soil series in the Burwardsley district of Cheshire were compared with those in similar soils in the Penrith and Solway districts of Cumbria. Since the Triassic bedrocks in Cheshire and Cumbria (Permian strata also outcrop near Penrith) only contribute the more resistant minerals which do not vary markedly in type, differences between soils in the two counties will help to indicate the source areas for a portion of the drift constituents (Tables 5 and 6).

The Cheshire soils and drifts generally have over 10% of augite, and indeed more than 40% of the heavy mineral content in a sample from the Newport series. Conversely, samples from Cumbria contain little augite. The other unstable ferromagnesian minerals, hornblende, hypersthene and enstatite are also more abundant in Cheshire, but differences in the three districts between the most resistant transparent minerals, rutile, zircon and tourmaline are less significant. This appears to be because the bedrocks, rather than an igneous or metamorphic source, have contributed these minerals, although during deposition of the bedrock itself the minerals could have come from such sources. There is almost no apatite in the Cumbrian tills although small amounts are present in glaciofluvial deposits.

Table 5. Comparison of more common Heavy Minerals (parts per thousand) in soils derived from Reddish Till in Cheshire and Cumbria

| Soil Series and Grid Reference of Sampling Site | Opaques | Rutile | Zircon | Tourmaline | Chlorite | Garnet | Apatite | Calcite | Epidote | Hornblende | Augite | Enstatite & Hypersthene |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1* CLIFTON 100 cm SJ 486502 | 630 | 11 | 53 | 45 | 14 | 13 | 7 | | 30 | 40 | 130 | 20 |
| 2 SALWICK 100 cm SJ 487501 | 570 | 20 | 81 | 64 | 5 | 14 | 37 | | Trace | 39 | 105 | 19 |
| 3 SALOP 100 cm SJ 487572 | 430 | 13 | 84 | 110 | 13 | 16 | 55 | 14 | 15 | 559 | 121 | 24 |
| 4 CLIFTON 100 cm NY 487404 | 670 | 29 | 100 | 32 | 5 | 16 | | Trace | | 57 | 9 | 5 |
| 5 CLIFTON 100 cm NY 532341 | 730 | 20 | 96 | 43 | 11 | 8 | | Trace | | 27 | 8 | Trace |
| 6 CLIFTON 100 cm NY 352733 | 440 | 15 | 27 | 30 | 430 | 5 | Trace | Trace | Trace | 15 | 5 | 10 |
| 7 CLIFTON 100 cm NY 395694 | 560 | 10 | 43 | 35 | 310 | 6 | | 17 | 5 | 12 | Trace | 5 |

* Samples numbered 1-3 are from Cheshire

4-5 from the Penrith district of Cumbria

6-7 from the Solway district of Cumbria

Table 6. Comparison of more common Heavy Minerals (parts per thousand) in soils derived from glaciofluvial deposits in Cheshire and Cumbria

| Soil Series and Grid Reference of Sampling Site | | Opaques | Rutile | Zircon | Tourmaline | Chlorite | Garnet | Apatite | Calcite | Epidote | Hornblende | Augite | Enstatite & Hypersthene |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NEWPORT 40 cm SJ 536582 | 1* | 580 | 11 | 21 | 37 | 7 | 9 | Trace | | Trace | 47 | 208 | 25 |
| NEWPORT 100 cm SJ 556582 | 2 | 350 | 13 | 8 | 32 | | 8 | 3 | | 8 | 67 | 434 | 6 |
| WICK 100 cm SJ 477503 | 3 | 540 | 13 | 132 | 28 | 28 | 5 | 18 | | 5 | 45 | 104 | 37 |
| BLACKWOOD 100 cm SJ 553857 | 4 | 240 | 33 | 104 | 187 | 6 | 20 | 176 | | 4 | 41 | 107 | 50 |
| SAND FROM BEESTON QUARRY | 5 | 375 | 10 | 13 | 78 | 8 | 11 | 40 | 290 | | 22 | 110 | 12 |
| NEWPORT 100 cm NY 551299 | 6 | 590 | 28 | 120 | 47 | 50 | 19 | 17 | | Trace | 21 | 11 | 11 |
| NEWPORT 100 cm NY 588367 | 7 | 730 | 47 | 146 | 38 | 3 | 5 | 17 | | | 6 | | 5 |
| SAND FROM BROWNRIGG QUARRY | 8 | 760 | 17 | 71 | 24 | 5 | 11 | 17 | 5 | 3 | 29 | 7 | 5 |
| NEWPORT 100 cm NY 350634 | 9 | 490 | 20 | 140 | 34 | 73 | 54 | 5 | | | 24 | 19 | 5 |

* Samples numbers 1-5 are from Cheshire, 6-8 from the Penrith district of Cumbria, 9 from the Solway district of Cumbria

There is a great deal of chlorite in the reddish till in the Solway district, much presumably moved from the Silurian rocks of southern Scotland during the last glaciation, but it is not generally significant in the other areas.

CONCLUSION

The heavy minerals in the reddish tills and glaciofluvial deposits can clearly differ quite markedly throughout north-west England. The samples analysed suggest that intra-county variation is as great as inter-county variation. Because quartz and orthoclase feldspar are abundant in all drift deposits and because the more varied and complex minerals only occupy a small fraction of any one drift the differences in mineral suites between areas are numerically small. The significance of such changes, apart from indicating the origins of a drift, in the sand fractions of soils is not yet understood although the complex chemical compositions of some of the heavy minerals probably makes them important reservoir of nutrients.

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# PROPORTIONATE AREAS OF DOMINANT SOIL GROUPS AND SOIL PARENT MATERIALS
## IN NORTHERN ENGLAND

The Soil Survey of England and Wales has utilised the services of a student vacation worker, S. Jarvis, to calculate the areas of all those delineations on the 1:1,000,000 published soil map which fall within the Survey's Northern Region. As this comprises Cheshire, South Yorkshire, Humberside and counties north to the Scottish border and is therefore roughly equivalent to the Discussion Group's domain, the exercise seemed to have sufficient potential interest to members to justify printing the results in the Proceedings.

The information (Tables 1 & 2) comprises actual and proportionate areas of land in which different soil groups, as classified by Avery (1973), and different parent materials are dominant. The proportions, in both cases, have also been represented by pie graphs (Figs. 1 & 2).

The area was divided into 2 x 2 km squares and the map unit to which each belonged was recorded. Squares which embraced a map unit boundary were allocated to the dominant unit. A graticule of east-west and north-south lines, 2 mm apart, on tracing paper was used to make the assessment.

The limitations are those inherent in the 1:1,000,000 map which are principally (1) the small scale, which means that although the map units represent land with both dominant and associated soils, the latter must be disregarded in this type of exercise; and (2) the reconnaissance nature of much of the soils information used in the compilation of the map.

Nevertheless, certain facts stand out, as follows. (1) the overwhelming predominance of stagnogley soils and their association with glacial drift. (2) The high proportion of brown earths. (3) The large proportion of shale and clay. (4) The greater area of alluvium than that of peat.

Members thus have for the first time an inventory of the soils and parent materials which form their common interest. Hopefully a 2nd edition of the 1:1,000,000 soil map will appear one day and, with it, the opportunity to update the information given here; and it will be interesting to see how the two assessments differ. Before then however we may one day have this information for all of England and Wales, and members will certainly be interested to know how the soil proportions in the North compare with the national figures.

REFERENCE

AVERY, B.W., 1973. Soil classification in the Soil Survey of England and Wales. J. Soil Sci. 24, 324-338.

Table 1.                    Parent Materials of Northern Region

| Parent Material | Pie graph code | soil types | % of soil area | % of total area | Actual area (km²) |
|---|---|---|---|---|---|
| Glacial Drift | | 28,30,55, 69 | 42.383 | 38.449 | 14,132 |
| Shale and Clay | | 27,36,51, 56,70, some 66 | 18,827 | 16.981 | 6,278 |
| Igneous and Metamorphic Rocks | | 63,66,67 | 7.720 | 7.003 | 2,574 |
| Glaciofluvial (and sandy glacial) drift | | 13,26,47, 62 | 7.378 | 6.692 | 2,460 |
| Limestone | | 10,14,16 21,60, some 66 | 6.827 | 6.187 | 2,274 |
| Alluvium | | 2,4,5,8, 59 | 6.527 | 5.921 | 2,176 |
| Peat | | 9, 71 | 5.243 | 4.756 | 1,748 |
| Sandstone | | 41, some 13 63, 66 | 2.946 | 2.671 | 982 |
| Blown Sand | | 1,43,65, some 47 | 2.160 | 1.959 | 720 |
| Urban | | | | 9.381 | 3,412 |
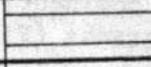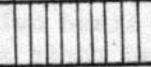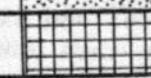
Total area = 36,756 km²

Total area less urban area = 33,344 km²

# Fig:I Soil Parent Materials of Northern Region
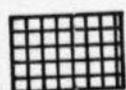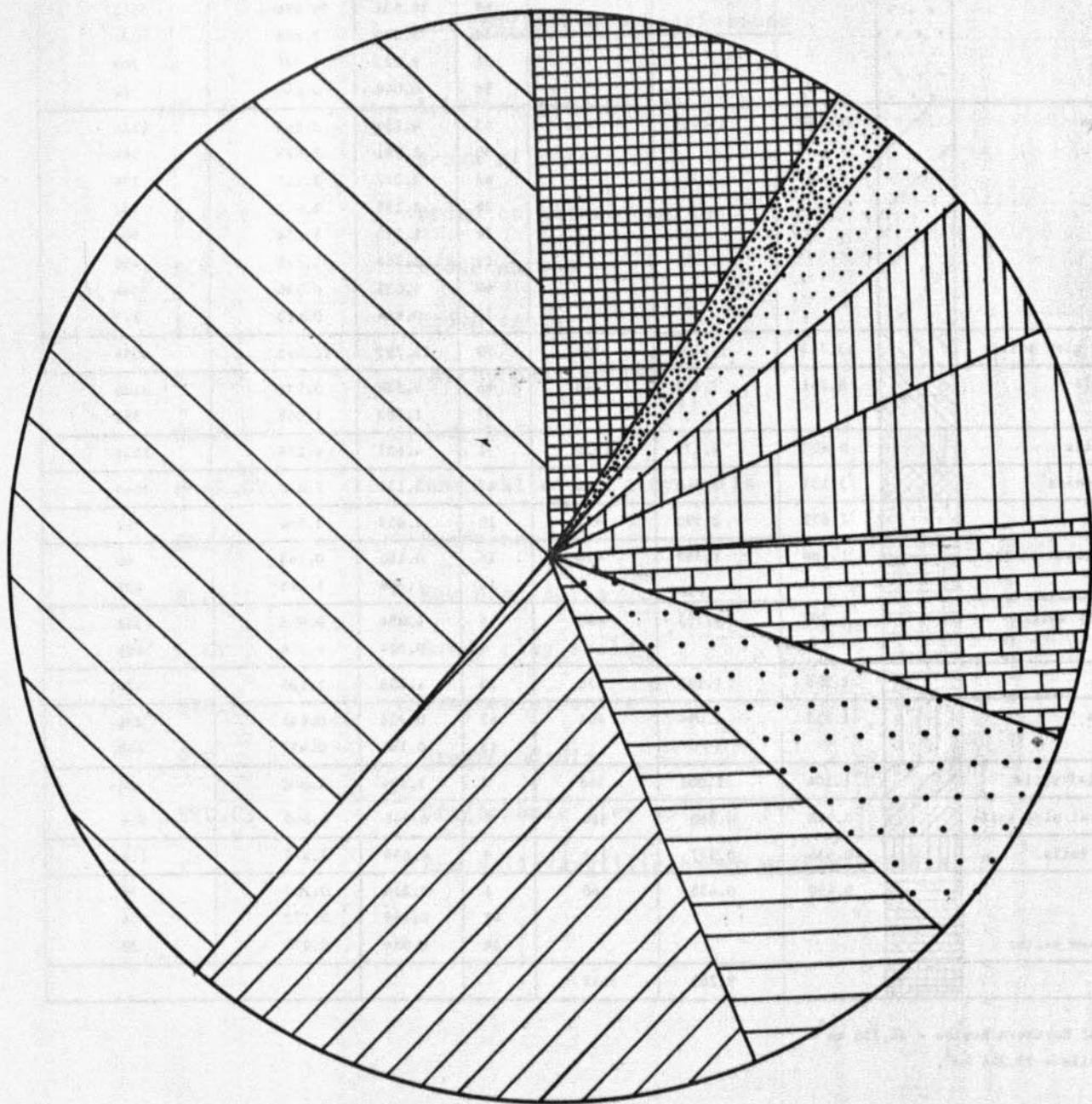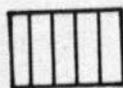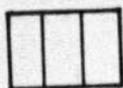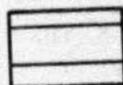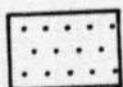


Legend:
- Urban
- Blown Sand
- Sandstone
- Peat
- Alluvium
- Limestone
- Glaciofluvial (and Sandy Glacial) Drift
- Igneous and Metamorphic Rocks
- Shale and Clay
- Loamy or Clayey Glacial Drift

Table 2.　　　　　Areas of dominant soil groups 1:250,000 map units in Northern Region

| Dominant soil group | Pie graph code | % of soil area | % of total area | Actual area (km²) | Map unit | % of soil area | % of total area | Actual area (km²) |
|---|---|---|---|---|---|---|---|---|
| Stagnogley soils | | 42.562 | 38.612 | 14192 | 55 | 20.765 | 18.838 | 6924 |
| | | | | | 69 | 16.531 | 14.996 | 5512 |
| | | | | | 59 | 3.095 | 2.808 | 1032 |
| | | | | | 51 | 2.123 | 1.926 | 708 |
| | | | | | 56 | 0.048 | 0.044 | 16 |
| Brown earths | | 16.268 | 14.757 | 5424 | 63 | 4.259 | 3.863 | 1420 |
| | | | | | 30 | 2.891 | 2.623 | 964 |
| | | | | | 62 | 2.327 | 2.111 | 776 |
| | | | | | 28 | 2.195 | 1.992 | 732 |
| | | | | | 26 | 1.512 | 1.371 | 504 |
| | | | | | 21 | 1.368 | 1.241 | 456 |
| | | | | | 60 | 1.032 | 0.936 | 344 |
| | | | | | 27 | 0.684 | 0.620 | 228 |
| Stagnohumic gley soils | | 13.783 | 12.405 | 4596 | 70 | 13.783 | 12.405 | 4596 |
| Stagnopodzols | | 8.241 | 7.476 | 2748 | 66 | 6.538 | 5.931 | 2180 |
| | | | | | 67 | 1.703 | 1.545 | 568 |
| Raw peat soils | | 4.607 | 4.179 | 1536 | 71 | 4.607 | 4.179 | 1536 |
| Sandy gley soils | | 3.131 | 2.840 | 1044 | 47 | 3.131 | 2.840 | 1044 |
| Rendzinas | | 2.855 | 2.590 | 952 | 10 | 2.855 | 2.590 | 952 |
| Brown calcareous earths | | 1.488 | 1.349 | 496 | 16 | 0.180 | 0.163 | 60 |
| | | | | | 14 | 1.308 | 1.186 | 436 |
| Alluvial gley soils | | 1.380 | 1.252 | 460 | 5 | 1.056 | 0.958 | 352 |
| | | | | | 4 | 0.324 | 0.294 | 108 |
| Brown sands | | 1.308 | 1.185 | 436 | 13 | 1.308 | 1.185 | 436 |
| Gley podzols | | 1.212 | 1.099 | 404 | 65 | 0.708 | 0.642 | 236 |
| | | | | | 43 | 0.504 | 0.457 | 168 |
| Brown alluvial soils | | 1.104 | 1.001 | 368 | 2 | 1.104 | 1.001 | 368 |
| Humic alluvial gley soils | | 0.948 | 0.860 | 316 | 8 | 0.948 | 0.860 | 316 |
| Earthy peat soils | | 0.636 | 0.577 | 212 | 9 | 0.636 | 0.577 | 212 |
| Raw soils | | 0.480 | 0.435 | 160 | 1 | 0.228 | 0.207 | 76 |
| Podzols | | | | | 41 | 0.168 | 0.152 | 56 |
| Argillic brown earths | | | | | 36 | 0.084 | 0.076 | 28 |
| Urban | | | 9.283 | 3412 | | | | |

Total Area of Northern Region - 36,756 km².
Area less soils - 33,344 km².

## Soil group abbreviations

| | |
|---|---|
| AL.GY | Alluvial gley soils |
| B.AL | Brown alluvial soils |
| B.CA.E. | Brown calcareous earths |
| B.E. | Brown earths |
| B.S. | Brown sands |
| E.PT. | Earthy peat soils |
| GY.P | Gley-podzols |
| H-AL.GY | Humic-alluvial gley soils |
| RE. | Rendzinas |
| R.PT. | Raw peat soils |
| S.GY | Sandy gley soils |
| STG. | Stagnogley soils |
| STP. | Stagnopodzols |
| STU.GY | Stagnohumic gley soils |
| X | Raw soils/Argillic brown earths/Podzols |
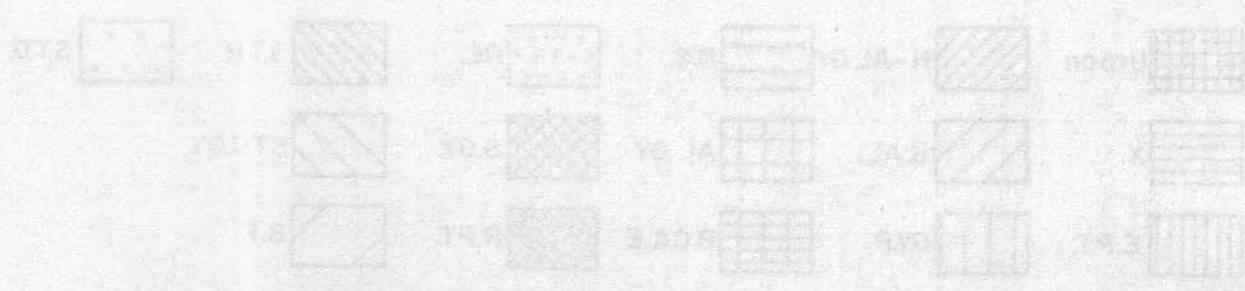
# Fig:2 Proportional Areas of Dominant Soil Groups (N.R.)



| | | | | | |
|---|---|---|---|---|---|
| Urban | H.-AL.GY. | B.S. | RE. | STP. | STG. |
| X. | B.AL. | AL.GY | S.GY. | STU.GY | |
| E.PT. | GY.P | B.CA.E | R.PT. | B.E | |