'A STUDY OF THE SUITABILITY OF CALLOW FOR RECLAMATION'

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ABSTRACT

The purpose of this project was to investigate the suitability of callow (calcareous clay overburden arising from the excavation of Oxford Clay) as a growing medium in reclamation schemes. Its abundance and relative "cheapness" means that it is an ideal top-soil replacement material, if it could be proved to be of benefit to reclamation schemes.

Samples of the callow were analysed in the laboratory for nutrient status, pH, water-relationships, cation exchange capacities and other soil-related variables.

A series of sites was established so that natural succession on callow could be studied, to investigate whether natural colonisation may provide clues as to the suitability of certain species for reclamation.

Field and greenhouse trials were carried out on the callow, to investigate the best types of agricultural uses and fertiliser regimes for use with callow as a growing medium.

A variety of grasses, legumes, herbs, shrubs and trees colonise the callow when it is left to natural succession. Natural succession, analysed by ordination techniques could not be related to any of the measured soil-related variables.

The callow was found to be deficient in nitrates and phosphates. Growth trial results confirmed these findings. A variety of grass seed mixes with or without legumes can be established on the callow, once nutrient deficiencies are corrected. Crops, such as winter wheat, barley and oil seed rape failed in all trials. Problems with drainage caused set-backs to the field trials section of the project.

If treated and cultivated at the correct time of year, callow can be considered to be a suitable growing material for standard agricultural grass seed mixes, once nutrient levels are increased. It is not advised that crops be grown on callow as a pioneer cover.

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1. OBJECTIVES

Two types of clay are used in brick making in the County of Bedfordshire; Lower Oxford Clay and Gault Clay, the latter being of much less importance than the former. The Oxford Clay lies over a wide area of the northern half of the County, although much is heavily blanketed with boulder clay and other drift deposits. The main exposure of importance in brick making lies in the south-west of Bedfordshire in the Marston Vale. Figure 1.1 shows the location.

One of the main uncertainties that has significant implications for the way the Brickfields are restored arises from the extent to which filling materials will be available, particularly from outside the County[1].

The issue of long distance transportation of filling material has been the subject of detailed examination at the Public Enquiry into the National Coal Board's proposals to exploit the coal reserves from North East Leicestershire[2].

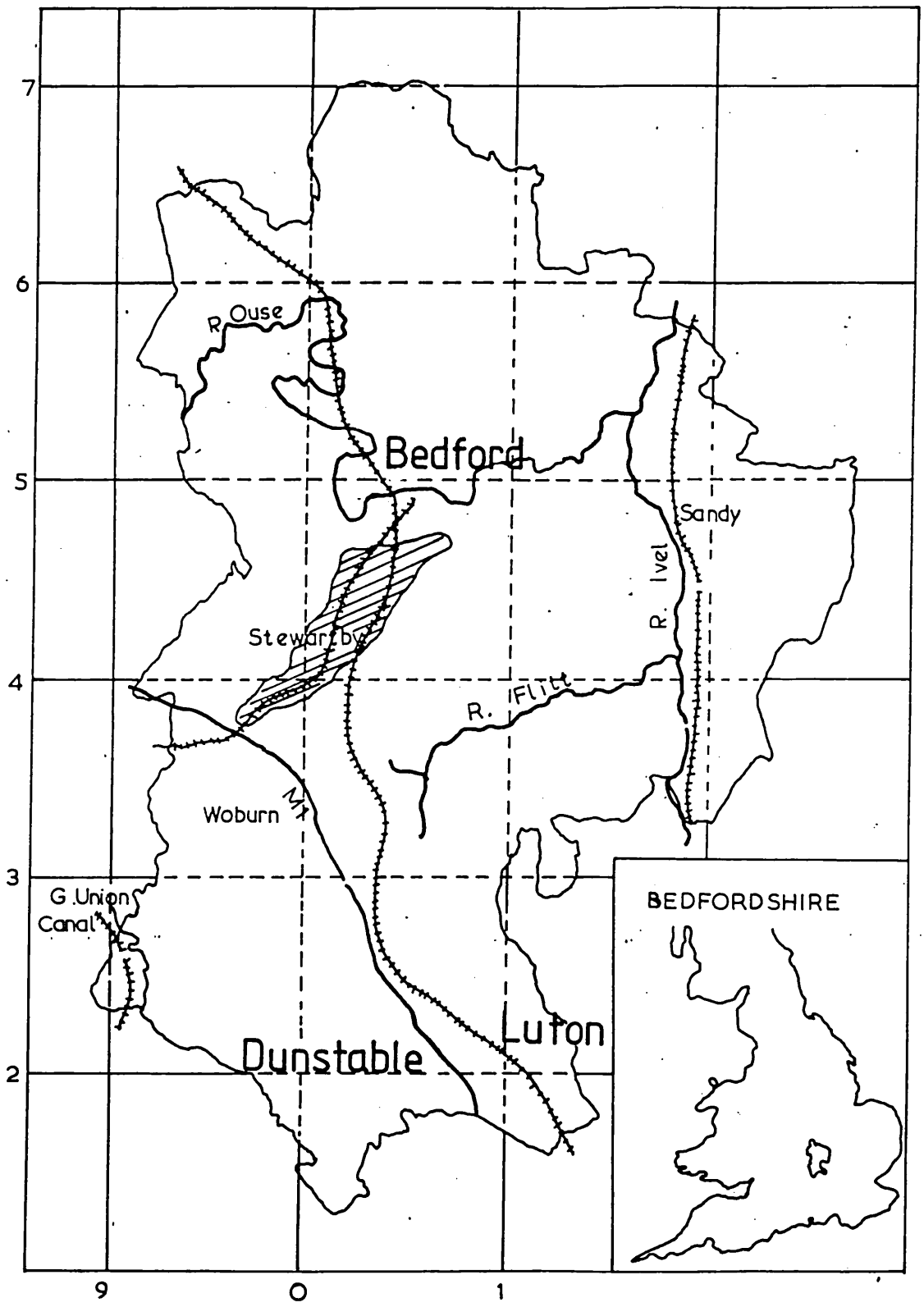
Once the pits have been filled, a major problem is the shortage of topsoil and soil forming materials. Also, until fairly recently, the topsoil removed from a site to be excavated for clay was tipped back into the worked out areas of the pit, together with the overburden, rendering the topsoil unavailable. Recent changes in working methods have, however, avoided this wastage.

The possibilities of utilising alternative soil forming materials are being investigated. In particular, the weathered clay overburden or "callow" is being considered as a potential growing medium.

Bedfordshire County Council's Oxford Clay Subject Plan Draft Policy 13 states

"In respect of all future extraction areas at both existing and new pits, all topsoil, subsoil and other overburden removed in the process of clay extraction will normally be retained on site for restoration work unless

FIGURE 1.1 LOCATION OF THE MARSTON VALE IN BEDFORDSHIRE



there are overriding reasons to the contrary.

Restoration proposals need to take into account the overall lack of topsoil in the Vale. Callow (the clay overburden), which varies in depth from three to six metres, is already used as an intermediate covering material for domestic waste and must be regarded as an important restoration material both as a capping medium before topsoil is replaced and potentially as a growing medium in its own right ..... The County Council will continue to encourage research and experiments with callow as a soil-forming medium."

The necessity of a detailed site and material investigation preceding full-scale reclamation work is well documented[3].

The above investigations form a progressive series - site inspections, laboratory analyses of waste materials, pot experiments away from the site, experimental field trials on the site and finally site monitoring to follow the success of particular treatments. Not all of these will be appropriate for any one type of waste material or for every specific reclamation scheme but they are each important for one situation or another[3].

The practical aspects of this project are therefore divided into three sections.

i. A study of the natural vegetation on callow over a long age series. This is to determine the types of plants that are able to colonise the material by natural agencies. These species and associations of species will provide clues to the types of vegetation suited to the use of callow in reclamation schemes.

ii. A detailed analysis of the callow to establish nutrient status, cation exchange capacities, soil-water relations, pH and other soil related variables. These analyses were carried out on samples over a wide age range in order to establish the rate

of development of the top layers of soil on callow.

iii. Greenhouse and field trials to investigate suitable seed mixtures and fertiliser regimes for use on callow in reclamation schemes.

It was hoped to be able to link up these three different sections in order to recommend future treatment for the callow when it is used for reclamation purposes.

2. INTRODUCTION

2.1. The Importance of Bedfordshire in Brickmaking

Bedfordshire has been an important centre for brickmaking for many centuries. The earliest surviving brick building in the County is Someries Castle. near Luton, dating back to 1448[4].

During the nineteenth century brick as a building material grew in importance. The railways brought about the large scale growth of the brickmaking industry, especially the gault clay in the eastern part of the county. Formerly the top callow had been used in brickmaking on a small scale. However, the grey-green clay deposit found underneath the callow, known locally as "knotts", proved ideal for making bricks, firstly at Fletton, near Peterborough in 1881. The sucess of the brickworks at Fletton led to other brick manufacturers exploiting the exposures of Oxford Clay. Clay extraction in the county rose from 132 225 tons in 1900 to 410 800 tons in 1908. By 1910 the Forder Works at Wootton Pillinge and Elstow was selling forty eight million bricks a year in spite of the depressed state of the building industry at the time.

London Brick Company, based at Stewartby, is now the sole manufacturer of bricks in the Marston Vale.

The production of bricks is closely dependent upon demand from the building trade. 1973 was the last year when all the big works in the Marston Vale were operating; at the end of the year Elstow was closed, in 1974 both Coronation and Lidlington ceased working. In 1976 the three remaining works manufactured 1191 million bricks which represented 45 - 50% of the national Fletton's production and about twenty per cent of all bricks produced in Britain.

Fletton bricks have, in the past, accounted for about 40% of all bricks produced in Great Britain, the Fletton and non-Fletton sectors of the brick industry experiencing the same cyclical demand. The popularity of the Fletton brick can be largely attributed to its low production costs.

Two types of Fletton are produced, the "facing" and the traditional "common". The market for the latter is, however, decreasing due to competition from concrete blocks. In the past the production of satisfactory facings has been restricted to 50% of total output although higher outputs of facings are being achieved by the installation of new machinery. The new works that London Brick hopes to build at Ridgmont and Stewartby would be capable of producing one hundred per cent facings and this flexibility would enable London Brick Company to respond more easily to future changes in demand for different types of bricks. Despite the fluctuations, London Brick is still the world's largest independent brickmaker, supplying forty per cent of the total U.K. market with "Flettons", Britain's standard brick for house building[5].

2.2. Geology of the Marston Vale

The Marston Vale is an area of level, low lying land (30 - 45 A.O.D.) bounded by the Greensand ridge to the south-east and a ridge of boulder clay to the west. The area is underlain by the Oxford Clay which is a Jurassic rock formation. Figure 2.1. shows the solid geology of Bedfordshire indicating the extent of the Oxford Clay Deposits and Figure 2.2. shows the surface geology of Bedfordshire.

The Jurassic strata run in a great belt across England from Dorset to Yorkshire as shown in Figure 2.3. The most important stratum economically, is the Oxford Clay, which runs in a belt from near Frome in Somerset to Brigg in North Humberside.

In the South Bedford area the Jurassic strata has no cover of Pleistocene deposits, while in the Peterborough area large areas are covered with the Pleistocene Fen deposits (islands of Oxford Clay are found to outcrop through the Pleistocene, these outcrops forming the sites of the Fletton Brickworks in the Peterborough area[6]).

The Oxford Clay deposits are thought to be the results of relatively continuous sedimentation in a deep sea environment[7]. The deposit is

FIGURE 2.1 SOLID GEOLOGY OF BEDFORDSHIRE

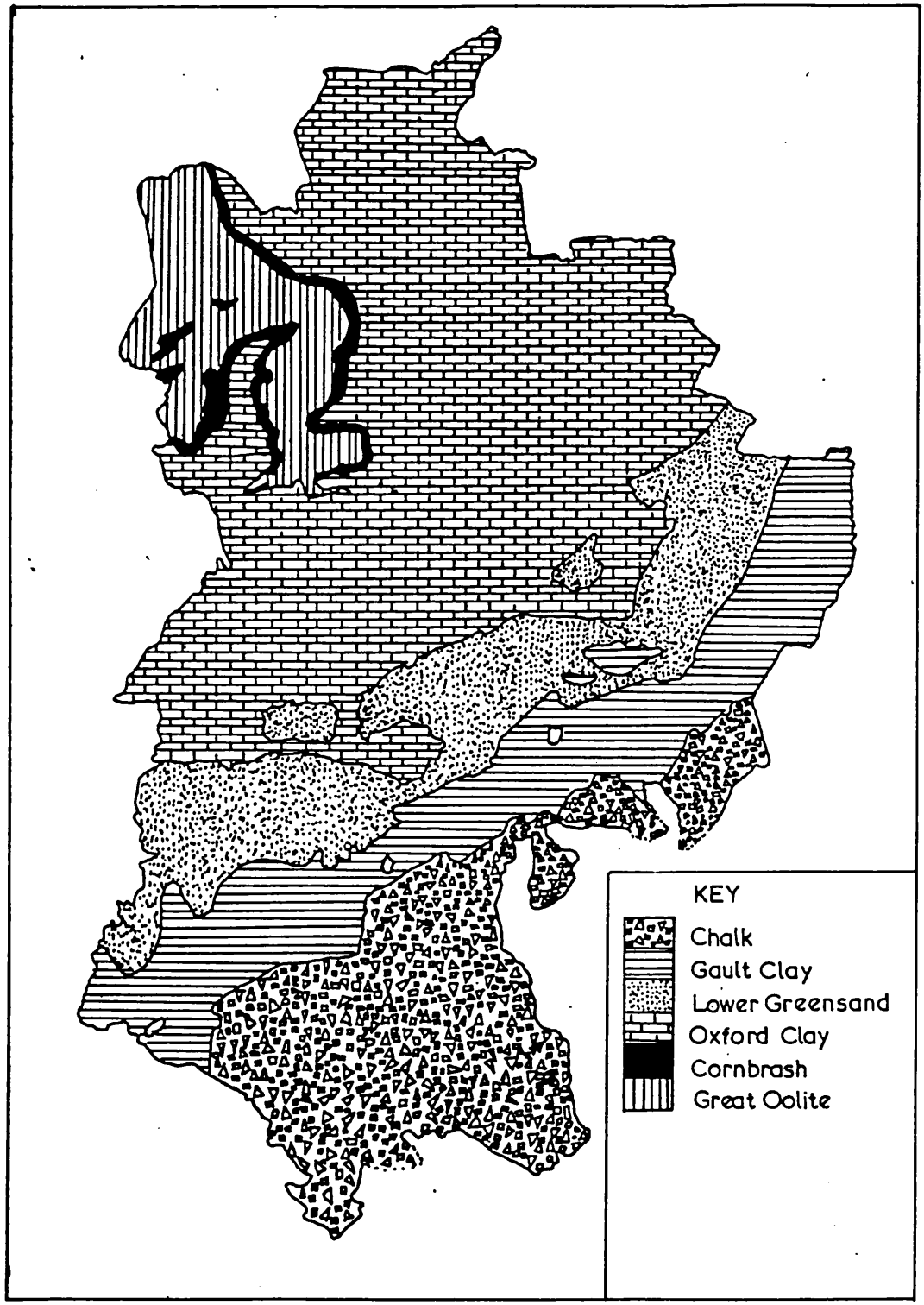
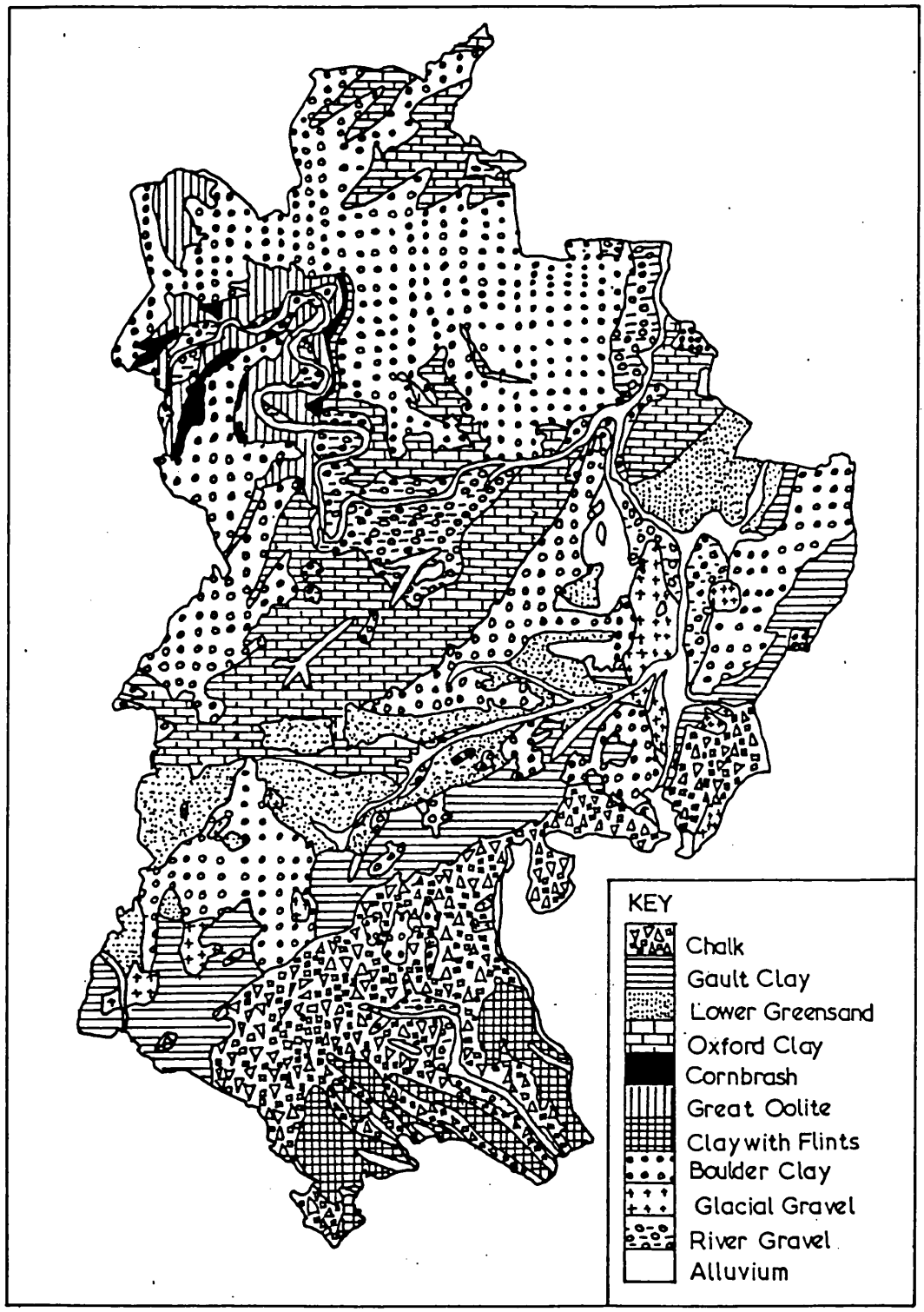
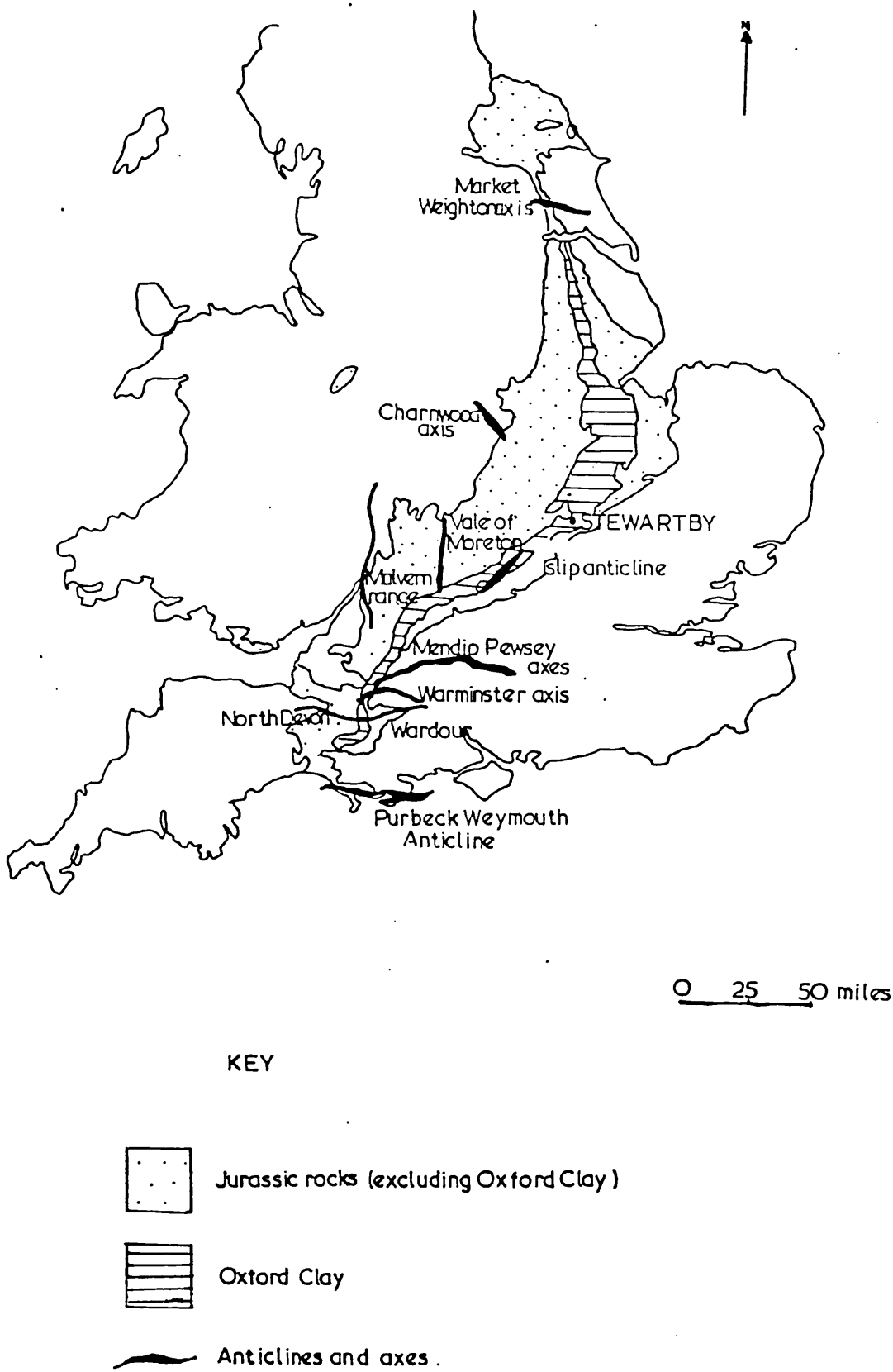


FIGURE 2.2 SURFACE GEOLOGY OF BEDFORDSHIRE



PRESENT OUTCROP OF THE OXFORD CLAY AND JURASSIC ROCKS IN SOUTHERN ENGLAND

FIGURE 2.3



not homogenous throughout; at various levels accumulations of calcareous material give rise to bands of limestone, varying in thickness from a few centimetres to over a metre and some beds include a proportion of sand. Concretionary nodules of calcareous stone and of pyrites (iron sulphide) and water-clear crystals of selenite (sulphate of lime) also occur frequently. The main mass of clay is greenish or bluish grey, becoming brown on weathering. Its consistency is generally tenacious, but it is shaly and laminated in places.

Underneath the Oxford Clay are clay and sandy beds known as the Kellaway Beds. These are generally blue in colour and have a thickness of three metres. Sometimes a sandy layer separates the Kellaway Beds and the Oxford Clay.

2.3. Oxford Clay Mineralogy

Mineralogical determinations carried out by x-ray diffraction, differential thermal and thermogravimetric analyses of the Oxford Clay by Perrin[9], Freeman [10, 11, 12] and Jackson and Fookes[13] show illite to be abundant, kaolinite subsidiary and quartz varies from trace to subsidiary amounts. Calcite is present in minor amounts and chlorite in trace amounts. X-ray analysis has shown the presence of considerable amounts of crystalline $CaCO_3$, FeS_2 and combustible organic matter. A sample of Lower Oxford Clay analysed by London Brick Products PLC showed that the clay component was 70% illite and 30% kaolinite. The Lower Oxford Clay used in the Fletton brick industry has a run-of-pit moisture content of 20 - 22% dry weight basis[14].

2.4. Soils of the Marston Vale

The soils of the area are developed on the callow and are categorised as the Rowsham series, formed on the Ampthill and Oxford Clays, with some drift mixtures. The Rowsham series is formed in a layer of clayey drift containing some stones and appreciable amounts of sand, often with

a narrow gravelly seam immediately overlying the Oxford Clay at depths of between eighteen and thirty-six inches. A dark brown clay loam or sandy clay loam surface horizon overlies an olive or greyish brown clay loam to clay subsoil with distinct fine ochreous mottling. Below, a discontinuous seam of gravelly sand clay loam overlies grey plastic clay faintly mottled with olive and brownish yellow, often with some small secondary calcium carbonate concretions.

These heavy soils are imperfectly or poorly drained and crack severely in periods of drought. A tilth suitable for drilling is often difficult to obtain and they are most suited to grassland farming. Effective artificial drainage is essential to make the best use of the land[15].

Jones and Fisher [16,17] carried out a soil survey of Quest Pit and Thrupp End (G.R 030 420 and 990 400). They found that the soil profiles at Quest Pit were typical of the Rowsham series. The topsoil was generally of clay loam texture with some profiles of clay texture. The depth of topsoil varied from 22 - 40cm with an average of 31cm. The immediate subsoil varied in texture from sandy clay loam to clay, but was predominantly clay loam or clay. Beneath this subsoil which varied from approximately 40cm to 70cm in thickness the texture was invariably clay. There were variations caused by locally occurring gravel lenses. Where these were present the soils were generally wetter and of poorer quality. This was reflected in reduced crop growth.

The soils were generally of M.A.F.F. grade 3b but with localised randomly distributed profiles of 3a quality. No particular area of the site could be designated as grade 3a[16].

Grade 3 agricultural land is defined as "land with moderate limitations due to soil, relief or climate or some combination of these factors. The range of cropping is generally restricted on land of this grade. Only the less demanding horticultural crops can be grown and towards

Table 2.1. Rowsham Series Profile (from King[15])

Location: Lower Farm, Millbrook (G.R. 023401).

Relief: Near bottom of even footslope.

Elevation: 165ft. O.D.

Slope: $< 1^{o}$

Aspect: N.N.E.

Parent Material: Loamy drift.

Land Use: Arable.

Horizons:

In.	
0 - 5	Dark brown (10 YR 3/3) friable clay loam; an occasional stone; moderate fine subangular to granular structure; abundant small and fine fibrous roots; merging boundary.
5 - 10	Dark yellowish brown (10 YR 4/4) firm clay loam; an occasional stone; moderate medium subangular blocky structure; common fine fibrous roots; narrow irregular boundary.
10 - 18	Olive-brown (2.5 Y 4/4) firm clay loam with many faint extremely fine yellowish brown and brownish yellow (10 YR 5/8 - 6/8) mottles; an occasional stone; moderate coarse subangular blocky structure; a few fine fibrous roots; merging boundary.
18 - 22	Greyish brown (10 YR 5/2) firm clay loam with distinct common extremely fine strong brown (7.5 YR 5/8) mottles; an occasional stone; moderate medium prismatic; a few fine fibrous roots associated with structure faces; narrow irregular boundary.
22 - 27	Greyish brown (10 YR 5/2) friable sandy clay loam with distinct common very fine strong brown mottles; slightly stony, up to small in size, subangular and rounded flints, occasional quartzite and sandstone fragments. Moderate medium prismatic, a few manganiferous patches; rare fine fibrous roots; sharp irregular boundary.

27-32+ Dark greyish brown (2.5 Y 4/2) firm clay with many faint very fine olive-yellow (2.5 Y 6/6) and distinct common very fine brownish yellow (10 YR 6/8) mottles, particularly associated with sandier pockets; moderate medium prismatic; some secondary carbonate concretions; rare fine fibrous root.

the bottom of the grade arable root crops are limited to forage crops. Grass and cereals are usually the principal crops"[18].

The M.A.F.F.'s resurvey of Grade 3 has subdivided it into three subgrades of decreasing quality, 3a, 3b and 3c. Brief descriptions are given below:-

3a

This land shares the moderate degree of limitation common to grade 3 but has some physical advantages which lead to appreciably better land than that of the remainder of the grade. These advantages may allow a wider range of crops to be grown or "usable" grass to be grown over a very long period together with average yields of barley or oats.

3b

Most of this land is typical of average production - typically of cereals and grass - although areas where yields are slightly below average are also eligibly provided there is an advantage such as greater flexibility of cropping. In the case of land which is primarily suitable for grass, there must be the particular advantage of a long growing season.

3c

This land has some physical characteristics which give a poorer production performance than that of other lands in the grade. This poorer performance may be in the form of higher risks, higher costs, lower flexibility or lower yields.

Part of the land at Thrupp End was on the Fladbury series of soils consisting of well-structured grey clay topsoil over grey, massive, strongly mottled grey subsoil. These soils were classified as Grade 4. This is because of the high clay content and impeded drainage.

2.5. Agriculture

The Marston Vale is an area of flat farmland. Cereals are the predominant crop with winter wheat and barley being the most important. Oil seed rape is also grown. The only area of Grade 2 agricultural land is south of Lidlington, beyond the extent of the workable deposit. The rest of the area is grade 3 or 4.

London Brick Farms P.L.C. farm approximately 1000 ha in the area. Their farming patterns are typical of the general pattern on the Vale. Crops on land farmed by London Brick Farms during 1983 were as follows:-[16]

	ha
Winter wheat	672
Oil seed rape	190
Winter barley	85
Established grass	8
New grass ley	6

In the past, cattle have been kept in the Vale; however, since the publication of "Fluorosis in Cattle - Animal Disease Survey Report Number 2"[19] when fluorisis severe enough to cause economic losses to farmers was found on a number of farms in the area, cattle rearing has decreased in importance.

Jones and Fisher[16] state that the reason cereal production has replaced dairy farming in the Vale over the last fifteen years is because of the high profitability of cereal growing throughout East Anglia as a whole. Certainly the E.E.C. subsidies on oil seed rape are an important factor in its increase in importance over the last few years.

A major limitation to agriculture in the area is caused by the heavy clay soil limiting access onto the land for a considerable part of the year. Agricultural operations require careful timing to prevent soil damage, hence the dominance of winter cereals.

Land drains are essential in these soils and London Brick policy is to underdrain all their land with pipes at 40m intervals with gravel backfill above the drains. Mole drains are drawn every three years at 2m intervals. In some areas drainage at closer spacing is necessary[16].

The majority of soils in the Marston Vale have ADAS P and K indices of 1 or 2 and 1 - 3 respectively. These are equivalent to 10 - 25 $mg.L^{-1}$ available phosphorus and 61 - 400 $mg.L^{-1}$ available potassium[20]. These are considered to be fairly low levels. Average wheat yields over all London Brick Farms land including 30 ha of restored land in 1982 was 6.8 $tonnes.ha.^{-1}$ [16]. Average 1982 yields of winter wheat in East Anglia were 6.3 $tonnes.ha.^{-1}$ [2].

2.6. Climate

The climate of Bedfordshire in common with most of East Anglia is slightly continental in character with warm summers and cool winters (average July temperature is 16.5°C; average January temperature is 3.0°C)[21].

Average maximum and minimum temperatures for Stewartby are shown in Figures 2.4. Monthly rainfall at Stewartby for the period 1970-1983 is shown in Figure 2.5. Average annual rainfall for Bedfordshire is shown in Figure 2.6.

It is evident from figure 2.5. that Stewartby does not experience the late winter/early spring dry period characteristic of East Anglia. The wettest month is August.

The mean average monthly precipitation for Stewartby is 50.2mm.

Spring 1983 was very wet nationwide, represented by the above average figures for April and May. This "played havoc with farming and sport from mid March to May"[22]. This was caused by a blocking ridge of high pressure over eastern Europe which had been keeping depressions almost stationary over Britain. London's April 1983 records of rainfall were the heaviest for the month since records began.

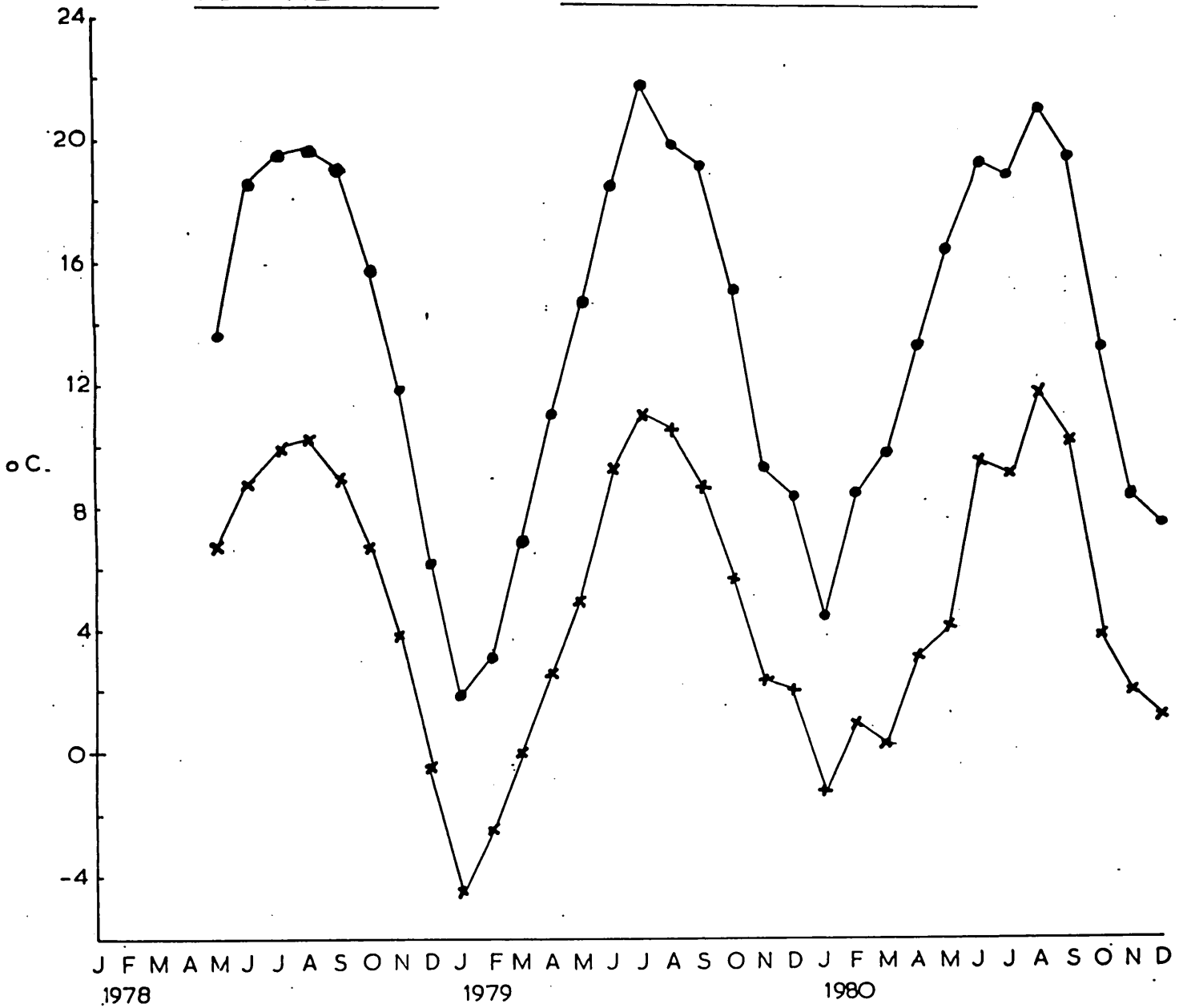
Farmers Weekly reported, "A succession of wet, cold and dismal days seriously disrupted cereal planting in May 1983 and thousands of fields in Britain were going without a vital dressing of lime because the land was too wet to take spreading tackle."[23]

After the very wet spring, summer 1983 was hotter than average with July and August maximum temperatures averaging over 25°C and minimum temperatures averaging over 12°C.

Wind speeds in the Marston Vale are low, only 10% of the year experiencing winds described as 'fresh' (9.0m.s^{-1}(17.5 kt) or greater). Seventy five per cent of all winds have speeds between 2.0 (3.9 kt) and 8.0 m.s^{-1} (15.5 kt). Calms exist for 6.9% of the time, a figure typical of inland locations in the British Isles.

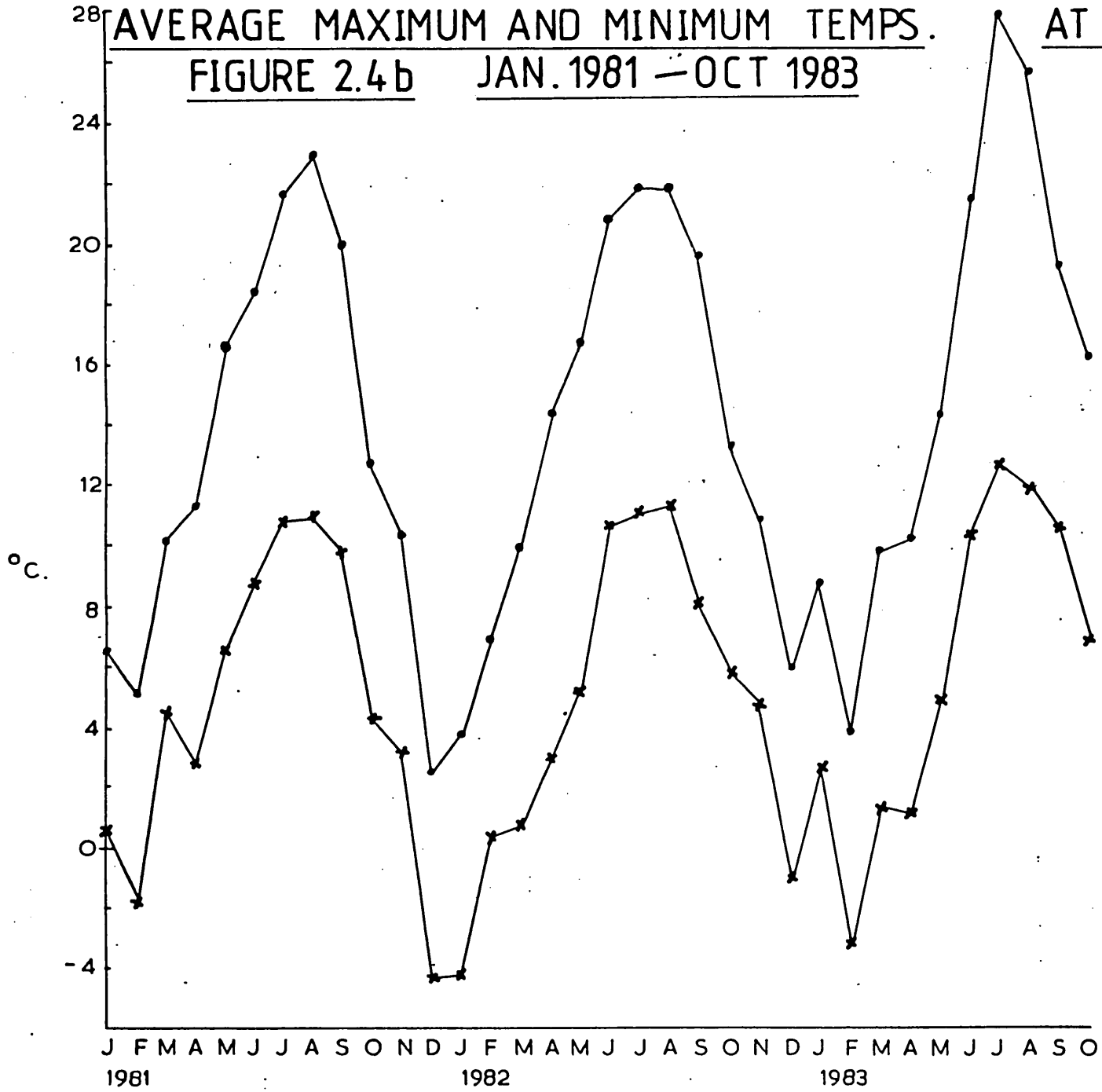
AVERAGE MAXIMUM AND MINIMUM TEMPERATURES AT STEWARTBY, MAY 1978 – DEC. 1980

FIGURE 2.4a



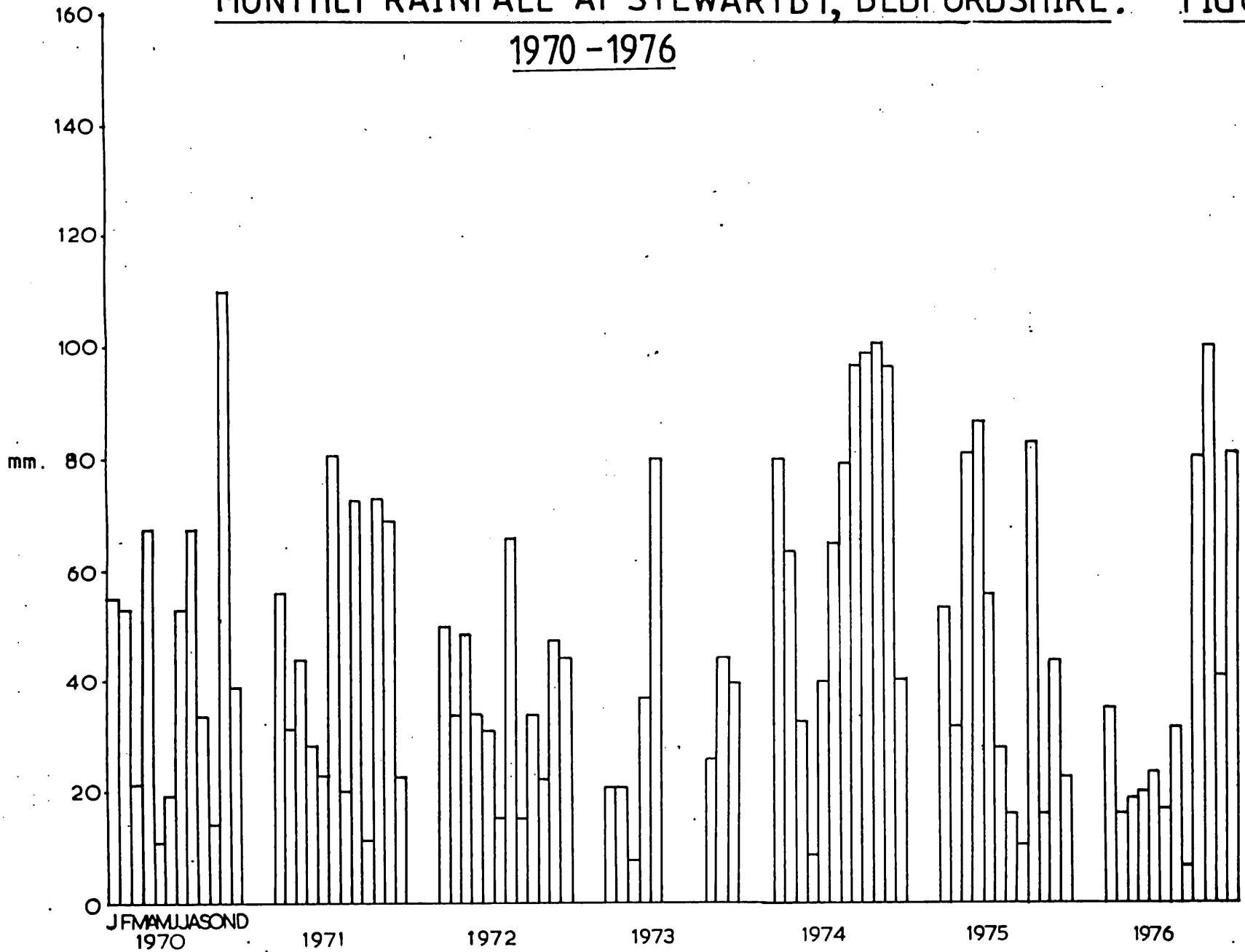
AVERAGE MAXIMUM AND MINIMUM TEMPS. AT STEWARTBY

FIGURE 2.4b JAN. 1981 — OCT 1983



MONTHLY RAINFALL AT STEWARTBY, BEDFORDSHIRE. FIGURE 2.5a

1970 - 1976



MONTHLY RAINFALL AT STEWARTBY, BEDFORDSHIRE

1977 - OCT 1983

FIGURE 2.5

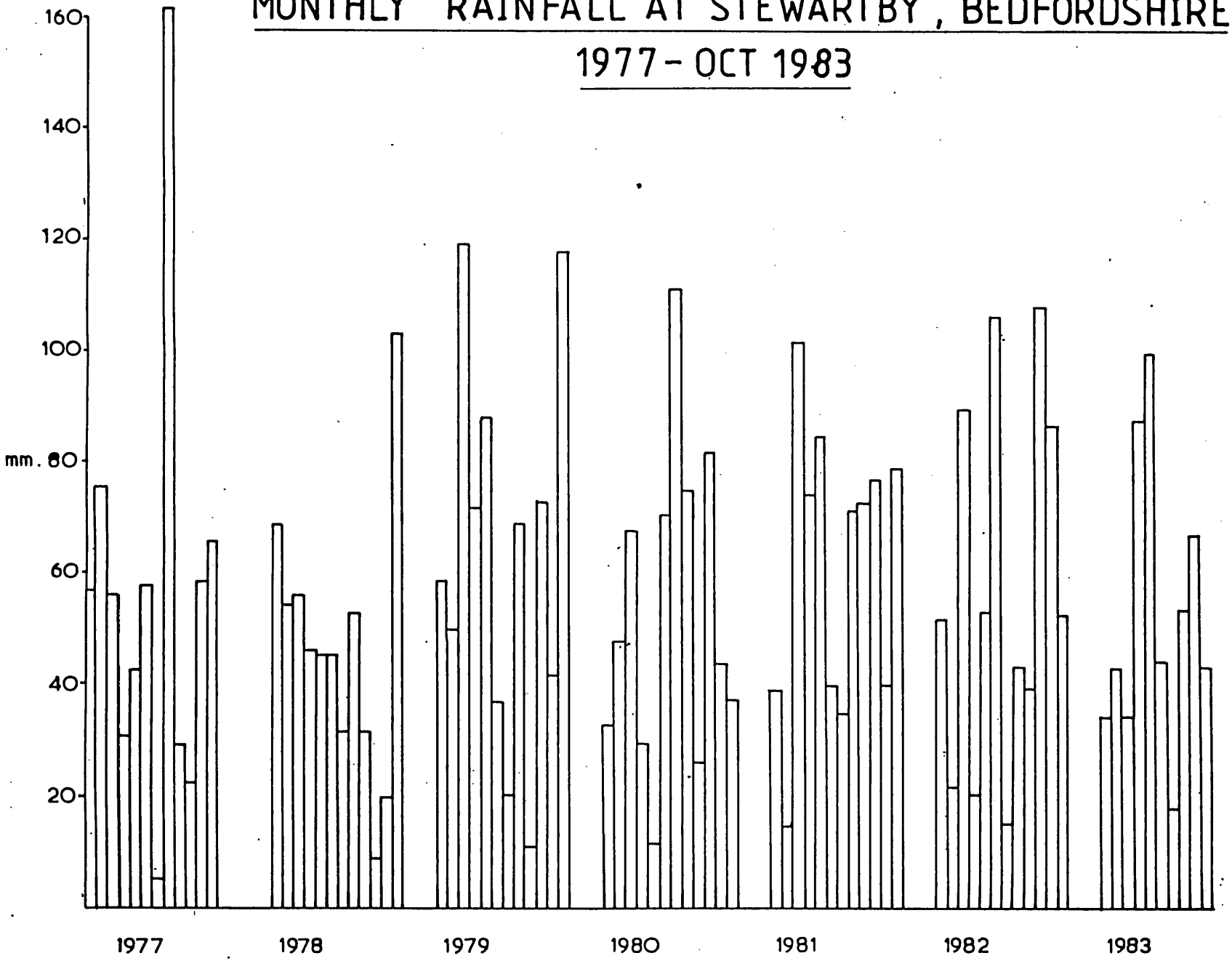
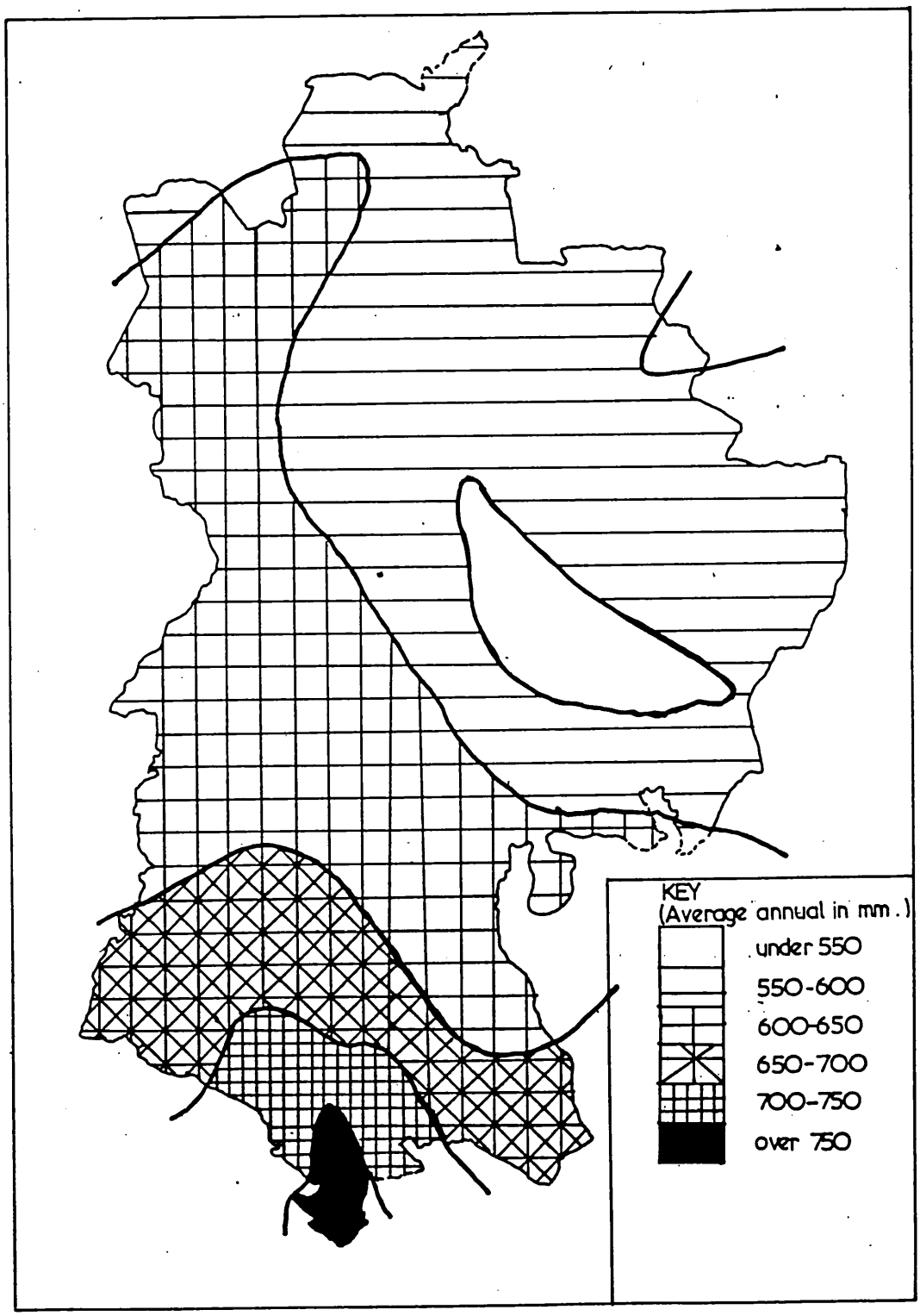


FIGURE 2.6 AVERAGE ANNUAL RAINFALL FOR BEDFORDSHIRE



The annual wind speed and direction rose at Cardington for 1971-1978 is shown in Figure 2.7. Winds from the 200-250° sector are common, occuring for 31% of the year; there is a second maximum in the 20-40° sector. North Westerly winds are rare and the frequency of winds in the 80-160° sector are comparably low.

The wind frequency pattern is subject to seasonal variations. January, February and March have increased frequencies of winds from the North-East and a corresponding reduction in the 200-220° sector. By May, winds with an easterly component of direction are rare and south and south westerly winds predominate. The summer months see a further increase in the dominance of south westerly winds and in August for example, 48% of winds are from the 200-280° sector. There is an increase in the percentage of calms in Autumn.

The relative frequencies of wind speed categories remain approximately the same throughout the year. Gale force winds are usually restricted to the December to May period and are most frequent in February.

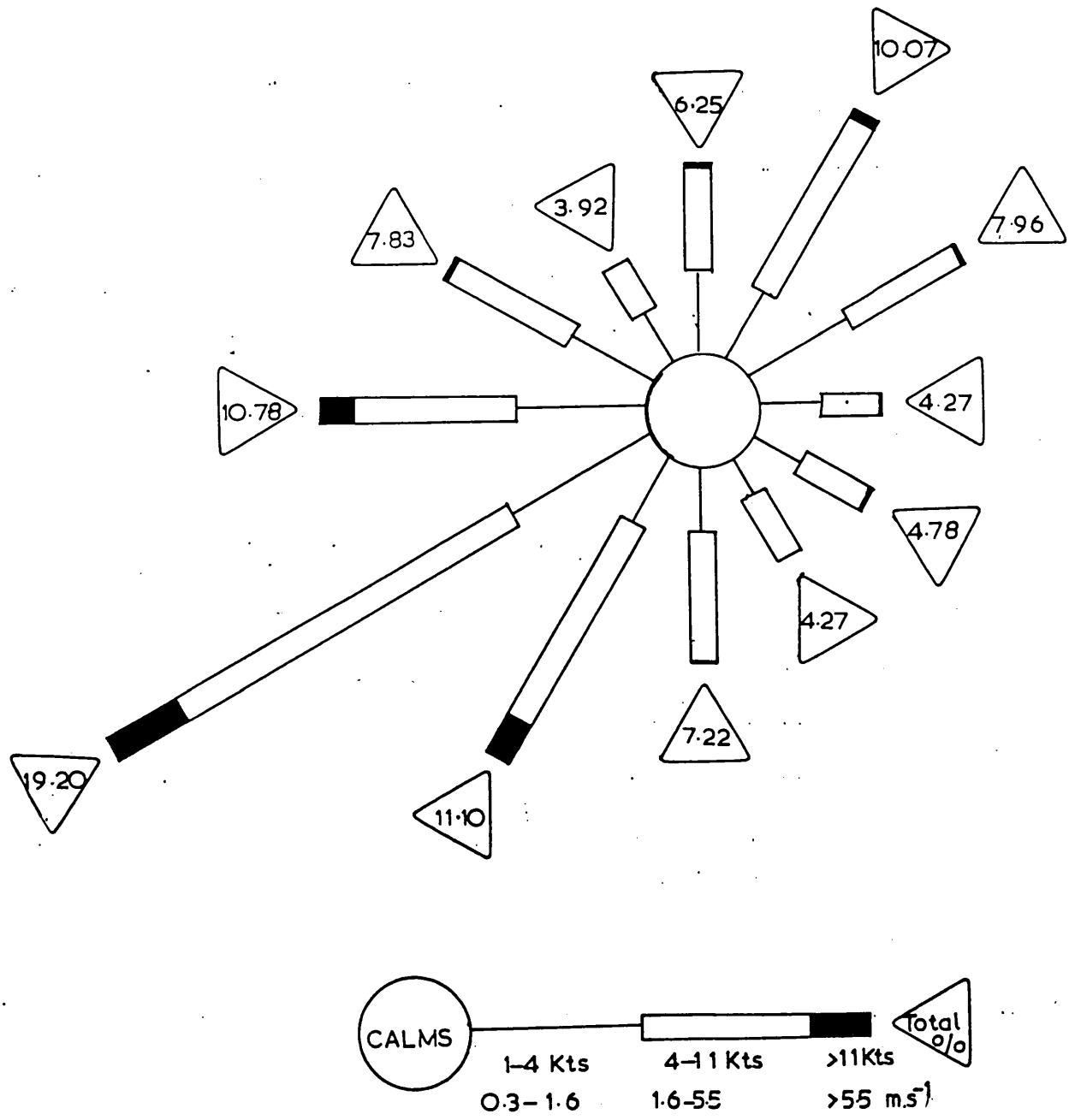
Temperature inversions of intensity 0.5°C or greater are common in the Marston Vale. Daytime temperature inversions frequency ranges from 55% in winter to 14% in summer.

2.7. Evapotranspiration

Rainfall and other forms of precipitation during the cold season of late autumn, winter and early spring is considerably in excess of the moisture loss from the soil by evaporation and transpiration (the water passing in through the roots of plants and out through the leaves).

This excess moisture initially serves to replace moisture extracted from the soil during the previous growing season. The surplus then drains away into the watercourses or if the soil is permeable, penetrates deeply to replenish underground storage water[16]. Since the clay overburden and clay soils of the Bedfordshire Brickfield are virtually impermeable a surplus of water causes ponding and waterlogging during the winter.

FIGURE 2.7 CARDINGTON WIND SPEED AND DIRECTION ROSE 1971-78



(From Cremer & Warner)

The soil contains its maximum quantity of water at the end of the winter period. During the summer the rate of moisture loss from the soil via plants to the air can exceed the rate of replacement by rainfall. The soil moisture content within the plant rooting zone thus decreases during the summer to be replenished during the following winter.

Jones and Fisher[16] calculated a water balance for Quest Pit using Cardington and Rothamsted rainfall data for the years 1961-1980. They found that the mean excess winter rainfall over this period was 132mm (23% of the annual rainfall) with a range of 0-272mm.

2.8. Environmental Problems of the Brickfields

2.8.1 Introduction

The extraction of clay and the brick making industry affects the environment in a number of ways; these include visual impact (although this is a declining problem due to the number of works that have been demolished); traffic problems associated with the close proximity to residential areas, dereliction and air pollution. The first three factors are dealt with in depth elsewhere[24,25,26], and are not directly relevant to the project. Air pollution in the Marston Vale has been a controversial issue for many years and is of relevance to the work carried out for this project. Thus research results to date are summarized below.

2.8.2. Air Pollution

Wide concern about the pollutants emitted from the Bedfordshire brickworks has been apparent for a number of years. The submission of proposals to rebuild brickworks in the Marston Vale by London Brick Company in 1979 provided the focus for local and national debate on the pollution issue which dominated consideration of the planning applications.[1]

The Oxford Clay has a high organic content which is burnt out during firing, providing about 75% of the energy required to make the bricks. The remainder of the fuel required to fire the bricks comes from coal (apart from the experimental methane fired kiln at Stewartby where methane harnessed from the London Brick Landfill Site at L-Field is used as a source of fuel[6]).

During the firing process the chemical changes that occur within the clay give rise to the polluting emissions discharged to the atmosphere. Some o. these emissions come from the coal, but the majority are produced from firing the clay. The pollutants produced are:-

i Acid gases; sulphur oxide and fluorides.

ii Odours; the mercaptans (aromatic hydrocarbons).

The emission of acid gases to the environment has been quantified by London Brick Company and by the Alkali Inspectorate. The odour emissions have been quantified for similar works in Cambridgeshire. Based on these figures the mass emission data for a standard 1.25 million bricks per week kiln is:-

i	Sulphur dioxide	0.26 tonnes. $hour^{-1}$
ii	Fluorides	2.55 kg. $hour^{-1}$
iii	Odour	$7.56 \times 10^{9} M^{3}$ $hour^{-1}$

The standards for emission control are set by the Alkali Inspectorate in accordance with the "best practicable means" clauses of the Alkali Act of 1906. At present it is considered by the Alkali Inspectorate that there are no practicable means of abating emissions at source. Thus, emissions are discharged, untreated into the atmosphere. The use of taller stacks in the future would not reduce the total amount of pollutants emitted but would reduce the ground level concentrations in the near vicinity of the works[1].

Investigations have been carried out by the Alkali Inspectorate and London Brick Company into abatement technology.

2.8.3. Monitoring Emissions

A range of measurements relating to emissions and ground level concentrations of the principal air pollutants are undertaken by local authorities and London Brick Products on a regular basis. Intermittent measurements relating to human health, animal health and crops have been made by a variety of bodies[27].

Atmospheric fluorides are measured in the Marston Vale by L.B.C. The Company operates:-

8 lime candle samplers

3 deposit gauges

1 volumetric fluoride sampler.

In addition, L.B.C. analyse the samples collected by a second volumetric fluoride sampler operated by North Bedfordshire District Council (N.B.D.C.).

Smoke and sulphur dioxide are also monitored in the area. The Company operates eleven lead dioxide candles (seven at sites where lime candles are also located) and daily SO_2 samples. In addition, North Bedfordshire District Council, Mid Bedfordshire District Council, Bedfordshire County Council, Woburn Sands and District Society, the Meteorological Office (Cardington) and Rothamsted Experimental Station operate daily smoke and SO_2 samples.

Measured atmospheric concentrations of fluorides in the vicinity of the Stewartby Works indicate that the annual average concentrations, up to 1980, were in the range 1-8$\mu g.m^{-3}$ with year to year variations within the range. Although there is uncertainty about the accuracy of these figures and whether they are representative (they were obtained from only two sites, one of which is close to the works and may therefore underestimate concentrations), it seems unlikely that the actual annual average concentrations will exceed the limits quoted. The lime candle results indicate that fluoride concentrations decrease with distance from the works as would be expected[27].

The Stewartby Works emit about 260 tonnes of fluoride per year, from nineteen chimneys, each at a height of 61m. Model calculations suggest that the annual concentration of fluoride at the N.B.D.C. site is 3 $\mu g.m^{-3}$. The Cremer and Warner model gives an even lower concentration[28].

No standards or guidelines have been adopted for ambient fluoride concentrations in the U.K. However, the quoted levels can be compared with the following:-

i The Threshold Limit Values of 2.5 $mg.m^{-2}$ for fluorides and 2 $mg.m^{-3}$ for HF adopted by the Health and Safety Executive for application to workplace atmosphere[29].

ii The Canadian recommended environmental standard of maximum acceptable 24 hour value (as HF) of 85 $\mu g.m^{-3}$ and a maximum desirable 24 hour value (as HF) of 40 $\mu g.m^{-3}$ [30].

iii The West German environmental standards of 5 $\mu g.m^{-3}$ (as HF) which for sampling periods of 30 minutes must not be exceeded for more than 5% of the year[30].

Observed Annual Average SO_2 levels in the Marston Vale are shown in Table 2.2.

The average Annual SO_2 concentrations for 1976-8 are shown in Figure 2.8 Average Annual fluoride concentrations for 1982 and projected future levels are shown in Figure 2.9. The latter diagram is based on the assumption that two new brickworks at Stewartby and Ridgmont are the only producers of bricks in the area. It is evident that predicted fluoride values for the future are about one fifth of the current contribution. Annual, daily and 1-3 hour concentrations are predicted to fall by up to 90% of the current values.

2.8.4 Effects of Pollutants on Human Health

Attempts to evaluate the effect of atmospheric emissions from brickworks on human health are complicated by the range of fluorine and sulphur compounds emitted. Possible synergistic or antagonistic reactions cannot be ruled out.

Table 2.2 Observed Annual Average SO_2 Levels in the Marston Vale

Site	Observed SO_2 Annual Average ($\mu g.m^{-3}$)	
	1977/78	1978/79
Aspley Heath	49	52
Husborne Crawley	63	76
Lidlington	66	61
Houghton Conquest	52	75
Wootton 1	38	50
Cardington	50	68

FIGURE 2.8 AVERAGE ANNUAL SO_2 CONCENTRATION (ug/m3) (1976-8)

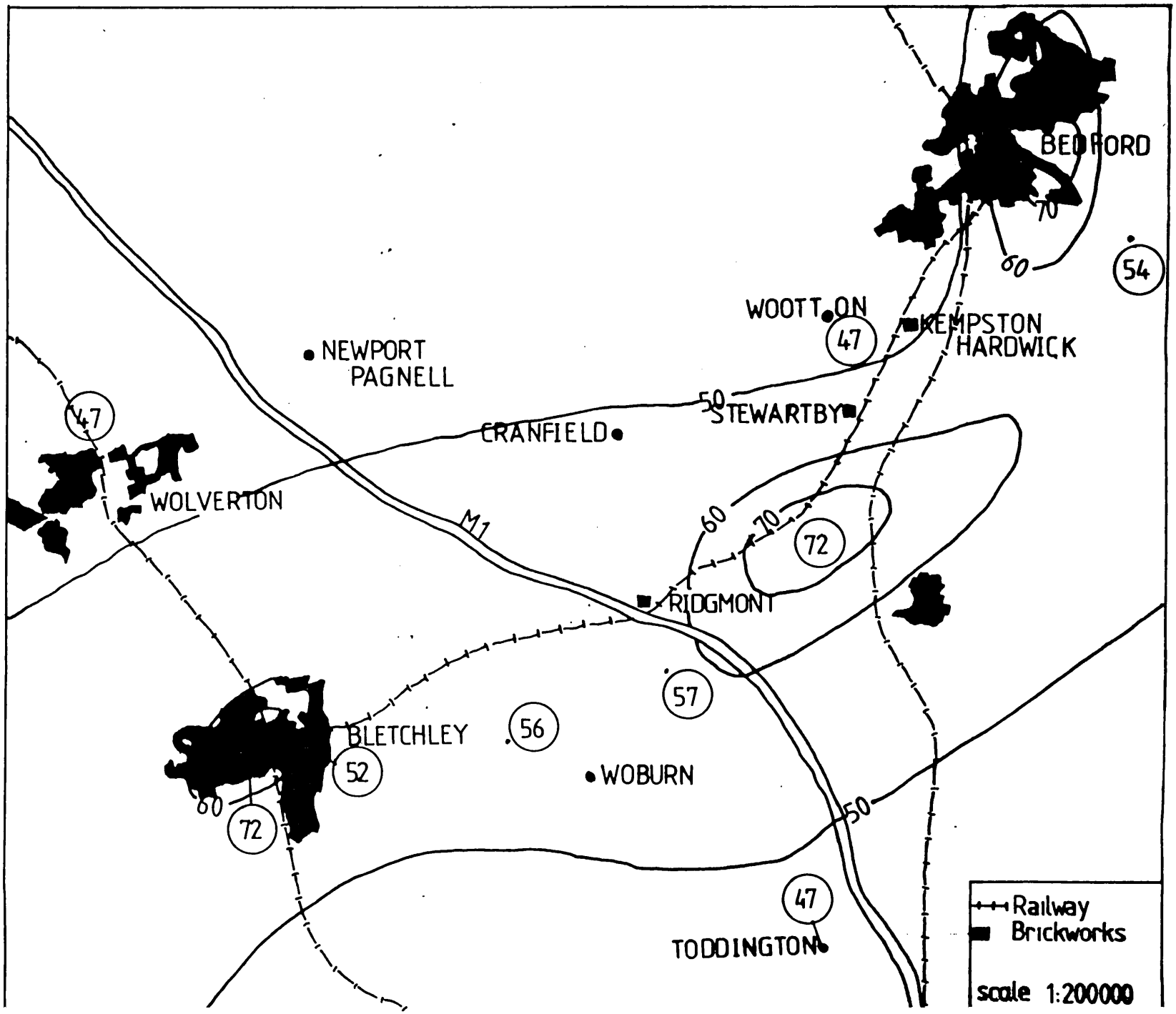
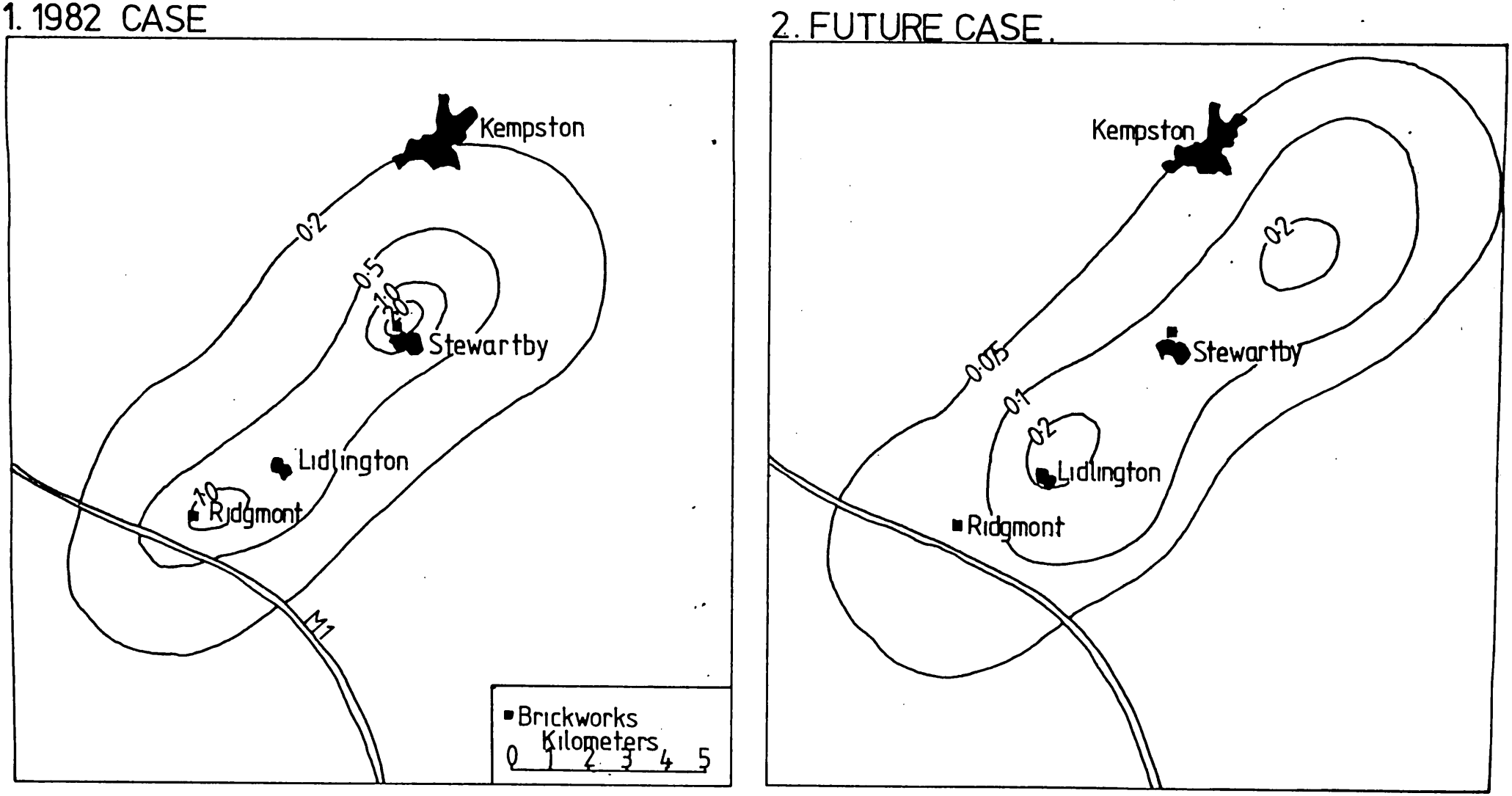


FIG 2.9 AVERAGE ANNUAL FLUORIDE CONCENTRATIONS (ugm^{-3})



i Sulphur Compounds

The principal sulphur compound emitted from the brickworks is sulphur dioxide, although sulphur trioxide, hydrogen sulphide, carbonyl sulphide and mercaptans are produced in trace quantities.

The World Health Organisation Environmental Health Criteria Report no. 8 , "Sulphur Oxides and Suspended Particulate Matter"[31], states that in morbidity studies concerned with short-term exposure to a combination of sulphur dioxide and total suspended particulates, the lowest daily average concentrations at which adverse effects were noted were 200 $\mu g.m^{-3}$ and 150 $\mu g.m^{-3}$ respectively. In long-term joint exposure studies, effects were noted at annual mean concentrations of 60-140 $\mu g.m^{-3}$ SO_2 and 100-200 $\mu g.m^{-3}$ for total suspended particulates.

Increases in mortality were reported in relation to episodes of high pollution with 24 hour mean concentrations of the order of 500 $ug.m^{-3}$ for SO_2 and 500 $ug.m^{-3}$ for smoke.

When these levels are compared with the observed SO_2 annual mean concentration in Bedfordshire which ranges from50-70 $\mu g.m^{-3}$ and the measured peak values within the day based on ten minute mean periods which occasionally have exceeded 1000 μgm^{-3} it can be seen that no adverse health effects would be expected at these concentrations.

Annual mean levels of sulphur dioxide in the brickworks area are lower than those in major urban areas and well below those that have been associated with chronic effects on health. However, the variation in concentration from day to day and minute to minute is greater than generally observed in the towns[27].

ii Fluorides

The fluorine compounds released to the atmosphere when bricks are fired include gaseous hydrogen fluoride and silicon tetrafluoride as well as stable inorganic fluorides. Hydrogen fluoride is corrosive and an irritant and the potential effects on humans could include acute effects on the

respiratory tract and skin and chronic effects from the uptake of any soluble fluorides.

The average annual concentrations of fluoride in air around the brickworks are unlikely to exceed 8 $\mu g.m^{-3}$ [27].

The intensity of acute reponses to concentrations of gaseous hydrogen fluoride have been shown in experiments as follows:-

2.5 $mg.m^{-3}$	No effects
8.2 $mg.m^{-3}$	Many persons experiencing discomfort.
24.5 $mg.m^{-3}$	All persons complain and object to staying in environment.
49.0 $mg.m^{-3}$	Definite irritation of conjunctiva, nasal passages, discomfort of larynx, trachea[32].

N.B. These are milligrams, as opposed to micrograms. Thus the levels in Bedfordshire are one thousand times lower than those at which acute symptoms start to show.

Several attempts at locating chronic fluoride symptons in the Marston Vale area have been made. However, no significant evidence has ever been found.[27,33,34]

iii Odours

There is no quantifiable evidence that the odours generated during the brickmaking process have any adverse effect on human health, animals or crops, despite their offensive nature.

2.8.5. Effects of Pollutants on Vegetation

Natural background levels of sulphur dioxide generally range between 0.28 and 2.8 $\mu g.m^{-3}$ (0.0001-0.001 p.p.m). Whenever mean annual local concentrations of sulphur dioxide exceed about 27-224 $\mu g.m^{-3}$ (0.01-0.08 $\mu g.g^{-1}$) extensive phytotoxic effects begin to appear in a number of species although some are affected at lower concentrations[35].

Symptoms vary considerably among different plant groups. In dicotyledonous plants acute damage causes marginal or intercostal necrotic areas. Damaged

areas at first appear dull dark green, but subsequently they become bleached to an ivory colour (or red or brown occasionally). The necrotic tissue is visible from both sides of the leaf and eventually this dead tissue will disintegrate or the leaf will be shed. Chronic injury is expressed as chlorosis, which frequently appears as a yellowing in intercostal areas. In monocotyledonous plants and grasses acute damage causes necrotic tissue usually appearing as a streak, beginning at the leaf tip and spreading to the base. Chronic damage may only appear as a bleaching of the leaf tips. In conifers, damage initially appears as banding around the needles and later the terminal portion turns reddish brown.

The phytotoxic effects of fluorides vary tremendously between plant groups. In broad leaf dicotyledons, if accumulation of fluoride by the leaf is relatively slow, the fluoride is translocated to the margins of the leaf where necrosis occurs. A distinct reddish brown band separates the necrotic tissue from the healthy tissue. If the ambient concentration of fluoride is high, accumulation of fluoride may occur at several points in the leaf. This results in a scattered distribution of necrotic and chlorotic tissue. In monocotyledons the tips of the leaves are the first area to become necrotic with a reddish brown margin. In cereals the necrotic tissue may appear almost white. In conifers injury begins at the needle tip and spreads to the base. Initially chlorotic, the tissue turns reddish brown with age. Plants vary tremendously in their susceptibility to fluorides. Certain varieties of gladiolus develop necrosis when fumigated with concentrations as low as 0.1 p.p.b. but other varieties are resistant at concentrations ten times higher[36].

Background concentrations of fluoride in plants generally vary between 0.5 and 25.0 $\mu g.g^{-1}$ fluoride by weight[37]. The range of 25-105 $\mu g.g^{-1}$ fluoride is the critical range of sensitive species[38]. Resistant species may accumulate several hundred $\mu g.g^{-1}$ before chlorosis or necrosis appears[39].

Table 2.3 shows the susceptibilities of selected plants to fluoride.

2.8.6. The Effect of Pollutants on Vegetation in the Marston Vale

Research at Rothamsted in the early 1970's attempted to determine whether levels of pollutants in the area of the brickworks were beneficial or harmful to the growth and yield of crops. An initial survey of hawthorn leaves showed that sulphur and fluoride content of the vegetation was closely dependent upon the activity of the brickworks. A comparison of the levels in leaves in 1972 and 1973 showed a decrease during that time, which was attributed to the closure of certain brickworks in the area.

Since 1976, Rothamsted Experimental Station have also examined the fluoride concentrations in barley crops grown in the field and compared these results with crops grown in plastic-covered, hooped-channels receiving filtered air. The ambient air contained a daily mean of 75-100 $\mu g.m^{-3}$ sulphur dioxide, the mean daily level of sulphur dioxide in the filtered chamber was 6 $\mu g.m^{-3}$. However, differences in growing conditions between the covered and uncovered crops meant that it was difficult to separate any growth effects due to filtration of pollutants from changes which occurred in the micro-environment. Despite this, initial findings suggested that although visual symptoms may not be apparent, low levels of pollutants were detrimental to crop production[40].

Later, open-topped chambers were designed to determine the effect of field concentrations of aerial pollutants on the growth and yield of spring barley. The charcoal filtered chambers enabled pollutant concentrations to be reduced by 60-70%. Cleaning the air increased straw and grain yields. The filtration was non-selective and did not identify the injurous agent[41]. Winter wheat is generally thought to be more tolerant to at least SO_2 than winter barley, but no information is available concerning tolerance levels of oil seed rape[42].

Table 2.3 Susceptibilities of Certain Plants to Fluoride

Family	Species	Plant	Susceptible	Intermediate	Resistant
Aceraceae	Acer negundo	Box Elder	—		
	Acer campestre	Hedge Maple		—	
	Acer plantanoides	Norway Maple		—	
Amaryllidacear	Narcissus sp.	Narcissus		—	
Betulaceae	Betula sp.	Birch species			—
Caprifoliaceae	Sambucus nigra	Elderberry			—
Caryophylliaceae	Stellaria media	Chickweed	—		
Chenopodiaceae	Chenopodium sp.	Goosefoot		—	
Compositae	Chrysanthemum sp.	Chrysanthemum			—
	Dahlia sp.	Dahlia		—	
	Helianthus sp.	Sunflower		—	
Cruciferae	Brassica oleracea	Cabbage			—
	Brassica oleracea	Cauliflower			—
Curcubitae	Cucumis sativus	Cucumber			—
Ericaceae	Rhododendron sp.	Rhododendron		—	
Fagaceae	Quercus sp.	Oak			—
Geraniaceae	Geranium sp.	Geranium		—	
G raminae	Hordeum vulgare	Barley (Young)	—		
	Hordeum vulgare	Barley (Mature)		—	
	Zea mays	Sweet Corn	—		
	Avena sativa	Oat (Young)		—	
	Avena sativa	Oat (Mature)			—
	Secale cereale	Rye (Young)		—	
	Secale cereale	Rye (Mature)			—
	Triticum sp.	Wheat (Young)		—	
	Triticum sp.	Wheat (Mature)		—	
Iridaceae	Gladiolus sp.	Gladiolus	—		
	Iris sp.	Iris	—		
Juglandaceae	Juglans nigra	Black Walnut		—	
	Juglans regia	English Walnut		—	
Leguminosae	Medicago sativa	Alfalfa			—
	Melilotus officinalis	Common Melilot		—	
	Pisum sativum	Garden pea			—
Liliaceae	Tulipa gesneriana	Tulip	—		
Pinaceae	Pseudotsuga menzeisii	Douglas Fir	—		
	Juniperus sp.	Juniper			—
	Pinus sp.	Pine species (Young)	—		
		Pine species (Mature) needles			—
Plantanaceae	Plantago sp.	Plantain			—
Platanaceae	Platanus acerifolia	London Plane		—	
	Platanus occidentalis	Sycamore		—	
Polygonaceae	Rumex sp.	Dock			—
Oleaceae	Fraxinus sp.	Ash sp.		—	
	Ligustrum sp.	Privet			—

Table 2.3 (continued)

Family	Species	Plant	Susceptible	Intermediate	Resistant
Rosaceae	Malus sylvestris	Apple		—	
	Pyrus communis	Pear			—
	Prunus domestica	Plum	—		
	Rosa odorata	Rose		—	
	Rubus idaeus	Raspberry		—	
	Fragutia sp.	Strawberry		—	
Salicaceae	Populus nigra	Lombardy Poplar		—	
	Salix sp.	Willows			—
Solanaceae	Solanum nigrum	Woody nightshade			—
	Solanumtuberosum	Potato			—
	Lycopersicon esculentum	Tomato		—	
Taxaceae	Taxus cuspidata	Spreading Yew		—	
Tiliaceae	Tilia cordata	European Lime		—	
Ulmaceae	Ulmus sp.	Elm sp.			—
Umbelliferae	Daucus carota	Carrot		—	
Violaceae	Viola sp.	Violet		—	

The only published report on the effect of the brickworks on trees in the Marston Vale is that of Gilbert[43]. He monitored a tree planting scheme over a ten year period measuring height increase, branching patterns, foliar damage and susceptibility to pests and diseases. Over three hundred trees distributed over 300 ha. were tagged and monitored.

Annual average height increases are shown in Table 2.4. These averaged data, however, hide a great deal of variation caused by interactions between the trees and environmental factors and variation in the performance of different species when grown in different mixes.

Populus x euramericana 'Serotina' was planted to form single species belts and copses where a quick effect was required. Most specimens were 12m tall in 1983 and had thick forked trunks. The bacterial canker Cryptodiaporthe populae destroyed an earlier planting of black Italian poplar.

Fraxinus excelsior (Ash), Acer campestre (Field maple) and Acer pseudoplatanus (Sycamore) mix was used extensively on exposed sites. In some plots, most specimens were reported to be "like beanpoles" with a minimum of lateral growth. They were also mis-shapen due to repeated die-back. Leaf scorch was unuaually severe in these species in 1971 and 1972. In addition a curling, thickening and deformation of the leaflets of ash trees was noted. Gilbert stated that these are typical symptoms of ash under stress from airborne fluorides; however there are many other reasons for these symptoms to occur, e.g. nutrient imbalance, insect and fungal attack.

Gilbert also studied a one-hectare plot near the centre of the brickworks which was planted with three year old Pinus sylvestris (Scotch Pine) and Larix decidua (European Larch). He reported that five years after planting, seventy five per cent of the pines had died and few survivors were more than 100 cm high. The annual average growth of 10 cm was frequently lost through die-back. Needle retention was one year and all showed severe tip burn. The loss of larch was 85%. He attempted to correlate annual ring

Table 2.4 Average Annual Height Increment for Eight Species in The Marston Vale, 1970-1980

Species	Sample Size	Average Annual Height Increment (cm)
Populus x euramericana 'Serotina'	45	46
Salix alba	30	47
Alnus incana	20	54
Fraxinus excelsior	47	19
Acer pseudoplatanus	47	14
Acer campestre	50	10
Quercus rober	32	9
Ulmus procera	45	7 (1970-'74)

widths with a "brick making parameter" which was the number of houses built per year. Because of the subjectiveness and dubious link between the number of houses built per year and annual brick production his results must be treated with caution. Despite this, his findings showing that the performance of trees in the area are related to their known sensitivity to airborne fluorides seems credible.

2.8.7. The Effect of Pollutants on Livestock

Aerial contamination of herbage and other leafy forage by fluorine compounds can cause economic loss arising from bone and tooth damage in grazing livestock[27]. Small amounts of fluorine are present naturally in most plants and animals. Herbage and most livestock feed contains between 1 and 15 ug.g^{-1} of this naturally occuring fluorine[44]. Levels above 15 $\mu g.g^{-1}$ are usually due to contamination. Legal limits to the fluorine content of feed are prescribed. For cattle this limit is 50 $\mu g.g^{-1}$ in the total diet and 30 $\mu g.g^{-1}$ during lactation when more food is eaten. At threshold toxic levels, intake must persist for a year or more before signs are seen. It is usually recommended that continuous intakes should not exceed 1.0 mgF per kg. of body weight per day and at 2.0 mgF per kg. body weight per day if there is a risk of damaging fluorisis.

The damage is caused by the accumulation of fluoride in bone until it is weakened and lameness occurs. Tooth lesions are a less important source of economic loss. Normal adult bone ash levels arising from uncontaminated feed are usually around 1000 $\mu g.g^{-1}$ and seldom above 2000 $\mu g.g^{-1}$ though bone levels continue to rise and in older cows levels may be higher. Bone damage is not common until levels of 6000 - 9000 $\mu g.g^{-1}$ are reached; at levels of 18000 $\mu g.g^{-1}$ fluorosis would certainly be expected.

In the vicinity of the brickworks aerial deposition of fluorides on herbage occurs and fluorisis may arise. Fluorides adhere to herbage and are eaten by cattle and sheep. Since very little grass growth occurs in the winter and animals are fed on hay and silage conserved in summer, winter herbage levels are important.

In Bedfordshire fluorosis occured in the late 1930's when the source of fluorine was shown to be the local clay. In the Ministry of Agriculture, Fisheries and Food survey of 1954-1957[19], of forty three farms investigated, nineteen were affected by damaging fluorosis, eight of these only slightly. Most of the affected farms were "between and among" brickworks or within about two miles to the north and east.

Since then the Marston Vale has changed its agricultural practices, and is now primarily an arable farming area. Between 1972 and 1982 only two cases of fluorosis were reported in the area. A bone sample from one farm was examined with a fluorine level in the range commonly associated with bone damage, though no clinical signs were reported. Bones from two other farms had elevated levels but not in the damaging range[27]. It seems clear from the evidence that the problem is much reduced since 1957. In the 1954-1957 period nine herbage sample averaged 63 $\mu g.g^{-1}$ and the lowest was 36 $\mu g.g^{-1}$. In the 1979 sampling program only one of the seventeen locations within two miles of a works had an average level over 40 $\mu g.g^{-1}$ and the average of the other sites was 26 $\mu g.g^{-1}$. An annual average herbage level of 40 $\mu g.g^{-1}$ is considered acceptable in the U.K.[27].

2.8.8. Conclusions

The conclusions of the Cremer and Warner report state that, "at the present time there is no justification with respect to human health for the introduction of acid gas abatement and that the case for fluoride removal with respect to grazing animals is unproven".[28]

3. BACKGROUND TO NATURAL COLONISATION

3.1. Natural Vegetation

As stated by Kershaw,[45] an area of bare ground does not remain devoid of vegetation for very long. The area is rapidly colonised by a variety of species which will subsequently modify one or more environmental factors. This modification of the environment in turn allows further species to become established. A subsequent development of the vegetation by this reaction of species on the environment, followed by the appearance of fresh species is termed succession.

Hodgson[46] studied the botanic interest and value of hard-rock quarries in the Sheffield region and concluded that natural colonisation is slow; also the nature of the vegetation produced by natural colonisation is determined by the ecology of the species in the surrounding area.

In Great Britain, the Nature Conservancy Council, the Royal Society for the Protection of Birds and several of the County Naturalists Trusts all have nature reserves on land derived from mining, quarrying or tipping wastes[47].

There are several reasons for this:-

i The presence of nationally or locally rare plants or animals. Some of these were once widespread but are now scarce or even confined to quarries.

ii The natural development of one or more types of habitat deemed to be worthy of conservation.

iii The recognition of the potential of a recently abandoned quarry for nature conservation.

iv The offer of a quarry free (or at a low price) once it has been worked out.

However, Ranson and Doody[47] state that it is questionable whether such conditions will develop in the future. Many factors operate against the leaving of man-made sites to develop plant and animal life naturally.

One of the most important factors is the Town and Country Planning (Minerals) Act, 1981 which empowers mineral planning authorities to impose restoration and aftercare conditions on consents for mineral extraction. It is Government policy that agricultural land taken for mineral workings should be restored for agriculture after working wherever possible. Land restored satisfactorily for agriculture helps to minimise the annual permanent loss of agricultural land for non-agricultural development[48].

From time to time, however, planners and operators will accept nature conservation over at least part of a recently disused quarry by either selling the land or relaxing restoration conditions so that a nature reserve can be established[47].

It has been found, increasingly, as the semi-natural grassland habitats have disappeared the full ranges of species present in some areas has only been maintained by the substitute habitat of disused mineral workings.

3.2. Natural Colonisation of Other Clay Substrates

Gimingham and Boggie[49] describe the stages in the recolonisation of a Norwegian clay slide. A catastrophic landslide in 1893 gave a precise date to the commencement of succession on the clay.

The landslip affected an area of 2.8 km^2 upon which several farms were situated. In this region the sides of the valley consisted of a series of river terraces. The strata of the terraces were composed of a deposit of very fine blue marine clay, overlain by a layer of sand and gravel. In the clay there are portions which are much softer than the rest, if these are set in motion under certain circumstances including abundant moisture, the whole mass may become fluid. The slide followed a winter in which there had been abnormally heavy snowfalls. The catastrophe left a basin shaped depression in the terrace surrounded by sheer cliffs or overhangs to the west and north west.

By 1898, when the first botanical surveys were carried out, a fairly large number of species was already established and in some parts closed communities had begun to form. The vegetation was derived from two sources - partly from extension of areas occupied by plants brought down on the floes and partly from invasion by species of the intact communities beyond the margins of the slide. A mixed assemblage of species was therefore available for colonisation including plants of pasture and arable land as well as those of spruce forest, alder thicket and bog.

Over a large part of the depression which was pure clay a relatively small number of species had become established. Among the species recorded as the most prominent were Tussilago farfara (Coltsfoot)+, Equisetum arvense (Common Horsetail), Triglochin palustre (Marsh Arrow-grass), Polygonum aviculare (Knotgrass), Rumex acetosella (Sheep's Sorrel) and Alopecurus geniculatus (Marsh Foxtail). Tussilago farfara was the only species forming complete cover, and even it was not widespread on the clay plain, but was found extending in circles from the "floes" on which it had been transported into the area. On the big clay mounds and ridges in the north of the area it had spread luxuriantly and by 1902 a large proportion of this area was completely covered. Relatively few other species were associated with it apart from Equisetum arvense which replaced Tussilago as dominant species of the low-lying damp ground. Parts of the cliff face were also colonised by Tussilago.

Vicia cracca (Tufted Vetch) was one of the species surviving on one of the "floes" carried down and stranded on the clay. This species was later found as one of the species colonising newly exposed clay by Gimingham and Boggie[49].

+ Classification follows that of Clapham, Tutin and Warburg[59].

A floristic survey of the area carried out in 1936 found that many of the species which had been abundant and widespread in 1898 had become reduced in importance including Tussilago farfara (Coltsfoot) and Equisetum arvense (Common Horsetails). Much of the clay area by this time was densely wooded by Alnus incana (Grey Alder) and species of Salix (Willow). In more open parts the field layer consisted of Filipendula ulmaria (Meadowsweet). Geum urbanum (Wood Avens) and Rubus idaeus (Raspberry). Where the canopy was denser the flora consisted of Oxalis acetosella (Wood Sorrel), Ranunculus repens (Creeping Buttercup), Anemone nemorosa (Wood Anemone) and Chrysosplenium alternifolium (Alternate-leaved Golden-saxifrage). Of these only Ranunculus repens had played a part in the original colonisation of the clay.

Attempts at planting Spruce and Pine in the 1900's on the clay slide were not successful. In spite of attempts to aerate the soil by cultivations, further improvements were necessary before afforestation of the clay could be produced. In 1903 the local forresters realised that Alder should be encouraged due to the beneficial effects upon the soil, both through the high rate of contribution of humus fron the leaf litter and through nitrogen enrichment by root nodules. The spread of Alder was therefore not hindered, although its only value was for fuel.

The vegetation after sixty years was analysed to examine in detail examples of the communities. An area of newly exposed clay was examined at the time; this was caused by small streams cutting channels in the clay. The most conspicuous colonists were Tussilago farfara and Equisetum arvense. The only legume to cover any appreciable area on the newly exposed clay was Trifolium repens (White Clover).

Further development of the flora is initiated by the spread of Trifolium repens. Other species which increased at this stage include Lotus corniculatus (Bird's-foot Trefoil), Festuca rubra (Red Fescue), Deschampsia cespitosa

(Tufted Hair-grass), Leontodon autumnalis (Autumn Hawkbit), Prunella vulgaris (Self-heal), Heiracium pilosella (Mouse-ear Hawkweed), Ranunculus repens (Creeping Buttercup) and Plantago major (Greater Plantain). Seedlings of Alnus incana (Grey Alder) later become numerous and the development of a closed community and the establishment of Alder scrub begins.

The establishment of Alder seedlings in the Tussilago-Equisetum community takes place in a period not exceeding twenty years from the date of the landslide or change in land form, and probably, in some parts, much quicker. After that the soil structure improves, the surface dries out, aeration increases and the upper ten centimetres of soil become rich in humus in the older woods.

Alnus incana is probably a seral dominant and would normally give way to Spruce after about thirty to forty years.

3.3. Flora of the Oxford Clay

Druce[50,51,52,53] described the flora of the Oxford Clay in several of his County Floras. From Druce's species lists several species appear to be common throughout the Oxford Clay. These include Picris echioides (Bristly Ox-tongue), Senecio erucifolius (Hoary Ragwort), Dipsacus fullonum (Teasel), Mentha spp. (Mint species), Juncus inflexus (Hardrush) and Pulicaria dysenterica, (Fleabane).

More recently Dony[54] has studied several different habitats on the Oxford Clay. Of particular interest are the trees and shrubs at Judges Spinney (G.R. TL017541). This is located on an area of Oxford Clay which is overlain with caps of calcareous boulder clay and is the only example of a beech wood which is not on chalk in Bedfordshire. Shrubs and trees recorded include Acer campestre (Common Maple), Carpinus betulis (Hornbeam), Corylus avellena (Hazel), Fraxinus excelsior (Ash), Quercus rober (Common Oak) and Ulmus spp. (Elm).

The other habitats on Oxford Clay studied by Dony include Marston Thrift (G.R. TL 974 415), Wootton Wood (G.R. TL 995 445) and Holcot Wood (G.R. TL 956 403).

3.4. Flora of the Clay Pits

Dony[53] suggests that the clay pits are slow to colonise but given time will produce a rich vegetation as some interesting species are found in places. A colony of Melampyrum pratens (Field Cow Wheat) is found in one of the worked out pits.

Polygonum amphibium (Amphibious Bistort), Typha latifolia (Lesser Reedmace) and Potamogeton natans (Broad-leaved Pondweed) appear when water settles in the pit. On the pool margins are found Epilobium hirsutum (Great Hairy Willow-herb), Sparganium erectum (Bur-reed), Juncus bufonius (Toad-rush), Juncus inflexus (Hard rush) and Phragmites communis (Reed)[55]. Willows follow and the pits take on a changed appearance, the sides quickly becoming colonised by Epilobium spp. (Willow-herbs), Erigeron canadensis (Canadian Fleabane), Tussilago farfara (Coltsfoot), Crepis vesicaria (Beaked Hawk's-Beard) and Picris echioides (Bristly Ox-tongue).

Dony[54] carried out a subjective qualitative assessment of the flora of Lidlington clay pit in 1949. The species recorded were designated subjective statements of their abundance.

Brown[56] studied the rates of soil formation on man-made surfaces, using Coronation Pit as his site for field work. Sites of ages between one and twenty five years were studied. Particular attention was paid to the earth-worms (Lumbricidae) and springtails (Collembola). A detailed study of plant species was also made. Forty species were recorded. Tussilago farfara (Coltsfoot) and Equisetum arvense (Horsetails) were recorded as having the greatest cover values.

Kelcey[57] studied the ecology of old clay workings in the Bletchley area. His report gives detailed species lists for a variety of habitats, but no record of abundance is included. Species were recorded as present or absent.

The sites at Bletchley are particularly noted for their orchids, including Ophrys apifera (Bee Orchid) and Dactylorchis fuschsii (Common Spotted Orchid). The spoil heaps and pit slopes support other species which are rare or uncommon in North Buckinghamshire (e.g. Blackstonia perfoliata (Yellow-wort) and Lotus tenuis (Slender bird's-foot trefoil).
A brickpit acquired by the Berkshire, Buckinghamshire and Oxfordshire Naturalists Trust contains colonies of green-winged orchids, Orchis morio[58].

Thus, to date, no detailed quantitative study of succession on an extensive range of datable surfaces on callow has been carried out, although a preliminary study was carried out in 1980[24].

3.5. The Contribution of Derelict Clay Pits Towards the Conservation of Rare Plants in the United Kingdom.

The areas of clay extraction such as those in Bedfordshire and Buckinghamshire are in areas of intensively farmed landscape. Clay excavations have developed as interesting wildlife habitats in otherwise agricultural terrain. Several of the disused claypits in Bedfordshire and Buckinghamshire have been leased or sold to the County Naturalists Trusts.
Bedfordshire and Huntingdonshire Naturalists Trust Ltd. purchased Ramsey Heights Clay Pit (G.R. TL 245 848) from Ramsey District Council in 1976. The reserve consists of a series of water filled pits, sites of buildings, orchards and rough grassland. The clay was dug in the nineteenth century for making roof tiles, bricks and field drains[60]. Nature Reserves and sites of special scientific interest also exist on London Brick land. The Company has three nature reserves, each managed by the Local Naturalists Trust[61].
A clay pit in Humberside provides the Northern limit of the rare purple broomrape Orobanche purpurea[62] and the workings of calcareous clays in East Cheshire contain plant species which are unusual in the County, e.g. Blackstonia perfoliata (Yellow-wort) and the hybrid orchid species Dactylorchis fuchsii x D. praetermissa[63].

Paradoxically reclamation of such sites is undesirable for conservation reasons and with limited efforts they can develop as nature reserves, educational sites or play areas[64].

Bugler[65] and others, have stated, erroneously, that clay spoil tips associated with brickworks are sterile moonscapes. Work by Kelcey, Brown and others[57, 56, 24] has shown that clay pits are floristically rich as well as being valuable for other forms of wildlife, including a variety of bird species[66]. They also act as islands of wildlife in a sea of intensive agriculture.

In Bedfordshire, Brogborough I Pit was allowed to flood in 1970 and is now considered by the County Council as an attractive feature of the landscape. The most important single feature of interest is the occurance of the Field Cow Wheat on the banks of the lake. The Planning agreement between London Brick Company and the County Council requiresthe Company not to use the pit except as lakes and associated areas reserved for fishing, recreation or wildlife conservation purposes[1].

Also the existing lagoon at Marston Moretaine Pit has been designated as a Nature Reserve.

However, one of the prime sites for nature conservation in Bedfordshire must be considered to be Coronation Pit. Browns' thesis in 1972 stated that interesting and ecologically stable areas with low carrying capacities could be created in Coronation[56]. Later studies have shown that the series of datable ridges provides an excellent substrate for the study of succession[24].

Despite this, the County Council describe Coronation Pit in the following words:-

"Part of the pit floor is flooded, the remainder comprising overburden returned to the quarry floor forming a moonscape".

If part of Coronation Pit is used as the site of the new works, the remainder of the pit would be well suited for a nature reserve or country park for both educational and wildlife conservational purposes. This would

be in accordance with the Oxford Clay Subject Plan Policy 7 which states:- "The County Council will excpect all restoration schemes to take full account of opportunities for retaining and creating wildlife habitats and to provide recreational facilities where appropriate".

3.6. Reclamation of Other Clay Overburdens

3.6.1. Definitions of Reclamation.

i Restoration

This is the recreation of conditions suitable for the previous use of the area.

ii Rehabilitation

This is the creation of conditions for a new and substantially different use of the mined or quarried area.

iii Reclamation

This is the returning of a derelict site to some use.

iv Derelict land

This is land so damaged by industrial or other development that it is incapable of beneficial use without treatment.

3.6.2. Examples of Reclamation Using Other Types of Clay Overburden

One example cited is that of Texas Gulf Inc.'s Kidd Creek Mine, near Timmins, Ontario which involved the largest Coronillia varia (Crownvetch) seeding in Canada at that time[67].

The pit consisted of approximately forty hectares of highly unstable clay slopes making up the upper part of the open pit where the clay overburden averages from eighteen to twenty four metres in thickness.

The clay contains up to sixty per cent moisture and was a potential danger if left unattended. It was also a difficult "gumbo" like material unsuited to conventional methods of rehabilitation. It was devoid of any organic content and bacterial life and had a pH close to neutral. The

magnesium content was high, a factor favourable to legumes. The first seeding in 1966 resulted in fast germination but because of its lateness in the season, the plants were not able to reach the given stage of their development which would permit them to survive the severe winter conditions at that latitude. The following spring, however, the hardy seeds germinated and provided an adequate cover for the second year. A second seeding was carried out in June 1967 with a booster dose of 450 $kg.ha^{-1}$ of Blue Chip Nitroform which resulted in lush growth up to the winter. That winter proved severe and caused the elimination of the weaker plants due to a light snowfall leaving an inadequate insulating cover.

In the spring thaw the moisture was heaved out, lifting bodily the crownvetch plants several centimetres out of the ground, although the plants had already established roots thirty to sixty centimetres deep. The gap created between roots and the repeated freeze-thawing cycle had caused the outer skins of the roots to separate from the plants.

The more resistant of the hardy seeds left germinated in the Spring and provided an adequate cover.

The areas covered in Crownvetch were densely covered by 1972 and spreading by rhizomes and re-seeding themselves. By the time of publication (1972) all soil movement had ceased. The ground was also reported to be appreciably drier because of the regulation evapotranspiration power of the plants.

The overburden from the English Midland ironstone workings consists of clays and limestones of the Jurassic period. The main material is a heavy clay little relieved by coarse particles: the overburden is therefore a mix of material of heavy clay texture interspersed with lumps of limestone which vary in size from five centimetres to large boulders.

There is a high level of calcium ($pH > 7$) and low levels of phosphorus and potassium. There is interaction between the calcium and phosphorus

and potassium, rendering what little there is, even more unavailable to plants. The top soil has been mixed into the overburden in places, but the dilution factor is so great that the resulting material has no organic matter or nitrogen.

There are signs of anaerobic conditions below the top ten centimetres, but gross water logging is not prevalent because of the hill and dale topography.

Colonisation by plants is slow because of the lack of major nutrients and the excess calcium. The result is a specialised flora consisting of plants which have good powers of seed dispersal and are able to tolerate the extreme soil conditions.

The vegetation remains open for many years. Shrubs such as Crataegus monogyna (Hawthorn) and Salix caprea (Goat Willow) invade but grow slowly. There is a lack of legumes because of the low levels of phosphorus. Natural soil development is therefore slow[3].

The overburden from the iron-ore producing area in the Mesabi Range in Minnesota consists of sand silt and clay layers and is nearly neutral in pH unless limestone pebbles are present. Mining started in 1892 and has left a series of spoil banks of different ages showing the process of colonisation and soil development. Invasion is by species which have good powers of dispersal. Prominent among the herbs are two legumes, Trifolium repens (White Clover) and Melilotus alba (Sweet Clover) which do not have good powers of dispersal but whose success must be related to their ability to fix nitrogen. Trees are only able to colonise in the early stages of succession when there is no competition, and then only in years when climatic conditions are suitable.

The impact of the vegetation is considerable (Table 3.1.). There is a continuous build-up of carbon and nitrogen in organic matter which has both a direct and indirect effect on the soil structure. The carbon/nitrogen

Table 3.1. Species Succession on Mesabi Iron-Ore Spoil Banks (herbs as % frequency, trees as number per 100m^2)[3]

Species	Age of Surface				
	2 yrs.	13 yrs.	21 yrs.	32 yrs.	51 yrs.
Trifolium repens (White Clover)	5	95	65	100	75
Poa pratensis (Smooth Meadow-grass)		85	100	70	65
Fragaria virginlana (Strawberry sp.)		45	25	80	95
Sonchus arvensis (Perennial Sow-thistle)		55	20	15	
Melilotus alba (White Melilot)		45	95		
Achillea millefolium (Yarrow)		30	10	40	15
Trifolium pratense (Red Clover)		10	30		
Cinna latifolia		15			
Solidago nemoralis (Golden-rod sp.)		20	15	40	20
Erigeron canadensis (Canadian Fleabane)		10			
Rubus idaeus (Raspberry)		10	30	15	75
Solidago gigantea (Goldenrod sp.)		10	10		
Phleum pratense (Timothy)		5	35		75
Agropyron repens (Couch-grass)			15		
Cirsium arvense (Creeping Thistle)			15		15
Equisetum arvense (Common Horsetail)			10		
Aster ciliolatus			5		15
Diervilla lonicera				15	
Aster macrophyllus				15	
Heiracium canadense (Canadian Hawkweed)				10	
Aralia nudicaulis					20
Bare substrate	100	55			
Litter		90	100	100	100
Populus tremuloides		2	12	92	49
Populus balsamifera			8	30	100
Prunus pennsylvania		3	4	2	
Salix sp. (Willow sp.)		3	4	7	

ratio is initially high, but as the legumes develop, the ratio falls quickly to levels found in better soils where there is good nitrogen cycling. After fifty years the total nitrogen in the soil reaches 1400 kg.ha^{-1}. The trees growing on the older banks therefore grow quicker than equivalent trees on younger banks[3].

An example of shallow, low level reclamation to agriculture after digging for clay is the site of the brickfield to the rear of Kempston House, Bedfordshire (G.R. 008 474). It was operated between at least 1869 and 1894 by Bingham Newland of Kempston House in 1869; in 1873 ownership passed to his brother, William Pritzler Newland (the Newlands were Bedford Brewers), but the brickyard was operated from at least 1888 by Samuel Foster, the Kempston Builder who also had a brickworks at Ravensden[4]. The site is shown in Plate 3.1.

Reclamation of the English Ironstone Workings has shown that when a dressing of complete fertiliser, 150 kg.N, 70.kg. P, 125 kg. K.ha^{-1} was given, satisfactory growth of grasses could be achieved. When the effects of individual nutrients were tried, the response to phosphorus was particularly marked. The most successful plants were vigorous species with strong root systems, including Dactylis glomerata (Cocksfoot), Fescuca pratensis (Meadow fescue), Lolium perenne (Perennial rye-grass), Phleum pratense (Timothy), also legumes were used including Medicago sativa (Lucerne), Trifolium hybridum (Alsike Clover), Trifolium pratense (Red Clover) and Trifolium repens (White Clover).

Surface consolidation recurred rapidly after seeding so grass growth became poor despite fertilisation. A more satisfactory sward could be obtained from Medicago sativa (Lucerne) and Dactylis glomerata (Cocksfoot) cut for hay or silage. Lucerne was able to tolerate the heavy clay and gave high yields if given adequate levels of high phosphate fertilisers. Cereals and root crops did not give satisfactory results because of problems with wet weather.

PLATE 3.1 SITE OF KEMPSTON HOUSE CLAY PIT



In the Mesabi Range most areas have been left to colonise naturally. Many of the worked out pits have been allowed to fill with water creating over 1200 ha of lakes which are a major recreational resource[3].

McRae carried out some field trials at Borough Green Quarry in 1979 in order to investigate the best way of establishing a grass cover on the part of the quarry which had been backfilled with Gault Clay. The trials included the use of sand or silt bed deposits laid over or mixed with Gault Clay and an investigation of the best grass species to sow.

The use of sand or silt bed deposits gave far better results than trying to establish grass directly onto Gault Clay. Simply laying the sand in a thin layer over the Gault Clay gave better results than rotovating the sand and clay together.

The relative performance of the different grasses and clover is given on a 0 - 10 scale, 10 being the best growth and 0 being no growth[68].

Table 3.2.
Borough Green Quarry Vegetation Trials

Species	Relative Performance
Italian Ryegrass (RVP)	10
Perennial Ryegrass (Kent Indigenious)	9
Perennial Ryegrass (S24)	8
Timothy (Oldenwalder)	7
Cocksfoot (Roskilde)	6
Creeping Red Fescue (Echo Daenfeldt)	4
Bent-grass (Colonial Highland)	3
Clover (Kent Wild White)	1

However, these results need to be treated with caution. Italian ryegrass is well known for its ability to grow well in its first season, but as it's a biennial it will die out in its second year. Conversely, cocksfoot and red fescue will perform better in their second and third year. The clover gave low germination results. The relatively poor performance of the fescue and bent grass were thought to be because of the fine seed. Thus the known tolerance of these species was of importance since they did not appear to germinate in the first place.

The reclamation of spoil heaps containing a high proportion of boulder clay produced during the opencast mining of brown coal in Germany is reported by Simon et al[69]. They state that reclamation is based on growing lucerne and cocksfoot and applying high rates of phosphate.

In Hungary Lotus corniculatus (Bird's-foot trefoil) and Sanguisorba officinalis (Great Burnet) gave a satisfactory hay yield in the first four years of reclamation of a spoil heap over a coal seam even when no fertiliser was applied. NPK fertiliser and dung increased the hay yield. Mixed sowing of Burnet with Bird's-foot trefoil is suggested for similar clay spoil heaps[70].

3.7. Reclamation of the Brick-pits to Agriculture/Forestry

There are three principal ways in which clay workings can be restored; by landfill, at a reduced level or by flooding.

Landfill involves backfilling excavated areas, usually to ground level or suitably surcharged in order to give topographical relief and improved drainage. Suitable filling materials include domestic and industrial waste and inert materials such as colliery spoil. The filling material is "capped" and soil layers replaced.

Restoration can take place at reduced level by providing the appropriate conditions i.e. contouring the pit base and re-spreading the soil layers to enable appropriate after-use to be established and to enable the satisfactory assimilation of the site into the landscape.

The Oxford Clay Subject Plan Policy 11 states "The County Council will expect the Stage 1 restoration schemes submitted in accordance with planning permissions 4/1980 and 2/1981 in respect of unworked areas to provide for restoration of pits to agriculture at a reduced level where no suitable filling materials are available at the time of submission".

Policy 13 states "In respect of all future extraction areas at both existing and new pits, all topsoil, subsoil and other overburden removed in the process of clay extraction will normally be retained on site for restoration work unless there are overriding reasons to the contrary".

Policy 14 states "Working and restoration schemes for clay extraction areas should observe the guidelines for the handling, storage and replacement of soils set out in Appendix 4 of this plan". The guidelines are reproduced in Appendix 1 .

The County Council has given considerable thought to the question of importing colliery spoil from Belvoir and fully supports such proposals, in the belief that it would result in a more rapid reclamation of despoiled land with consequent environmental gains.

Should all, or significant quantities of spoil become available for restoration purposes in the Marston Vale, then it would represent a central element within the overall strategy since it would enable the restoration of a substantial proportion of current worked areas to ground level.

The current shortage of filling material and the timescale involved in restoration remain fundamental issues. London Brick Company's extraction programme has in recent years created approximately 3 million cubic metres (m.cu.m) of void space annually in addition to the existing backlog of about 80 m.cu.m. In contrast the amount of material being deposited as fill is between 600 000 and 700 000 cu.m. annually.

The County Council's restoration strategy for the Vale has therefore been heavily influenced by the backlog of workings requiring restoration and the poor prospects for obtaining sufficient filling materials to quickly restore the workings to ground level. The uncertainty of whether adequate supplies of fill can be obtained results in the continued dereliction of large areas of land from which clay has been extracted. Where filling materials are available it may take twenty years for an individual working to be completely restored. Thus it is the Planning

Department's belief that some workings are suitable for restoring at reduced levels. Also, filling materials, when available should be concentrated at a limited number of sites in order to speed up restoration and that whenever possible restoration to a suitable afteruse should be carried out progressively.

The restoration proposals in the Oxford Clay Subject Plan suggest that after-uses for the individual pits are as follows:

Elstow The final restoration of the site will be carried out by backfilling with appropriate waste to ground level, contouring and landscaping for agricultural use.

Kempston Hardwick: If no guaranteed source of filling material is available to enable restoration to ground level, Stage 1 and Stage 2 restoration proposals for Kempston Hardwick pit should show the contouring of the pit floor for agricultural or recreational use and the retention of the existing lagoon for recreational use.

Coronation: Stage 1 restoration proposals for the unworked portion of Coronation Pit should, in the absence of guaranteed sources of filling materials, make provisions for progressive restoration to agriculture at reduced level.

Quest: The Stage 1 and Stage 2 restoration schemes for Quest Pit should make provision for progressive restoration to agriculture at reduced level.

Houghton Conquest: Stage 1 and Stage 2 restoration schemes for Houghton Conquest Pit should make provision for progressive restoration at reduced level.

L Field: The County Council will encourage the earlier and progressive restoration at L Field by supporting proposals which concentrate available filling materials to the pit and maximise existing rail reception facilities. Final contours for this site should enable afforestation and agriculture to be established.

Rookery: Final restoration proposals for Rookery should provide for the early restoration of Rookery South using domestic refuse or other suitable waste material, and Rookery North using inert waste, subject to the possible importation of colliery spoil from north east Leicestershire not being prejudiced. Stage 1 restoration proposals should ensure the restoration of the South-West part of the pit if this area is worked, and the landscaping of the fault area.

Marston Moretaine: The County Council will support the establishment of a Nature Reserve at the existing lagoon at Marston Moretaine Pit. In the event that further clay is extracted from the permitted area the County Council will seek an agreed restoration scheme that provides for its restoration at reduced level unless guaranteed sources of filling material are available.

Brogborough 2: If insufficient suitable filling material is available to ensure the implementation of the approved scheme for the restoration to ground level of Units 1, 2 and 3 in Brogborough 2 Pit, alternative Stage 1 restoration proposals should show the reclamation of the existing void space on a similar timescale, including restoration to agriculture at low level.

Brogborough 1: The County Council will consider Brogborough No. 1 lake to be restored when the approved scheme for stabilising the banks has been implemented and subject to a satisfactory landscaping scheme being carried out.

Lidlington: Subject to it not being required for a scheme involving the importation of colliery spoil from north east Leicestershire, restoration proposals for Lidlington pit should provide for restoration by backfilling with appropriate waste materials. The area already backfilled will be reserved for possible future use as a reception area for imported waste.

Thrupp End/Estcheat: Stage 1 and Stage 2 restoration schemes for Thrupp End/Estcheat pit should make provision for progressive restoration at reduced level.

The County Council's Subject Plan Policy 37 is: "In accordance with restoration Policy 6 the County Council will encourage the large scale planting of woodland on visually prominent restoration sites where this will substantially enhance the landscape value of the Marston Vale".

Policy 38 is: "Species of trees selected for planting schemes should wherever planting conditions permit, be those normally occurring around the Marston Vale.

In the special circumstances normally associated with restored land choice of species should be related to:-

(i) Potential for successful establishment.

(ii) Potential as a "nursery" crop.

(iii) Potential for successful integration into the landscape".

3.8. Restoration to Recreational After-uses

The water filled pits already serve as recreational areas for sailing, wind surfing, water-skiing and fishing.

Where pits are designated as Nature Reserves then such recreations as walking and bird watching are relevant. Fishing is not recommended in Nature Reserves due to the poisoning effects of lead weights on wild fowl. This is said to be the reason for the decline in the number of swans in the Country in recent years.

However, where the Subject Plan states for example, Kempston Hardwick pit floor should be contoured for agricultural or recreational use and the retention of the existing lagoon for recreational use; the question arises what "recreational use" does The Planning Authority have in mind for the pit bottom after contouring?

A recreational use which has not been considered for the clay pits is that of artificial-slope skiing or grass skiing. The steep sides of the claypits

would make excellent slopes. For grass-ski slopes the clay would have to be seeded with low cost grass/legume mixture. The flat bottom of the pit, if levelled would make an excellent, safe, running-out area and bumps and hollows created by the callow would make an interesting mogul field. Initially, the cost of establishing an artificial slope would be capital intensive, but it would have the benefit of being used throughout the year. There are no grass skiing facilities or artificial ski slopes in Bedfordshire. It is estimated that three million people in Britain are skiiers, and that number expands every winter. Thus there would certainly be the demand.

3.9. Other Uses for the Bedfordshire Clay Pits

Kelcey[64] and Gordon[71] believe that derelict land is a valuable resource and has great potential and provides tremendous opportunities. It may form an important landscape feature, especially in areas of low topography and is part of the cultural and industrial development of an area. Gordon states that mineral workings are important monuments to Britain's pioneering industrial land. He thinks that it is as desirable to schedule pits, tips and earthworks as it is to schedule buildings and artifacts before uncontrolled enthusiasm hides them from generations[71]. He states that the resilience, robustness and interests of derelict land provide excellent play areas for children and motorcyclists.

"Derelict land often forms the only large expanse of land that is not well manicured. People can take their dogs for walks, train whippets and pigeons free of restrictions. The retired can squat, smoke, reminisce and grow old and die in comfortable surroundings".[65]

4. FIELD WORK SITES

The sites chosen for field work were those which would provide a good indication of natural colonisation and soil development on callow over a long age series.

Site ages were recorded as the year in which the dumping (or excavating) of callow ceased. In the older pits where the callow was used for making bricks and tiles the age was taken as the year of closure of the works. Thus although the callow dumping/digging may have taken place over many years, the age given to the site in the successional series is that of the end of dumping/digging.

The determination of site ages was often the limiting factor. It was also important that sites chosen had not had their natural regeneration interfered with; through landfill, site clearance or extensive site management. It was difficult to find older clay pits which had not had some kind of management practised.

4.1. Quest Pit (G.R. TL 027 419)

When freshly excavated callow was required for greenhouse trials, the new site at Quest Pit was used. The location of the pit is shown in Figure 4.1. Permission was granted by the Council in July 1980 for a revised area of working extending to 84 ha. with an estimated void capacity of 12.9 m.cu.m. Extraction of callow has already started, in order to replace Rookery Pit as the knotts supplier for Stewartby Works. Plate 4.1. shows the drag line in Quest Pit excavating callow in the summer of 1983.

4.2. Rookery Pit (G.R. TL 015 412)

Existing experience and knowledge had shown that Rookery Pit provides a good sequence of natural colonisation in the early stages of succession on callow.

Rookery Pit consists of a working area of 156 ha. of which 121 ha. had been worked by 1982[1]. The pit is divided into two sections by an unworked area as a result of a geological fault in the clay. Overburden from Rookery South

FIGURE 4.1 LOCATION OF SURVEY SITES IN AND AROUND STEWARTBY

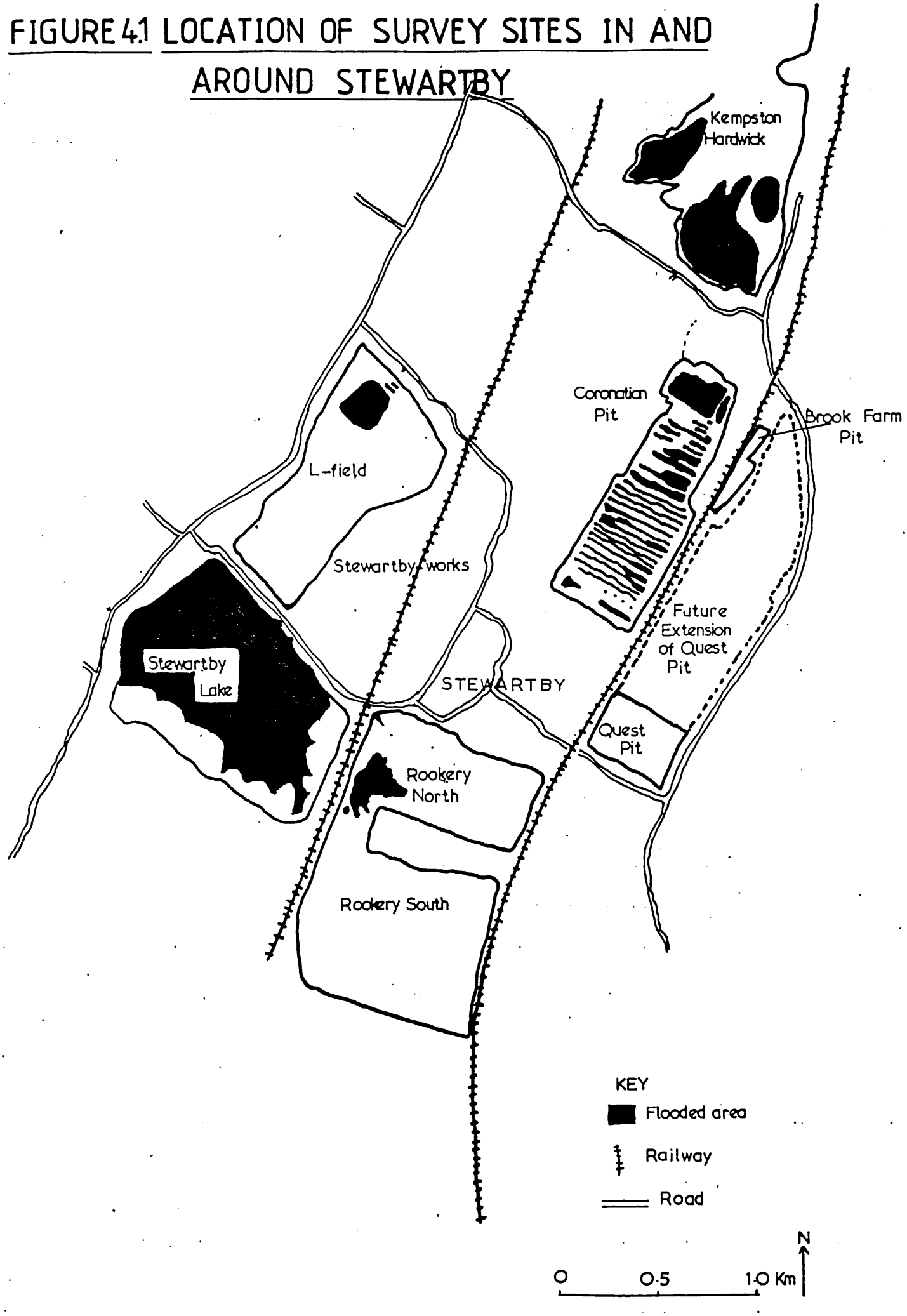


PLATE 4.1 DRAG LINE IN QUEST PIT (SUMMER 1983)



PLATE 4.2 ROOKERY PIT, GENERAL VIEW



PLATE 4.3 ROOKERY PIT, FLORA



has been slurried and disposed in the northern section, as has Quest Pit callow. The callow disposal has reduced the pits void capacity to 25 m.cu.m. in 1982[1]. Some brick bats have also been dumped in Rookery North and a liquid waste disposal scheme was operated by Easidispose as shown in Fig. 4.2; however it appears that this no longer occurs[72]. Apart from this, no restoration has been carried out.

A proposal to use domestic refuse in Rookery South has been considered favourably by the County Council. Domestic Refuse is considered to be an appropriate filling material subject to its transportation by rail. London Brick Company have indicated that a rail terminal could be constructed along the South West margin of the pit connected to the Bedford-Bletchley line and that its capacity could be up to 3200 tonnes of waste per day[1].

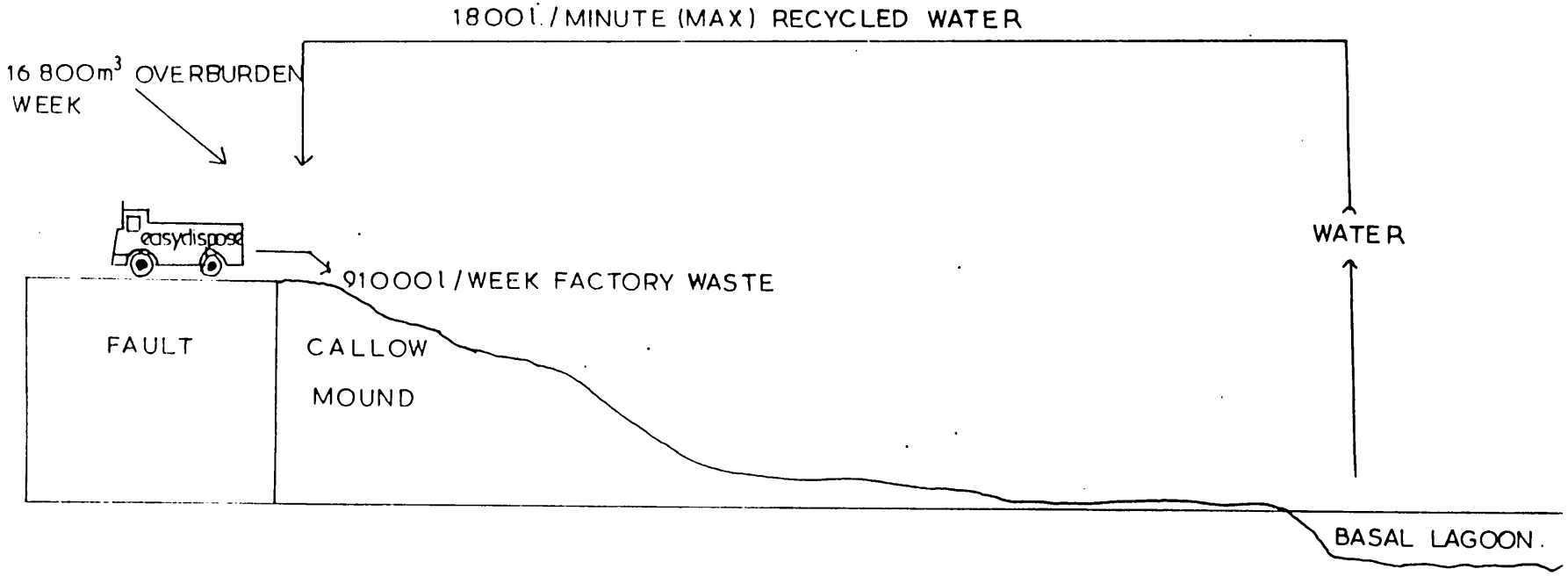
The Northern section of Rookery Pit is, by reason of its proximity to Stewartby Village, considered to be suitable for taking inert filling material only.

Excavation of the Extreme South West corner of the permitted area would open up a view of the whole pit from the Millbrook-Lidlington Road. Because of this London Brick Company agreed to leave an area unworked if the programmed move to Quest Pit allows[1]. The location of the pit is shown in Figures 4.1 and 4.3.

4.3. L-Field

Extensive field work was carried out at L-Field during 1980. However, since then the willow/grassland habitats have been cleared in order to establish a trial water purification system for the leachate from the rubbish disposal area. Thus it could not be included in this survey, although results from the 1980 field work are discussed later.

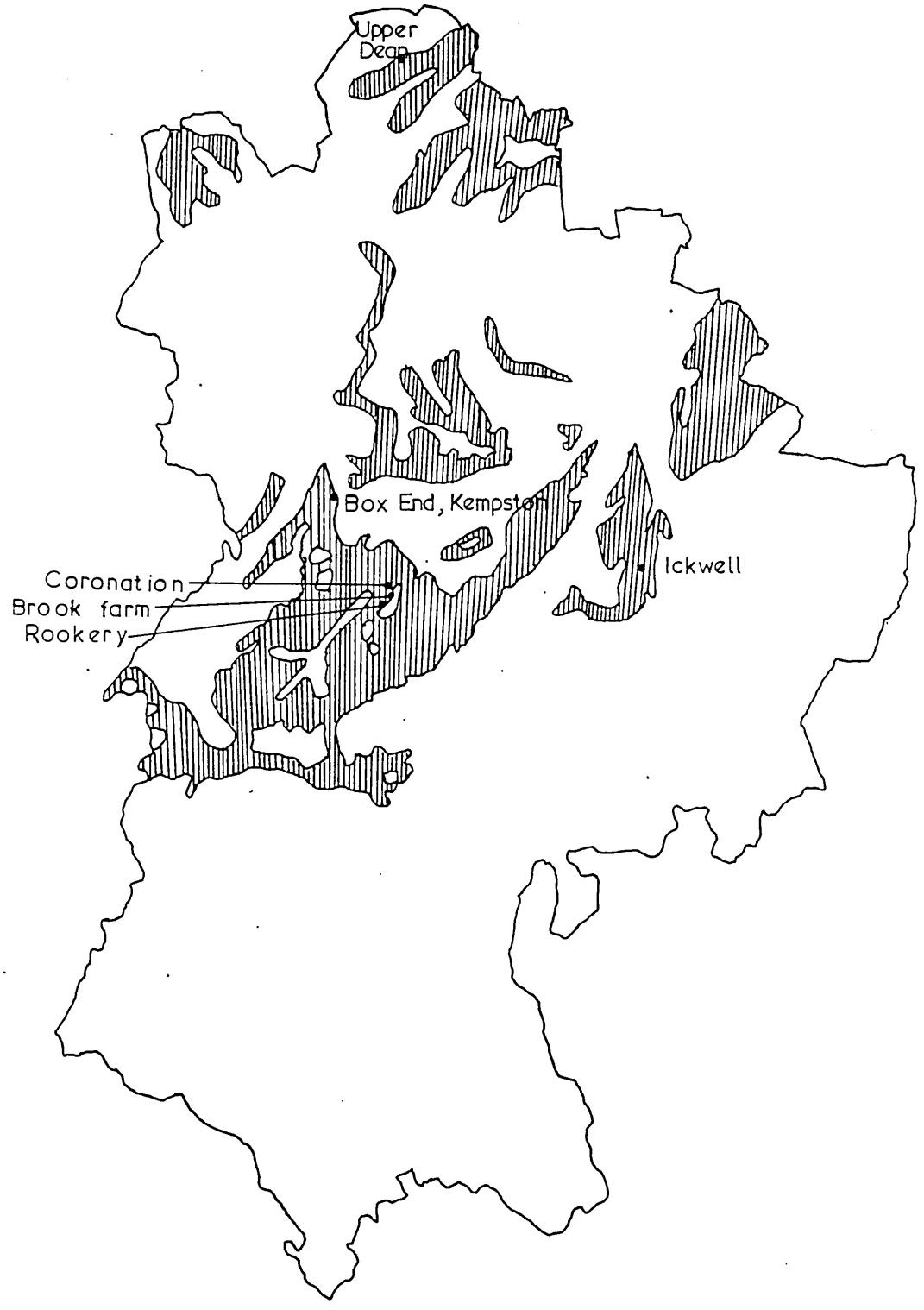
FIG4.2 PROCESS OF WASTE DISPOSAL IN ROOKERY PIT.[24]



B.O.D.'s UPON ENTRY

		mg/l
	GELATIN	20-30 000
LEATHER	WASTES	2-3000

FIGURE 4.3 LOCATION OF THE SAMPLING SITES IN BEDFORDSHIRE



4.4. Coronation Pit

This pit was chosen as it provides a range of substrate ages in the mid part of the age series. In many ways it is an ideal site for the study of succession as the ridges could be dated accurately from the callow-line survey. Sites aged thirteen, twenty, twenty-seven, thirty-one, thirty-six, forty and forty-four years were used for callow analysis. These sites were studied for natural vegetation in the summer of 1983 and therefore their ages in the natural colonisation chapter are increased by one year.

Coronation workings were covered by a permission dated 1952 and extends to 152 ha. of which only 48 ha. have been worked. The works were opened in 1935 by the Bedford Brick Company Ltd., and were taken over by the London Brick Company Ltd. in 1936. Workings progressed in a southerly direction and ceased in 1974.

The width of the working face has varied, as shown in Figure 4.1; the width of the 1970 face was about 250 m. The mean depth of the pit is 9 metres.

The clay was excavated by dragline. The overburden was cut back to form a clear step of unweathered clay. The demarcation between yellow brown callow and blue knotts is a clear one. The knotts dragline was then positioned on the step and after digging the clay it transferred it to a conveyor system to the works.

The overburden stripped off was deposited as a ridge parallel to the working face by means of a gantry stacker which dumped the overburden in a series of cones which coalesce laterally to form a ridge.

The working face was cut at an angle of about 60^{o}, the overburden at a slightly lower angle.

The pit sides assume a distinct form with the upper weathered callow material resting at a lower angle than those in the unweathered material beneath. The pit sides are subject to slumping, especially in the areas between ridges[56].

Ridges could be dated as they were dumped parallel to the working face, approximately twelve to twenty four months after knotts excavation. Thus allowing for knotts excavation, followed by callow dumping by a gantry stacker the callow ridges could be allocated a fairly accurate age.

However, Brown states that the pit was not worked in a systematic way in the 1941-1948 period. Also excavation was stopped in April 1970 and resumed in May 1972. Ridges were deposited at a rate of two a year[56].

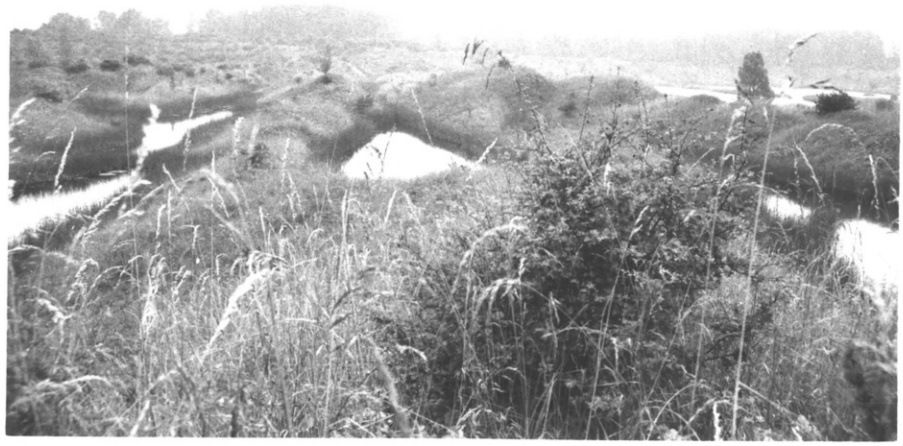
On the whole, the ridges are highest at the pit edge and decrease on moving eastwards although height varies considerably. Some ridges are inaccessible due to dumping starting some way from the pit border. Between each callow ridge is a flooded area, the border of which is colonised with Juncus spp. (Rushes). The size of the flooded area is dependent upon the amount of callow in the adjacent ridges as slumping of the callow would cause a reduction in the flooded area.

Planning Permission was granted by the CountyCouncil in July 1980 for phase I and II of the new Stewartby works to be built in the southern portion of the worked out area.

The Oxford Clay Draft Subject Plan states that interim measures "to improve the appearance of the site should be carried out: including dewatering, levelling the pit floor, provision for draining the site and establishing grass cover."

However, if left to itself, Coronation Pit provides an excellent wildlife habitat and would be a useful site for educational and recreational purposes. The varied nature of the site, the shallow water and the callow promentories increase the site's conservation potential. The variety of habitats provided makes Coronation one of the most interesting pits for conservation purposes. The location of the Pit is shown in Figures 4.1 and 4.3.

PLATE 4.4 CORONATION PIT



4.5. Jubilee Pit, Buckinghamshire (G.R. 868 312, Sheet 152)

The location of Jubilee Pit and the associated workings and callow tips can be seen in Figures 4.4 and 4.5. Jubilee Pit was started in 1934 and abandoned in 1949. Thus its age, for the purpose of this study was estimated as thirty-three years.

It has a perimeter of 621.8 m and a maximum plumbed depth of 27.5 m producing a cone shaped basin containing about 585×10^6 litres of water. A narrow ditch connects the lake to a stream that flows along the north-west side.

The lake is surrounded by a narrow strip of steep sided land comprising a spoil heap of overburden, remnant agricultural land and a small waste brick tip which has been landscaped.

The spoil heap at Jubilee lake is roughly triangular, the steep face on the lake side being unstable and producing an open habitat in places where slumping has occurred whilst the more gentle slope on the other two sides have a more continuous sward.

Kelcey listed the "more interesting flowering plants" on the spoil heap of Jubilee Pit as follows:-

Ophrys apifera (Bee Orchid)

Dactylorchis fuchsii (Common Spotted Orchid)

Briza media (Common Quaking Grass)

Erigeron acer (Blue Fleabane)

Cirsium acaulon (Ground Thistle)

These species were recorded in abundance in 1972[57].

The remainder of the land is occupied by tall grassland, scrub and a small area of woodland. A large hawthorn hedge runs along the north-west boundary of the site.

Since the 1972 study, the eastern margin of the pit has been landscaped and the species composition of the spoil heap has changed. It is difficult, however, to do a direct comparison of species as the 1972 study was not limited to the spoil heap area.

Jubilee Pit and callow mound can be seen in Plate 4.5.

FIGURE 4.4 LOCATION OF THE TWO BLETCHLEY SITES

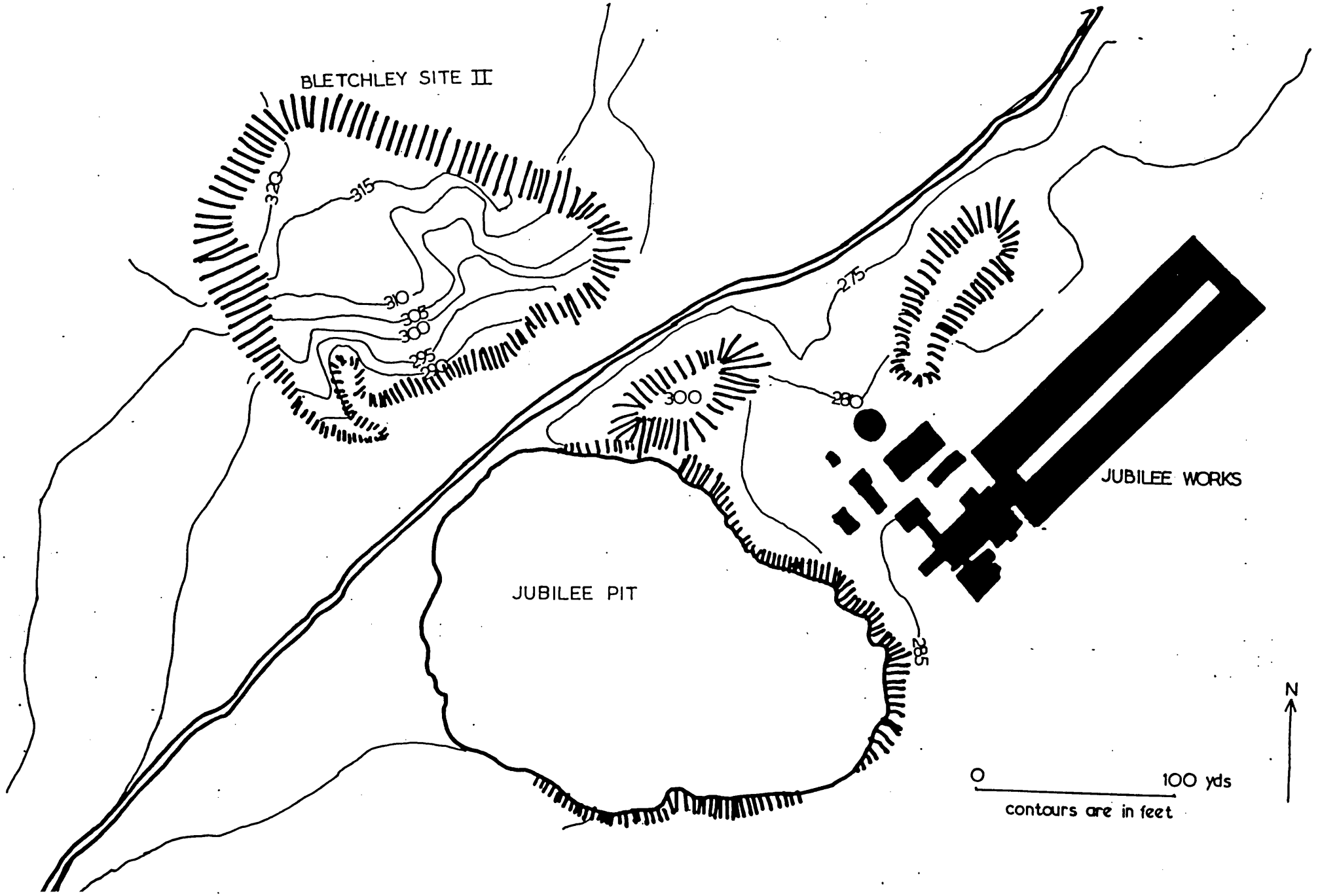
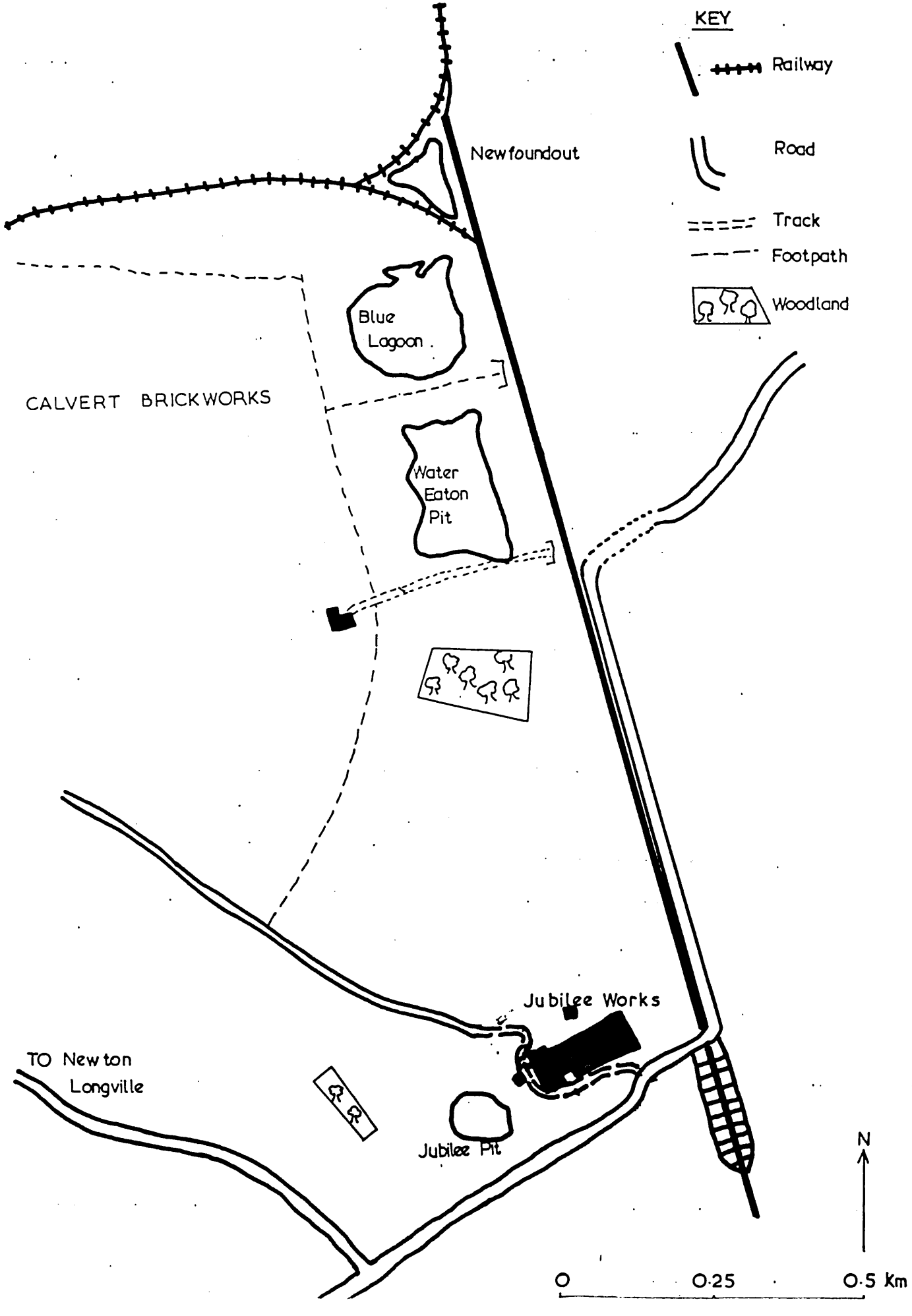


FIGURE 4.5 LOCATION OF JUBILEE PIT



4.6. Bletchley Site II Buckinghamshire (G.R. 868 314, sheet 152)

This is a callow heap formed between 1934 and 1946 using overburden from Jubilee Pit. Its location is shown in Figure 4.4. It was aged as thirty-six years at the time of vegetation survey. It is approximately eighteen metres high and covers an area of 3.25 ha. The peripheral outward facing slopes are steep. The topography is variable with hummocks and hollows. Some of the latter are waterfilled. It is partially wooded, with Crataegus spp. (Hawthorn) being dominant. The wetter areas are covered with reeds (Phragmites communis) and other tall grasses. The majority of the tip is open grassland with numerous Dactylorchis fuchsii (Common Spotted Orchids). Rubus fruticosus (Brambles) are increasing in abundance.

4.7. Upper Dean Clay Pit, Bedfordshire (G.R. TL 039 683)

This clay pit and works were in operation before 1853. Its date of closure is estimated as 1923. It was a fairly small concern, the pit being about 100m by 100m. The only remains of the works are a levelled area adjoining the road. The pit is an "overgrown hollow" which is often waterfilled[4]. Crataegus monogyna (Hawthorn), Salix spp. (Willows), Rosa canina (Dog Rose) and Urtica dioica (Stinging Nettles) are the dominant species. There is very little ground cover, the canopy is mainly Crataegus monogyna. Its location is shown in Figure 4.3.

4.8. Ickwell Clay Pit (G.R. TL 151 458)

Ickwell clay pit was in operation by 1929. It was shown on a map surveyed in 1881-2; it was still operating in the early 1890's but shown as an "Old Clay Pit" in 1902. (Thus its estimated date of closure is 1895). The pit is surrounded by housing development and it is in its natural state. The centre is a small pond, demonstrating hydroseral succession on its margin. Tree species present on the ponds margin include Quercus rober (Pedunculate Oak), Crataegus monogyna (Hawthorn), Rosa canina (Dog Rose), Acer pseudoplatanus

PLATE 4.5 JUBILEE PIT



PLATE 4.6 UPPER DEAN CLAY PIT



(Sycamore), Ulmus procera (English Elm), Pinus sylvestris (Scotch Pine), Fraxinus excelsior (Ash), Malus sylvestris (Crab Apple) and Sambucus nigra (Elder). Ground flora is diverse. For the location of this pit see Figure 4.3.

4.9. Box End, Kempston Clay Pit (G.R. TL 010 491)

Again this was a small concern in comparison with the large Fletton Brick Pits of modern times. This pit is behind the Slaters Arms, in the grounds of Brick Kiln Cottage. The cottage was built with the bricks and tiles left on the site of the kiln.

The works were in operation between at least 1853 and 1883. By 1915 it was described as "worked out". Its estimated date of closure is 1890.

The pit is very uneven, being flooded in the deepest part. It is an area of woodland being dominated by Fraxinus excelsior (Ash), Crataegus monogyna (Hawthorn), Salix spp. (Willows), Ulmus procera (English Elm), Sambucus nigra (Elder), Acer pseudoplatanus (Sycamore), Populus alba (White Poplar) and Malus sylvestris (Crab Apple) are also found. The ground flora is fairly diverse, its location is shown in figure 4.3.

4.10. Brook Farm Clay Pit (G.R. TL 034 432)

This was worked before 1833 and ceased operation shortly after 1885. Its estimated age was therefore ninety-six years in 1983. It is very close to Coronation Pit, being the other side of the railway line. It is approximately 500 m by 100 m.

A cross section through the pit is shown in Figure 4.6.

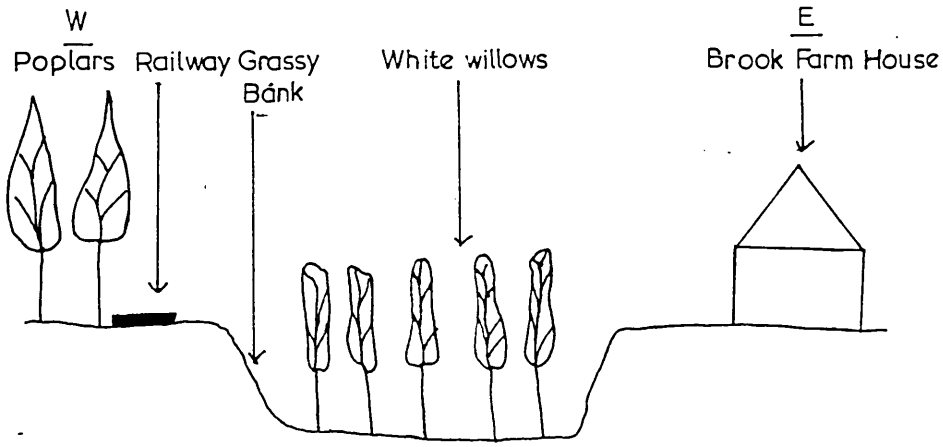
PLATE 4.7 ICKWELL CLAY PIT



PLATE 4.8 BOX END KEMPSTON CLAY PIT



FIGURE 4.6 Cross section through Brook farm clay pit (not to scale)



The western bank of the pit is open grassland with Primula veris (Cowslip), Centaurea scabiosa (Greater Knapweed), Chrysanthemum leucanthemum (Ox-eyed Daisy), Vicia spp. (Vetches), Lotus corniculatus (Bird's-foot Trefoil) common.

In contrast the pit bottom and some of the lower slopes are vegetated with Crataegus monogyna (Hawthorn), Quercus rober (Pedunculate Oak), Rubus fruticosus (Blackberry) and Sambucus nigra (Elder) with very little ground flora due to waterlogging. The southern area of the pit has a white willow plantation (Salix alba), planted in rows as shown in plate 4.9. These trees are tall, thin, overmature specimens. Attempts at aging them using a tree corer indicated that they were approximately fifty years old.

This site was not used for soil analyses due to problems of waterlogging, flooding and access, but was included in the natural vegetation series.

PLATE 4.9 BROOK FARM CLAY PIT



Table 4.1 Summary Table Showing Details of Field Work Sites

Site No.	Age at Time of Vegetation Survey	Age at Time of Callow Analysis	Nature of Site	Location
		0	Landfill site	Brogborough
1	1	1	Callow Mound	Rookery
2	3	-	Callow Mound	Rookery
3	4	4	Callow Mound	Rookery
4	6	6	Callow Mound	Rookery
5	10	10	Callow Mound	Rookery
7	14	13	Callow Ridge	Coronation
6	16	16	Callow Mound	Rookery
8	21	20	Callow Ridge	Coronation
9	28	27	Callow Ridge	Coronation
10	32	31	Callow Ridge	Coronation
14	33	33	Callow Mound	Jubilee Pit(Bletchley)
11	36	35	Callow Ridge	Coronation
15	37	36	Callow Mound	Bletchley Site 11
12	41	40	Callow Ridge	Coronation
13	45	44	Callow Ridge	Coronation
16	61	60	Uneven Hollow	Upper Dean
17	88	87	Uneven Hollow	Ickwell
18	94	93	Uneven Hollow	Box End Kempston
19	97	-	Callow Bank	Brook Farm

5. CALLOW ANALYSIS

5.1 Sampling Techniques

5.1.1. Introduction.

Inadequate or faulty sampling can give a completely wrong assessment of the nature of the material, which in turn will lead to inappropriate remedial procedures[3].

Despite this, in view of the variability of soils, it seems impossible to devise an entirely satisfactory method for sampling[73]. It is obvious that the detail of the procedure should be determined by the purpose for which the sample is taken.

The purpose of callow analysis in the present study is to provide an overall picture of the status of the material as a growing medium; establishing nutrient status, pH, soil-water relationships and other factors related to its proposed use as an alternative to top-soil.

In order to achieve comparable results, soil sampling and analysis were carried out using standard methods, over as short a time period as possible. It must be taken into account however that the soil sampling program took three consecutive days to complete and each batch of analyses took up to three weeks.

A trade-off had to be made, therefore, between statistical accuracy using large numbers of replicates at each site and comparability and practicality.

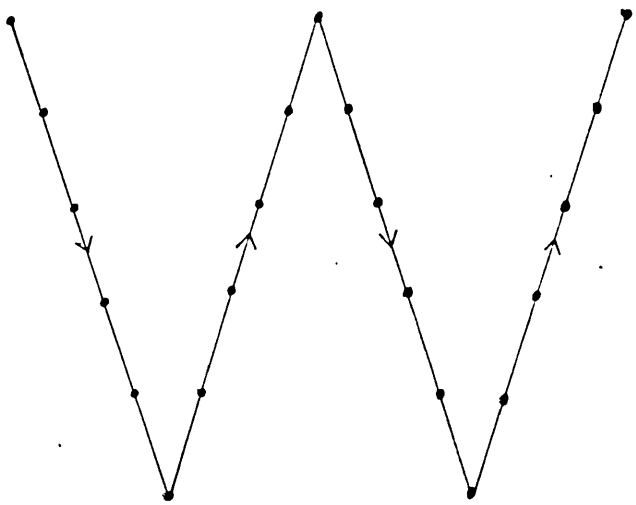
Sampling for any detailed study should allow for the inherent variability of soil materials.

A high degree of spatial variability may exist over quite small areas. Often the extent of this variation is not known beforehand and hence sufficient samples must be taken in order to obtain a reliable measure of it. The absence of any indication of site variability can make it difficult to assess the significance of any changes such as seasonal variation which may be implied by the data.

The minimum number of replicates needed can be calculated statistically if certain data are available. However, the available analytical facilities and the time available set the upper limit.

Two alternative approaches for sampling a particular area are in common use. One employs random numbers, often in relation to a fixed co-ordinate grid reference drawn for a site being studied. The other system depends on sampling at regular intervals along a grid network. Often the lines of a "W" are followed as shown in Figure 5.1.

Figure 5.1. Non-Random Soil Sampling Technique Following a Zig-Zag Course[74].



The difficulty with this method, however, is analysing the large numbers of samples obtained. Often it necessitates bulking, in which individual samples are combined to give a composite mixture. It may give a reasonable mean value for the soil but hides any site variability.

The presence of animal droppings can result in a localised increase in certain nutrient levels in the soil surface which might escape undetected if the site is known to be otherwise fairly uniform and only one or two composite samples are analysed[75].

5.1.2. Sample Collection.

A variety of equipment is available for taking soil samples. The choice is governed by the nature of the soil and the investigations to be carried out. An initial consideration is whether the final data is required on a volume or weight basis. If weight is the basis, a trowel may be sufficient but it may be difficult to obtain uniformity of samples by this method.

Where soil volume must be known, a metal cylinder or corer is used. Compression is reduced to a minimum by the use of wide cylinders. Probes with longitudinal slits are sometimes used but some inter-horizon contamination is possible and these are usually confined to exploratory work.

Stainless steel is the most durable material for cylinders but cheap serviceable corers can easily be made from extruded mild steel tubing.

For all corers it is necessary to attach a horizontal "tommy bar" to give a twist leverage during insertion into the soil.

Soil augers working by a screw thread mechanism cause mixing of the horizons and were therefore not considered suitable.

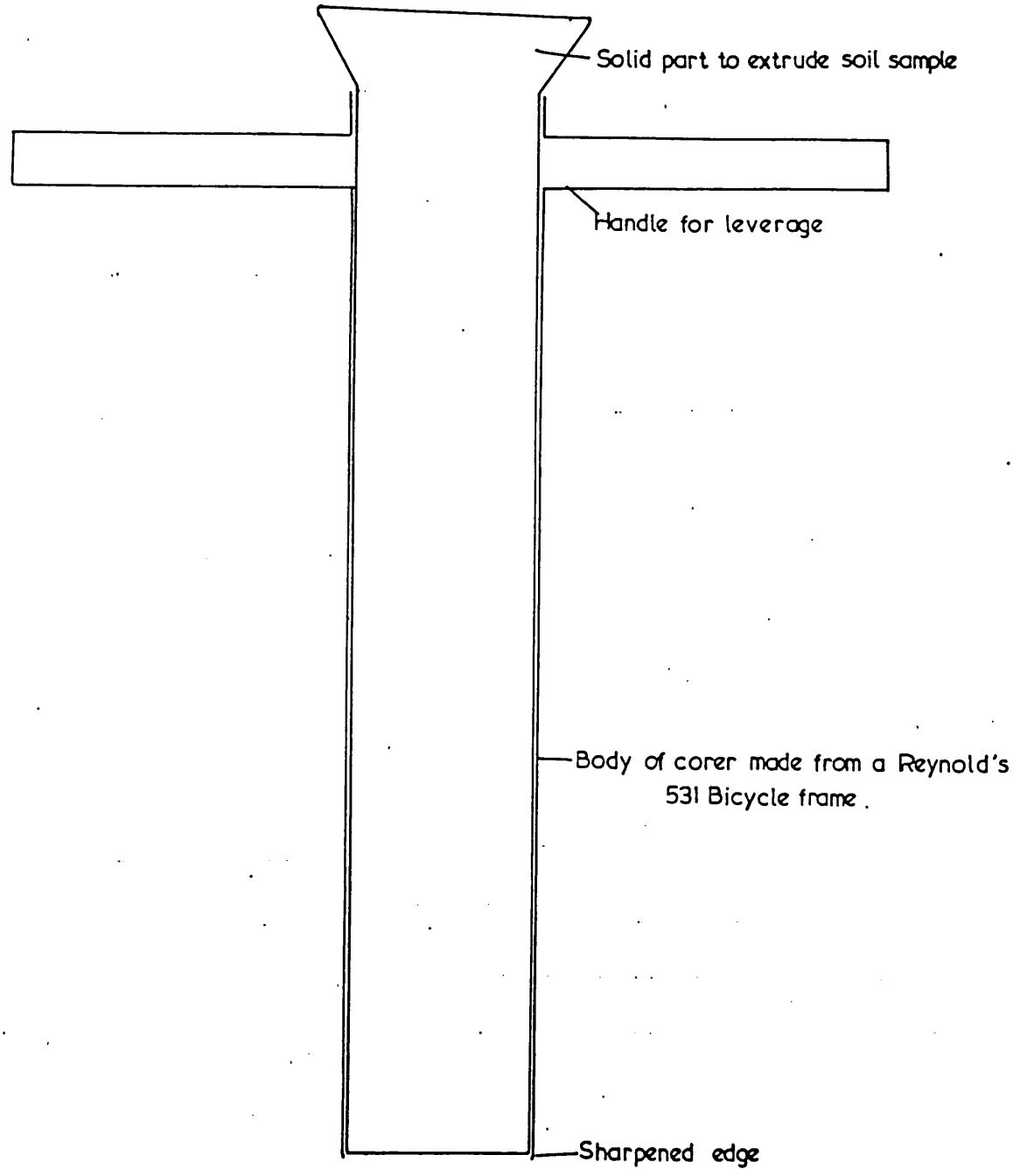
The corer which was used for most soil sampling is shown in Figure 5.2. Details of the corers used for soil volume analysis are given in section 5.15.

5.1.3. Time of Sampling.

Some consideration was given to the time of sampling. Little evidence has been produced for any diurnal variation in chemical content, but changes with season may occur[74]. Phosphorus availability may increase between spring and summer and Saunders and Metson[76] have shown that inorganic nitrogen levels are higher in the spring. However, previous work has shown that spatial variability is likely to conceal any seasonal change[77].

The time of sampling was crucial when analyses on fresh material has to be made. Due to the strict timetable of this project, the time available

FIG 5.2 SOIL CORER



for soil analytical work was limited to that time not used for field work or the setting up and monitoring field trials. Thus the only time available for the large-scale analytical program was during the winter months of 1982/3 and the autumn of 1983 after the completion of all field work.

5.1.4. Sampling Program.

The soil corer shown in Figure 5.2 was used for all the analyses apart from those requiring known soil volumes. Samples were dug to a uniform depth of ten centimetres. Due to the wet nature of the callow during sampling in November/December 1982 little compression occurred.
Due to the time consuming nature of the sampling and the distance between the sites, the initial sampling program took place over three days. The weather at the time of sampling was cold and frosty, as shown in Table 5.1.

On return to the laboratory, three out of four of the cores from each random point were air dried at room temperature for over a week. Then they were bulked, put through the jaw crusher and sieved to < 2mm. The fourth core of each random point was used for fresh material analysis.

Sites used for callow analysis in this batch were Brogborough, Rookery, Coronation, Ickwell, Upper Dean and Box End Kempston, providing an age range from one to ninety-three years. The two sites at Bletchley were not incorporated into the analyses.
A second batch of samples was dug in the same manner, using the same coring tool, for nitrogen analysis; during the 3rd and 4th March 1983. Only one core was needed from each random point. Three random samples were taken from each site. The weather at the time of sampling is shown in Table 5.1.

Water relationships and bulk densities were carried out using a different method, using a coring device of known volume. This method is described in Section 5.15.

Table 5.1. Meteorological Records at Stewartby at the Time of Sampling.

	Rainfall (mm)	Wind Strength	Wind Direction	Temperature			
				Max.	Min.	Wet	Dry
1982:							
29th November	-	V.Lt.	W.S.W.	6.0	-2.5*	0.8	0.8
30th November	-	Calm	N.W.	5.5	-6.0*	-3.2	-3.6
1st December	(trace)	V.Lt.	E.N.E.	1.0	-5.0	2.0	2.2
(* Freezing Fog)							
1983:							
3rd. March	-	Lt.	S	6.5	3.5	7.0	7.7
4th March	-	Lt. Mod.	N	0.0	1.0	4.5	4.7

5.2. Moisture Content of Fresh Samples

5.2.1. Methods.

Approximately two and a half grams of fresh callow was accurately weighed into a crucible of known weight. The crucible and sample were then transferred to an air circulation oven set at 110°C for twenty four hours or until a constant weight was obtained. The crucible was then transferred to a dessicator and was allowed to cool. The crucible and dry soil were weighed and the percentage water content was calculated.

This process was repeated in 1983 using the nitrogen analysis samples.

5.2.2. Results.

The December 1982 results are shown in Figure 5.3. The March 1983 results are shown in Figure 5.4. The graphs show the mean+ and standard error+ of five samples at each site. In December the mean water content varied between 7.1% and 24.9% there was no relationship between water content and age, the correlation coefficient+, $r = 0.23$; the probability , p is therefore not significant (N.S.).

In March, the mean water content had increased to between 21.3% and 38.2%. These results show a positive correlation between mean water content and age of the callow, $r = 0.81$; $p < 0.005$.

These results may indicate that the water content of the callow increases during the winter.

The positive correlation between water content and callow age in March, but not in December is hard to explain. It may be that during the winter months the water content fluctuates, depending upon micro climatic and microtopographic factors, but later in the spring when the callow is saturated, a steady state of water retention is maintained.

In order to see whether there is any difference between these two sets of results, a paired t-test was carried out on matching data. The mean results

+For statistical definitions see Appendix II.

FIGURE 53 MOISTURE CONTENT OF FRESH SAMPLES : DECEMBER '82

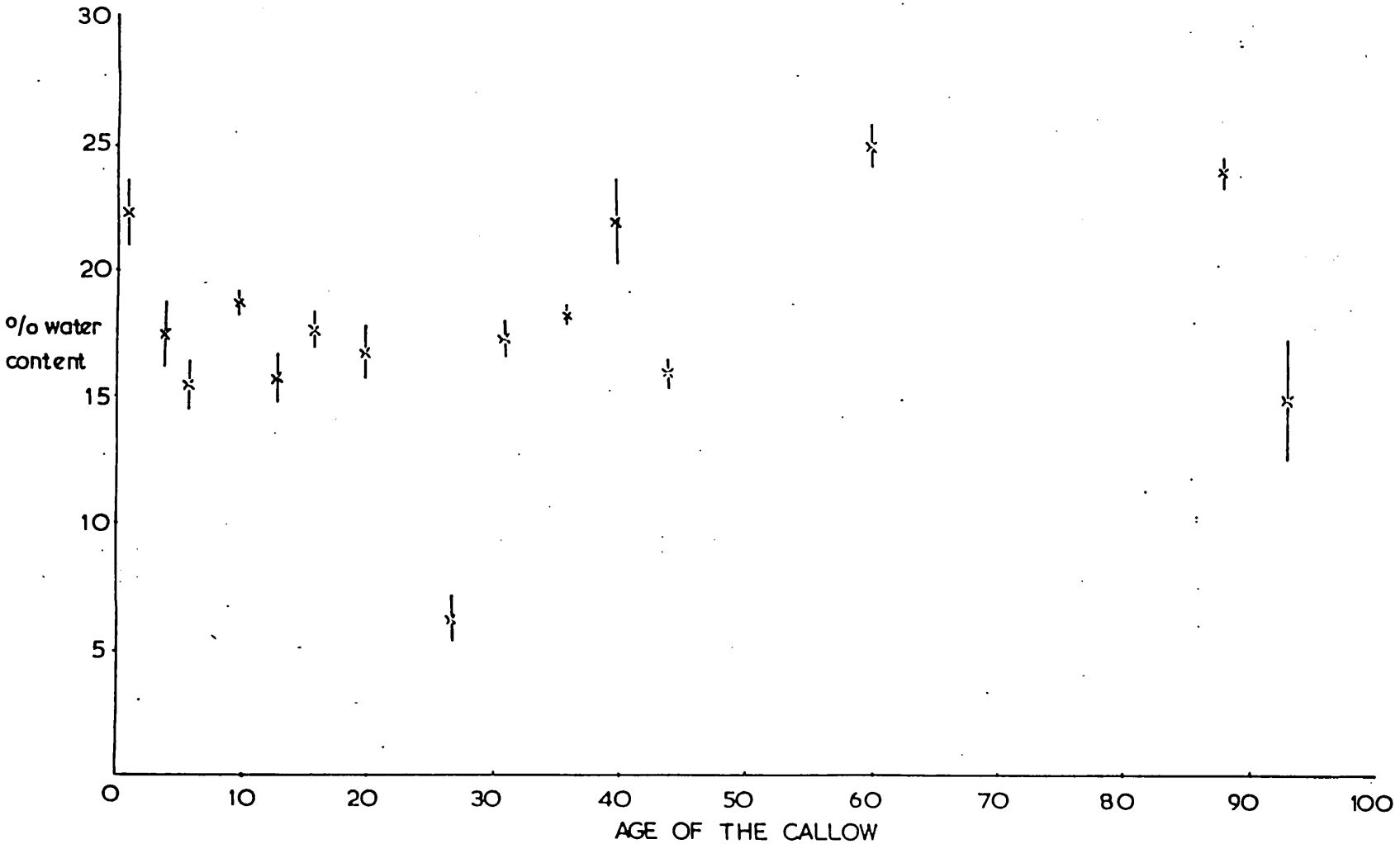
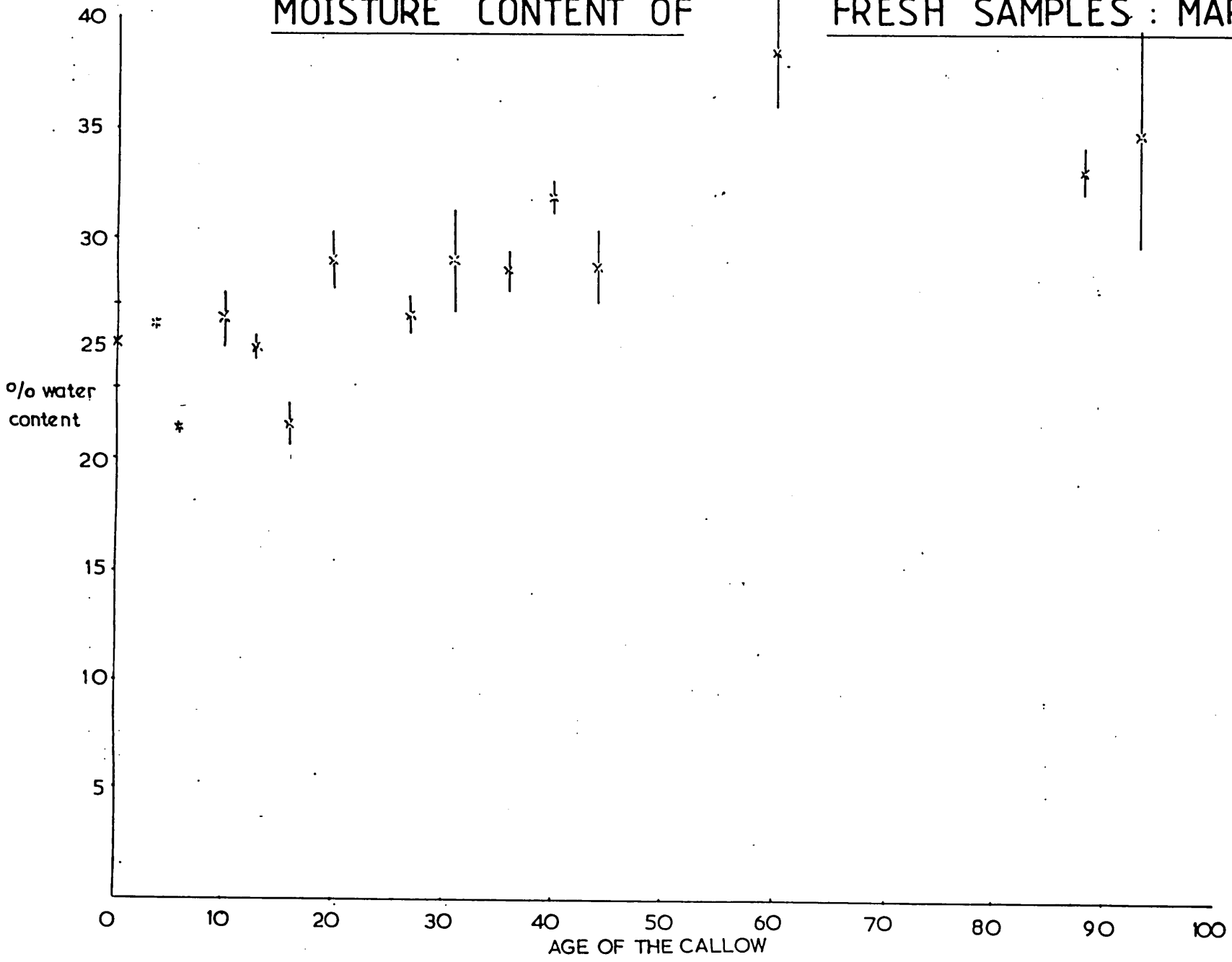


FIGURE 5.4

MOISTURE CONTENT OF FRESH SAMPLES : MARCH '83



for the March tests were compared with the mean results of the December tests. The end t-value was 9.14, for fourteen pairs of results. The significance of this was $p<0.001$. That is, there is a highly significant difference between the moisture content of the callow in March and December.

5.3. pH Measurements in Distilled Water

5.3.1. Method.

To a ten gram sample of fresh callow in a 50ml beaker was added a 25ml volume of distilled water. The suspension was stirred at regular intervals for thirty minutes using a glass stirring rod. Then the pH was measured with a glass electrode; the suspension was stirred well before the electrode was immersed. The pH was measured using a Phillips P.W. Digital pH Meter.

5.3.2. Results.

Results are shown in Figure 5.5. Each result is the mean of five random samples. The pH varied between 7.0 at Box End Kempston (93 years) and 8.3 in Coronation (44 years). There is no relationship between pH measurements in distilled water and age of the callow sample. Box End Kempston has a lower pH than the other locations. This will be discussed later. From these results, and results obtained in 1980[24], callow can be described as a calcareous, basic soil material.

5.4. pH Measurements in Calcium Chloride

5.4.1. Method.

Calcium chloride masks variability in salt content of soils, maintains a flocculated condition and decreases the junction potential effect[74]. To a ten gram sample of fresh callow in a 50ml beaker, a 25ml volume of 0.01 M$CaCl_2$ was added. The suspension was stirred at regular intervals for thirty minutes using a glass stirring rod. Then the pH was measured with a glass electrode, the suspension was stirred well before the electrode was immersed.

FIGURE 5.5 DISTILLED WATER pH MEASUREMENTS

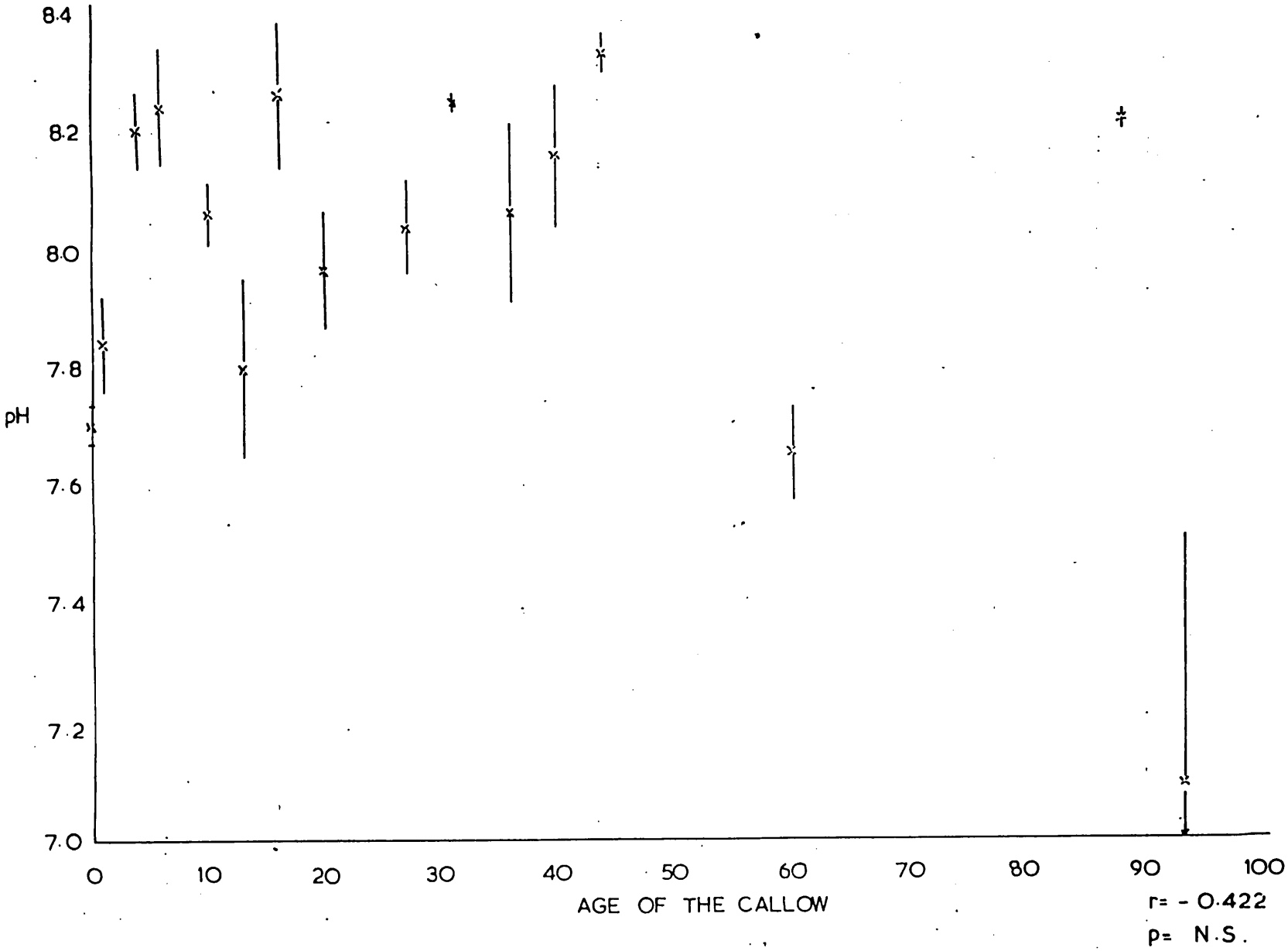
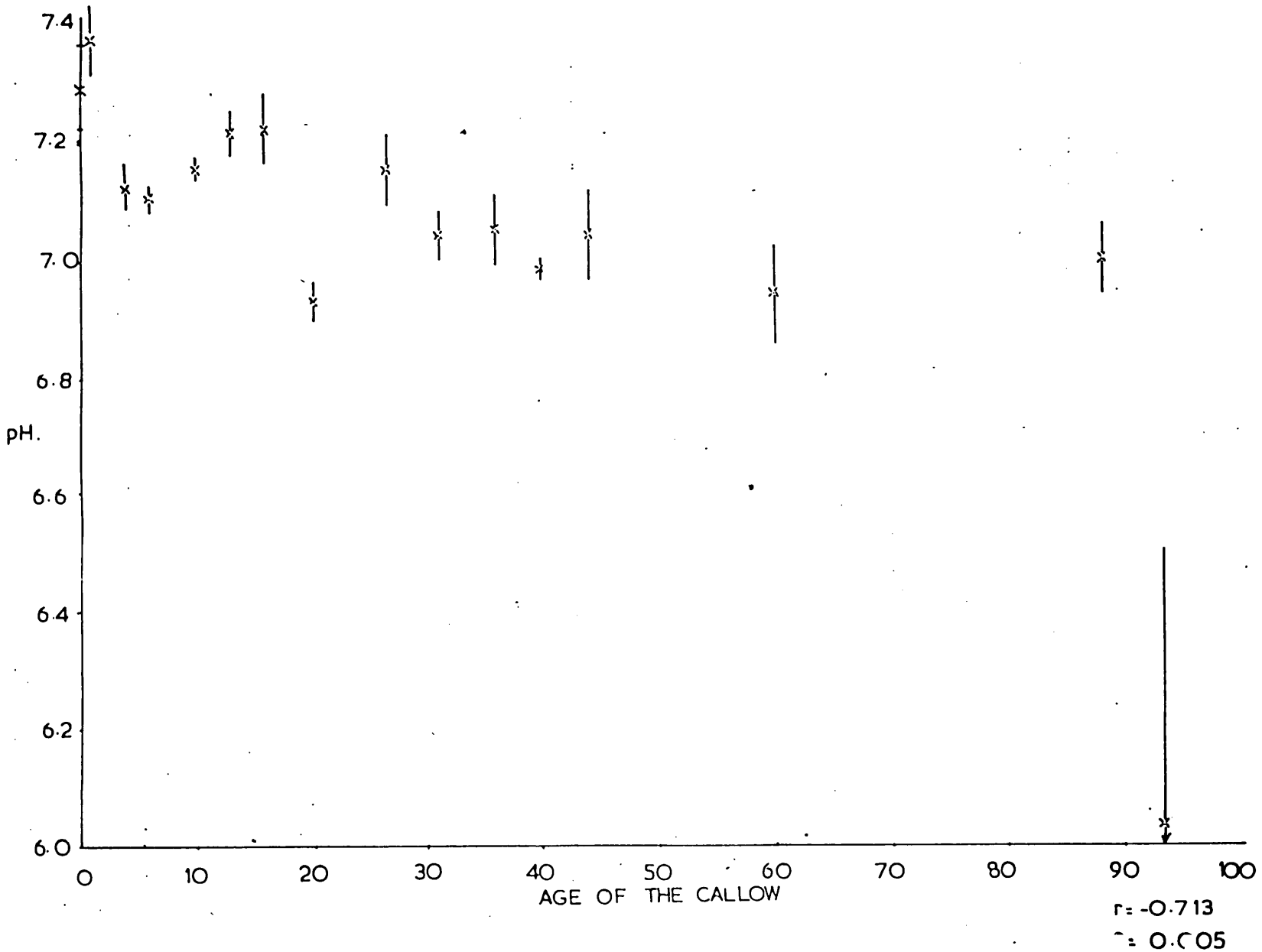


FIGURE 5.6 CALCIUM CHLORIDE pH MEASUREMENTS



5.4.2. Results.

Results are shown in Figure 5.6. Each result is the mean of five random samples. The pH scale has been shifted downwards in this solution. The results still indicate a basic, calcareous nature of the callow. Here the relationship between pH in calcium chloride and age shows a highly significant negative correlation, decreasing with age. ($r = -0.713$; $p < 0.005$).

5.5. Cation Exchange Capacities

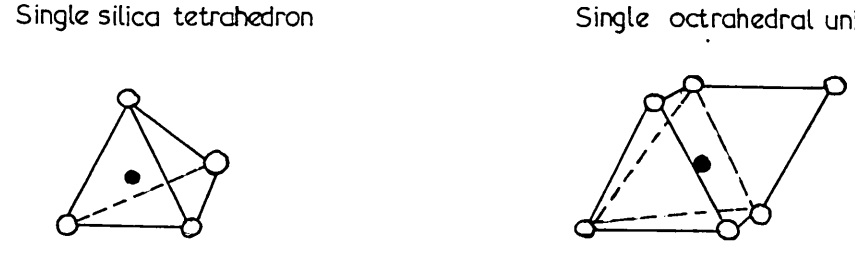
"The cation exchange reaction is the second most important in nature, surpassed in fundamental importance only by the photosynthetic process of green plants".[78]

5.5.1. Introduction.

Clay minerals possess the property of adsorbing definite quantities of cations(and anions) usually from solution and also of exchanging these readily for other ions in equivalent quantities. The ions are adsorbed onto the surfaces of the mineral particles and do not usually affect the structure of the clay lattice subunits. The exchange capacity reflects intrinsic properties of the clay mineral.

Clay minerals are composed of two basic building blocks; the silica tetrahedra and aluminium octohedra. These are shown in Figure 5.7.

Figure 5.7. The Structure of the Clay Lattice Subunits.



Properties of clay minerals of importance when considering cation exchange capacity are as follows:

i Isomorphic Replacement.

When clay minerals are formed, silicon and aluminium can be replaced in them by atoms of similar diameter. The common replacements are:-

Si^{4+} by Al^{3+} in the tetrahedra

Al^{3+} by Fe^{3+}, Mg^{2+} Fe^{2+}, Mn^{2+} in the octahedra.

However, the sizes of the atoms are of importance. Aluminium atoms are larger than silica; all the others are larger than aluminium.

Isomorphic replacement puts a degree of stress on the crystal structure. Therefore replacement can only be tolerated to a certain extent.

Most replacements give a gain in negative charge to the soil lattice and therefore after substitution there is excess negative charge in the clay lattice.

ii Broken Hydrogen Bonding.

In the same micaceous clay the weak hydrogen bonding is broken allowing water to enter between the lattice layers, thus the clay can swell and contract between the layers. The dissociation of hydrogen ions from hydroxyl ions is dependent upon pH.

iii Increased Surface Area.

Broken edges of silica tetrahedra sheets give rise to an increased surface area and supplies a surplus of negative charges on the minerals.

A colloid is a substance in a peculiar physical state (colloidal state) which imparts to certain soil constituents (such as clay) their plastic or sticky properties[79].

Charges on the colloidal complex are predominantly negative because of:-

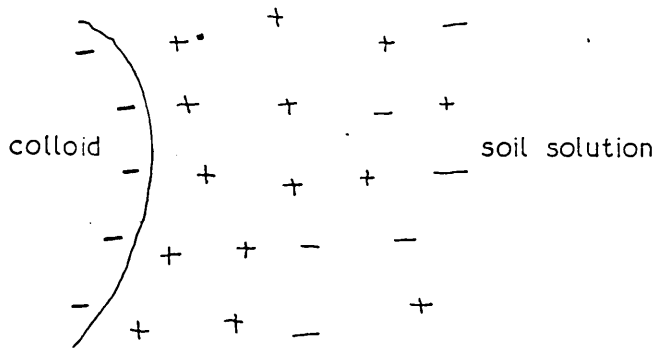
i The distortion of clay minerals by hydroxylions.

ii The dissociation of humic acids in humus.

iii Carboxyl groups dissociate to give $COO^- H^+$. This reaction is pH dependent. Once this has happened, other ions can be attracted to COO^-. The ions usually attracted are the bases which set up an electrostatic balance.

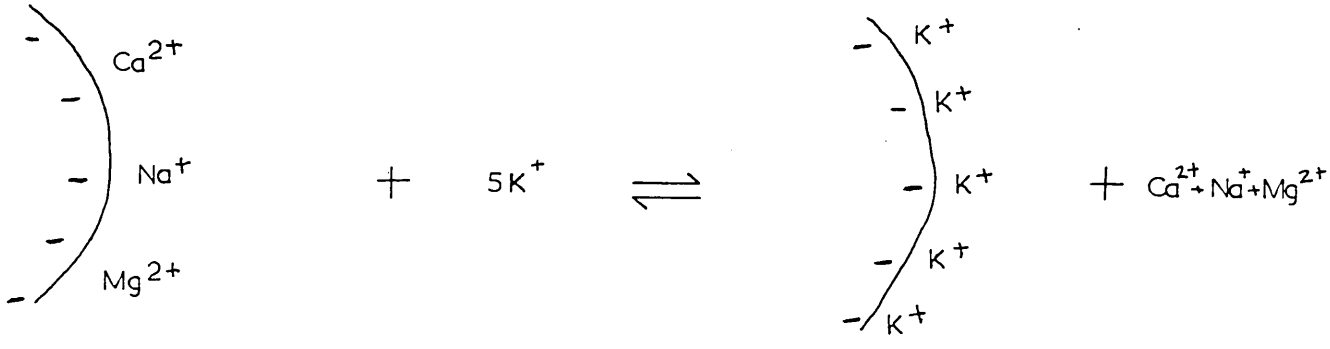
In soil solutions a diffuse double layer of cations is associated with the colloid. The anions in the soil are in reverse concentration until a distance is reached when the two are balanced. This situation is shown in Figure 5.8.

Figure 5.8. The Attraction of Cations to a Colloidal Surface.



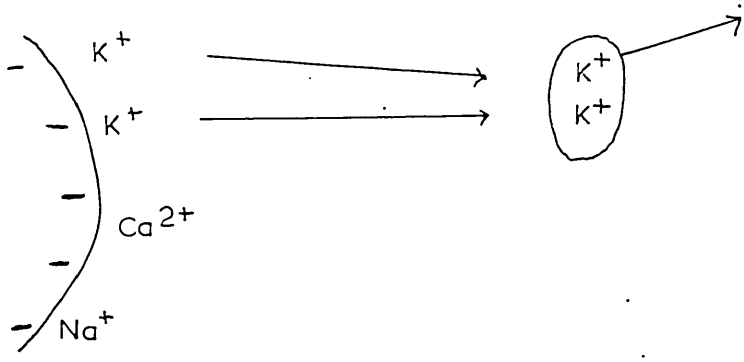
The cations held onto the surface of the colloid are readily exchangeable with other species. For example, if potassium is added to the soil surface, in the form of a K-based fertiliser, some potassium will displace other ions from the colloidal system. This is shown in Figure 5.9.

Figure 5.9. The Addition of a Potassium Based Fertiliser to a Soil Colloid System.



An equilibrium will be reached when the soil cations are balanced. If the potassium concentration is lowered, for example by uptake by plant roots then adsorbed potassium can be released from the exchange complex into solution, as shown in Figure 5.10.

Figure 5.10. The Release of Potassium into Solution.



Soils vary considerably in their concentrations of ions. This exchange complex in the soil is a reservoir of ions which can renew the ions of the soil solution; it is therefore a buffer to the depletion of ions in the soil.

The cation exchange capacity is the number of negative charges per unit weight of soil. It is measured in mille-equivalents per one hundred grams of soil (meq. $100g^{-1}$ soil). The level has to be expressed at a given pH as it is pH dependent.

It is measured by saturating the exchange complex with one type of cation, e.g. sodium, and then estimating the concentration of this cation.

At fixed pH the cation exchange capacities are similar using calcium, magnesium, sodium or ammonium.

Some cations give different estimates due to the specific reaction with colloidal surfaces. Different cations have different exchange powers; early experiments consisted of saturating soil with barium and placing that soil in 0.1N chloride solution of different cations.

The order of power of replacement of cations is as follows:-

$Li < Na < NH_4 \simeq K < Mg < Ca$

For any one ion there is an equilibrium between the amount adsorbed and the amount in solution.

Changing the concentration of one ion will shift equilibrium for that ion and also shift equilibrium for all other ions.

However, Bower et al[79] report that cation exchange powers of saline and alkali soils are subject to difficulties not ordinarily encountered with other soils such as those from humid regions. These difficulties arise from the content of carbonate salts of calcium and magnesium and of soluble salts and from the slow permeability to aqueous solutions. Solutions capable of extracting exchangeable cations from soils dissolve all or most of the soluble salts and significant amounts of the carbonates of calcium and magnesium, if present. The dissolving of salts necessitates independent determinations of soluble cation content and correction of the exchangeable cation analysis for their presence. The occurance of calcium and magnesium carbonates prevents accurate determination of exchangeable calcium and magnesium and, in some method of analysis, requires application of a positive correction factor to values obtained for cation exchange capacity.

5.5.2. Methods.

The method used was that of Bower et al[74] using a determination with sodium, although it was realised that the high calcium carbonate content of the clay may have caused a proportion of calcium ions to be left on the exchange sites due to the poor replacing ability of the solution. This would give a lower cation exchange capacity than anticipated.

Three random samples from each site were used; results were calculated on a dry weight basis, allowing for the water content of the air-dried samples.

Four grams of medium and fine textured callow of known moisture content were transferred to a 50ml round-bottomed, narrow neck centrifuge tube and 33ml N NaOAc solution of pH 8.2 were added. The stoppered tube was shaken for five minutes on a shaking machine and centrifuged for five minutes at 1500 r.p.m.; the clear supernatent was then discarded. The sample was treated with three additional 33ml portions of N NaOAc solution for a total of four treatments.

Then the sample was suspended in 33ml 99% ethyl alcohol, shaken for five minutes, centrifuged and the clear supernatent liquid was discarded. The sample was then washed with two additonal 33ml volumes of ethanol. The adsorbed sodium was replaced from the sample with three 33ml portions of N NH_4OAc, the decante being collected in a 100ml volumetric flask. The solution was made to volume and mixed and the sodium content was determined by the flame emission method of the Atomic Absorption Spectrophotometer set at 589mm.

An alternative analytical method, pretreatment of a 2% clay suspension with a sodium saturated cation exchange resin, is not suitable for clays as their coarse nature makes suspension impossible and caused clogging of the resin column[80].

Sodium standards were made from a stock solution of 100 $ug.g^{-1}$ Na by dissolving 0.2542 g dry NaCl in water and making the solution up to a litre. Working standards were made by diluting the stock standard to produce a rangefrom 0 to 10 $\mu g.g^{-1}$ Na. All standards were stored in plastic bottles.

A calibration curve was prepared from the standard range after setting the top standard to a suitable scale deflection and the 0 $ug.g^{-1}$ standard to zero.

The samples were aspirated into the flame under the same conditions as the standards. The top, zero and an intermediate sample were checked regularly. Blank determinations were also run. The instrument atomizer was flushed frequently with water and at the end of the run.

The calibration curve was used to determine $ug.g^{-1}$ sodium in the sample solution.

The cation exchange capacity of each sample was calculated as follows:-

$$\text{Meq. exchange capacities per 100g soil} = \frac{\mu g.g^{-1} Na}{22.99\ (N)} \times \frac{100}{\text{soil wt.}}$$

5.5.3. Results.

Results of the cation exchange capacities are shown in Figure 5.11. Values are between 11.2 and 21.8 meq. $100g^{-1}$ soil. There is no relationship between cation exchange capacity and age of the callow; $r = 0.35$; p = N.S. The majority of the results are between 12 and 17 meq. $100g^{-1}$ soil. Variance within one site is fairly low. Upper Dean Clay Pit shows the highest cation exchange capacities. This is probably caused by the high humus content of the callow samples.

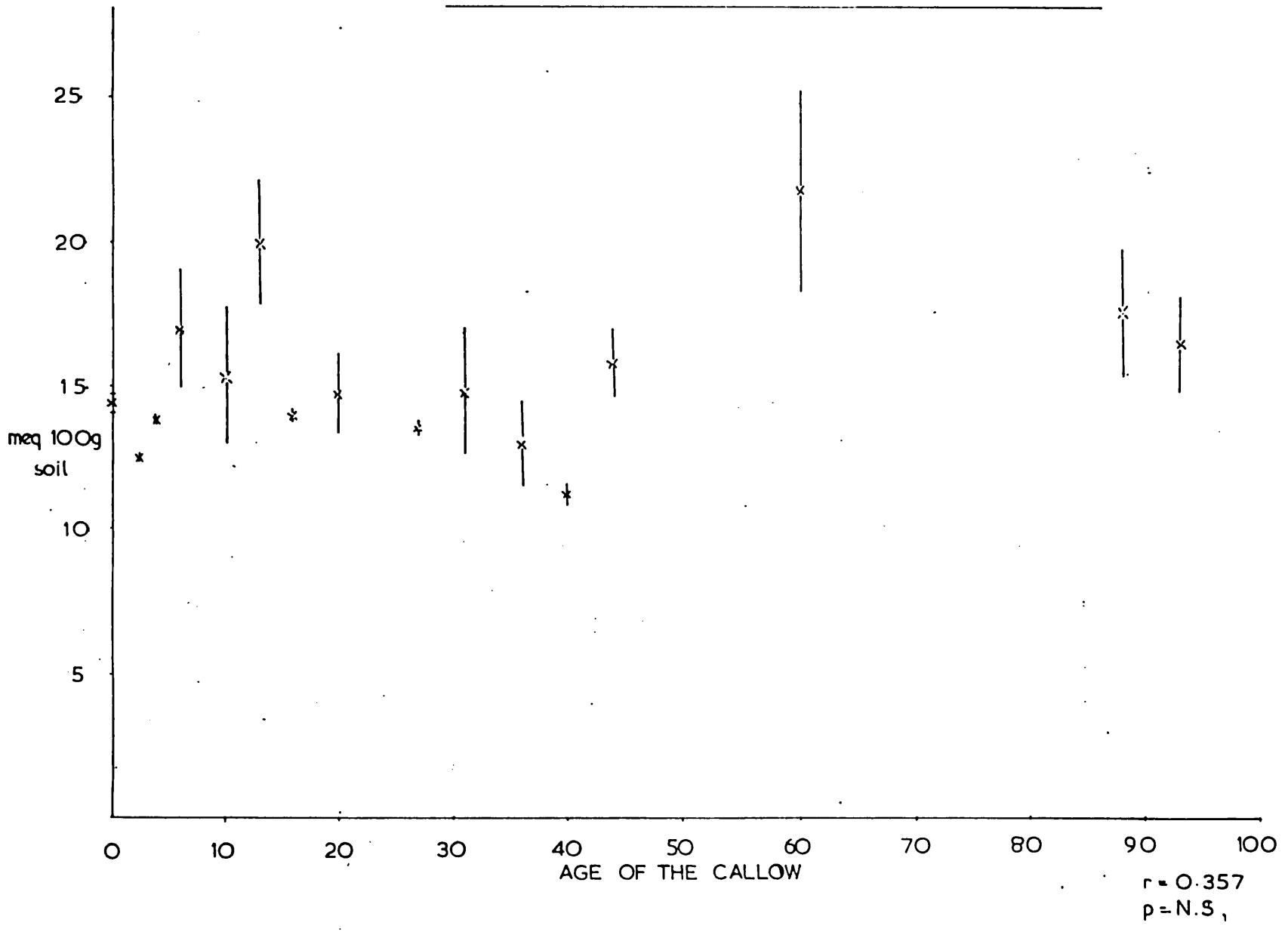
5.6. Loss on Ignition

5.6.1. Introduction.

The results from quantitative ashing of soils are usually expressed as "loss on ignition" and as such are a rough indication of the organic

FIGURE 5.11

CATION EXCHANGE CAPACITIES



matter present in the soil. Loss on ignition is not a true measure of organic matter because at the temperature of ashing some bound water is lost from clay minerals and is included in the overall loss. Multiplication of the result by a factor gives a crude estimate of the organic carbon content of the soil.

5.6.2. Method.

The method adopted was that of Allen[75]. Oven dried soil samples were used throughout.

One gram of crushed and seived (< 2mm) clay samples were placed in vitreosil crucibles of known weight, weighed accurately and dried at 110°C overnight in an air circulation oven. The moisture content could be calculated after weighing.

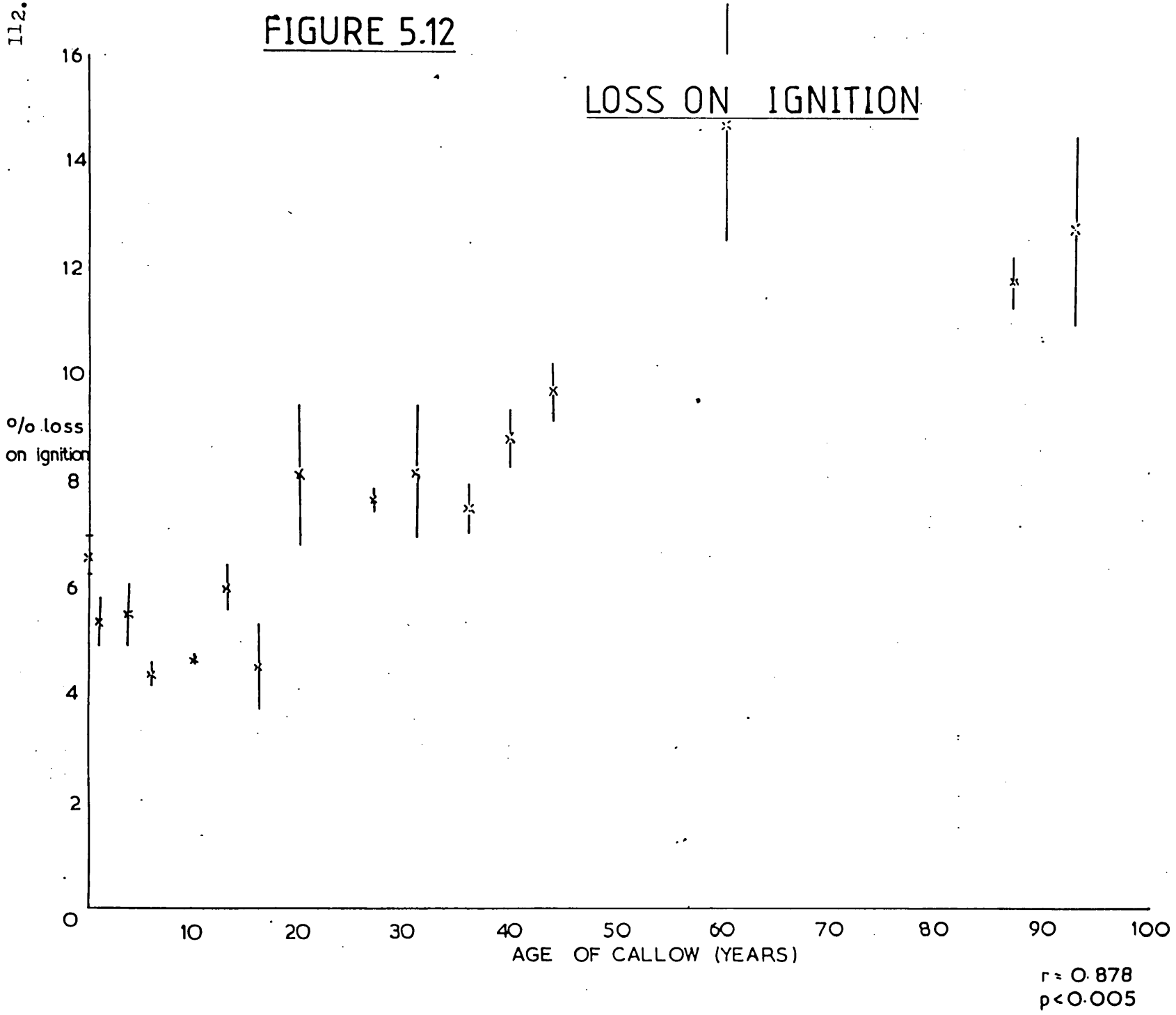
The samples were then transferred to a muffle furnace and the temperature was allowed to rise slowly to 450°C and then the samples remained at this temperature for four hours. When cool, the samples were transferred to a dessicator, cooled at room temperature and weighed. Percentage loss on ignition was calculated from weight loss during combustion.

$$\text{Loss on ignition (\%)} = \frac{\text{weight loss (g)} \times 100}{\text{oven dry weight (g)}}$$

5.6.3. Results.

Results are shown in Figure 5.12. There is a significant positive correlation between loss on ignition and age of the callow: the levels increase from 4% in the early stages of succession to 12-15% later on. It must be remembered that the Oxford Clay contains a high proportion of organic, fossilised material which is an important factor when making bricks, as it means that they are virtually self-fired. The increase in loss on ignition is not quite linear; there are some dissimilarities. For example, Brogborough callow has a higher value than that of the Rookery 1 year sample. This is probably because of the storage of the callow heap at Brogborough allowing

FIGURE 5.12


LOSS ON IGNITION
16
14
12
10
8
6
4
2
0
% loss on ignition
10
20
30
40
50
60
70
80
90
100
AGE OF CALLOW (YEARS)
r = 0·878
p < 0·005

for the build up of organic materials before it was spread on the refuse disposal site. Also the callow was allowed to lie fallow for some time before cultivation. Another factor of importance when considering the Brogborough site is that when the callow was stripped there was no separation between the topsoil, subsoil and overburden. Thus, a mixing of the various levels must have occurred; this mixture was later classified as "callow". Another factor, which is little understood, is the affect of the underlying layers of refuse on the callow cap.

The one and four year old site in Rookery have higher loss on ignition values than the six and ten year old sites. This may be caused by the liquid refuse disposal scheme operated by Easidispose in Rookery Pit; where liquid organic wastes are dumped over the side of the fault with the slurried callow, so that the process of breakdown of the organic materials could occur over the large callow surface area. Liquid wastes disposed of in this manner included washing water from chicken and potato factories, gelatin and leather wastes.

Another anomoly in the series is Upper Dean Clay Pit (age 60 years). It has a considerably higher loss on ignition value than both of the older sites in Kempston and Ickwell. This may be caused by the high rate of humus accumulation in the soil at this site.

Taking into account the general trend shown in Figure 5.12 and allowing for a four per cent loss on ignition value in the raw callow, the process of accumulation of organic material in the clay can be seen to increase at quite a fast rate.

5.7. Conductivity

5.7.1. Method.

The method adopted was that of the Soil Survey of England and Wales[81]. Twenty grams < 2mm air dried soil was placed in a 50ml beaker and enough

water was added to saturate the soil. Then the solution was stirred gently, covered and allowed to stand overnight. The correct volume of water was found to be 20ml. The solution was stirred again and small quantities of water were added to achieve the following criteria:-

i Tap the beaker on the bench, free water should not separate onto the surface of the soil.

ii Soil paste glistens as it reflects light.

iii Soil paste flows slightly when the beaker is tipped.

iv Soil paste slides freely and cleanly off a spatula except in the case of heavy clays.

The saturated paste was transferred on to a toughened filter paper in a Buchner Filter funnel, suction was applied and the filtrate was collected in a sample glass.

Only small quantities of the filtrate were extractable (5ml). Because of this a dilution factor of 1:10 was made.

The conductivity cell was inserted into the diluted filtrate contained in the sample glass. The conductivity meter reading was recorded (Rt ohms) and the temperature of the extract and the cell constant were noted.

The conductivity meter readings were corrected to 25°C using the temperature factor (ft) given in Table 5 of the Soil Survey of England and Wales Laboratory Handbook[81].

Three random samples were used for each site. Corrections were made for the dilution factor.

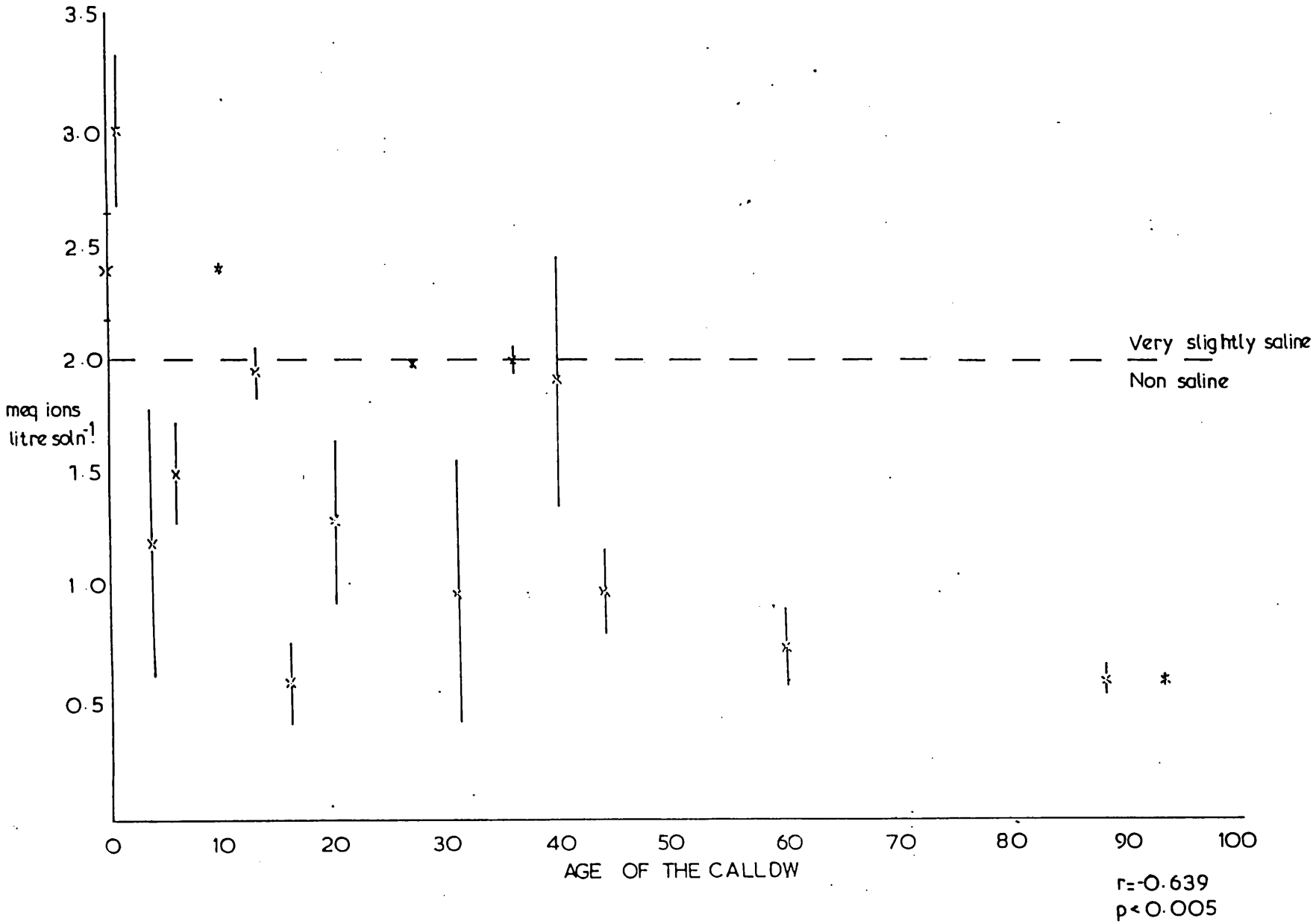
$$\text{The Conductivity m.mho.cm}^{-1}\ (25^{\circ}\text{C}) = \frac{\text{Cell Constant} \times 100}{\text{Rt (ohms)}} \times \text{ft}$$

5.7.2. Results.

Specific Conductivity of the callow is shown in Figure 5.13. The results show a significant negative correlation between conductivity and age of the callow. That is, on aging, conductivity decreases.

FIGURE 5.13

SPECIFIC CONDUCTIVITY OF THE CALLOW



A part of the Salinity Scale, adopted from description of Schofield[82] is given as follows:

Specific Conductant of the Saturated Extract of Soils, mmhos.cm^{-1}.

0 - 2 Non Saline

Salinity effects most negligible.

0 - 0.1% of salts in moisture saturation extract.

2 - 4 Very Slightly Saline

Yields of very sensitive crops may be restricted. 0.1 - 0.3% of salts in moisture saturation extract.

Thus callow samples are mainly in the 0-2 mmho.cm^{-1} range and are therefore non saline. In the early part of the series some are in the 2-4 mmho.cm^{-1} range and are very slightly saline.

Therefore dissolved salt levels should not cause any problem in the growing of crops on the callow.

The relationship between decreasing conductivity levels and age will be discussed later.

5.8. Salt Content

5.8.1. Method.

The meq. salts per litre can be calculated directly from specific conductivity measurements.

meq. salts per litre = 12.5L mmho.cm^{-1}

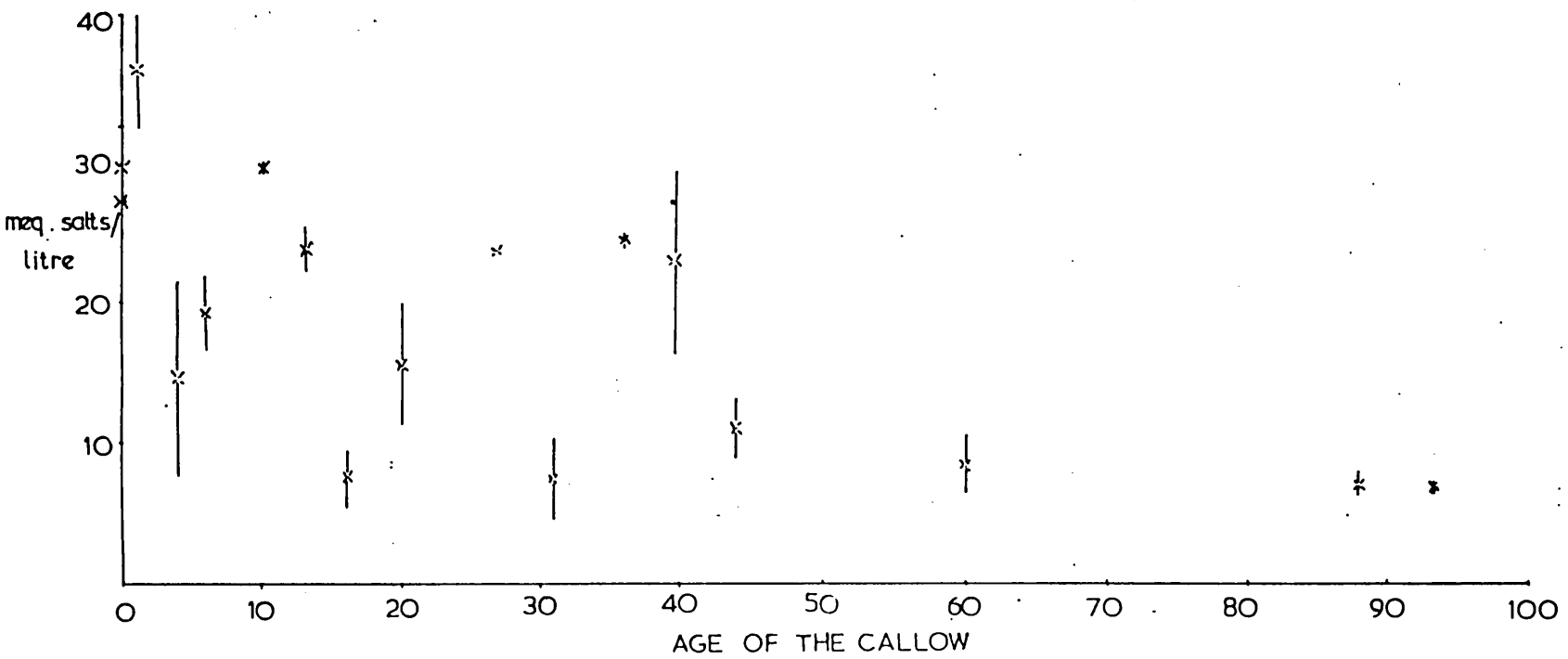
Where L is the specific conductance of the test solution.

5.8.2. Results.

The meq. salts per litre of saturated callow are shown in Figure 5.14. The results show a similar trend to those of specific conductivity, as expected. The salt levels decrease with age, the correlation being a highly significant negative value; ($r = 0.633$; $p < 0.00\ 5$).

FIGURE 5.14

MEQ SALTS PER LITRE OF SATURATED CALLOW



5.9. Sodium Levels

5.9.1. Introduction.

Sodium, potassium, calcium and magnesium may all be analysed using the same extractant procedure. The procedure for individual ions should obviously give an indication of the concentration of ions available to the plants and also the capacity of the material to keep supplying ions to the solution once some have been removed by the plant roots. This is not easy as elements behave differently and are differentially affected by other features of the material.

Thus extractant procedures differ from material to material and from element to element. Commonly used methods are water, dilute acid, salt solutions, E.D.T.A. and others. Water removes that which is immediate in solution; the acid and salt extracts give a better correlation with plant yields over time[3].

Calcareous soils present serious difficulties because calcium carbonate is partially soluble, even in the more neutral extractants[74].

Bower et al[79] discuss the calcareous and saline soils in this respect and advocated a high pH sodium acetate extractant. The simplest approach is to take the pH of M ammonium acetate extract from pH7 to pH9 by the addition of ammonia. The amount of extractable calcium obtained is quite arbitrary, though it includes only a minimum of carbonate-calcium. There is probably little point in separating "true" exchangeable calcium and carbonate calcium dissolved by mild extraction since the latter is part of the soil nutrient potential[74].

Magnesium is also affected in a similar way, although to a lesser extent, in the extraction of soils containing magnesium carbonate.

The extractant used was ammonium acetate pH 9 as relatively little calcium carbonate is dissolved at this pH.

5.9.2. Method.

Five gram samples of air-dry seived callow were weighed into 250ml plastic bottles.

125ml of M NH_4OAc, pH 9 was added to each sample. The bottles were then shaken for an hour on a shaking machine.

The solutions were filtered through number 44 filter paper into polythene bottles, rejecting the first 10ml.

The moisture contents of the samples were determined at the time of weighing in order to correct the results to a dry weight basis.

Two blanks were run, with extractant only.

Sodium standards were made up by firstly making a stock solution of 0.2542g dry NaCl in water made up to a litre. This gives a 100 $\mu g.g^{-1}$ solution. The working standards between the range of 0-5 $\mu g.g^{-1}$ Na were made by dilution.

The appropriate amount of extractant was added to match the samples.

The 589nm wavelength of the Atomic Absorption Spectrophotometer was selected and the sodium lamp was attached. The gas pressure and slit width were adjusted as required. A calibration curve was prepared from the standard range. The sample solutions were aspirated into the flame under the same conditions as the standards. The top, zero and intermediate standards were checked frequently. The instrument atomiser was flushed regularly with distilled water.

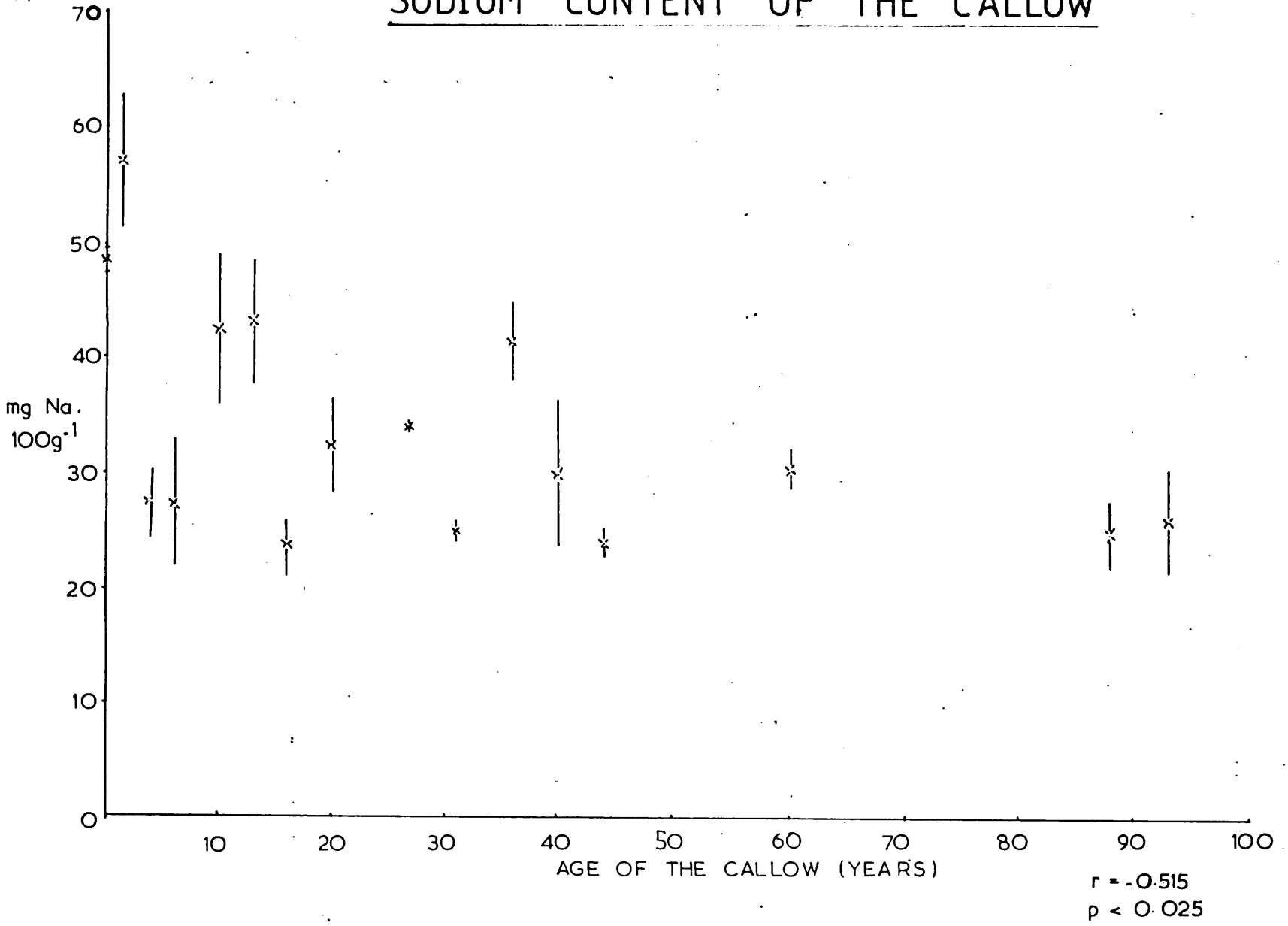
The calibration curve was used to determine $\mu g.g^{-1}$ in the sample solutions. Blank determinations were used to determine background levels, the blank results subtracted as necessary.

5.9.3. Results.

Results are plotted in Figure 5.15. Each point is the mean of three random samples; standard errors are plotted.

FIGURE 5.15

SODIUM CONTENT OF THE CALLOW



The levels of sodium are shown to decrease with age. There is a high negative correlation between mean sodium levels and age; $r = 0.515$, p 0.025. The levels are highest at the one year old site in Rookery ($\bar{X}$ = 57.0mg. $Na.100g^{-1}$) and fluctuate to a low level at sixteen years in Coronation (23.8 $mg.Na.100g^{-1}$) but increase again after that to 41.5 $mg.Na.100g^{-1}$ at thirty six years. After forty years the sodium content levels off at a mean value of about 25 $mg.Na.100g^{-1}$. These results will be discussed in Section 5.19.

5.10. Magnesium Levels

5.10.1. Introduction.

Atomic absorption is without doubt the best available method for the determination of magnesium in solution. Its advantage for magnesium lies in its greater precision, sensitivity and convenience compared with colorimetric methods. Unlike sodium, potassium and calcium, flame emission is too insensitive to be applied.

Certain elements interfere with absorption in the flame and present problems because of this. In organic materials, calcium, aluminium and phosphorus all have an effect. Strontium and lanthanium are effective releasing agents but strontium precipitates with sulphuric acid. If lanthanium is going to be used, the same amount has to be present in samples and standards. Most instruments will detect concentrations of 0.005 $\mu g.ml^{-1}$ magnesium or less.

It was considered, that as these analyses are primarily for comparative purposes and secondly as an indication of soil nutrient levels, that the addition of an extra variable such as strontium may reduce comparability rather than enhance it. Therefore, in this instance, the samples were aspirated in the flame without the addition of lanthanium or strontium .

5.10.2. Methods.

The sample aliquots produced for the sodium analyses were used throughout.

The 285.2 mm wavelength was selected on the Baird Atomic Absorption Spectrophotometer. The air and gas flows and slit widths were adjusted as necessary. All other settings were checked, as recommended. The hollow cathode lamp was allowed adequate time to stabilise.

The standards were made from stock solution of 100 $\mu g.g^{-1}$Mg which was made by dissolving I.0136g $MgSO_4 7H_2O$ in water containing 1ml H_2SO_4. This was then diluted to 2L. Working standards were prepared in the range of 0-3 $\mu g.g^{-1}$ Mg.

Two blanks were also made up. The samples were diluted until they were in the required concentration range.

The standards were used to prepare a calibration curve to obtain $\mu g.g^{-1}$Mg in the sample solution.

If C = $\mu g.g^{-1}$Mg. obtained from the graph then for soil extracts:-

$$\text{Extractable Mg}(mg.100g^{-1}) = \frac{C\mu g.g^{-1} \times \text{soln.Vol.(ml)} \times 10^3}{10^4 \times \text{sample wt.}}$$

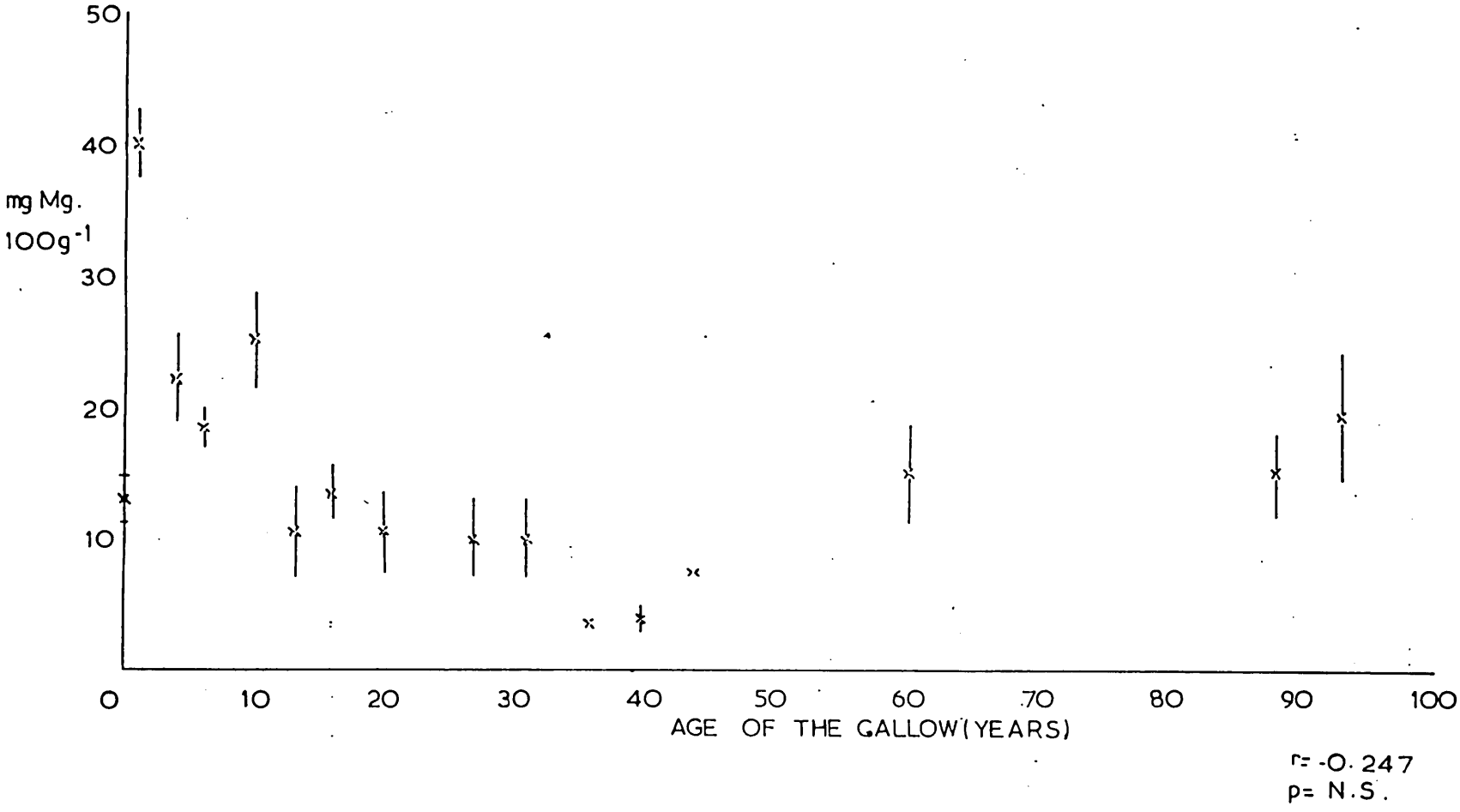
5.10.3. Results.

The mean result of three random samples at each location is plotted together with the standard error, in Figure 5.16. Like sodium, magnesium levels decrease with age. Again the highest levels are recorded in the one year old site in Rookery Pit. Despite the trend towards decreasing levels with age, the correlation coefficient r = 0.247; the probability p, is not significant. However, if the last four results are omitted from the calculation of the correlation coefficient, r = -0.751, $p < 0.005$. Thus the result becomes a highly significant, negative correlation. That is, as age increases so magnesium levels decrease.

The last two graphs indicate a leaching of soluble salts through the soil profile. This leaching appears to be a short time scale phenomenon occurring in the first forty five years or so.

FIGURE 5.16

MAGNESIUM CONTENT OF THE CALLOW



5.11. Potassium

5.11.1. Introduction.

Although potassium is present in relatively large amounts in most soils, its soil chemistry is very complex and most of it is fixed in a form not available to plants. Clay minerals are significant in fixation and release of this element, and Richards and McLean[83] have shown that these effects are directly related to the extent of drying prior to extraction. A general review was given by Agarwal[84]. A more theoretical view of soil potassium was given by Beckett 85, 86 who discussed the ratios of the activities of soil cations as a measure of labile potassium. Many extractants have been used, but their usefulness seems limited[75]. M ammonium acetate is considered to provide the ecologist with sufficient information in the first instance.

5.11.2. Methods.

The filtrate obtained from the sodium analyses extractant was again used for potassium.

Potassium standards were made from a stock standard solution. The stock solution was made up to 1000 $\mu g.g^{-1}K$ by dissolving 1.9068g dry KCl in water and making up to one litre. The working standards were made by serial dilution to provide a range from 0 - 100 $\mu g.g^{-1}K$.

The 766mm wavelength of the A.A. was selected.

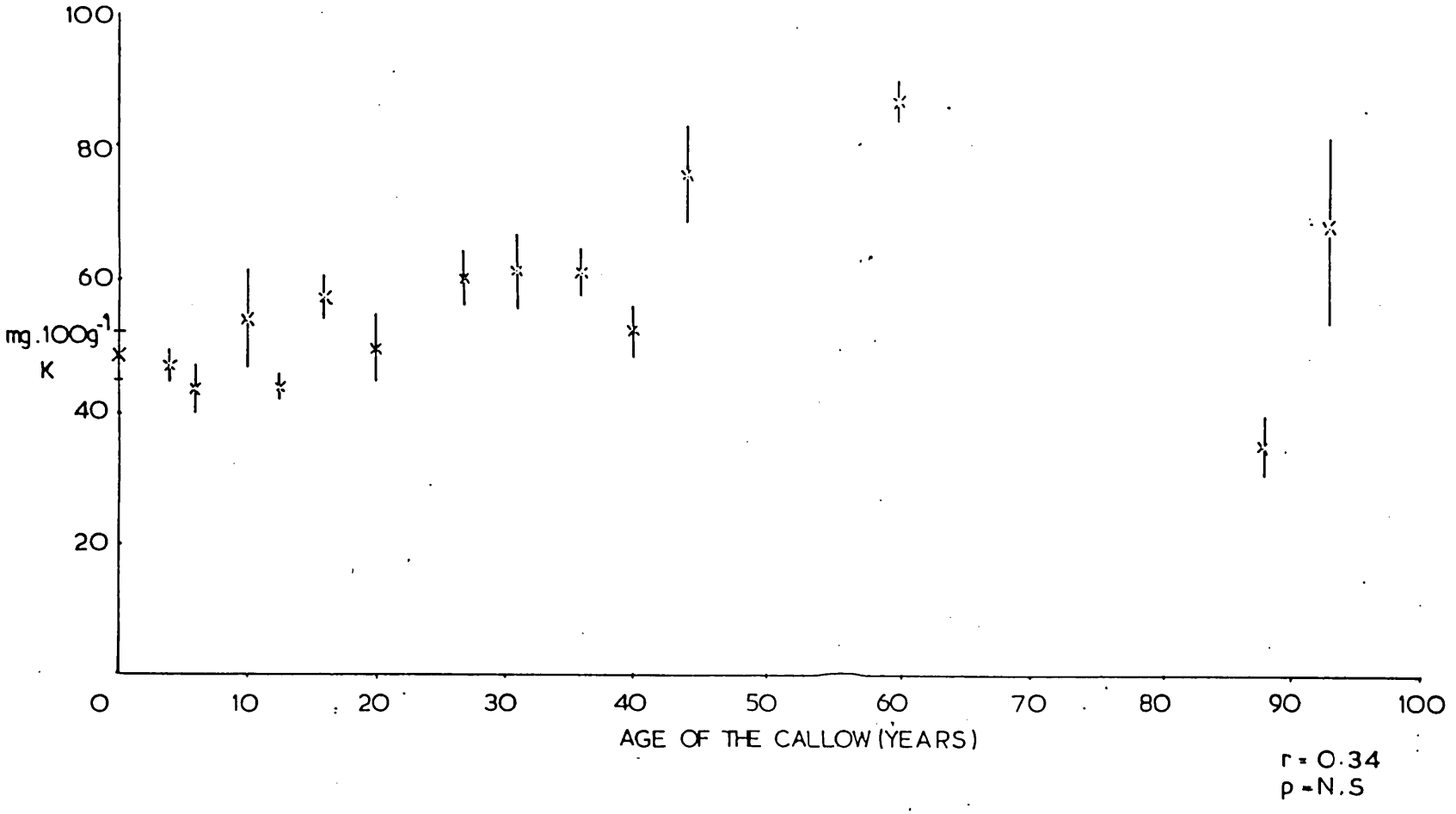
5.11.3. Results.

The mean results of three random samples at each location and their standard error are shown in Figure 5.17. Mean potassium levels are between 35.2mg.K $100g^{-1}$ soil and 85.7 mg.K.$100g^{-1}$ soil.

There is a general trend of increasing potassium levels with age until sixty years, after that the results are variable. The correlation coefficient, $r = 0.34$. The probability is not significant. However, if the last two

FIGURE 5.17

POTASSIUM CONTENT OF THE CALLOW



sites, Ickwell and Box End Kempston are omitted from the analysis, the correlation coefficient $r = 0.83$, $p < 0.005$. That is, the relationship is one of a highly significant positive correlation. The anomalies at the end of the age series will be discussed later.

5.12. Calcium

5.12.1. Introduction.

The calcium content of chalk or limestone soils may be 30% or more. In most non-calcareous soils the forms of calcium are more variable but it is still an important soil element. Certain types of soils have significant amounts of calcium phosphate or sulphate and many contain calcium in feldspars, amphibolites and various clay minerals. Calcium has a physical role in soil and is important in flocculating clay particles.

In vegetation calcium is essential for apical and root tip development and accumulates in cell walls as calcium pectate. It is one of the dominant elements in the skeletal structures of many animal groups.

The concentration ranges usually encountered are as follows:-

Mineral soil	0.5 to 2% (excluding calcareous)
Organic soil (peat)	0.1 to 0.5%

Soil extractions 10 to 200mg.100g^{-1} (excluding calcareous)[75]

The application of flame emission and atomic absorption have not been straightforward because of interference.

As already stated (Section 5.9.1.), calcium is the least accurate of the determinations due to interference by other elements and also due to the highly variable nature of the callow, containing calcareous "nodules".

5.12.2. Method.

The sample solutions used in the sodium analyses were again used for calcium analyses. Calcium standards were made up by firstly making a stock solution of 1000 $\mu g.g^{-1}Ca$. by dissolving 2.4973 g dry $CaCO_3$ in about 200ml water, containing 5ml conc. HCl. This was then heated to drive off CO_2, cooled and made up to one litre.

The working standards were prepared by serial dilution to give a range of between 0 and 100 $\mu g.g^{-1}$. The extractant was included as appropriate. The samples were diluted to a convient range and aspirated under the same conditions as the standards using the 422.7mm wavelength of the Baird Spectrophotometer with emission facilities.

Blank determinations were carried out in the same way and subtractions were made where necessary.

If C = $\mu g.g^{-1}$ Ca obtained from the standard graph, then for soil extracts:-

$$\text{Extractable Ca}(mg.Ca100g^{-1}) = \frac{C(\mu g.g^{-1}) \times \text{soln volume} \times 10^3}{10^4 \times \text{sample weight}}$$

5.12.3. Results.

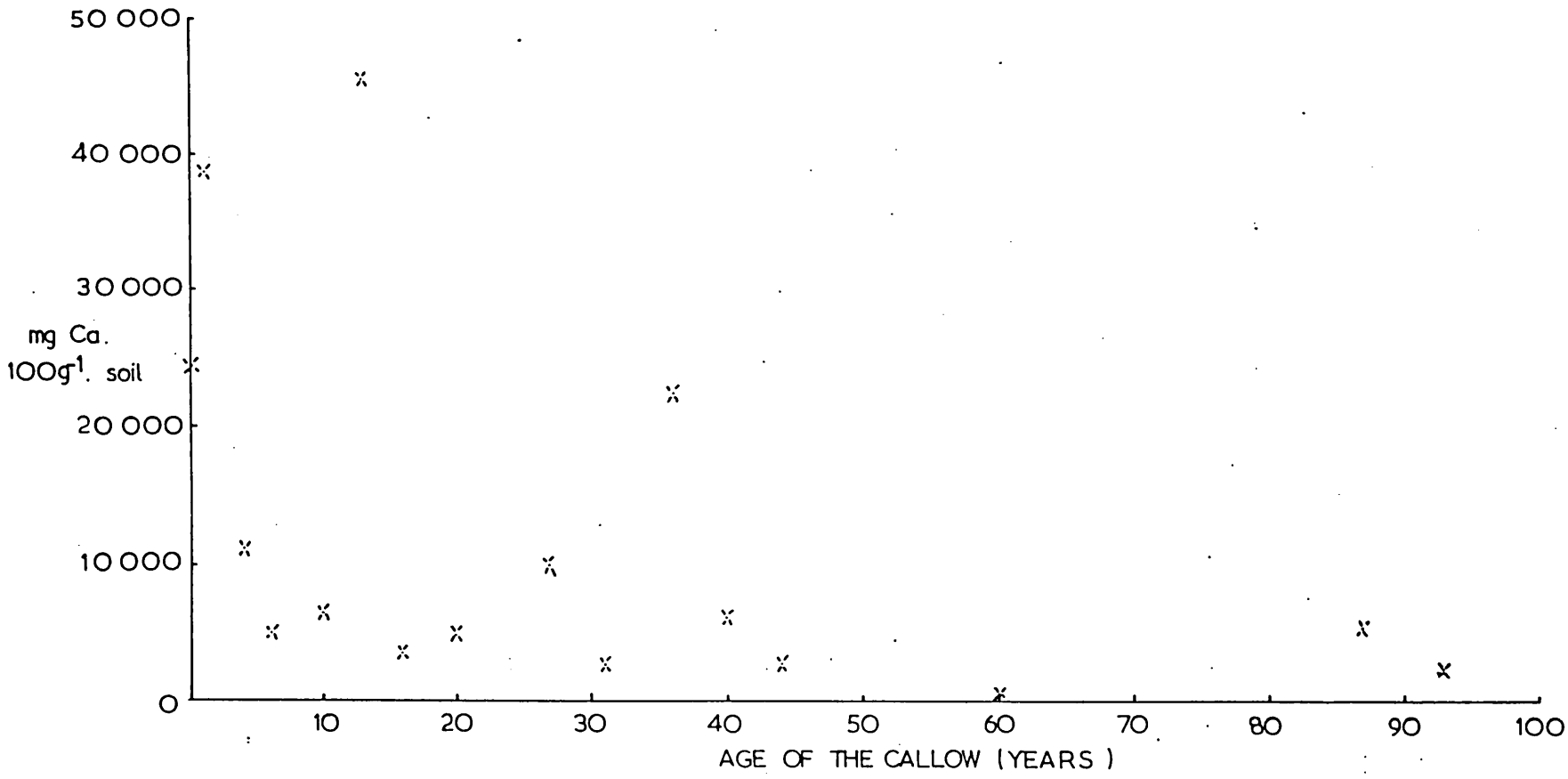
The results are shown in Figure 5.18. The results vary between 45 489mg. $Ca.100g^{-1}$ soil and 975 $mg.Ca.100g^{-1}$ soil. Despite the highly variable results, there is a general trend of decreasing calcium levels with age. The correlation coefficient, $r = -0.457$, $p<0.05$. These results are probably caused by leaching of the soluble salts through the soil profile. Again, the levels stabilise after 40 years, fluctuating around the 1000 - 5000 mg. $Ca.100g^{-1}$ soil level.

5.13. Phosphorus

5.13.1. Introduction.

More attention has probably been given to the study of extractable forms of phosphorus than to almost any other nutrient in the soil. Reasons for this include the vital role that it plays in metabolism coupled with the fact that levels, even in fertile soils, are often no more than adequate. The availability to plants depends on various factors including the extent to which it is mineralised and refixed in the environment of the plant root. The available content cannot be determined by extraction methods and the extractants employed have been developed to extract one or more fraction.

FIGURE 5.18 CALCIUM CONTENT OF THE CALLOW



The more soluble forms in acid or neutral soils can be extracted with 1% citric acid[87], 2.5% acetic acid etc., while sodium bicarbonate buffered at pH 8.5 has been widely used for calcareous soils[88].

Olsen's extractant is appropriate for chalk and limestone material. Some organic matter is also extracted but organic phosphorus will not be estimated by the colorimetric method.

5.13.2. Method.

Olsen's Reagent was made in the following way:

210g $NaHCO_3$ was dissolved in water in an aspirator and 100ml MNaOH was added. This was then diluted to 5 l. and mixed well. The result should be 0.5M $NaHCO_3$ buffered at pH 8.5.

Five grams of air dried, seived callow was weighed into a polythene bottle. 100ml of Olsen's Reagent was added. The bottle was then shaken for 30 minutes on a rotary shaker. The solution was filtered through number 542 filter paper.

Two blanks were also set up. The moisture content of the samples was determined at the time of weighing.

It was important to neutralise the extract with 10% V/V H_2SO_4 before colour development in the molybdenum blue procedure. However, this causes the solution to bubble and causes problems in the development of colour. Therefore a few drops of 10% nitric acid were added to stop the sample bubbling. Both these were measured during the procedure so that the ratio could be worked out. e.g. 10 ml. of soil extract was used with 3.0 ml of 10% V/V H_2SO_4 and 1 ml of nitric acid.

Colorimetry is almost always used for the determination of phosphorus as phosphate. The molybdenum blue method is based on the formation of a heteropolyphosphomolybdate complex when an acid molybdate is added to a solution containing orthophosphate. Reduction of this colour gives the characteristic blue colour.

The molybdenum blue colour is developed in aqueous solutions and may be used for all ecological materials except where phosphorus levels are very low.

The reagents necessary were made as follows:-

i Phosphorus Standards.

Stock solution (1 ml = 0.1 mgP). 0.4393g dry KH_2PO_4 was dissolved in water and diluted to 1 litre. Working standards (1ml = 0.002 mgP) - the stock solution was diluted fifty times. This was made up freshly at intervals.

ii Ammonium-molybdate-sulphuric acid reagent.

25g $(NH_4)_6MO_7O_{24}.4H_2O$ was dissolved in about 200 ml water in a beaker. This was warmed slightly to dissolve the solids. 280 ml conc. H_2SO_4 was carefully added to about 400 ml water. The molybdate solution was filtered into the acid mixture, mixed thoroughly and made to 1 litre when cool. This solution was then kept in the dark.

iii Stannous chloride reagent.

0.5 g $SnCl_2.2H_2O$ is dissolved in 250 ml 2% V/V Hcl. This is prepared immediately before use.

A standard range from 0 - 0.003 mgP was set up by pippetting from 0 to 15 ml. of working standard into 50 ml volumetric flasks. Olsen's reagent was included so that results were comparable with the samples.

A 10ml. aliquot of sample solution was pippetted into a 50 ml volumetric flask. From this point, samples and standards were prepared in the same way. The solutions were diluted until the flasks were about two thirds full. 2 ml ammonium molybdate reagent was added to each and then mixed. 2 ml stannous chloride reagent was added to each flask and then mixed. Each flask was then diluted to volume and then timed from this stage. They were left for thirty minutes.

The optical density was measured at 700 nm using water as a reference.

A calibration curve was prepared from the standards and is used to determine mgP in the sample liquid.

Blank determinations are carried out in the same way and subtracted where necessary.

If C = mg.P obtained from the graph, then for soil extracts:-

$$\text{Extractable } PO_4^{3-} \text{ (mg.100g}^{-}\text{)} = \frac{C(\text{mg.}) \times \text{solution volume (ml)} \times 10^3}{10 \times \text{aliquot (ml)} \times \text{sample wt.}}$$

5.13.3. Results.

Once background levels had been taken into account, the levels of phosphate in the samples were not detectable. The practical limit for estimation by this method is about 0.1 µg phosphorus. Thus a second method was attempted for low concentration samples.

5.13.4. Procedures for Low Concentration Samples.

Here the phosphomolybdate complex is extracted in n-butanol and the colour is developed in the organic phase. This method is particularly useful for natural waters and other materials where phosphorus levels are very low. It is possible to adjust the relative amounts of aqueous and organic phases to obtain high concentrations in the latter.

The method is reproducible to $\pm$ 2% at normal concentrations. The detection limit is about 0.01 µg phosphorus as orthophosphate.

5.13.5. Method.

Reagents required:-

i Phosphorus standards.

ii Ammonium molybdate - sulphuric acid reagent.

iii Stannous chloride reagent.

iv n - Butanol.

These were prepared in the same way as stated in 5.13.2.

The working standard was pipetted into three different separating funnels to give a standard range from 0 to 0.01 mg P.

1ml = 0.002 mg.P

3ml = 0.006 mg.P

5ml = 0.01 mg.P.

Soil extractant, comparable with the sample aliquot was included in the standards. The fourth standard, 0 mg.P, was obtained by setting up a separating funnel without any working standard.

A 10ml aliquot of sample was pipetted into another separating funnel. From this point onwards the samples and the standards were treated in the same way.

They were saturated with n-butanol, then shaken for one minute and allowed to separate. The aqueous layer was rejected. 5ml of water was added, followed by 2ml stannous chloride reagent. The samples were shaken for one minute and allowed to separate. The aqueous layer was rejected. The optical density was measured at 730 nm. A calibration curve was prepared from the standards and was used to attempt to determine mg.P in the samples.

A blank determination was carried out in the same way and results were subtracted where necessary.

In order to increase concentrations further, 20 g callow samples were used throughout. Calculations are the same as in Section 5.13.2, allowing for moisture content in the soil samples.

5.13.6. Results.

The samples were again below detectible limits for phosphate using this procedure for low concentrations. Assuming that the detectible limit is 0.01 mg.P $100g^{-1}$ soil, levels present throughout the callow age series are below this range.

5.14. Total Nitrogen.

5.14.1. Introduction.

Nitrogen is essential for all organisms and is present in living organisms as a structural component of amino-acids (proteins and enzymes), nucleotides, porphyrins, alkaloids and some lipids. Residues of these and other forms,

together with synthesised material constitute soil organic matter which contains the greater part of soil nitrogen[74].

Levels of inorganic nitrogen (ammonium-, nitrate-, nitrite - nitrogen) are relatively low in soils yet these are the forms available for plant uptake. In general ammonium - nitrogen is retained on clay colloids and is higher in acid soils whilst nitrate - (and nitrite-) nitrogen are more freely soluble and are higher in base rich soils. The availability and relative amounts of the ions vary with season and climate.

The concentration ranges generally encountered are given below.

For total nitrogen:-

Mineral soils 0.1 to 0.5%

Organic soils 0.5 to 1.5%

Soil extractions NH_4^+-N 0.2 to 3 $mg.100g^{-1}$

NO_3^--N 0.1 to 2 $mg.100g^{-1}$

Plant materials 1 to 3%

The classical Kjeldahl digestion system is still the main analytical technique for nitrogen and its compounds in biological materials.

An estimate of total nitrogen content in soil materials can be made from ignition loss at 400°C.[74]

N = L.O.I. x (0.022 - 0.03)

Assume loss of ignition = 4%

Correction factor = 0.025

N = 4 x 0.025%

= 0.1%

= 1000 $mg.N.100g^{-1}$

However, this equation gives only a general approximation and little emphasis should be placed on it.

The Kjeldahl conversion of nitrogen to $(NH_4)_2SO_4$ is employed in macro, micro and ultra micro procedures. However, fresh material can only be handled on a macro scale. It is usually satisfactory to digest freshly ground air dried

material but where much labile nitrogen is present (as in many animal and microbial tissues) it is necessary to digest fresh samples.
The method used here - Kjeldahl's analysis, only estimated total organic - N and ammonium nitrogen. Nitrates are not included but the amounts present in normal unfertilised vegetation material is very small[74].

5.14.2. Method.

Although the original Kjeldahl procedure has been modified many times, the determination of total nitrogen is still not as simple as it is often thought to be. It is subject to difficulties, many of which will lead to low results. For example, an hour of digestion may be necessary, after the digest turns clear, to release all of the nitrogen; the most important considerations being the catalyst selected and the digestion temperature. If the temperature is too low (below 360°C) the release is slow or incomplete and if too high (over 410°C), some loss of NH_3 from the mixture results. Jackson[74] states that the soil should be more finely ground than the sample size would ordinarily require in order to assure complete oxidation of the organic matter within the small aggregates. However, this was not possible as freshly used samples were used. Instead, soaking clay soils in water helped achieve complete oxidation.

i Apparatus.

Needed apparatus consists of a Kjeldahl digestion manifold, a Kjeldahl NH_3 distillation rack, 800 ml. Kjeldahl flasks, a 25ml. pipette, 500 ml. conical receiver flasks with 8 mm diameter receiver tubes long enough to reach from the bottom of the conical flask to the distillation condenser, burettes and an analytical balance.

The special Kjeldahl digestion rack with fume aspirator should have H_2SO_4 fume disposal facilities through a large water pump disposing the fumes by evacuation. The shut-off and regulatory valves for the water line which flushes condensed acid out of the lead manifold is shown in Figure 5.19. A similar set of valves regulate the flow through the suction pump at the end of the manifold. These are also shown in fig.5.19.

ii Procedure.

A weighed callow sample of 3.0g (not ground; freshly excavated) was dropped into a 500 ml Kjeldahl digestion flask.

Then 4 glass beads

4 Kjeldahl catalyst tablets; sodium sulphate

2 Kjeldahl catalyst tablets; copper sulphate

1 Kjeldahl catalyst tablet; selenium

40 ml distilled water

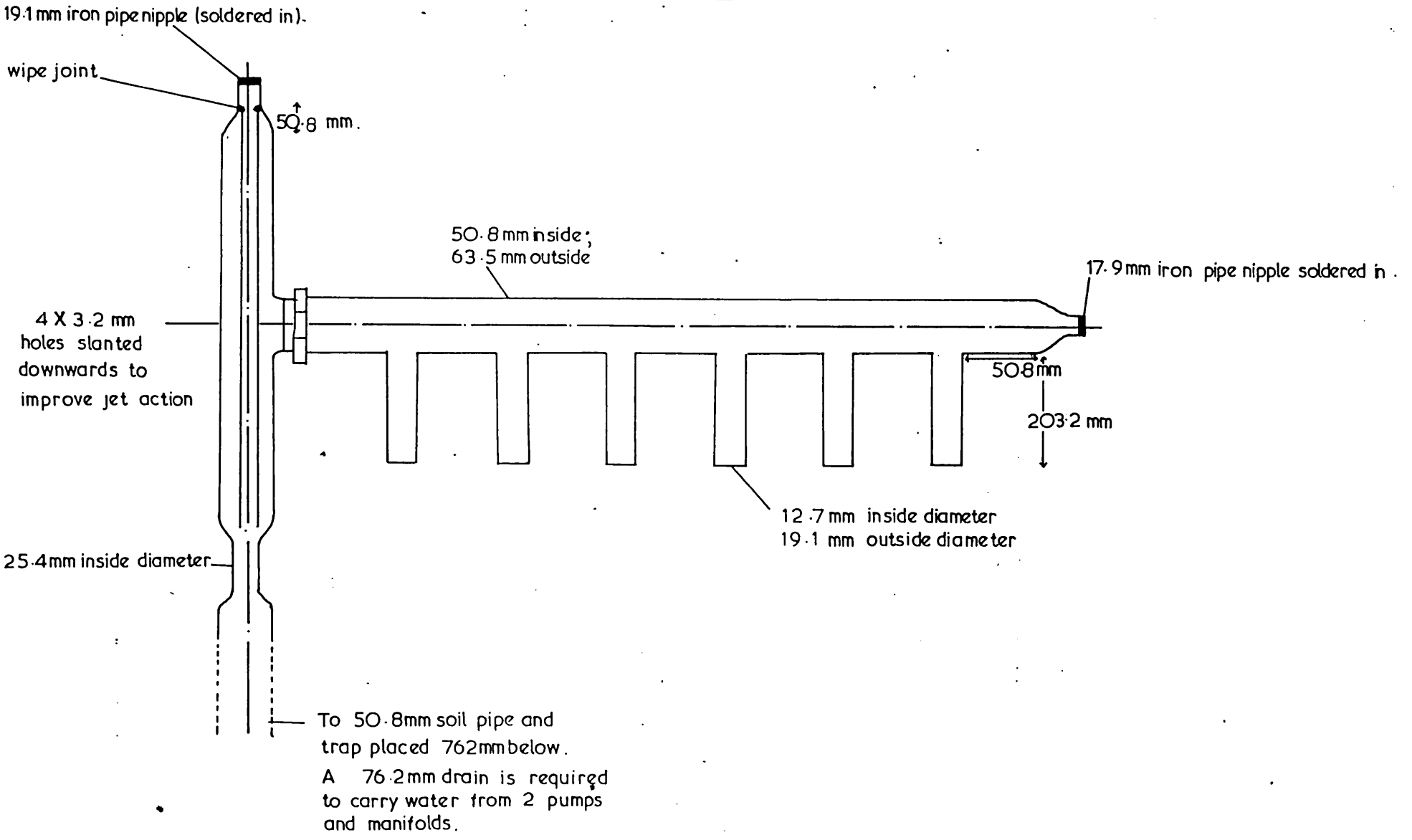
were added to the flask, and shaken. 20 ml of concentrated H_2SO_4 was carefully added to each flask and the contents were mixed by swirling. The digestion was then commenced.

The digestion was effected on the Kjeldahl digestion rack with a low flame for the first 10 - 30 minutes until frothing stopped. Then the flame was increased so that it did not touch the flask above the liquid layer. The heating was continued until all organic matter was destroyed, best judged by timing the digestion for less than thirty minutes after the solution had turned clear or white.

At the end of digestion the heating was stopped; fume exhaustion was continued until the fuming stopped. When the flasks were cooled sufficiently for crystals to form in places, approximately 150 ml distilled water was added and the liquid was mixed until the glass balls were freed from their coagulating solution.

The solution was then ready for determination of the ammonium content.

FIGURE 5.19 PUMP AND MANIFOLD FOR KJELDAHL DIGESTION APPARATUS



Approximately 25 ml of 4% boric acid was poured into a 250 ml conical flask, 5 drops of methyl red were added. A glass receiver tube was attached to the still at one end and a rubber extension was added to the other end of the tube. The conical flask was elevated onto a pile of six brickettes so that the end of the rubber tube was below the surface of the boric acid in the flask.

The cooling water was turned on in the condenser unit.

The contents of the Kjeldahl flask were mixed by rotation and the flask was placed on the distillation stand and checked for a good fit with the condenser connection. Then about 120 ml 50% NaOH was poured into the Kjeldahl flask. The solution was mixed so that layering did not occur. The bunsen burner was lighted, the flask attached to the still and heating started. Immediately on application of heat, a glass stopper was applied to the top most part of the apparatus to stop the ammonia being lost out of the system. The flame size was controlled to stop "bumping". About 50 ml was distilled; the methyl red indicator changed colour from purple to green.

The glass stopper was removed before the heat was switched off to stop the sucking back of the boric acid into the Kjeldahl flask.

The boric acid was then back titrated with a standard acid, N/10 HCl. At the end point the blue-green colour disappeared and the solution turned purple on the addition of an additional drop.

5.14.3 Results

The total nitrogen content was calculated in the following way. (Results were corrected to an oven dry-soil weight basis).

$$\% \text{ N in soil} = (T - B) \times N \times \frac{1.4}{S}$$

in which

T = Sample titration, ml. standard acid.

B = Blank titration, ml. standard acid.

N = Normality of standard acid.

S = Sample weight, gm[75].

The results, showing the mean and standard error of three random samples for each site are shown in Figure 5.20. The total nitrogen content increases with age, the correlation coefficient, $r = 0.734$, $p < 0.005$. Mean results vary from 645.8 mg.N.100g.$^{-1}$ soil to 4734.2 mg.N.100g.$^{-1}$ soil. The highest result was found at Upper Dean Clay Pit (sixty years); Box End, Kempston (ninety three years) showed the greatest variability.

5.15. Field Capacity

5.15.1. Introduction.

For the following tests the soil needs to be in its natural condition, neither broken nor compressed[81]. Field capacity is defined as the maximum amount of water which a freely drained soil can hold[89]. The samples were obtained as follows:-

i Simple corer type samplers were prepared by cutting off the roll edge of tall slim cans, for example tomato tins, baked bean tins or similar.

ii Each can was weighed and numbered carefully. The bottom end of each can was perforated.

iii The random sampling sites were chosen. The tin can was driven into the ground until the perforated end was flush with the surface; the soil was not measurably compressed.

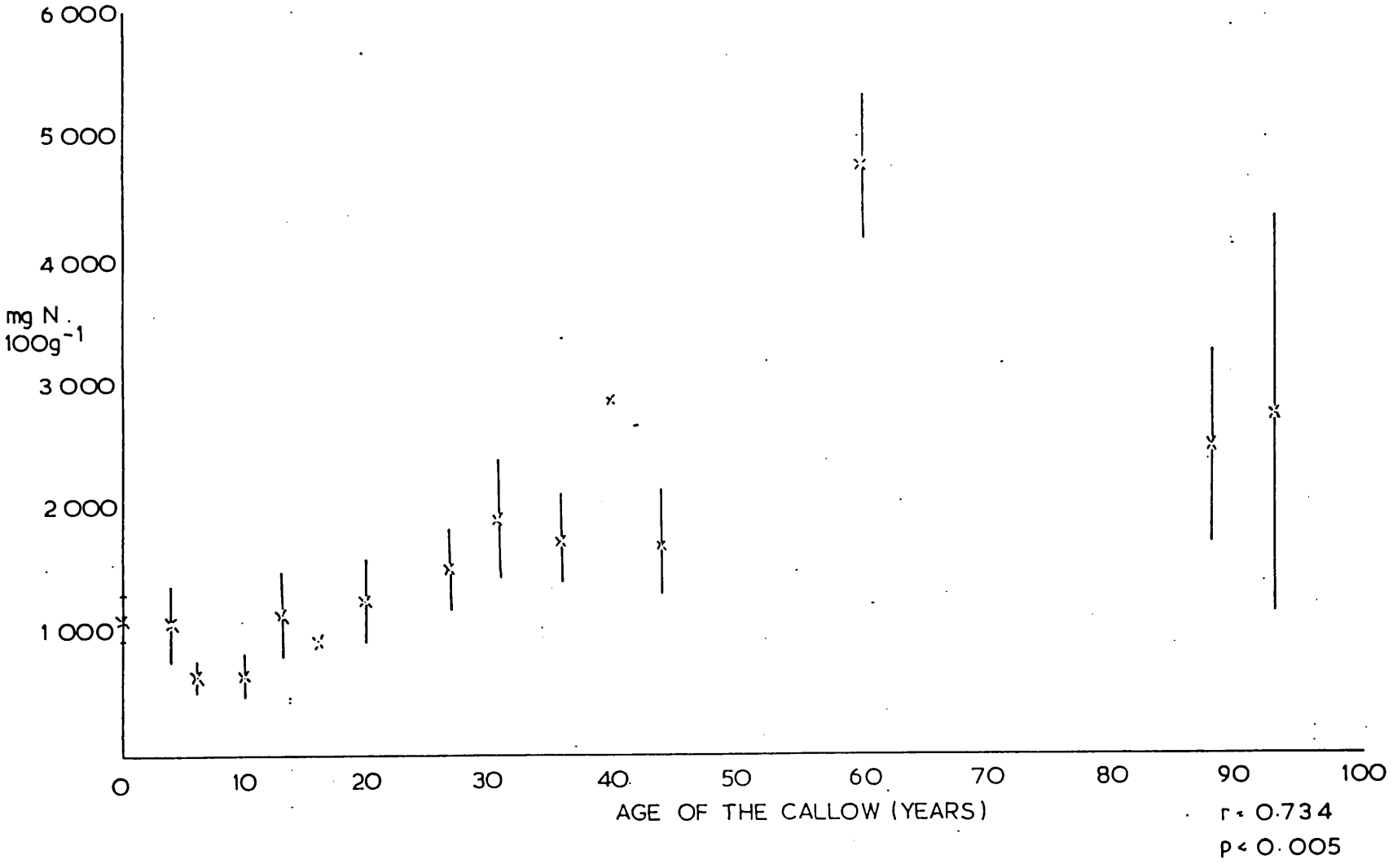
iv The can was carefully dug out, its outer surface was wiped clean. The soil at the open end of the can was then levelled with a sharp knife. The tin and soil sample were then placed in a plastic bag which was then sealed. The tin can and soil sample were weighed as soon as possible.

5.15.2. Method.

On returning to the laboratory, after weighing, the cans were lowered carefully into a large container containing distilled water. They were left in position until the soil was thoroughly soaked. In order to replicate the experiment, this was timed as one hour. The cans were then removed from the water and allowed to drain freely for thirty minutes or until the water

FIGURE 5.20

TOTAL NITROGEN CONTENT OF THE CALLOW



ceased to drip from the perforations. The outsides of the cans were dried carefully with blotting paper and then the cans were carefully weighed. Any increase in weight at this time was due to water uptake and the field capacity could then be determined by oven drying and weighing.

5.15.3. Results.

Percentage field capacity is shown in Figure 5.23. Each point is the mean of two samples from each site. There is a high positive correlation between percentage field capacity and age. ($r = 0.74$, $p < 0.005$). It is interesting to note how close the samples (taken in October 1983) were to field capacity at this time, by comparing the percentage moisture content (Figure 5.22) with the percentage field capacity (Figure 5.23). (The two sites at Bletchley were also included in this group of experiments).

5.16. Maximum Water Capacity

5.16.1. Introduction.

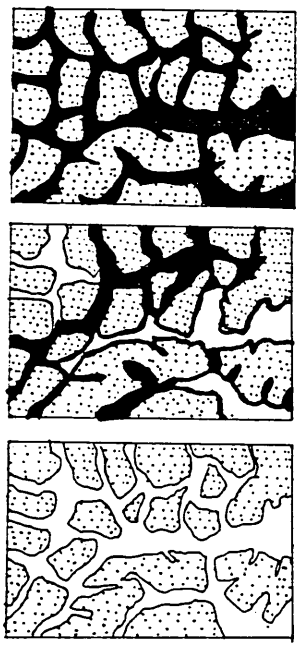
This is the maximum amount of water the soil can hold if drainage is prevented and all the air is displaced; it is equivalent by volume to pore space.

5.16.2. Method.

The soil samples were collected as stated in 5.15.1. The cans were weighed and numbered.

A wide measuring cylinder or jar was filled with water to a level which would just cover the can. This level was then marked on the side of the cylinder with a chinograph pencil. The mark was labelled (X). The can and soil sample were then lowered carefully into the water, excavating the soil on entry to the water, to displace the air in the soil sample. The new water level was then marked (Y). The cylinder and the can were washed out and the soil was discarded. The cylinder was then refilled to its original level (X). The perforations on the bottom of the tin can were sealed with sticky-tape and then can was filled to the brim with water. The can was

FIGURE 5·21. SOIL MOISTURE DIAGRAM[127]



Saturated soil: all the pores are filled with water.

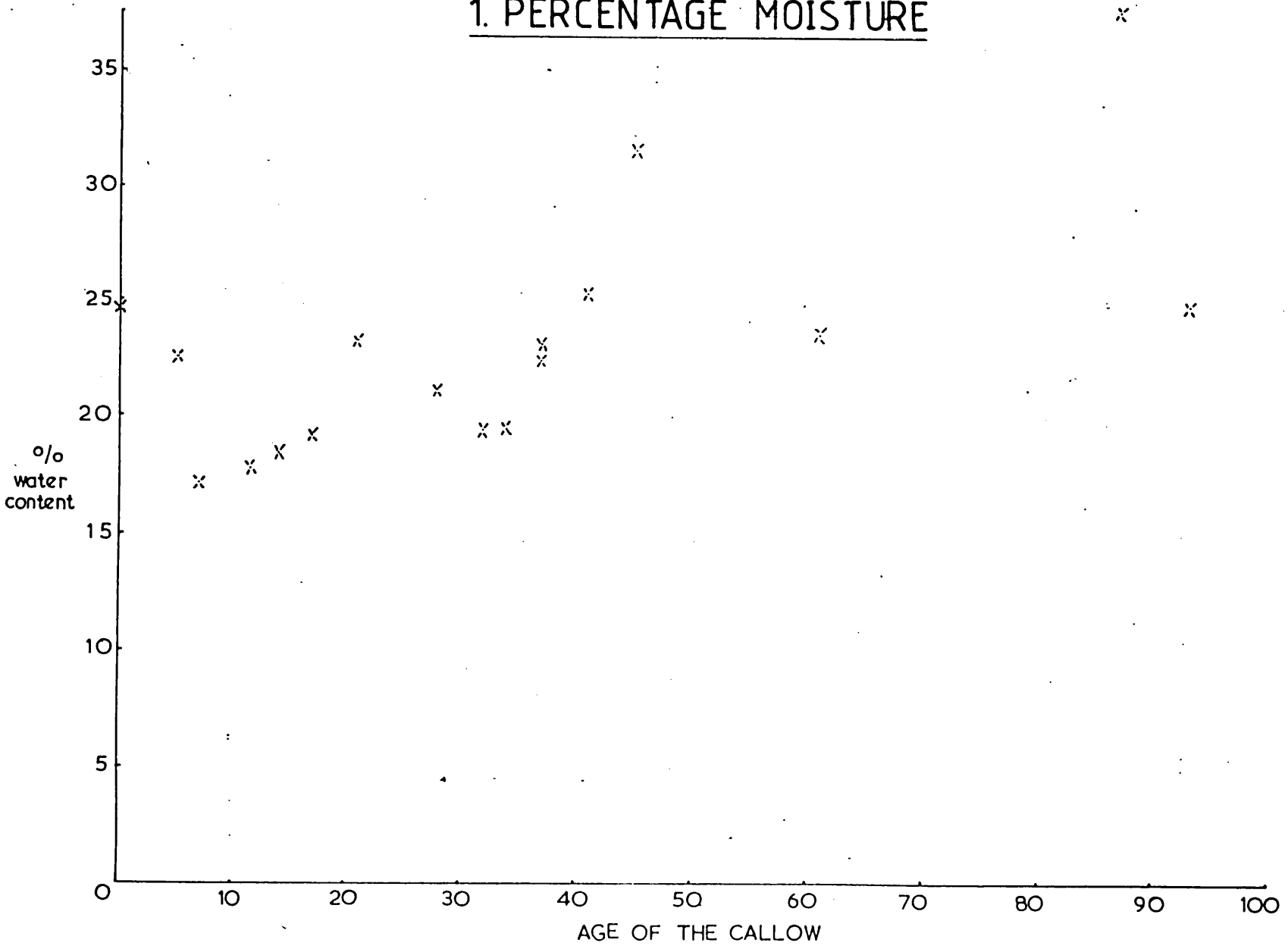
Field capacity: Gravitational water has drained from the larger non capillary pores but the smaller retain the capillary or available moisture.

Wilting point: only hygroscopic water remains, too tightly held in the very finest pores to be of use to plants.

WATER RELATIONS OF THE CALLOW : OCT '83

FIGURE 5.22

1. PERCENTAGE MOISTURE



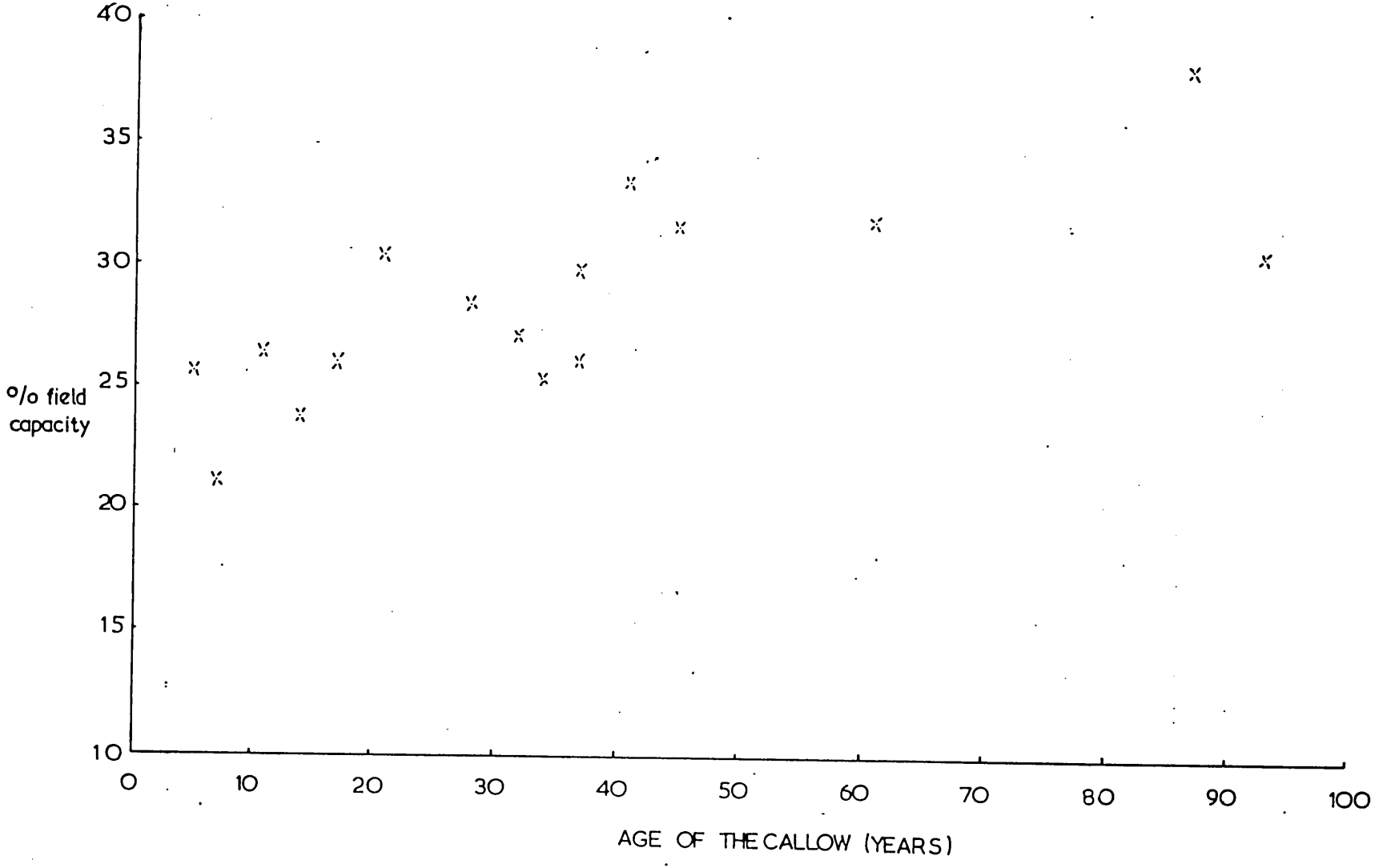
r = 0.663

p < 0.01

WATER RELATIONS OF THE CALLOW : OCT '83

FIGURE 5.23

2. PERCENTAGE FIELD CAPACITY



$r = 0.746$

$p < 0.005$

lowered gently into the cylinder. The new water level was marked (Z). Finally, the volume of air displaced was determined by using a measuring cylinder to establish the quantity of water which was necessary to establish the difference in level between (Y) and (Z).

Z - Y = volume of Air in Soil Sample.

Pore space (percentage by volume) could then be calculated from the results.

5.16.3. Results.

Results are shown in Figure 5.24. The results are the mean of two random samples from each site. Pore space varies from 21% to 81%. Although there is a trend of increasing pore space with age up to sixty years, the two older sites are much lower than would be expected from the general trend. This means that the correlation is distorted. If the last two results are omitted, the correlation coefficient, $r = 0.76$, $p < 0.005$, i.e. there is a highly significant positive correlation between pore space and age.

5.17. Bulk Density

5.17.1. Introduction.

Soil bulk density (Db) is the ratio of the mass of the bulk of soil particles to pore spaces in a sample. (Blake, in Black[131]).

In a given volume of soil some of the volume is occupied by the solid particles of the soil, the rest by air - or water-filled pores. Thus, although the solid particles themselves weigh over two and a half times as much as an equivalent volume of water, a similar volume of dry soil may only weigh one to one and a half times as much as the same volume of water. This is expressed by saying the bulk density of a soil is 1.0 to 1.5 $g.cm^{-3}$, i.e. the weight per unit volume[127].

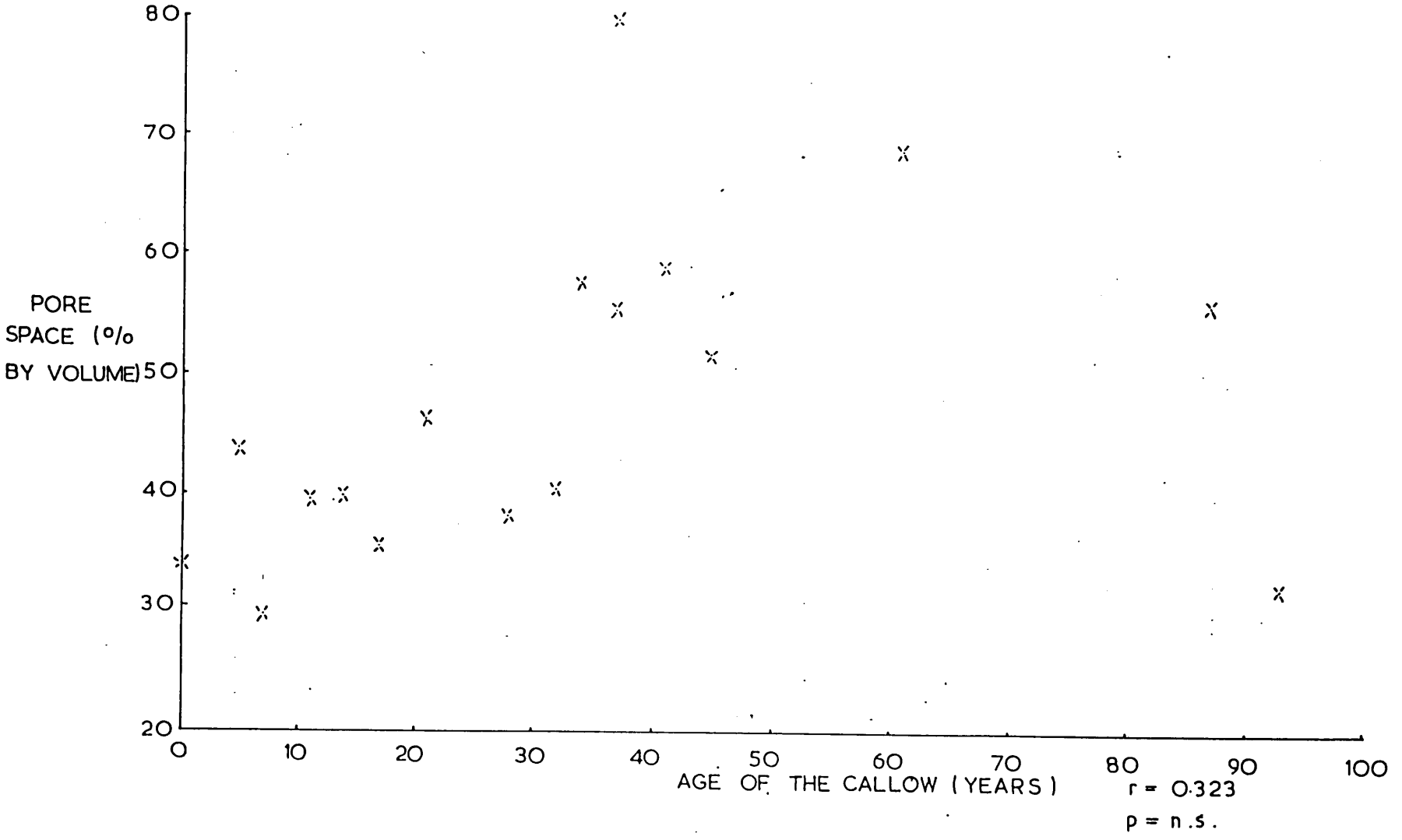
5.17.2. Method.

The method used is that of the Soil Survey of England and Wales[81]. They state that this method can be used in the field to get a better estimate of air capacity and available water.

WATER RELATIONS OF THE CALLOW : OCT 83

FIGURE 5.24

3. PORE SPACE



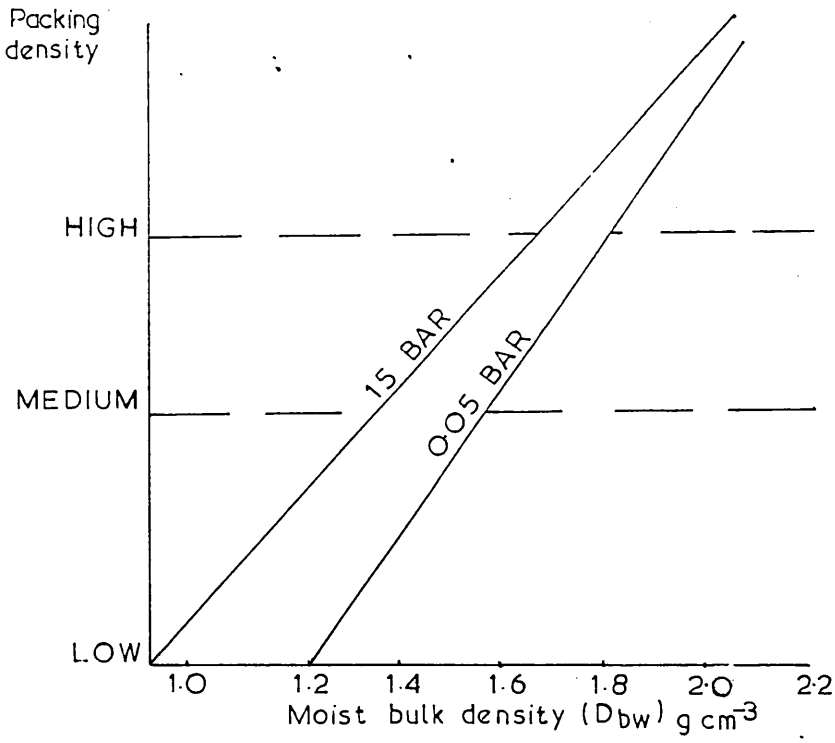
A coring device of known volume ($V_1 cm^3$) and known weight ($W_1 g.$) was used to obtain a soil sample. It is preferable to take samples when the soil is at or near field capacity. This was the case with the October 1983 samples. The sample was weighed as accurately as possible on return to the laboratory.

The moist bulk density (D_{bw}) is calculated:-

$$D_{bw} = \frac{W_2 - W_1}{V_1} \quad gcm^{-3}$$

The Soil Survey of England and Wales have drawn up a relationship between moist bulk density and packing density. This is shown in Figure 5.25.

Figure 5.25. Relationship between Moist Bulk Density and Packing Density.



The appropriate point on the Dbw axis is found and examined to find whether a vertical line meets the 0.05 and 15 bar lines within one packing density class. For example if the D_{bw} is between 1.56 and 1.70 the soil has medium packing

density, if D_{bw} is <1.38 the soil has low packing density and if > 1.81 a high packing density.

For other values of moist bulk density in the range 1.38 to 1.56 and 1.70 to 1.81 it is necessary to establish whether the soil material is nearer to 15 bar or 0.05 bar suction to attribute a packing density class.

5.17.2. Results.

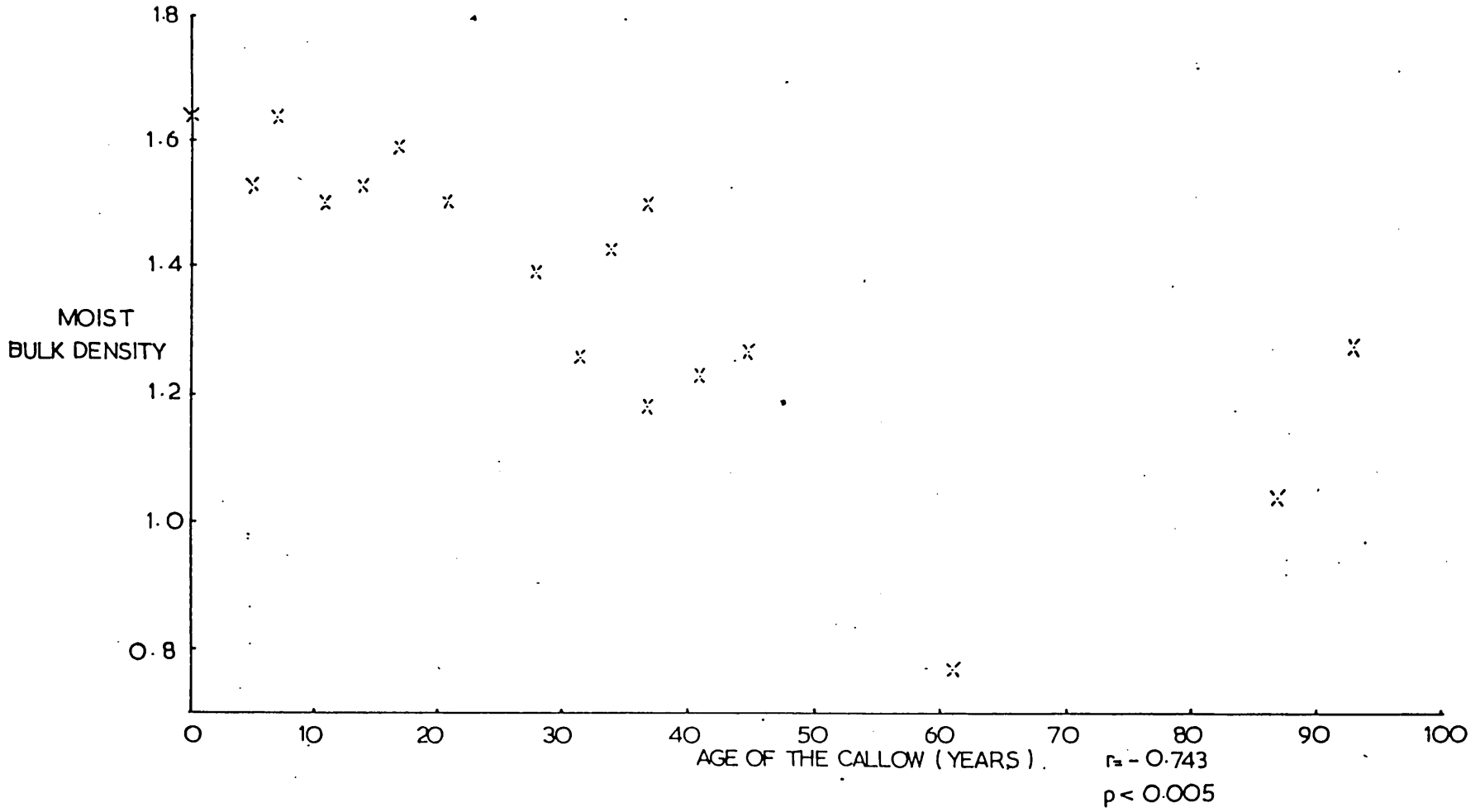
The average results of two random samples at each location are shown in Figure 5.26. The mean results vary between 0.75 and 1.60 $g.cm^{-3}$ moist bulk density. Thus as the majority of samples are below 1.38 $g.cm^{-3}$, the majority have a low packing density. There is, however, a high negative correlation between moist bulk density and age, $r = -0.743$, $p < 0.005$. Thus as the callow ages its bulk density decreases and its packing density also decreases. Two of the earlier results are between 1.56 and 1.70 D_{bw} and are therefore in the medium packing density, the rest of the samples must therefore be somewhere between the medium and low packing densities, depending upon their suction pressures.

5.18 . Soil Profile Development on Callow

A detailed investigation into soil profile development on callow was not undertaken as part of this research project. However, Brown[56] studied the rates of soil development on man-made surfaces in the early 1970's. Some of his results will be noted here, as his field work site was Coronation Pit. At the time of his study Coronation Pit was still being worked. Some of his work is summarized in Table 5.3. The soil structure related to the change in the material from the flaky shale of the un-weathered Oxford Clay to a compact structureless clay and finally (after thirty years) a "soil" showing evidence of physical and biological activity. Brown suggested that the presence of rabbits, which were then present in the first five years, and moles, which colonised after twelve years, were the prime causes of

WATER RELATIONS OF THE CALLOW: OCT '83 FIGURE 5.26

4. BULK DENSITY



mixing and disturbed deeply buried material. Lumbricids (earthworms) colonised after eight to nine years, but not in large numbers. Worm burrows and casts were shallow for the first fourteen years.

The zone between nine and thirteen years recorded the accelerated break up of the clay brought about by the action of moles and the deep tap roots of some thistles. The increasing volume of accumulated litter and humus on the surface did not appear to be incorporated very quickly. There was no evidence of mixing by Lumbricids until the ridges were about fifteen years old. By fifteen years however, there was a continuous network of roots and much of the clay was traversed by earthworm burrows. An Ao horizon of 3 to 5cm persisted from the fifteen to twenty year section of the sequence. Interestingly, the soil structure was most highly developed in the eighteen to twenty year zone.

The depth of root development provided indications of the stages of soil formation. The depth of maximum root penetration increased from 3cm at three months exposure to 20cm after five years. From nine to eighteen years the maximum depth was much greater because of the thistles present from nine - twelve years and deep rooting grasses from eleven to eighteen years. At eighteen to twenty years the sites became more stable with maximum rooting depths of 40cm. The zones of maximum root development were thought to be controlled by two species Tussilago farfara (Colt's-foot) and Equisetum arvense (Horsetails) which have similar rooting depths although the latters' tended to go slightly deeper.

The total profiles provided further information. Litter formation did not start for two years and then the development of a L - F - H zone was very slow, taking fourteen to fifteen years before a constant humus horizon was present. This reached its maximum in the eighteen to twenty year period, after which there was a recession back to little or no humus.

Table 5.2. A Comparison of Average Moisture Contents at all Sites at Three Different Times. Field Capacity is also included.

	% Moisture			
Site Age (-1 year for Dec. '82 samples)	Dec.'82 n = 5	March '83 n = 3	Oct.'83 n = 2	Field Capacity n = 2
0 (Quest)	-	-	24.6	-
5	17.1	25.2	22.4	25.6
7	15.6	21.3+	17.1	21.1
11	18.7	26.3	17.8	26.4
14	15.7	25.0+	18.5	23.7
17	17.9	21.5	19.2	26.0
21	16.7	28.9	23.2	30.4
28	7.1	26.5	21.1	28.8
32	17.1	29.9+	19.4	27.1
34 (Bletchley)	-	-	19.5	25.4
37	18.2	28.6	22.4	29.9
37 (Bletchley)	-	-	23.1	26.1
41	21.7	31.9	25.4	33.5
45	16.0	27.5	31.7+	31.7
61	24.9	38.2	23.6	31.8
87	23.9	33.3	37.7	38.1
93	14.8	34.8+	24.9	30.6

+ indicates levels at or above field capacity.

Table 5.3. General Characteristics of the Soil in Coronation Pit[56].

Age (Yrs.)	0	5	10	15	20	25	30
Soil Structure+	P	P/C	C/D	D/S	S	D	D
Rooting Depth (cm) 1. Max. Depth	3	20	8	60	40	40	40
Horizon Features (cm) 1. Thickness of L-F-H Layers	0	5	0	5	3	1	2
2. Thickness of 'A' Horizon	0	20	30	30	30	30	30
3. Calcareous concretions. 1. Depth	-	-	5	5	3	-	-
2. Thickness	-	-	5-6	5-6	4-5	-	-
Water Stable Aggregates (% weight of sample)	0	0	12	28.3	31.5	27.1	25.4

+ P = Primary Flakes
C = Fine Compact Clay
D = Clay with Structure Developing
S = Broken by Worm Casts, with Aggregates noticeable.

The percentage of water stable aggregates corresponded closely to the observed distribution of earthworms.

Brown stated that all these factors pointed to a general development of a true "soil" towards the twenty year period, and then a partial degeneration after this point, but offered no explanation for this.

5.19. Discussion

The moisture content of the callow was measured in December 1982, March 1983 and October 1983. In March and October 1983 the moisture content was significantly correlated with age; percentage moisture increasing with increasing age. Results were higher in March 1983 and October 1983 than in December 1982. These results are summarised in Table 5.2 for easy comparison. Also included in this table, is a listing of mean field capacity levels. The average results which exceed field capacity are marked with an asterisk. It can be seen that none of the mean December '82 results had reached or exceeded field capacity, five of the March '83 results had, and one of the October '83 results had. However, the majority of March results are very close to the levels required for field capacity to be attained. On those sites where field capacity had been exceeded, water logging would have taken place.

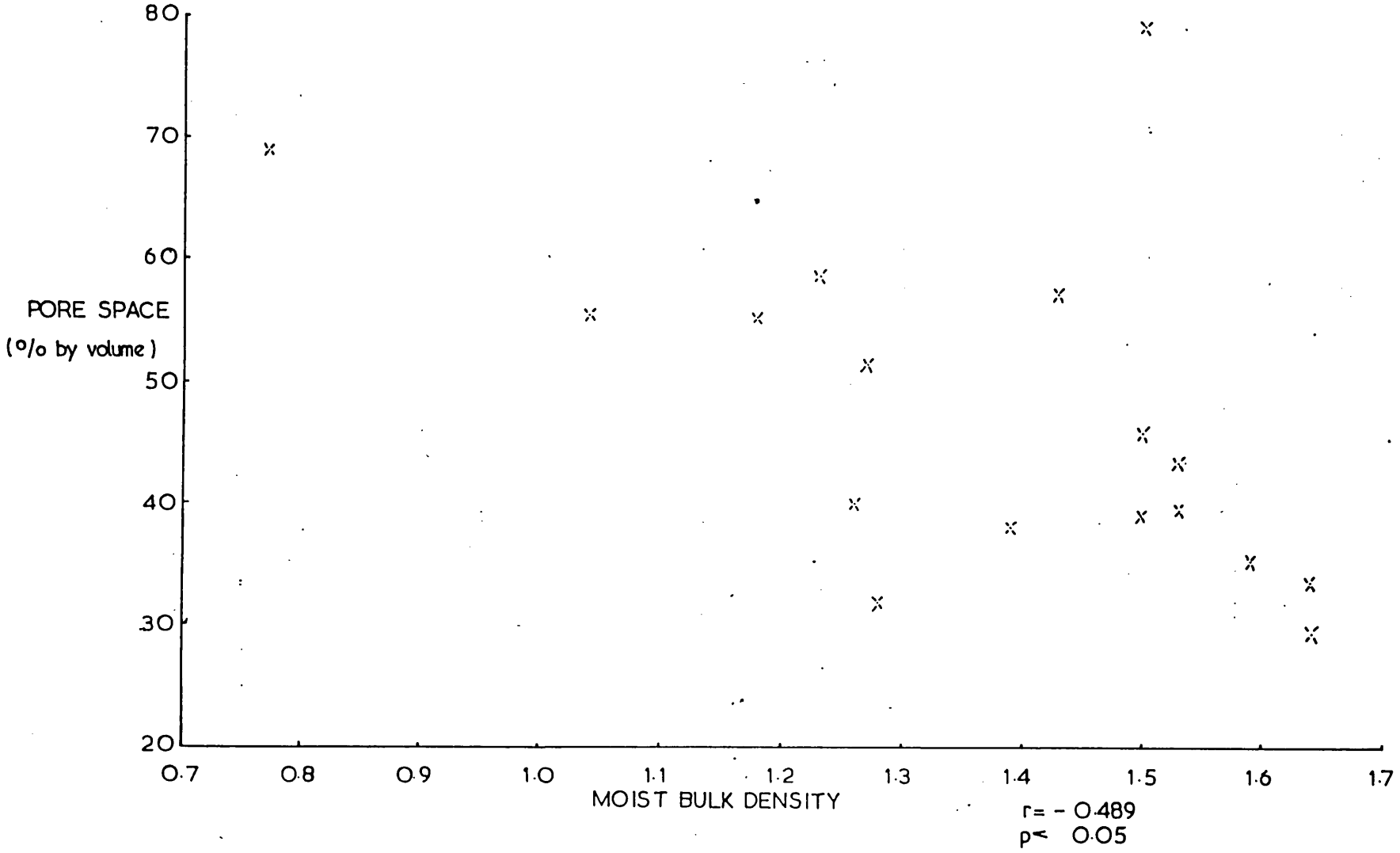
The increase in moisture content with age can be linked to several other measured variables, including pore space and bulk density. (Pore space increases with age up to sixty years and bulk density decreases with age). These factors could be caused by increased aeration of the callow by earthworms and other macro and microfauna. Also the incorporation of humus into the callow would increase the moisture retention capacity and associated variables.

Although pore space is not correlated with age over the whole age series, by excluding Ickwell and Box End Kempston (the last two points on the graph), the relationship shows a positive correlative. Therefore there must be some factor operating at these two sites which distorts the relationship between porosity and age. The bulk density results decrease with age, as would be expected with an increase in pore space. However, the two oldest sites have higher bulk densities than would be expected from a theoretical straight line relationship, but they do not distort the results sufficiently to cause the correlation coefficient to become "not significant".

Packing densities are in the mid to low range. These are perhaps lower than would be expected from a solid raw overburden such as callow.
The relationship between bulk density and pore space is plotted in Figure 5.26. The relationship is a negative one; pore space decreases with increasing bulk density. The correlation coefficient $r = -0.48$, $p\ 0.05$. That is, the relationship is significant at the five per cent probability level.

The pH of callow fluctuates between 7.0 and 8.3 in a 2:1 soil:distilled water ratio and between 7.4 and 6.0 in a 2:1 soil: calcium chloride solution. Thus the callow is a basic, calcareous material of high pH. (Its lime requirement in growth trials is zero[24]).
As a soil solution becomes more dilute, the pH of an acid soil would rise. This is because in soils the concentration of H^+ or Al^{3+} is greatest nearer the negatively charged soil colloids and a gradient exists from that particle into the solution. Therefore the thicker the paste into which the electrode is placed, the more intimate the contact of the electrode with the compressed acidity surrounding the colloidal particles, and the lower the pH value. As more water is added, the ion layer would become more and more diffuse, until the electrode measures the pH of the liquid phase of the suspension.

FIGURE 5.26 THE RELATIONSHIP BETWEEN BULK DENSITY AND PORE SPACE



Usually, as the salt concentration of a soil increases, the measured pH decreases. This is apparent when comparing the distilled water and the calcium chloride pH results. The cations of the chloride solution undergo cation exchange with the exchange acidity in the soil to release acid into the soil solution.

The pH result at Box End Kempston is considerably lower than the others in both solutions. This could be caused by the continually wet, near saturation levels experienced at this site, causing the clay to become anaerobic and therefore giving rise to a decreased pH level. However, on inspection of the mean moisture levels the only time the callow at Box End exceeded field capacity was during the March 1983 analysis, after a very wet autumn and winter. Several other sites also experienced a moisture content beyond field capacity at this time.

Other possible reasons are:-

i An inherent difference in the callow at this site.

ii A difference caused by treatment during digging or dumping. The callow heaps left here were uneven mounds and hillocks with no overall pattern. Certainly Box End was more overgrown than the other sites.

The mean cation exchange capacities fluctuate between 11.2 and 21.8 meq. $100g.^{-1}$ soil, with the majority of sites having results between 12 and 17 meq. $100g.^{-1}$ soil.

Although these results are not high, they are considerably higher than some soils e.g. Podzols as these will have lost a lot of ions from their upper surface due to leaching and thus will have a lower capacity to absorb ions. The capacity of a soil to absorb and hold cations and to exchange species of these ions, in reversible chemical reactions is a quality for both soil fertility - nutrition studies and for soil genesis.

Thus this type of data is widely used in soil classification considerations.

Among the factors contributing to differing cation exchange capacities are:-

i Variations may depend upon the pH at which the determination was made, due to differing reactivity of the various exchanges in the soil systems - clay minerals, hydrous oxides, amorphous compounds and organic material.

ii Variations in results with chemical composition of the exchanging or displacing solution used.

Certain species of ions are more readily displaced or exchanged than others.

Some uses, inferences and interpretations from cation exchange capacities include:-

i Inferences as to clay mineral species present in the soil. Clay minerals have been determined to have the following ranges in cation exchange capacities (in meq. $100g.^{-1}$ soil), as measured by the ammonium acetate pH7 method:-

Kaolinite	3-15
Smectite group	80-150
Illite	10-40
Vermiculite	100-150
Chlorite	10-40

ii Relative degrees of weathering of the soil. Low cation exchange capacities are correlated with disappearance or absence of primary weatherable minerals and accumulation of secondary clay minerals of low cation exchange capacities as a result of the weathering process. High cation exchange capacities are associated with less weathered soils with primary weatherable materials as a plant nutrient reserve. An arbitary breaking point between high and low levels is 10 meq. $100g.^{-1}$ soil.

iii Agronomic and forest nutrient significance. High cation exchange capacities of mineral salts indicate a high plant nutrient storage capacity.

iv Engineering practise. Mineral soils (low in organic matter) with very high cation exchange capacities (greater than 20-25 meq.100g.$^{-1}$ soil) are likely to contain significant amounts of montmorillonite with associated high shrinkage swell potential and high linear extensibility.

From these facts it can be concluded that there is probably a proportion of kaolin, illite and chlorite in the callow. As already seen (Section 2.3) Illite is abundant, Kaolinite is subsidiary and chlorite is present in trace amounts.

It would be expected that low cation exchange capacities would increase as the humus and nitrogen content increases. However, this is not the case; there is no relationship between cation exchange capacities and age of the callow. However, the humus and nitrogen content of the callow increase with age. This must mean that there is a high degree of weathering in the callow once it is exposed. Primary weatherable minerals therefore disappear through leaching and these may be replaced by secondary clay minerals of low cation exchange capacities.

However, the capacities present in the callow indicate a high plant nutrient storage capacity.

The loss on ignition results are highly correlated with age. Results increase with increasing age. This is due to the increase in humus in the callow, which was evident on examination of the different cores. The high levels at Upper Dean Pit are possibly due to the fact that the area was covered in hawthorn scrub which would give a high humus content. Also there was a vast quantity of plant material in the callow here including decayed and part-decayed leaves, twigs, roots and branches which would increase the loss on ignition values. The percentage loss on ignition is seen to double every thirty to fifty years.

If Jacksons' equation[74] is used to convert loss on ignition results to total nitrogen content, the results are as shown in Table 5.4. If a comparison is made between estimated nitrogen values and actual nitrogen values, as in Table 5.4., it is seen that there is a high correlation between the two sets of data, the estimated nitrogen values being slightly higher than actual values in all cases except at Ickwell Clay Pit (eighty seven years) and the forty year old site in Coronation. From these results, it is evident that a fairly accurate indication of nitrogen content in the callow can be gained from loss on ignition results. The latter are easier, quicker and do not require so much specialised equipment. A paired Students' t-test was carried out on the two sets of results to see if they varied statistically. The resulting t value = 1.583, p = 0.13 i.e. there is no difference between the two sets of data as this result is not significant.

The levels of nitrogen found in the callow are exceptionally high for an overburden material. It must be remembered that a high proportion of this nitrogen is not 'plant available'; it is the organic fraction of the clay that plays an important part in the brick making process using the lower knotts. It is caused by the high level of fossilised material in the clay.

Although the total nitrogen in the soil may appear adequate, only a fraction of the total is available to the plant. The bulk is tied up in proteins in various stages of degradation. As nitrate is generally released it is absorbed and utilized by the plant. As long as plant materials are not removed, the amount available is usually balanced by the nitrogen utilised and no acute deficiencies arise. However, the net nitrogen supply might be low and limit growth even in an apparent healthy community.

Growth in a natural community is often limited by nitrogen, and an addition would greatly accelerate growth. However, the resulting lush plants would be highly sensitive to moisture and heat stress and at risk from insect and fungus pathogens[90].

The results from the conductivity and saline tests show that the salt levels in callow decrease with age, probably caused by leaching of the material during the weathering process. Conductivity is also shown to decrease with age; most of the callow samples having mean values below 2.0 meq. ions. $litre^{-1}$ solution which means that the salinity effect is negligible - this may however indicate a nutrient deficiency[3].

Sodium content also decreases with age. Average sodium levels decrease from 57 mg. $Na.100g^{-1}$ to 25 mg. $Na.100g^{-1}$. The zero aged site at Brogborough had a lower mean value than would be expected from the trend, probably because the callow had been left fallow for some time after it was installed as a cap on the landfill site. Results seem to level off at about 25 mg. $Na.100g^{-1}$ after sixty years.

The magnesium content also decreases with age, until after forty four years of age and then it begins to increase again. The reasons for this are unclear.

The potassium levels increase with age up to sixty years in the timescale, thereafter they fluctuate. Potassium is one of the ions attracted to the exchange sites on the clay particles. The levels found in the callow, measured as plant available potassium levels are unlikely to limit growth.

Calcium levels are very high, varying from between 800 and 46 000 mg. $Ca.100g^{-1}$ soil, causing the callow to be a basic, calcareous material. The actual measured levels are likely to be arbitary, but they do show a general trend of decreasing calcium with age, possibly due to leaching of soluble salts through the profile.

Phosphate levels in callow are extraordinarily low. They are so low that they are not detectable by either method. These results are similar to those of London Brick Products Ltd., who have carried out analyses of leachates running through callow[91].

The phosphate results are of great significance when considering the use of callow as a growing medium: unless the phosphate levels in callow are rectified, phosphate deficiency is likely to occur.

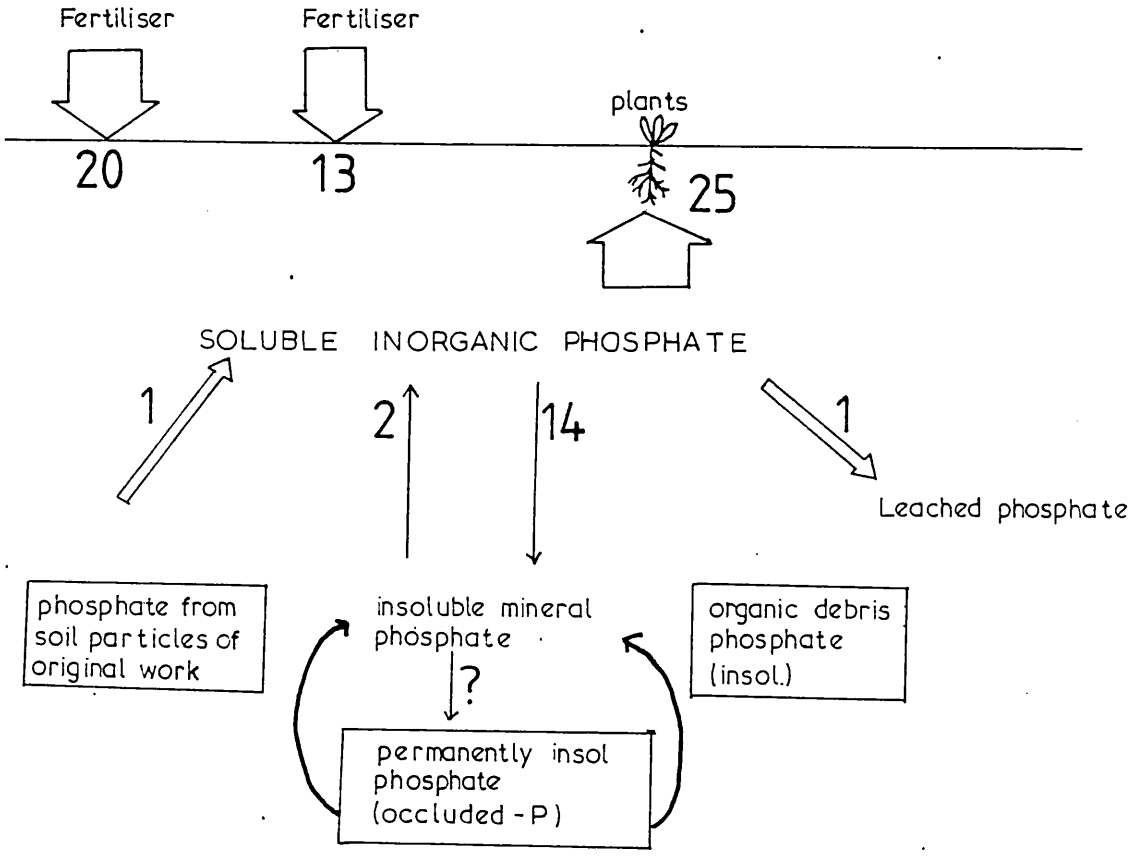
Table 5.4. Average Total Nitrogen Levels Calculated from Loss on Ignition Results and Total Nitrogen Results by Analysis.

Age of site (yrs.)	(L.O.I. x 0.025) Total Nitrogen %	mg. N. $100g^{-1}$ callow	
		Total Nitrogen Calculated	Total Nitrogen By Analysis
0	0.165	1650	1093.8
1	0.135	1350	------
4	0.1375	1375	1042.5
6	0.110	1100	639.0
10	0.115	1150	645.8
16	0.1125	1125	932.5
13	0.15	1500	1133.0
20	0.205	2050	1242.4
27	0.1925	1925	1493.2
31	0.205	2050	1931.1
36	0.19	1900	1709.0
40	0.2225	2225	2868.2
44	0.2425	2425	1685.5
60	0.3500	3500	4734.2
87	0.295	2950	2477.9
93	0.320	3200	2778.6

Treshow[90] states that phosphorus is likely to be deficient in any soils other than those formed from parent materials high in phosphate or those in which phosphate is likely to have accumulated through years of fertilisation. The available phosphate is absorbed by the plant roots and utilised by the plant in large quantities. The amount present in a crop may very from 15 $kg.ha^{-1}$ for apples to 130 $kg.ha^{-1}$ for grapes.

Figure 5.28.

The four phosphate Reservoirs which supply phosphate to water in the soil as it is removed by Plants.



The numbers, refer to an average hectare of British soil, show a net loss to plants of 5kg. ha^{-1}. $year^{-1}$, after allowing for the return of most plant phosphorus as manure or compost. The deficit is made good by the addition of 13kg. ha^{-1}. $year^{-1}$ of inorganic fertiliser phosphate, a surplus of 8 kg.ha^{-1} year which ends up in the occluded compartment[90].

An understanding of phosphate sources in soils would be of use here:- the water in the soil is a very dilute solution of inorganic phosphate at a concentration of less than one part per million. This phosphate represents enough only for three days supply to growing plants. The rest is held in "phosphate reservoirs" which supply more phosphate to the water as it is removed by plants. There are four types of reservoir, the mineral phosphate of the parent rock; precipitated metal phosphates, chiefly calcium but also iron and aluminium phosphates; organic phosphates, also precipitated as metal salts; and adsorbed phosphate, that is, phosphate held to grains of soil by chemical interaction with metals on the surface of the grain[92]. This is shown in Figure 5.28.

One of the benefits that a clay soil possesses which is not apparent in a sandy soil, is the capacity to hold plant nutrients on the surface of the particles. The loss of nutrients by leaching in a clay soil is lower than that experienced in a sandy soil.

Clay particles hold much more water than sand particles, largely because they have a high surface area to be covered in water. An amount of water that may cause leaching in a sandy soil might not wet a clay soil deep enough to cause leaching. Dissolved nutrients become lost from the clay soil only when water penetrates beyond the reach of plant roots and becomes drainage water.

Soils containing too much clay may have high water holding capacities but inadequate aeration. A high content of organic matter is as helpful for overcoming the problem of too much water in a clay soil as it is for the problem of too little water in a sandy soil. Organic matter helps to hold the clay particles together in clusters that have air space btween them.

The most prevalent problems with clay soils are caused by their stickiness when wet. Also they are slippery when wet and hard when dry so that the

optimal moisture content for working a clay soil is in the mid-range when they are dry enough to lose their stickiness but moist enough to avoid being hard. Even so, ploughing and other tillage operations require considerably more power in clay soils than in sandy or loam soils. Hence the terms "heavy" for clay soils and "light" for sandy soils.

6. NATURAL VEGETATION ANALYSIS

6.1. Objectives of the Vegetational Survey

i To establish the relationship between the environmental factors and succession.

ii To assist in establishing any underlying causes of plant succession on the callow.

iii To establish the relationships between the various species in the successional series.

iv To determine whether species composition is dependent wholly upon age of the callow, or whether other, measurable or unmeasurable environmental factors not related to age play an important role.

v To determine whether it would be possible to immitate the environmental changes responsible for bringing about natural change, in an artificial environment.

vi Not all naturally occuring species are of use in reclamation schemes. Thus the species that are likely to be of importance should be identified and the environmental factors responsible for their occurrence should be extrapolated.

vii However, succession is caused by a variety of environmental factors all acting simultaneously. These variables are not necessarily discrete entities but may act in an additive or synergistic manner.

viii The presence of one species may be dependent upon the presence of another species - this should be investigated if possible. For example, if species number 93 occurs in sites of fifteen years of age onwards, imitating the environmental conditions that are measurable at that site does not necessarily ensure that species 93 can be established artificially. Ecological systems are far more complex than that. It is not just the measurable environmental factors that are important but also the entire microhabitat and

microclimate found at that species position in a natural community which would be responsible for its survival.

6.2. Sites Used in the Vegetation Study

The sites are described in detail in Chapter 4. They are as follows:- Rookery Pit, Coronation Pit, Upper Dean Clay Pit, Ickwell Clay Pit, Box End Kempston Clay Pit and Brook Farm Pit in Bedfordshire and the two Bletchley sites in Buckinghamshire.

The age series of the vegetation survey is shown in Table 6.1. The ages are not necessarily the same as those in Chapter 5 as the vegetation survey was carried out over two growing seasons.

Some points of interest here include aspect and location. The sites in Rookery were of variable aspect. The one year old site was facing west (situated at the end of the fault). Dumping of callow re-started at this site on the opening of the Quest Pit callowing operation in 1982. The three year old site in Rookery was the only one on the south side of the fault, facing south. The four and six year old sites in Rookery were facing north. The ten year old site was facing west and the sixteen year old site was facing south in Rookery North.

In Coronation Pit the ridges were orientated in an east-west direction, thus both north and south aspects of all the ridges were included in the random sampling study. The flooded areas either side of the ridges were not used.

The sloping banks of Brickfields Site I at Bletchley were both used. They were orientated in a north-easterly - south-westerly direction. The aspects of the randomly located quadrats were recorded.

Brickfields Site II at Bletchley was facing south in most parts, but the top of the plateau was fairly flat, undulating in places.

Table 6.1. The Age Series of the Vegetation Survey

Site No.	Age of Site (Years)	Name of Site
1	1	Rookery
2	3	Rookery
3	4	Rookery
4	6	Rookery
5	10	Rookery
7	14	Coronation
6	16	Rookery
8	21	Coronation
9	28	Coronation
10	32	Coronation
14	33	Bletchley
11	36	Coronation
15	37	Bletchley
12	41	Coronation
13	45	Coronation
16	61	Upper Dean
17	88	Ickwell
18	94	Box End Kempston
19	97	Brook Farm

6.3. Background to Vegetation Survey Methods.

An introduction to classical ecological concepts is necessary at this point.

The question arises whether any natural classification of plant communities is possible, and if so, how it may be achieved? For example, are plant communities more than abstractions made by ecologists from vegetation, the variation of which is continuous in space and perhaps time? This leads to the question of whether communities may be classified[93].

There is the view that there are no discontinuities in natural vegetation except where there are discontinuities in the physical environment, as at the junction between the outcrops of different geological strata. This view, of a continuum of vegetation implicit in the outlook of many ecologists was stated by Gleason[94] and has been developed more recently by Curtis and his associates[95,96,97] who have applied it to the description of vegetation and correlation with environmental gradients and by Whittaker[98].

At the other extreme there is the view of the community as an organism (Clements)[99] and as a quasi-organism (Tansley)[100] postulating that the individuals and species within a community so interact as to increase one anothers potentiality of survival. This concept implies sharply defined boundaries between one community and another. If communities do have sharply defined boundaries it follows that they must have some degree of reality as units.

Rejection of the organismal concept of the community does not necessarily exclude the existance of separate communities as units, apart from effects of environmental discontinuities.

Communities might be clearly distinguished in the field, but the communities so distinguished might form a continuum not susceptible to classification except by drawing arbitary boundaries[93].

6.4. Introduction to Ordination.

The continuum theory of vegetation postulates that a hypothetical species response to an environmental factor would be a bell-shaped (Gaussian) curve. In reality this is not the case. The curve will often be skew rather than Gaussian shaped. A hypothetic example of a vegetation continuum is shown in figure 6.1.

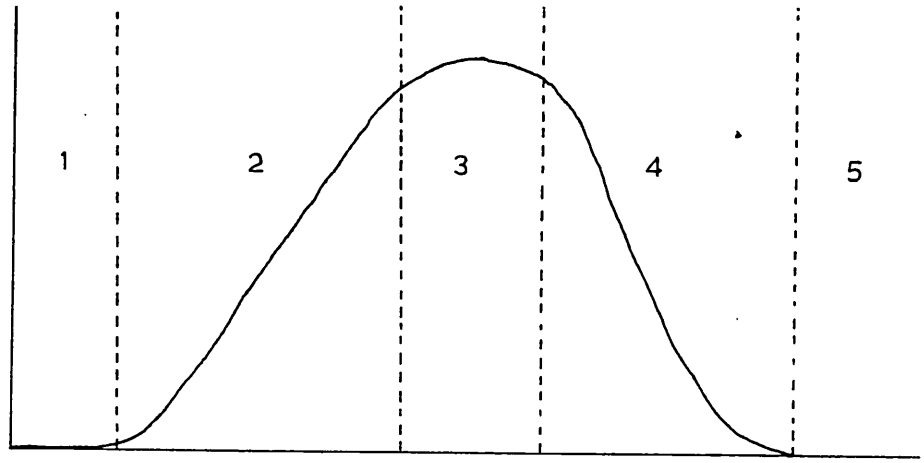
By extending this theory to a group of species it will be noticed that most species have different optima and the amplitude of many species overlap to give a continuous variation along the axis being measured, e.g. there will be a vegetational or floristic gradient with respect to the environment.

Many methods of ordination assume linear curves along environmental gradients. However, most research workers have shown that gradients are not linear; but are between linear and curvilinear. In rare cases it is possible to examine the parts of the continuum in the field, e.g. altitude up a mountain, succession along a time series, or a hydrosere out of a pond margin. More often there is a mosaic of the different parts of the continuum. This is because normally vegetation is responding simultaneously to more than one environmental factor, e.g. water content and nutrient levels. Thus the environment should be regarded as a multidimensional mosaic.

Techniques which pick out the continua from data collected and by placing the samples and the stands in a particular order which best reveals the underlying continua are called ordination techniques.

A definition of ordination is "A graphical arrangement of stands or species in relation to axes which represent gradients or unknown environmental factors. The term gradient analysis is the same as ordination"[101].

Figure 6.1. Continuum Concept of Vegetation



1. Intolerance, level too low for survival e.g. nutrient deficiency.
2. Limitation by shortage, more or less linear relationship.
3. Optimum intensity, some other factor may limit growth.
4. Limitation by overabundance, more or less linear relationship.
5. Intolerance, level too high e.g. toxicity effect.

The two types of ordination are:-

i Direct Gradient Analysis.

This is the response of vegetation to a known environmental factor.

ii Indirect Gradient Analysis.

This is when the environmental gradients are unknown and the object is to identify them.

Both of these methods are concerned with exploring relationships between environmental gradients and species.

i Direct Gradient Analysis - ordination based on some evident and apparently important physical gradient. Whittaker called this Gradient Analysis[102]. The method takes some well-marked gradient - for example altitude in the Great Smoky Mountains and assigns scores to the species according to their altitudinal preferences. Sites are then ordinated by taking averages of the scores of the species which occur in them. The great advantage with this method is that there is never any difficulty with interpretation. The site score is roughly an index of altitude, or water relations or some other well-understood physical variable[103]. This method, however, has a subjective element in that the outcome of the weighting has an effect on the outcome of the analysis. Thus it is possible to distort the values so much that a continuum is established where one does not exist.

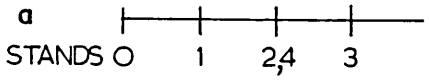
ii Indirect Gradient Analysis is used when the environmental factors are not known. The methods are objective as the stands are arranged by mathematical optimization methods using "best fit" equations. The end results are correlated with environmental factors. The order reflects the best fit of stands along environmental gradients. A simplified method is given below:-

Assume a survey of vegetation cover has been carried out in four stands, each showing the same three species. The species are given objective values of cover between 0 and 3. The geometric structure of the data is shown below.

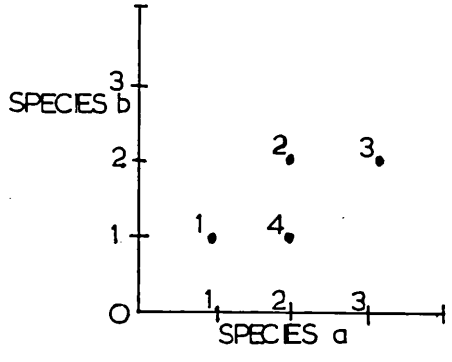
Geometric Structure of Data.

SPECIES \ STAND	1	2	3	4
a	1	2	3	2
b	1	2	2	1
c	2	1	1	3

In order to represent the st ands in species space an axis is drawn for species a.

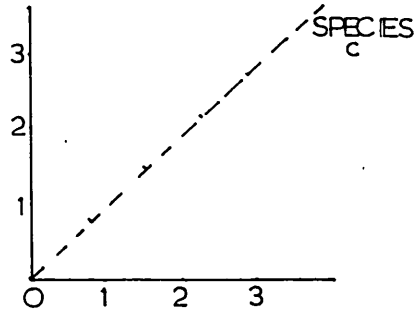


If this is expanded to a two dimensional space a representation of stands becomes:-



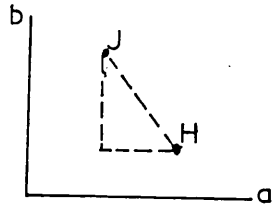
It is apparent that stands which are the most different lie further apart. St ands which are floristically similar lie close together.

In order to extend the series to include three species, a third axis is included as follows:-



A fourth species cannot be plotted in a fourth dimension so a different approach has to be used.

In order to estimate interstand distance in a three dimensional example the shortest distance "as the crow flies" is measured between all possible pairs of stands. Such distance is called Euclidean distance.



In order to estimate the distances between stand J and stand H in the above example the hypotenuse can be calculated. In multidimensional space this can be formulated as follows:-

$$Djh = \sqrt{\sum_{i=1}^{m} (xij - xih)^2}$$

Where:-

Djh = Euclidian distance between stands j and h

xij = Abundance of species i in quadrat j

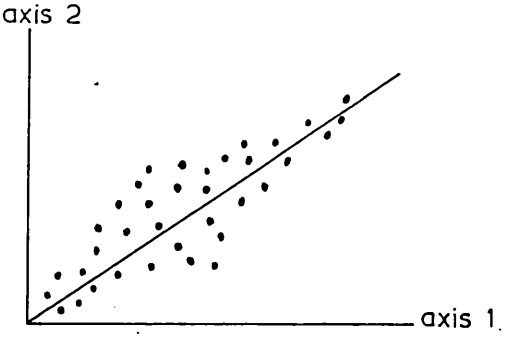
xih = Abundance of species i in quadrat h

A distance chart can be formulated:-

STANDS	1	2	3	4
1	0	1·73	2·45	1·41
2		0	1·00	2·24
3			0	2·45
4				0

Using these distances a stand constellation diagram can be constructed.

If stands come from homogenous data and a marked gradient is apparent in the plotted stand diagram, usually an ellipse or hyperellipsoid is obtained as follows:-



This shows stands are ordered along a hypothetical factor, along theoretical axes.

Many models developed have assumed euclidean distance is equal to:-

$D = 1 - C^{104}$

Where

D = Euclidean distance

$C = \frac{2W}{A + b}$

Where c = coefficient between any two stands (Sörenson coefficient)

W = sum of lesser values when the stands are compared.

A = Sum of abundance values in first stand.

b = Sum of abundance values in second stand.

However, Gittins[105] has found that 1 - C is not a measure of euclidean distance between two stands and its use distorts ordination.

Orloci[106] suggested the use of Pythagorus' theorem to find final positions of stands.

Principal components analysis is a method of ordination developed early in the century, but it has only been widely used since computers became available. The method takes point scatter in an abstract way and plots the axes in a way to account for variance. The orientation of the axes is arranged so that the sums of the squares are minimized. Principal components analysis has been used by many ecologists. For example Goldsmith[107] studied the salt gradient in a sea cliff vegetation in Anglesey.

However, all the methods mentioned so far assume a linearity of data, whereas in reality species exhibit gaussian or shewed characteristics.

A method of ordination which does not assume linearity is Reciprocal Averaging[103]. This is closely allied to direct gradient analysis and is a variety of principle components analysis.

An example of reciprocal averaging ordination is shown below. In reality, due to the large amounts of data involved, all calculations are carried out by computer.

An example of Reciprocal Averaging Ordination.

1. Data matrix.

	STANDS 1	2	3	4
a	100	6	0	15
SPECIES b	30	74	1	0
c	62	3	1	5
d	3	11	83	1

Values indicate percentage cover.

2. Species weightings are allocated. These can be random values. By convention these are scaled so that the smallest is 0 and the largest is 100. Values used here are:-

A = 100

B = 50

C = 100

D = 0

The computer assigns weightings at random.

3. Weighted averages are obtained by multiplying each species at each site by its weighting and then doing a sumation for each stand.

Stand 1 = 90.77

Stand 2 = 48.94

3 = 17.65

4 = 95.24

4. An improved species weighting is obtained by the reciprocal process using stand weightings.

i.e. Species A = $\frac{(100 \times 90.77) + (6 \times 48.94) + (0 \times 17.65) + (15 \times 95.24)}{(100 + 6 + 0 + 15)}$

= 89.25

The new weightings are rescaled so that the smallest is 0 and the largest is 100.

Thus A = 100

B = 55.95

C = 98.52

D = 0

5. The processes (3 + 4) are repeated until, in two successive iterations, the rescaled values of species weights are unchanged. In the above example the final species weights would be approximately:-

A = 100

B = 73

C = 98.5

D = 0

And the stands would be

Stand 1 = 93

2 = 62

3 = 2

4 = 95

6. It is worthwhile recording the species and stands in the data matrix to correspond with the above ranking. The data matrix is ordered below to show the major floristic gradient (axis 1).

	STANDS			
	4	1	2	3
a	15	100	6	0
SPECIES b	5	62	3	1
c	0	30	74	1
d	1	3	11	83

The species scores form a series of overlapping, gaussian shaped curves whose peaks lie on the leading diagonal. Exceptional values (e.g. Stand 1, Species A) indicate the existence of other gradients in the data, a second axis might account for these[101].

The process is named "reciprocal averaging" because the species scores are averages of the stand scores and reciprocally the stand scores are averages of the species scores[103].

6.5. Methods of Random Sampling.

The chosen methods of random sampling of the vegetation had to conform to several requirements.

i The method chosen had to give a sample at each site that was suitable for statistical analysis. Thus the sampling programme had to be as random as possible.

ii The method had to be free from bias.

iii The method had to be easy to use and to replicate at each site, so that each sample set was comparable with the others.

iv The method had to allow for problems of site and habitat variety.

The sampling program carried out had to satisfy both the scientific and statistical requirements as well as being practical in the given circumstances. After consideration the following method was applied.

A double sampling method was used, using both square and point quadrats. The square quadrats had sides 0.5M x 0.5M and the point quadrat used was an elongated pin. However, the use of a pin of finite diameter gives a value of cover greater than the true value because plants are touched that would not make contact with the axis of the pin[93].

Cover was recorded on the presence of an aerial part, rather than rooted part; hence "shoot frequency" and not "root frequency" was used.

The method of random sampling was the same as used in the 1980 survey[24].

At each site, where practical, a survey line was made at right angles to the pit wall, preferably in the centre of the callow mound or ridge. The survey line served as a permanent reference transact. Sampling sites were determined with pairs of random numbers, the first pair denoting distance from the transect origin (in metres), the second pair, the distance at right angles away from the transect (in metres). The direction of the latter depended upon whether the random number was above or below the median. Thus numbers from 00 to 49 would give a random point to the right of the tape and those from 50 to 99 would be to the left.

At each randomly located sampling site, the square quadrat was placed so that its south-west corner was at the intercept of the X and Y axes. In this manner a sample of vegetation was obtained which was considered to be randomly selected. At some sites, however, it was not possible to be truly random due to the size and nature of the sites. If it was found to be impossible to use this random-number sampling method, then an "over-the-shoulder" technique was operated.

The square quadrat data was collected in the form of presence/absence of species. All species of vascular plants were recorded within the randomly located quadrats. No attempt was made to identify the micro-species of Heiracium (except Heiracium pilosella). Liverworts, bryophytes and lichens were not identified.

The point quadrats were placed on the four corner points of each square quadrat, so that an estimate of percentage cover at each site could be made. If more than one species touched a point quadrat, both species were recorded. In recording hits made by point quadrats the frequency sampled by quadrats of, theoretically infinitesimallay small size is being recorded. Three comments need to be made:-

i Effect of pin diameter.

ii The practise of using a frame of pins, often ten in a line instead of a single pin.

iii The effect of inclining pins from the vertical.

The sample obtained by the use of a pin is not a point but a circular area of the same radius as the pin. Thus the true percentage cover is exaggerated. The error introduced is not the same for different species but will be greater for species having small or much elongated or dissected leaves than for species with large or more or less isodiametric leaves.

A difficulty arose when the number of contacts per pin was recorded for tussock species. In the centre of the tussock the number of contacts was too large to count.

Single points will give a more accurate estimate than the same number of points in a group. If cover were random or aggregated only in such small units that the reading for one pin was independent of those for pins adjacent to it, this procedure would not seriously affect the accuracy of data thus obtained though even then it may be open to some theoretical objection because of the lack of statistical independence of the observations[93].

The number of randomly located quadrats studied at each site depended on two factors:-

a The size of the area; the sample areas in Rookery were $100M^2$, those in Coronation were considerably smaller.

b The minimum number of quadrats required by plotting species/area curves for each site. Examples of these are shown in the 1980 survey[24], pp 40-41.

It appeared that either 50 or 100 random square quadrats was sufficient for each site. Between 200 and 400 point quadrats were therefore studied at each site.

In Upper Dean, Ickwell and Kempston Clay Pits where a canopy layer existed, in addition to the ground flora, the canopy flora was recorded above each quadrat, but these were not incorporated into the quadrat data.

6.6. Results From Random Vegetation Sampling.

The results are split up into two groups; those from the point quadrat survey and those from the square quadrats survey.

6.6.1. Point Quadrats

The results from the point quadrats analyses are given in table 6.2. The figures given refer to percentage cover. That is, the proportion of ground occupied by perpendicular projection on to it of the aerial parts of individuals of the species under consideration.

Table 6.2. **Point Quadrats Species Lists**
(Figures indicate percentage cover)

Species	AGE AT TIME OF SURVEY (YEARS)																			
	Rookery						Coronation							Bletchley		Others				
	1	3	4	6	10	16	14	21	28	32	37	41	45	33	36	61	88	94	97
1. Achillea millefolium								1			0.5		1.5	10	6				0.5
2. Agrimonia eupatoria															0.5				0.5
3. Agropyron repens		0.3	2.5	2	1.9	2.5	7	0.5											
4. Agrostis canina																	16		
5. Agrostis stolonifera		0.8	11.5	0.8	1	13	28	7.5	4	1.3				2.5		7.5	2		
6. Agrostis tenuis											0.5								
7. Alopecurus geniculatus	0.3																		
8. Alopecurus myosuroides	1.3	3.5																	
9. Anagallis arvensis	0.3	0.5																	
10. Arenaria leptoclados														1.3	0.5				
11. Arrhenatherum elatius			1		1	74		32	30	38	23	23	48	3	12				61
12. Atriplex hastata	0.3																	0.5	
13. Brachypodium sylvaticium															2.5				
14. Bromus ramosus														0.8			0.5		
15. Carex flacca														0.3	1				
16. Carex obtrubae																	0.5		
17. Centaurea nigra															1.5				8
18. Centaurea scabiosa																			0.5
19. Cerastium arvense		0.3																	
20. Cerastium holostoides	0.3	0.3																	
21. Chrysanthemum leucanthemum							0.5	0.5	1.7	1	0.3		2	1					
22. Cirsium acaulon															0.5				
23. Cirsium arvense		35	3	48		0.5	2.5	1.5		1.7		0.7	3.5	0.5			2		2.5

Species	Rookery						Coronation							Bletchley		Others			
	1	3	4	6	10	16	14	21	28	32	37	41	45	33	36	61	88	94	97
24. Cirsium vulgare		0.8	0.5	0.3					0.5										
25. Conium maculatum																0.5	0.5		
26. Convulvulus arvense						0.5		0.5		0.7	0.5	2.3	45						
27. Crataegus monogyna										0.3	0.5	0.3	0.5	2.5	3.5				
28. Crepis sp.														0.3					
29. Crepis vesicaria ssp. taraxifolia				0.3	0.5				1.0	0.7	1.5								
30. Dactylis glomerata						5.1	4.5		1.0	4.3	6	3	1.5	4	1		0.5		15
31. Dactylorchis fuchsii								0.5											
32. Daucus carota								1	3.5	11.3	9	4.7	7	4	1				
33. Deschampsia cespitosa							2							3.5	3.7				
34. Dipsacus fullonum		0.3		0.3				1											
35. Epilobium hirsutum																4			
36. Equisetum arvense														6	8				
37. Erigeron acer														0.5					
38. Festuca sp											1.3								
39. Festuca arundinacea								7	9.5	8.7	24	13	12	0.3					5
40. Festuca rubra										4	23	17	15						21
41. Festuca ovina														15.5	11.5				
42. Festuca pratensis							1												
43. Galium aparine																	1.5		
44. Glechoma hederacea																		1	
45. Heiracium pilosella										0.3		0.5	6	0.3			0.5	30	
46. Heiracium sp.										0.7	3	6.7	3	0.5	1.5				2
47. Heracleum spondyleum									1	3					0.3	2			

Table 6.2. (Continued)

	AGE AT TIME OF SURVEY (YEARS)																							
	Rookery						Coronation							Bletchley		Others								
	1	3	4	6	10	16	14	21	28	32	37	41	45	33	36	61	88	94	97					
48. Holcus lanatus		0.3	3.5	0.3		0.5	0.5	8.5	3	1.7	1	0.3	0.5	0.3	0.3									
49. Hypocheiris radicata											2	0.7												
50. Juncus inflexus						0.5						0.3		1										
51. Lathyrus pratensis										1.3	11				0.5				1.5					
52. Leontodon autumnalis						0.5	0.5		0.5	1				1										
53. Leontodon hispidus						0.5				0.7	0.5	28	7.5	23	8.5				0.5					
54. Lolium perenne			5	0.8					1.5	1.0					0.3									
55. Lotus corniculatus									3	0.7	2	1	11		12									
56. Medicago lupulina			0.5	0.3	0.5	27		0.5		1	0.3	13		1.3										
57. Melilotus officinalis								4	1.5	5.7	5.5	14	3.5						0.5					
58. Mentha aquatica																	1.5							
59. Moss - (variety of spp.)			2	4.8		1.4		1				0.7		0.8		0.5	0.5	27	0.5					
60. Pastinacea sativa														0.3										
61. Phleum bertolonii															1									
62. Phragmites communis																								
63. Picris echioides	0.5	16.5	14	15	7	1	8.5		1.5	0.3														
64. Plantago lanceolata								15	12	12	10.5	7	5.5	4.3	5.5									
65. Plantago major			0.5	0.5	0.5	0.5								0.3		0.5								
66. Poa annua	0.5			1.5	2																			
67. Poa angustifolia									6															
68. Poa pratensis											0.5	0.3							0.5					
69. Poa trivialis			1							0.3						0.5	1.5							
70. Polygonum aviculare	1.8			0.3												0.5								
71. Polygonum sp.																								
72. Potentilla reptans				0.8	0.5									0.5	1				4					
73. Prunella vulgaris				0.5		0.5			0.5					1.8	1									
74. Ranunculus repens							1									1	0.5							
75. Rorippa sylvestris			0.5																					
76. Rosa canina														0.5			1		1					
77. Rubus fruticosus agg.															1.5		2	0.5	22					
78. Rumex crispus														0.8					0.5					
79. Rumex sanguineous																3	3.5							
80. Rumex obtusifolius																1								
81. Rumex sp.																	0.5							
82. Salix alba																0.5								
83. Sambucus nigra														0.3		0.5								
84. Scirpus lacustris				0.3		1.4																		
85. Senecio erucifolius			1		1		1		0.5	1	1	1.3	0.5		1.5									
86. Senecio jacobaea				10	2.5	2.8	3							15	15		0.5							
87. Senecio squalidus										0.3														
88. Solanum dulcamera																0.5								
89. Sonchus asper	0.3	0.3									0.5		1											
90. Stachys sylvatica																	1.5							
91. Stellaria media		0.3																						
92. Trifolium pratense														0.3										
93. Trifolium repens						0.5									1									
94. Tripleurospermum maritimum ssp. indorum	1.3	6			2																			
95. Trisetum flavescens														0.5										
96. Tussilago farfara	1.8	22	34	4	34	28	8	29	31	24	18	14	13	3	2.5									
97. Urtica dioica																3.5	5	7.5	0.5					
98. Vicia sativa ssp. angustifolia								1.5		1.3	5.5		0.5											
99. Vicia cracca									0.5				0.5						0.5					
100. Viola sp.															0.5									

Table 6.3. Point Quadrats Species List - Key

No.	Species	English Name	Family
1	Achillea millefolium	Yarrow	Com
2	Agrimonia eupatoria	Common Agrimony	Ros
3	Agropyron repens	Couch-grass	Gra
4	Agrostis canina	Brown Bent-grass	Gra
5	Agrostis Stolonifera	Fiorin	Gra
6	Agrostis tenuis	Common Bent-grass	Gra
7	Alopecurus geniculatus	Marsh Foxtail	Gra
8	Alopecurus myosuroides	Black Twitch	Gra
9	Anagallis arvensis	Scarlet Pimpernel	Pri
10	Arenaria leptoclados	Lesser Thyme-leaved Sandwort	Car
11	Arrhenatherum elatius	Oat-grass	Gra
12	Atriplex hastata	Hastate Orache	Chen
13	Brachypodium Sylvatium	Slender False-brome	Gra
14	Bromus ramosus	Hairy Brome	Gra
15	Carex flacca	Caranation-grass	Cyp
16	Carex otrubie	False Fox-sedge	Cyp
17	Centaurea nigra	Lesser Knapweed	Com
18	Centaurea scabiosa	Greater Knapweed	Com
19	Cerastium arvense	Field Mouse-ear Chickweed	Car
20	Cerastium holostoides	Common Mouse-ear Chickweed	Car
21	Chrysanthemum leucanthemum	Ox-eye Daisy	Com
22	Cirsium acaulon	Stemless Thistle	Com
23	Cirsium arvense	Creeping Thistle	Com
24	Cirsium vulgare	Spear Thistle	Com
25	Conium maculatum	Hemlock	Umb
26	Vonvulvulus arvense	Bindweed	Con
27	Crataegus monogyna	Hawthorn	Ros
28	Crepis sp.	Hawk's beard	Com
29	Crepis vesicaria ssp. taraxacifolia	Beaked Hawk's-beard	Com
30	Dattylis glomerata	Cock's-foot	Gra
31	Cactylorchis fuchsii	Common Spotted Orchid	Orc

Table 6.3. (continued)

No.	Species	English Name	Family
32	Daucus carota	Wild Carrot	Umb
33	Deschampsia crespitosa	Tufted hair-grass	Gra
34	Dipsacus fullonum	Teasel	Dip
35	Epilobium hirsutum	Great Hairy Willow-herb	On
36	Equisetum arvense	Common Horsetail	Eq
37	Erigeron acer	Blue Fleabane	Com
38	Festuca sp.	Fescue sp.	Gra
39	Festuca arundinacea	Tall Fescue	Gra
40	Festuca rubra	Creeping Fescue	Gra
41	Festuca avina	Sheep's Fescue	Gra
42	Festuca pratensis	Meadow Fescue	Gra
43	Galium aparine	Cleavers	Rub
44	Glechoma hederacea	Ground Ivy	Lab
45	Heiracium pilosella	Mouse-ear Hawkweed	Com
46	Heiracium sp.	Hawkweed	Com
47	Heracleum spontyleum	Hogweed	Umb
48	Holcus lanatus	Yorkshire Fog	Gra
49	Hypocheiris radicata	Cat's Ear	Com
50	Juncus inflexus	Hard-rush	Jun
51	Lathyrus pratensis	Meadow Vetchling	Pop
52	Leontodon autumnalis	Autumnal Hawkbit	Com
53	Leontodon hispidus	Rough Hawkbit	Com
54	Lolium parenne	Perennial Rye-grass	Gra
55	Lotus corniculatus	Birdsfoot-trefoil	Pap
56	Medicago lupulina	Black Medick	Pap
57	Melilotus officinalis	Common Melilot	Pap
58	Mentha aquatica	Water Mint	Lab
59	Moss		
60	Pastinacea sativa	Wild Parsnip	Umb
61	Phleum bertolonii	Cat's-tail	Gra
62	Phragmites communis	Reed	Gra
63	Picris echioides	Bristly Ox-Tongue	Com
64	Plantago lanceolata	Ribwort	Pla
65	Plantago major	Great Plantain	Pla

Table 6.3. (continued)

No.	Species	English Name	Family
66	Poa annua	Annual Poa	Gra
67	Poa angustifolia	Narrow-leaved Meadow Grass	Gra
68	Poa pratensis	Meadow-grass	Gra
69	Poa trivialis	Rough Meadow-grass	Gra
70	Polygonum aviculare agg.	Knotgrass	Pol
71	Polygonum sp.	Knotgrass sp.	Pol
72	Potentilla reptans	Creeping Cinquefoil	Ros
73	Prumella vulgaris	Self-heal	Lab
74	Ranunculus repens	Creeping Buttercup	Ran
75	Rorippa sylvestris	Creeping Yellow-cress	Cru
76	Rosa canina	Dog Rose	Ros
77	Rubus fruticosus agg.	Blackberry	Ros
78	Rumex crispus	Curled Dock	Pol
79	Rumex sunquineous	Red-veined Dock	Pol
80	Rumex obtusifolius	Broad-leaved Dock	Pol
81	Rumex sp.	Dock	Pol
82	Salix alba	White Willow	Sal
83	Sambucus nigra	Elder	Cap
84	Scirpus lacustris	Bulrush	Cyp
85	Senecio erucifolius	Hoary Ragwort	Com
86	Senecio jacobaea	Ragwort	Com
87	Senecio squalidus	Oxford Ragwort	Com
88	Solanum dulcamera	Woody Nightshade	Sol
89	Sonchus asper	Spiny Sow-Thistle	Com
90	Stachys sylvatica	Hedge Woundwort	Lab
91	Stellaria media	Chickweed	Car
92	Trifolium pratense	Red Clover	Pap
93	Trifolium repens	White Clover	Pap
94	Tripleurospermum maritimum ssp. indorum	Scentless Mayweed	Com
95	Trisetum flavescens	Yellow Oat	Gra
96	Tussilago farfara	Coltsfoot	Com
97	Urtica dioica	Stinging Nettle	Urt
98	Vicia sativa ssp. angustifolia	Narrow-leaved Vetch++	Pap
99	Vicia cracca	Tufted Vetch	Pap
100	Viola sp.	Violet sp.	Vio

++ Not in Clapham, Tutin and Warburg but in Keble Martin.

Table 6.4. **Plant Families Key**

Ac.	Aceraceae
Arac.	Araceae
Aral.	Araliaceae
Bor.	Boraginaceae
Cap.	Caprifoliaceae
Car.	Caryophyllaceae
Chen.	Chenopodiaceae
Com.	Compositae
Con.	Convulvulaceae
Cru.	Cruciferae
Cyp.	Cyperaceae
Dip.	Dipsaceae
Dio.	Dioscoreaceae
Eq.	Equisetaceae
Eu.	Euphorbiaceae
Fag.	Fagaceae
Gen.	Gentianaceae
Ger.	Geraniaceae
Gra.	Graminae
Jun.	Juncaceae
Lab.	Labiatae
Ol.	Oleaceae
On.	Onagraceae
Orc.	Orchideae
Pap.	Papilionaceae
Pla.	Plantaginaceae
Pol.	Polygonaceae
Pri.	Primulaceae
Ran.	Ranunculaceae
Res.	Resedaceae
Ros.	Rosaceae
Rub.	Rubiaceae
Sal.	Salicaceae
Scr.	Scrophulariaceae
Sol.	Solanaceae
Urt	Urticaceae
Vio.	Violaceae

The information in Table 6.2. is kept in its site position rather than age position in the first instance. This is because there is an overlap between the last site in Rookery and the first site in Coronation and the two Bletchley sites and the Coronation series.

A listing of the species English Names and families is given in Table 6.3. Some of the more common species showing successional trends are plotted in Figure 6.2. Percentage cover data from the point quadrats is plotted against age at each site. From the diagram it is evident that certain species are common in the pioneer stages of succession on callow, these include Picris echioides (Bristly Ox-tongue) and Tussilago farfara (Coltsfoot). The majority of the grasses; Agropyron repens (Couch-grass), Agrostis stolonifera (Fiorin), Arrhenatherum elatius (Oat-grass), Dactylis glomerata (Cock's-foot), Festuca arundinacea (Tall fescue), and the legumes, Lotus corniculatus (Birdsfoot-trefoil), Melilotus officinalis (Common Melilot) and Medicago lupulina (Black Medick) become important later on in the successional series.

It is interesting to note the break in successional trends at the two Bletchley sites (aged 33 and 36 years). This is evident in Arrhenatherum elatius (Oat-grass), Daucus carota (Wild Carrot), Melilotus officinalis (Common Melilot), Plantago lanceolata (Ribwort) and Tussilago farfara (Coltsfoot). From these observations it must be taken into account that although the sites at Bletchley are developed on the same material, the distance between the Bedfordshire and Buckinghamshire sites and the different seed banks available must create a considerable difference in the development of the flora on callow.

The majority of species disappear at the sixty-one year old site. This seems to be the major break in the series. This is probably due to the different nature of the site, it being a small callow hollow from a worked out pit and not a callow mound, as were the previous sites.

FIGURE 6.2 SUCCESSIONAL TRENDS IN SOME OF THE MORE COMMON SPECIES.

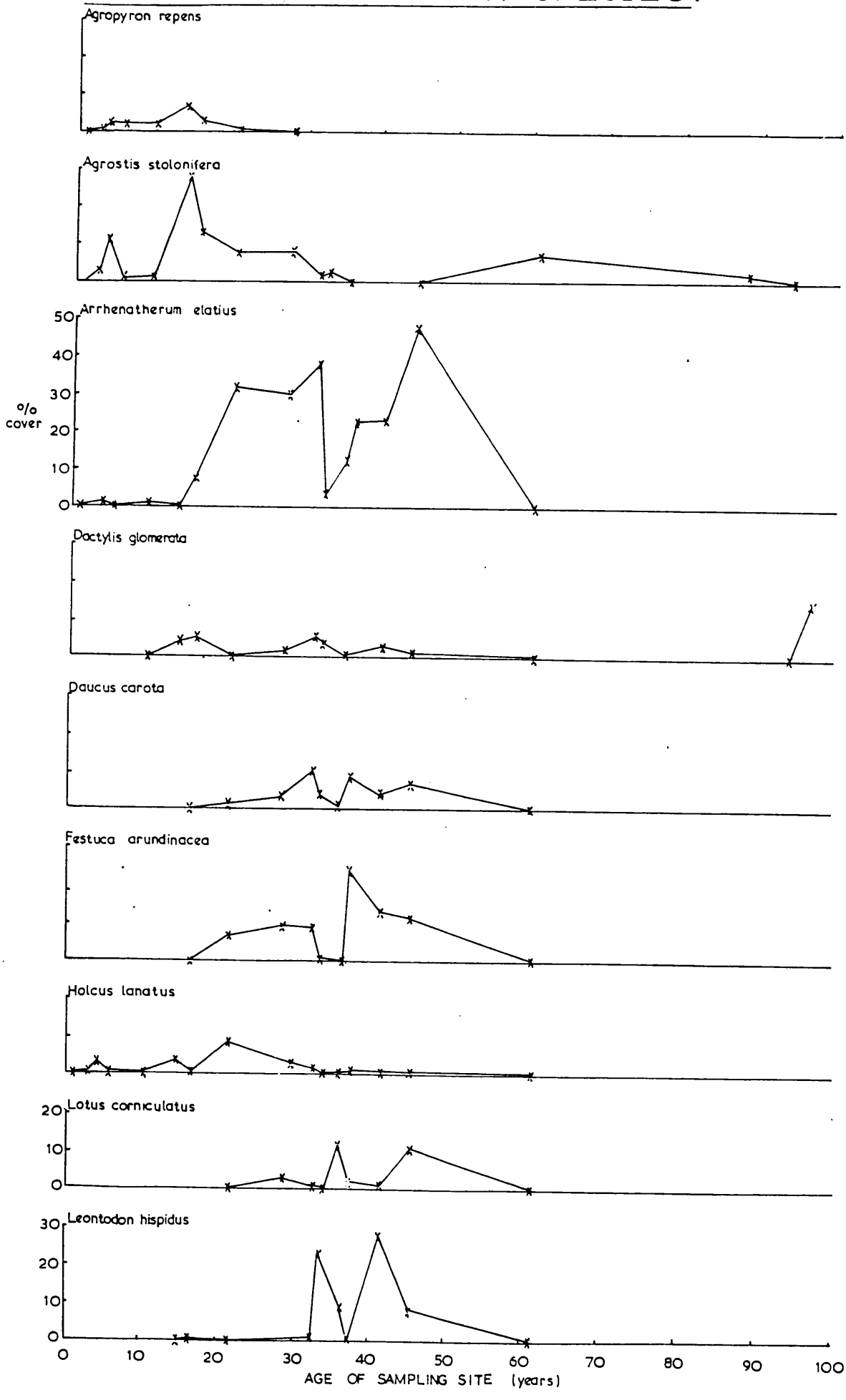
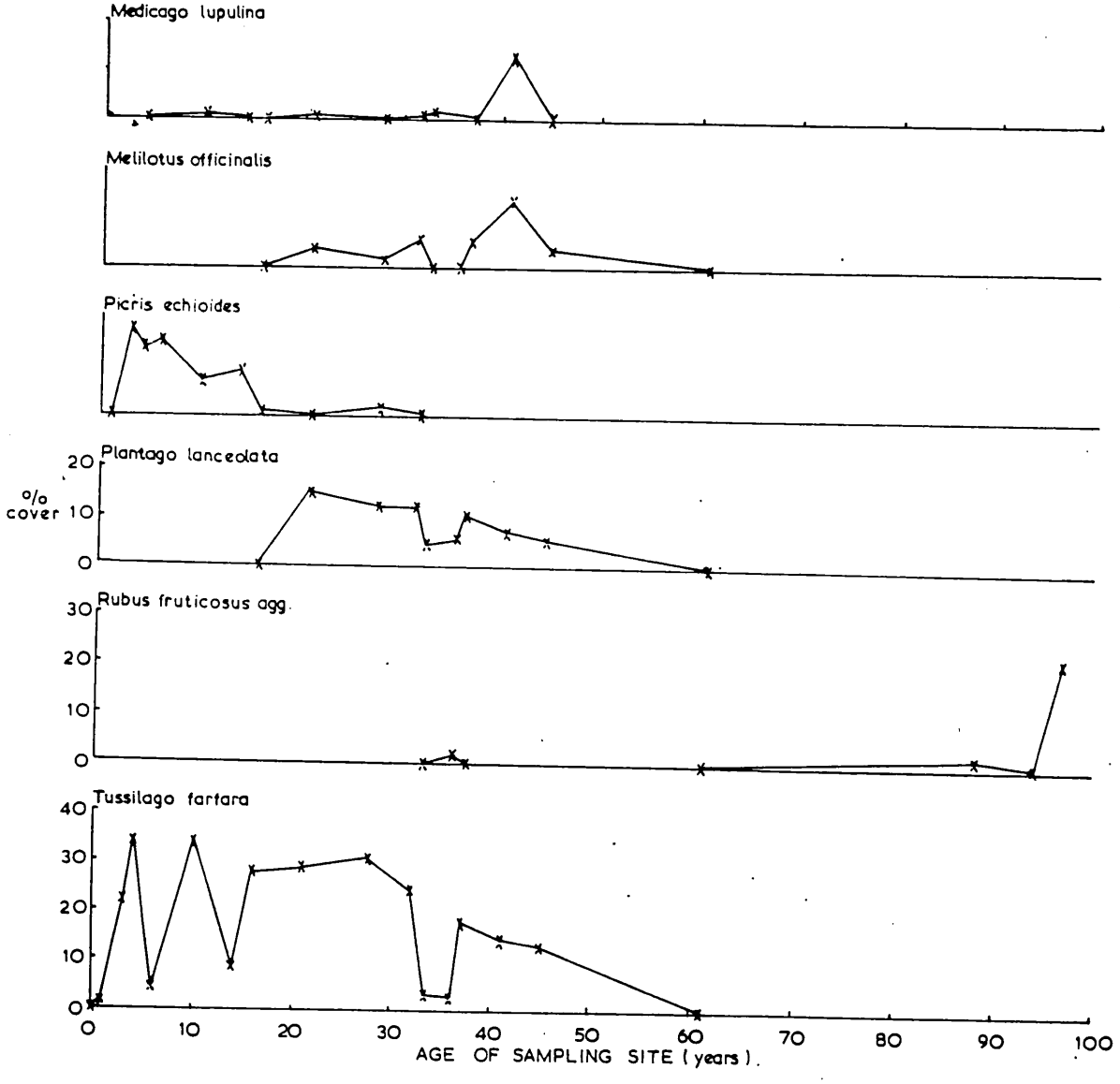


FIGURE 6.2 CONTINUED



Although a variety of species was found at this and the later sites little continuation occurred, apart from Rubus fruticosus agg.(Brambles) which were found at Bletchley and then reappeared in the age series at Upper Dean (sixty one years of age) and increase to a maximum at Brook Farm. Had the age series continued, no doubt the species would have increased in percentage cover.

The results from the point quadrat tables were used in a "reciprocal averaging" analysis; a non-linear method of ordination of vegetation, as described in section 6.4.

The data was set up as a file on the College computer using the operating system Nos. 1. The data was analysed using a package for classification, ordination and pattern analysis. The program used was RECAV from the library called ECOLIB.

Two sets of ordination data are plotted. Stand data are shown in figure 6.3. and species data are shown in Figure 6.4. In each case four axes are extracted; axis one is plotted against axis 2, axis 3 and axis 4. The species diagram key is the same as Table 6.2. Although one hundred species were included in the calculations not all the species could be plotted on the scale given, due to clutter at certain points. When this happened, as large a number as possible were plotted around one point. Wherever possible all species were included in the diagrams.

It is apparent, from the stand ordination diagrams that axis 4 shows the greatest successional trends. From the axis 1 v. axis 4 stand ordination diagram it is noticeable that stands 16, 17 and 18 do not fit into the series; stands 14 and 15 (Bletchley) are displaced upwards slightly - if they fitted exactly into the age/succession series they ought to have been placed between stands 10 and 12. It is interesting to note that although Upper Dean, Ickwell and Box End Kempston do not fit into the series along axis 4, Brook Farm does.

FIGURE 6.3 RECIPROCAL AVERAGING
1. STAND ORDINATION : POINT QUADRATS

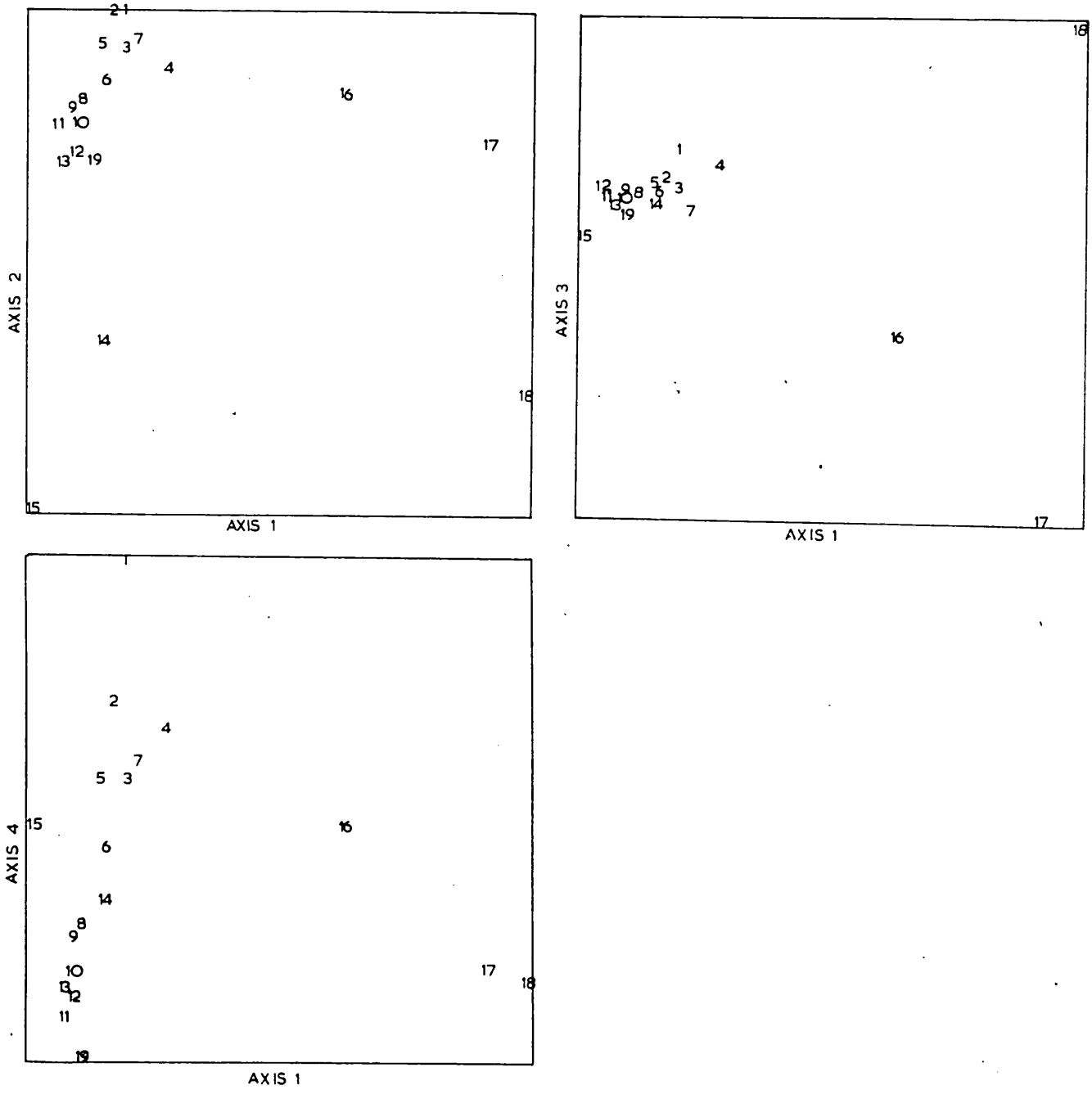
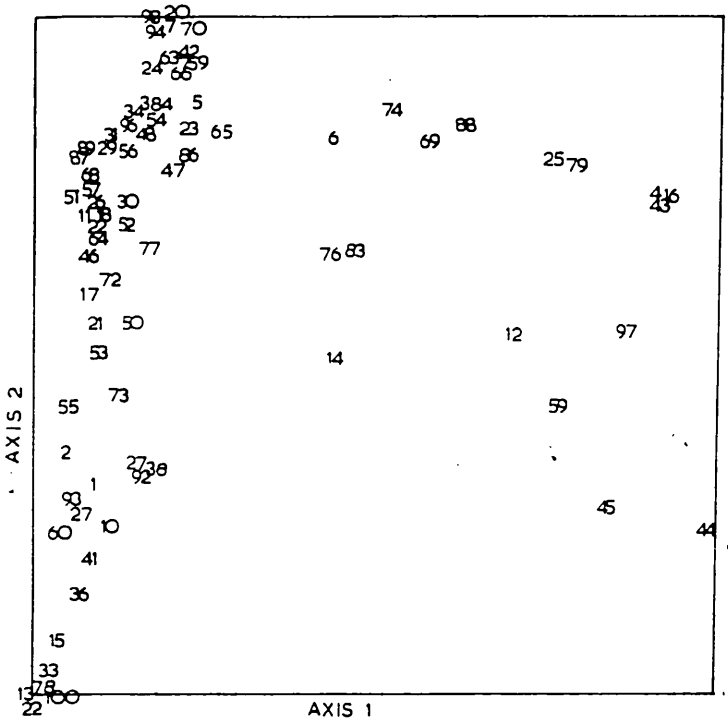
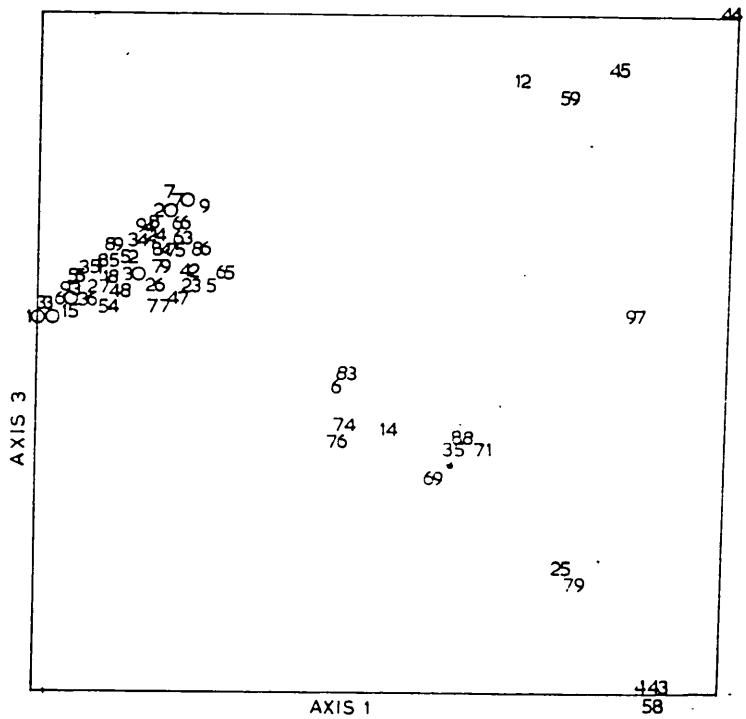
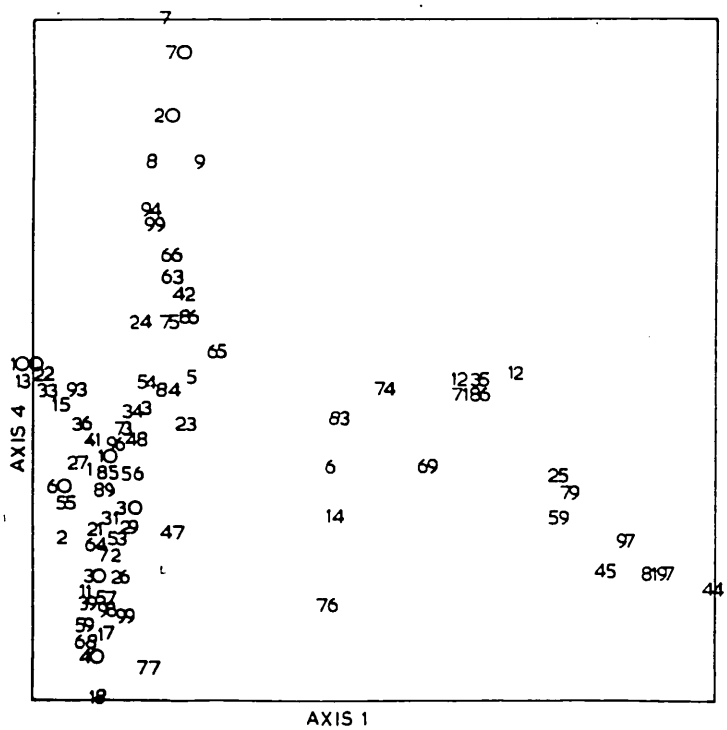


FIGURE 6.4 RECIPROCAL AVERAGING
2. SPECIES ORDINATION: POINT QUADRATS







Axis one shows some kind of environmental gradient where stand 18 is at one extreme and the gradient progresses through 17, 16, 4 and then the other stands including 19 are clumped together. However, when comparing axis 1 results to all the results obtained in callow analysis no direct relationship to any of the measurable environmental factors are apparent.

There are problems associated with attempting to investigate reasons for stand positions along the axes. One of these problems has already been mentioned elsewhere - that of the time lag been soil analyses and the majority of vegetation analyses. The second problem is comparability - several of the sites were not included in the soil analyses series thus the relevant results from the ordination diagram cannot be compared to the opposite environmental results. The reasons for exclusion were discussed earlier (chapter 5).

Axis 2 is also difficult to explain, as stands 1 and 2 are at one extreme, 16, 17 and 19 are at the lower end of the middle bunch and 15, 14 and 18 are at the other extreme.

Axis 3 positions stand 18 at one extreme and the majority (including 19) are clumped around a central point, with stands 16 (Upper Dean) and 17 (Ickwell) at the other extreme. No measurable environmental soil-related factor follows this pattern.

Considering species ordination diagrams, axis 1 plotted versus axis 2 is relevant; there are two trends in the diagram; one in a north-south direction and the other in a wide sweeping curve in a south-easterly direction. The first north-south grouping of species is the major one. Starting at the top of the diagram the species include 98, 20, 7, 94 and 70. These are Vicia sativa ssp. angustifolia (Narrow-leaved Vetch), Cerasium holostoides (Common Mouse-ear Chickweed), Alopecurus geniculatus (Marsh Foxtail), Tripleurospermum maritimum (Scentless Mayweed) and

Polygonum aviculare agg. (knotgrass). These are all common species of grassland and waste places and are found generally in the early - early/mid stages of the age series being studied.

The next group of species in this gradient includes species 42, 9, 63, 75, 66 and 4. These are Festuca pratensis (Meadow Fescue), Anagallis arvensis (Scarlet Pimpernel), Picris echioides (Bristly Ox-tongue), Rorippa sylvestris (Creeping Yellow-cress), Poa annua (Annual Poa) and Agrostis canina (Brown Bent-grass). These are classified as weed species of cultivated land. The majority are either stoloniferous or procumbent. Picris echioides is ubiquitous on the callow.

Further along the north-south trend is a clump of species, 3, 84, 34, 54 and 96. These are Agropyron repens (Couch-grass), Scirpus lacustris (Bulrush), Dipsacus fullonum (Teasel), Lolium perenne (Perennial Rye-grass) and Tussilago farfara (Coltsfoot). Beyond this clump is a large grouping containing species 57, 51, 11, 18, 22 and 85. These are Melilotus officinalis (Common Melilot), Lathyrus pratensis (Meadow Vetchling), Arrhenatherum elatius (Oat-grass), Centaurea scabiosa (Greater Knapweed), Atriplex hastata (Hastate Orache), Cirsium acaulon (Stemless Thistle) and Senecio erucifolius (Hoavy Ragwort). Most of these (excepting Atriplex hastata) are common on the open, better drained slopes of callow in the mid age range. Atriplex hastata is generally found in the wetter areas such as pond margins.

Descending beyond the main group are species 77, 72, 17, 21, 50 and 53. These are Rubus fruticosus agg. (Brambles), Potentilla reptans (Creeping Cinquefoil), Centaurea nigra (Lesser Knapweed), Chrysanthemum leucanthemum (Ox-eyed Daisy), Juncus inflexus (Hard-rush) and Leontodon autummalis (Autumnal Hawkbit). Most of these are indicative of the well-drained slopes of the mid-age range except Juncus inflexus which is found on pond margins.

The last group in the southern part of the axis are species 41, 36, 15, 33 and 18 which are Festuca ovina (Sheep's fescue), Equisetum arvense (Common Horsetail), Carex flacca (Carnation-grass), Deschampsia cespitosa

(Tufted hair-grass), Rumex crispus (Curled Dock) and species 100, Viola sp. (Violet sp.). These are all found in the wetter, flatter, low-lying regions. Thus it appears that the trend down axis 2 is primarily one of water relationships going from dry to wet habitat species, although this relationship cannot be confirmed from actual measurable variables.

The other curve in this diagram is one of a south-easterly direction along axis 1. This starts at the major grouping of species and extends outwards to species 65, 23, 5 and 6. These are Plantago major (Great Plantain), Cirsium arvense (Creeping Thistle), Agrostis stolonifera (Fiorin) and Agrostis tenuis (Common Bent-grass), which are all prostate or stoloniferous. Then the curve travels in an easterly direction with species 74, 69, 25, 29, 97, 76 and 83. These include Ranunculus repens (Creeping Buttercup), Poa trivialis (Rough Meadow-grass), Conium maculatum (Hemlock), Urtica dioica (Stinging Nettles), Rosa canina (Dog Rose) and Sambucus nigra (Elder). The species at the end of this curve are 12, 59, 45 and 44. These are Atriplex hastata (Hastate Orache), Mentha aquatica (Water Mint), Glechoma hederacea (Ground Ivy) and Heiracium pilosella (Mouse-ear Hawkweed). It is very difficult to explain this curve as a variety of species from a variety of habitats are scattered within it.

If axis 1 versus axis 3 is considered, the species at the top of the diagram include 44 and 45 which are Heiracium pilosella and Glechoma hederacea and then the grouping continues to 59 and 12 (Mosses) and Atriplex hastata, after which the majority of the species are grouped in a clump above the mid point of the diagram. Beyond the main clump are species 83, 6, 14, 76 and 74 which are Sambucus nigra (Elder), Agrostis tenuis (Common Bent-grass), Bromus ramosus (Hairy Brome) and Rosa canina (Dog Rose) and Ranunculus repens (Creeping Buttercup). At the bottom of this series are species 25 and 79, which are Conium maculatum (Hemlock) and Rumex sanguineous (Red-Veined Dock). This axis is hard to explain in environmentally recognisable terms.

However, axis 4 undoubtedly represents the age series. The species at the top of the axis 1 versus axis 4 ordination diagram are common of the early stages of succession, e.g. 7, 70, 20, 8 and 9. These are Alopecurus geniculatus (Marsh Foxtail), Polygonum aviculare agg. (Knotgrass), Cerastium holostoides (Common Mouse-ear Chickweed), Alopecurus myosuroides (Black Twitch) and Anagallis arvensis (Scarlet Pimpernel). At the bottom of this axis are species such as 64, 72, 30, 26, 57, 46, 39, 98, 99, 68, 40 and 17 and 18. These are Plantago lanceolata (Ribwort Plantain which is found at sites between 21 and 45 years of age), Convulvulus arvense (Bindweed), at sites between 21 and 97 years), Melilotus officinalis (Common Melilot, found at sites between 21 and 97 years but mainly in the mid-range of the series), Heracleum spondyleum (Hogweed), found at sites between 28 and 61 years of age, Festuca arundinacea (Tall fescue found at sites between 21 and 97 years), Vicia Sativa ssp. angustifolia (Narrow-leaved Vetch, found in Coronation Pit in the mid-age range) and Vicia cracca (Tufted Vetch) also found in Coronation. Poa pratensis (Meadow-grass found in Coronation and Brook Farm), Festuca rubra (Red fescue found at the two Bletchley sites) and Centaurea nigra (Lesser Knapweed) and Centaurea scabiosa (Greater Knapweed) both found only at Brock Farm.

From the detailed analyses given above it is evident that axis 4 is the most representational of the age series. Axis 1 is related to water content but axes 2 and 3 cannot be explained in terms of known environmental gradients.

6.6.2. Square Quadrats.

The results from the square quadrats species analysis are given in Table 6.5. The figures given refer to the number of occurrences out of one hundred randomly thrown quadrats. This type of analysis is considered to be less

Table 6.5. Square Quadrats Species List
(Figures indicate Percentage Occurrence)

	AGE AT TIME OF SURVEY (YEARS)																		
	ROOKERY						CORONATION							BLETCHLEY		OTHERS			
	1	3	4	6	10	16	14	21	28	32	37	41	45	33	36	61	88	94	97
1. Acer pseudoplatanus																	4	24	
2. Achillea millefolium								4		2	14		10	86	54				18
3. Agrimonia eupatoria														1	8				10
4. Agropyron repens		3	25	8		41	28	18	10					1					
5. Agrostis stolonifera	2	4	33	9	12	65	90	28	22	24	2			26	2	22	4		
6. Agrostis tenuis											8			3	4	6			
7. Alopecurus geniculatus	1	1																	
8. Alopecurus myosuroides	14	40	2																
9. Anagallis arvensis				3															
10. Arenaria leptoclados														62	20				
11. Arrhenatherum elatius			4		14	35		52	33	94	80	80	86	15	22				92
12. Arum maculatum																	2	8	
13. Atriplex hastata		1	4																
14. Anthemis arvensis			4																
15. Agrostis canina																	40		
16. Bellis perennis											2			1					
17. Blackstonia perfoliata														11	2				
18. Brachypodium sylvaticum															8				
19. Bromus erectus									2										
20. Bromus ramosus														2			4		
21. Barbarea vulgaris			2																
22. Carlina vulgaris														3					
23. Carex flacca														2	34				
24. Carex hirta															2				

Table 6.5. (continued)

	AGE AT TIME OF SURVEY (YEARS)																		
	ROOKERY						CORONATION							BLETCHLEY		OTHERS			
	1	3	4	6	10	16	14	21	28	32	37	41	45	33	36	61	88	94	97
25. Carex obtrubae																	2		
26. Centaurea nigra														3	14				40
27. Centauvea scabiosa																			2
28. Cerastium arvense		2												1					
29. Cerastium holostoides	3	2		1			2	4	6		2								
30. Centaureum erythrea							2												
31. Chamaenerion angustifolium						4								1					
32. Chrysanthemum leucanthemum		1				2		4	10	12	26	10	2	33	16				4
33. Cirsium acaulon		4		4	22	6								11					
34. Cirsium arvense		32	33	60	51	4	52	32	10	32	12	9	26	8	2		6	2	12
35. Cirsium vulgare	1	5	42	1				4	6		4	10							
36. Conium maculatum																2	6		
37. Convulvulus arvense			10				2	20		12	4	26	32				2	32	
38. Crataegus monogyna									2		4	2	10	46	56	2	6	2	6
39. Crataegus oxycantha					2					4				2					
40. Crepis sp.				1		2								9					
41. Crepis vesicaria ssp. taraxifolia			2	1	8	17	4		2	8	24	4							
42. Cynosurus cristatus														1					
43. Dactylis glomerata						37		4	28	32	46	26	30	62	28		2		12
44. Dactyorchis fuchsii								2							12				
45. Daucus carota								11	60	64	78	66	64	59	46				2
46. Deschampsia cespitosa							4							42	70				
47. Dipsacus fullonum			2			7	2	8					6						
48. Epilobium hirsutum		2	2			4	2	2											
49. Epilobium tetragonium		1	2				12		2		6								

Table 6.5. (continued)

	AGE AT TIME OF SURVEY (YEARS)																			
	ROOKERY						CORONATION							BLETCHLEY			OTHERS			
	1	3	4	6	10	16	14	21	28	32	37	41	45	33	36	61	88	94	97	
50. Equisetum arvense														62	42				4	
51. Erigeron acer														23	8					
52. Festuca arundinacea				-		4	20	32	30	18	56	60	2	2					22	
53. Festuca rubra									6	-50	38	12	1						44	
54. Festuca sp.													2					6		
55. Festuca ovina													72	46						
56. Fraxinus excelsior																	2			
57. Festuca pratensis										2										
58. Galium oparine																	11	8		
59. Galium verum													1							
60. Geranium dissectium	1	1	2	2		2														
61. Geum urbanum																2				
62. Glechoma hederacea																4		18		
63. Hedera helix										4					2		8	86		
64. Heiraclum pilosella								2		4	4		10	27	6					
65. Heiracium sp.						4				7	42	42	28	10	22					
66. Heracleum spondyleum								6	14	24	8	10	6	2	6	12				
67. Holcus lanatus		3	15	5	8	13	62	50	28	34	40	12	22	8	10				10	
68. Hypocheiris glabra											4									
69. Hypocheiris radicata									8	2	30	4	10	3	14				2	
70. Heiracium vagum						2														
71. Juncus effusus																	4			
72. Juncus inflexus						2						4		1						

Table 6.5. (continued)

	AGE AT TIME OF SURVEY (YEARS)																			
	ROOKERY						CORONATION							BLETCHLEY			OTHERS			
	1	3	4	6	10	16	14	21	28	32	37	41	45	33	36	61	88	94	97	
73. Lamium purpureum										4										
74. Lapsana communis														2						
75. Lathyvus nissolia											2									
76. Lathyrus pratense										16	48	8	12		6					
77. Leontodon autumnalis					12	4	4		8	14		2	4	14	8					
78. Leontodon hispidus					2	17			6	4	6	74	38	87	50				8	
79. Lolium perenne			23	8		2	4		10	16	14	10	10		4					
80. Lotus corniculatus									14	2	12	14	4	79	36					
81. Lotus tenuis														2						
82. Leontodon taraxacoides														1						
83. Medicago lupulina			8	2	16	94	2	2	6	12	6	6		6	14					
84. Melilotus officinalis								32	28	32	40	72	54	1	2				4	
85. Mentha aquatica																	22			
86. Myosoton aquaticum																2				
87. Melilotus altissima																			4	
88. Pastinacea sativa																		1		
89. Phalaris arundinacea															2				6	
90. Phleum bertolonii														5						
91. Phragmites communis														1	8					
92. Plantago lanceolata							2	70	60	62	50	68	52	60	60				6	
93. Plantago media										6	2		2							
94. Plantago major			2	3	2	6		2						5		6				
95. Poa annua		3	2		17	45		2												

Table 6.5. (continued)

	AGE AT TIME OF SURVEY (YEARS)																		
	ROCKERY						CORONATION							BLETCHLEY			OTHERS		
	1	3	4	6	10	16	14	21	28	32	37	41	45	33	36	61	88	94	97
96. Poa angustifolia						4			12										
97. Poa compressa												2							
98. Poa pratensis		-						2		2	8	14		1					4
99. Poa trivialis			2							2				1		6		2	4
100. Picris echioides	12	66	71	87	82	50	84		24	20	8								
101. Polygonum aviculare	19	4	6	4		2													
102. Polygonum persicani	1																		
103. Potentilla reptans			2	3	2	9							4	8	32	6			54
104. Prunella vulgaris				2	4	2			6			2		17	16				
105. Prunus spinosa														1					
106. Populus sp.												2							
107. Quercus rober																	2		
108. Ranunculus acris														1					
109. Ranunculus repens							18					6				4		2	
110. Reseda lutea												2							
111. Rorippa sylvestris			4																
112. Rosa canina														17	16	2	12		6
113. Rosa sp.														4	4				
114. Rubus fruticosus agg.												8		5	8	2	18	4	5
115. Rumex crispis	1			3			2												
116. Rumex sanguineous																36	20		
117. Rumex obtusifolius																2			
118. Salix alba																4	2		
119. Sambucus nigra														2		2			

Table 6.5. (continued)

	AGE AT TIME OF SURVEY (YEARS)																		
	ROCKERY						CORONATION							BLETCHLEY			OTHERS		
	1	3	4	6	10	16	14	21	28	32	37	41	45	33	36	61	88	94	97
120. Scirpus lacustrus						2													
121. Senecio erucifolius		1	21	3	6	4	68	8	22	28	24	30	36	32	40				
122. Senecio jacobaea	2		8	69	47	54	88		2			6		29	18		2		
123. Senecio squalidus								2		4									
124. Senecio viscosus		2												34					
125. Silaum silaus																			
126. Solanum dulcamera																4	8		
127. Sonchus arvensis																			
128. Sonchus asper	6	9		2	2	2					4	4	2						
129. Stachys sylvatica																	12		
130. Stellaria media	1													1					
131. Senicio vulgaris																		2	
132. Scrophularia nodosa																		2	
133. Tamus communis																	2		
134. Taraxacum officinale	1					19			2	4				11					
135. Trifolium pratense			4						2	2	2		2	5	6				
136. Trifolium repens						4	4		2	6				4	14				
137. Tripleurospermum maritimum ssp. inodorum	8	62	15	7	73	7	12										8		
138. Trisetum flavescens														13					
139. Tussilago farfara	9	51	79	15	71	100	54		76	82	74	78	48	53	39	50			
140. Urtica dioica																	22	36	48
141. Vicia sativa ssp. angustifolia							14	30	16	47	58	6	12						
142. Vicia cracca								4	6	2			4						4

Table 6.6. Square Quadrats, Species List-Key

	Species	English Name	Family
1	Acer pseudoplatanus	Sycamore	Ac
2	Achillea millefolium	Yarrow	Com
3	Agrimonia eupatoria	Common Agrimony	Ros
4	Agropyron repens	Couch-grass	Gra
5	Agrostis stolonifera	Fiorin	Gra
6	Agrostis tenuis	Common Bent-grass	Gra
7	Alopecurus geniculatus	Marsh Foxtail	Gra
8	Alopecurus myosuroides	Black Twitch	Gra
9	Anagallis arvensis	Scarlet Pimpernel	Pri
10	Arvenaria leptoclados	Lesser Thyme-leaved Sandwort	Car
11	Arrhenatherum elatius	Oat-grass	Gra
12	Arum maculatum	Lords-and-Ladies	Arac
13	Atriplex hastata	Hastate Orache	Chen
14	Anthemis arvensis	Corn Chamomile	Com
15	Argostis canina	Brown Bent-grass	Gra
16	Bellis perennis	Daisy	Com
17	Blackstonia perfoliata	Yellow-wort	Gen
18	Brachypodium sylvaticum	Slender False-brome	Gra
19	Bromus erectus	Upright Brome	Gra
20	Bromus ramosus	Hairy Brome	Gra
21	Brabarea vulgaris	Winter-cress	Cru
22	Carlina vulgaris	Carline Thistle	Com
23	Carex flacca	Carnation-grass	Cyp
24	Carex hirta	Hairy sedge	Cyp
25	Carex otrubae	False Fox-sedge	Cyp
26	Centaurea nigra	Lesser Knapweed	Com
27	Centaurea scabiosa	Greater Knapweed	Com
28	Cerastium arvense	Field Mouse-ear Chickweed	Car
29	Cerastium holostoides	Common Mouse-ear Chickweed	Car
30	Centaureum erythcea	Common Centaury	Gent
31	Chamaenerion angusfifolium	Rosebay Willow-herb	Ona
32	Chrysanthemem leucanthemum	Ox-eye Daisy	Com
33	Cirsium acaulon	Stemless Thistle	Com

Table 6.6. (continued)

	Species	English Name	Family
34	Cirsium arvense	Creeping Thistle	Com
35	Cirsium vulgare	Spear Thistle	Com
36	Conium maculatum	Hemlock	Umb
37	Convulvalus arvense	Bindweed	Con
38	Crataegus monogyna	Hawthorn	Ros
39	Crataegus oxycantha	Mid land Hawthorn	Ros
40	Crepis sp.	Hawk's-beard	Com
41	Crepis vesicaria ssp. taraxacifolia	Beaked Hawk's-Beard	Com
42	Cyosurus cristatus	Crested Dog's-tail	Gra
43	Dactylis glomerata	Cock's-foot	Gra
44	Cactylorchis fuchsii	Common Spotted Orchid	Orc
45	Daucus carota	Wild Carrot	Umb
46	Deschampsia cespitosa	Tufted hair-grass	Gra
47	Dipsacus fullonum	Teasel	Dip
48	Epilobium hirsutum	Great Hairy Willow-herb	Ona
49	Epilobium tetragonium	Square-stemmed Willow-herb	Ona
50	Equisetum arvense	Common Horsetail	Eq
51	Erigeron acer	Blue Fleabane	Com
52	Festuca arundinacea	Tall Fescue	Gra
53	Festuca rubra	Creeping Fescue	Gra
54	Festuca sp.	Fescue Species	Gra
55	Festuca ovina	Sheep's Fescue	Gra
56	Fraxinus excelsior	Ash	Ol
57	Festuca pratensis	Meadow Fescue	Gra
58	Galium aparine	Cleavers	Rub
59	Galium verum	Lady's Bedstraw	Rub
60	Geranium dissectum	Cut-leaved Cran's-bill	Ger
61	Geum urbanum	Wood Avens	Ros
62	Glechoma hederacea	Ground Ivy	Lab
63	Hedera helix	Ivy	Aral
64	Heiracium pilosella	Mouse-ear Hawkweed	Com
65	Heiracium sp.	Hawkweed	Com
66	Heracleum spondyleum	Hogweed	Umb
67	Holcus lanatus	Yorkshire Fog	Gra

Table 6.6 (continued)

Species		English Name	Family
68	Hypocheiris glabra	Smooth Cat's Ear	Com
69	Hypocheiris radicata	Cat's Ear	Com
70	Heiracium vagum	Hawkweed	Com
71	Juncus effusus	Soft-rush	Jun
72	Juncus inflexus	Hard-rush	Jun
73	Lamium purpureum	Purple Dead-nettle	Lab
74	Lapsana communis	Nipple-wort	Com
75	Lathyrus nissolia	Grass Vetchling	Pap
76	Lathyrus pratensis	Meadow Vetchling	Pap
77	Leontodon autumnalis	Autumnal Hawkbit	Com
78	Leontodon hispidus	Rough Hawkbit	Com
79	Lolium parenne	Perennial Rye-grass	Gra
80	Lotus corniculatus	Bird's-foot Trefoil	Pap
81	Lotus tenuis	Narrow-leaved Bird's-foot Trefoil	Pap
82	Leontodon taraxacoides	Hawkbit	Com
83	Medicago lupulina	Black Medick	Pap
84	Melilotus officinalis	Common Melilot	Pap
85	Mentha aquatica	Water Mint	Lab
86	Myosoton aquaticum	Great Chickweed	Car
87	Melilotus attissima	Yellow Mililot	Pap
88	Pastinacea sativa	Wild Parsnip	Umb
89	Phalaris arundinacea	Reed Canary-grass	Gra
90	Phleum bertolonii	Cat's-tail	Gra
91	Phragmites communis	Reed	Gra
92	Plantago lanceolata	Ribwort	Pla
93	Plantago media	Hoary Plantain	Pla
94	Plantago major	Great Plantain	Pla
95	Poa annua	Annual Poa	Gra
96	Poa angustifolia	Narrow-leaved Meadow-grass	Gra
97	Poa compressa	Flat-stalked Meadow-grass	Gra
98	Poa pratensis	Meadow-grass	Gra
99	Poa trivialis	Rough Meadow-grass	Gra

Table 6.6 (continued)

Specimen		English Name	Family
100	Picris echioides	Bristly Ox-tongue	Com
101	Polygonum aviculare agg.	Knotgrass	Pol
102	Polygonum persicana	Common Persicana	Pol
103	Potentilla reptans	Creeping Cinquefoil	Ros
104	Prunella vulgaris	Self-heal	Lab
105	Prunus spinosa	Blackthorn	Ros
106	Populus sp.	Poplar	Sal
107	Quercus rober	Pedunculate Oak	Fag
108	Rannunculus acris	Common Meadow Buttercup	Ran
109	Rannunculus repens	Creeping Buttercup	Ran
110	Reseda lutea	Wild Mignonette	Res
111	Rorippa Sylvestris	Creeping Yellow-cress	Cru
112	Rosa canina	Dog Rose	Ros
113	Rosa sp.	Rose species	Ros
114	Rubus fruticosus agg.	Blackberry	Ros
115	Rumex crispus	Curled Dock	Pol
116	Rumex sanguineous	Red-veined Dock	Pol
117	Rumex obtusifolius	Broad-leaved Dock	Pol
118	Salix alba	White Willow	Sal
119	Sambucus nigra	Elder	Cap
120	Scirpus lacustris	Bulrush	Cyp
121	Senecio erucifolius	Hoary Ragwort	Com
122	Senecio jacobaea	Ragwort	Com
123	Senecio squalidus	Oxford Ragwort	Com
124	Senecio viscosus	Sticky groundsel	Com
125	Silaum silaus	Pepper Saxifrage	Umb
126	Solanum dulcamera	Woody Nightshade	Sol
127	Sonchus arvensis	Corn Sowthistle	Com
128	Sonchus asper	Prickly Sowthistle	Com
129	Stachys sylvatica	Hedge Woundwort	Lab
130	Stellaria media	Chickweed	Car
131	Senecio vulgaris	Groundsel	Com
132	Scrophularia nodosa	Figwort	Scr

Table 6.6. (Continued)

	Specimen	English Name	Family
133	Tamus communis	Black Bryony	Dio
134	Taraxacum officinale	Dandelion	Com
135	Trifolium pratense	Red Clover	Pap
136	Trifolium repens	White Clover	Pap
137	Tripleurospermum maritimum ssp. indorum	Scentless Mayweed	Com
138	Trisetum flavescens	Yellow Oat	Gra
139	Tussilago farfara	Coltsfoot	Com
140	Urtica dioica	Stinging Nettle	Urt
141	Vicia sativa ssp. angustifolia	Narrow-leaved Vetch	Pap
142	Vicia cracca	Tufted Vetch	Pap

useful than point quadrat data because a species may occupy all of the quadrat or only a small percentage of the quadrat. In both cases it is only recorded as present or absent and given a score of "one" or "zero".

However, as the survey is of the same nature as the 1980 analyses[24] the results will be included here for comparison.

The English Names and Family Names are given in Table 6.6. The Family name abbreviations are the same as those used in Table 6.4., where the key can be found.

Because of the infinitely larger sampling size compared with point quadrats a larger number of species is included in the list (142 compared with 100 from the point quadrat list). Secondly, the additional species appear to be the less common ones, such as Arum maculatum (Lordsand Ladies) and Tamus communis (Black Bryony) Thirdly, the range of the more common species is extended as the likelihood of a point quadrat touching a species is not so great as its inclusion in a square quadrat. This is evident for species such as Cirsium arvense (Creeping Thistle) and Crepis vesicaria ssp. taraxifolia (Beaked Hawk's-beard).

The tables are kept in the order of their site position, rather than age position, as in Table 6.2.

The results from the square quadrats survey were used in a "reciprocal averaging" analysis in the same manner as for the point quadrat results.

Stand ordination diagrams from the square quadrats data are shown in Figure 6.5. Axis 1 plotted against Axis 2 shows that Axis 2 is the most representative of succession. Again, it is evident that stands 16, 17 and 18 are out of alignment but the other stands fit into a fairly orderly age series. It is interesting to note that stands 14 and 15, the two Bletchley sites are more advanced in the age series than Brook Farm, the oldest site.

FIGURE 6.5 RECIPROCAL AVERAGING
3. STAND ORDINATION : SQUARE QUADRATS

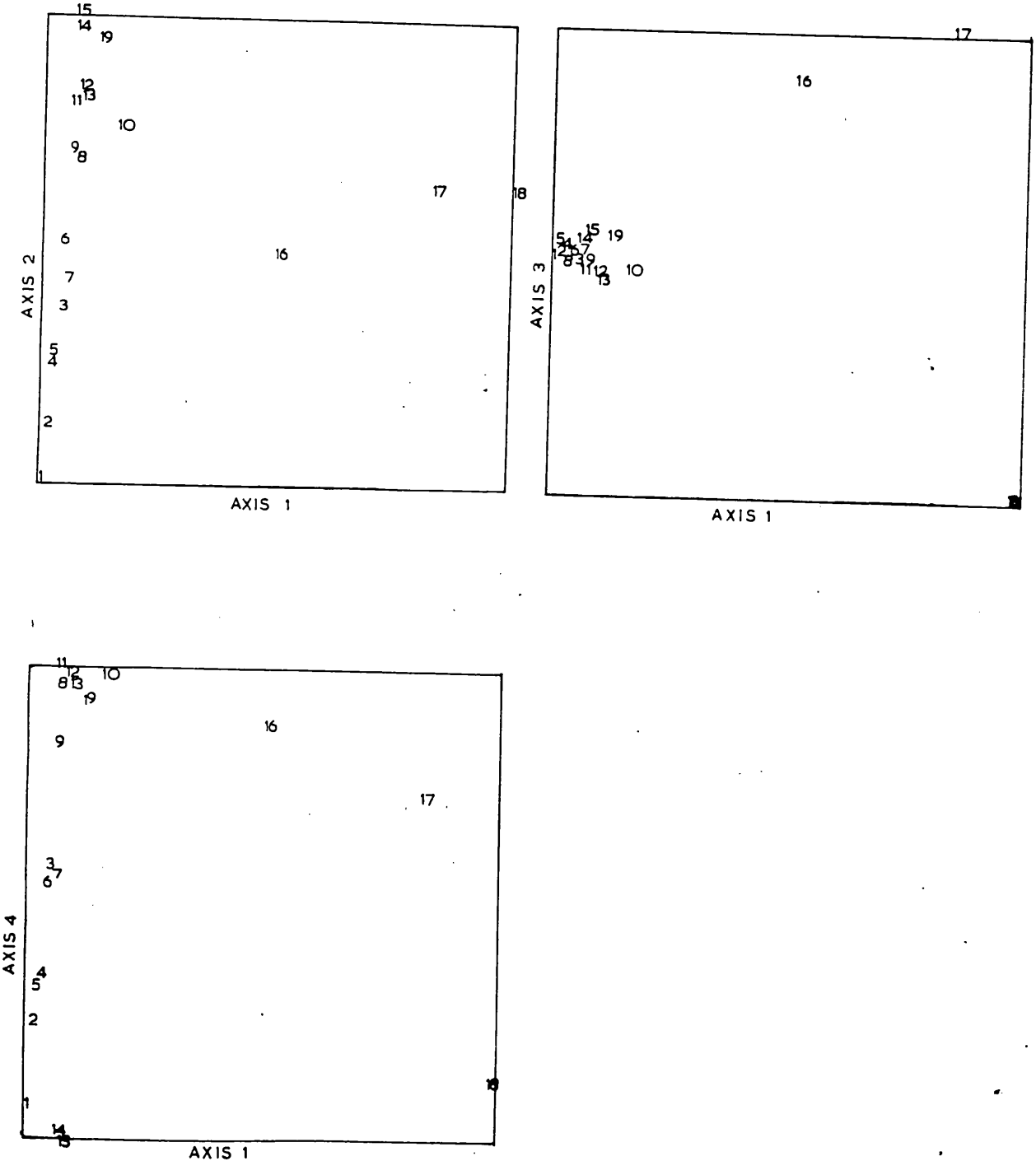
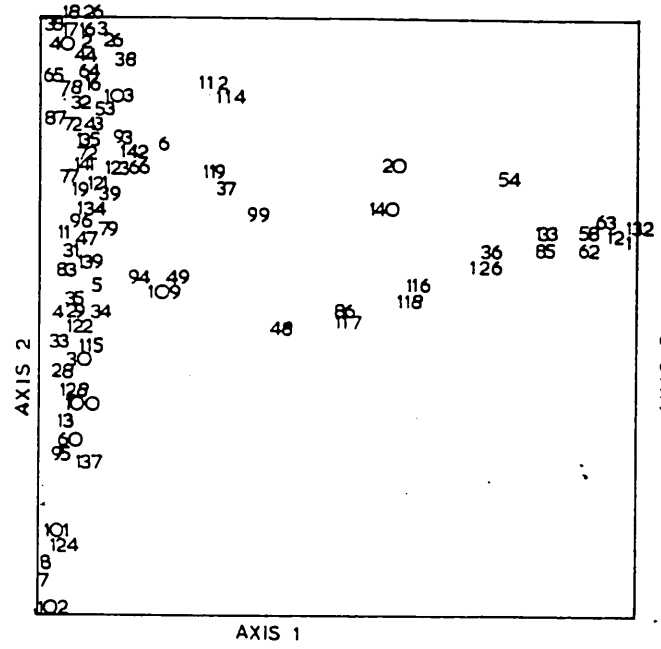
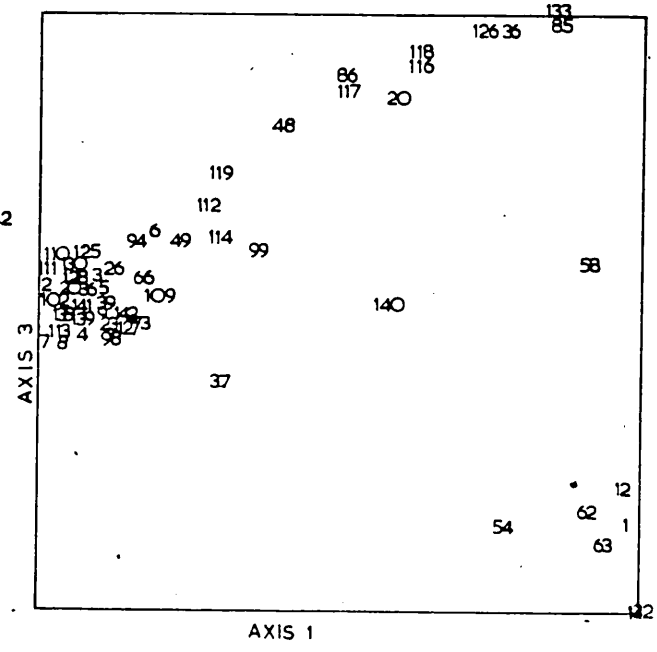
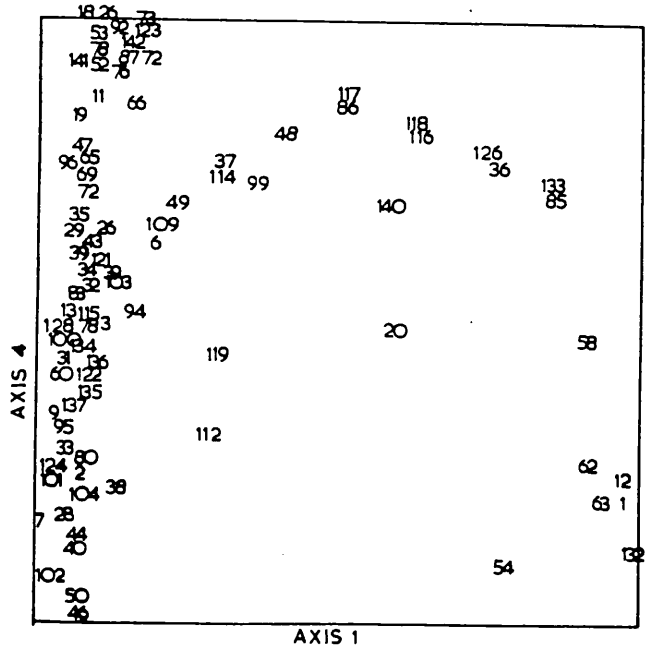


FIGURE 6.6 RECIPROCAL AVERAGING
4. SPECIES ORDINATION : SQUARE QUADRATS







It appears that Axis 1 may represent the transition from the open grassland type habitat to the closed woodland habitat found in the older pits.
Axis 3 cannot be explained in terms of known environmental variables.
Most of the stands are clumped around a mid point: stands 16 and 17 (Upper Dean and Ickwell) are at the top of the scale and 18 (Box End Kempston) is at the lower end of the scale.
Axis 4 could be related to succession, except that the two Bletchley stands are out of place, being at the bottom of the scale, below stand 1.
It is here that the missing soil data for the Bletchley sites would have been useful as they may have indicated the important differences between the callow at these sites and that in the Bedfordshire sites.
Species ordination diagrams from the square quadrats data are plotted in Figure 6.6. In the first diagram, that of Axis 1 v. Axis 2 there are two obvious gradients: the first runs in a north/south direction; the second runs in an easterly direction along axis 1. The species in the first gradient start with number 102, Polygonum persicaria (Common Persicaria), followed by species 7, 8, 101 and 124. These are Alopecurus geniculatus (Marsh Foxtail), Alopecurus myosuroides (Black Twitch), Polygonum aviculare agg. (Knotgrass) and Senecio viscosus (Sticky Groundsel). These are all species found very early in the successional series (except Senecio viscosus which is also found at Bletchley.
The next major grouping includes species 137, 60, 13, 100, 128, 28 and 30. These are Tripleurospermum maritimum ssp. inodorum (Scentless Mayweed), Geranium dissectum (Cut-leaved Cranes-Bill), Atriplex hastata (Hastate Orache), Picris echioides (Bristly Ox-tongue), Sonchus asper (Prickly Sowthistle), Cerastium arvense (Field Mouse-ear Chickweed) and Centaureum erythraea (Common Centaury). These species are found primarily in the first sixteen years of the series; some are also found in lower frequencies in later stages of the age series.

Above this another group of species, number 83, 139, 31, 79, 134, 121, 19 and 72 are found in the mid-range of the age series and include Medicago lupulina (Black Medick), Tussilago farfara (Coltsfoot), Chamaenerion angustifolium (Rose-bay Willowherb), Lolium perenne (Perennial Rye-grass), Taraxacum officinale (Dandelion), Senecio erucifolius (Hoary Ragwort) and Bromus erectus (Upright Brome). Tussilago farfara is the most widespread species on the callow. All these species are common in the open grassland habitat; they are not present in the later stages when the habitat changes to woodland.

The top group of species in the north/south gradient include 3, 26, 38, 2, 44 and 80. These are Agrimonia eupatoria (Common Agrimony), Centaurea nigra (lesser Knapweed); (Both found at Brook Farm and Bletchley), Crataegus monogyna (Hawthorn) found from the mid range of Coronation sites onwards, Achillea millefolium (Yarrow) found in Coronation, Bletchley and Brook Farm; Dactylorchis fuchsii (Common Spotted Orchid) found at Coronation and Bletchley and Lotus corniculatus (Bird's-foot Trefoil) which is found at sites between twenty eight years and forty five years including Bletchley.

As these species are found at the top of axis 2 it appears that the closed woodland species do not fit directly into the successional series shown in sites up to 45 years of age. Brook Farm site is more closely related to the trends shown up to 45 years, than are the sites of Upper Dean, Ickwell and Box End Kempston.

The second gradient in the first diagram is the one running along axis 1, away from the main branch just discussed, which is widest at its break from the main branch and narrows on moving in an easterly direction. The species nearest the north/south gradient include 6, 112, 114, 119 and 37. These are Agrostis tenuis (Common Bent-grass), Rosa canina (Dog Rose), Rubus fruticosus agg. (Brambles), Sambucus nigra (Elder) and Convulvulus arvense

(Bindweed). Apart from Convulvulus which is fairly widespread, all the other species are found later on in the age series and are indicative of the transition from open grassland to woodland.

The next group of species includes 20, 140, 116 and 118 which are Bromus ramosus (Hairy Brome), Urtica dioica (Stinging Nettle), Rumex sanguineous (Red Veined Dock) and Salix alba (White Willow). These species are indicative of the closed woodland habitat.

The end group of species along axis 1 includes 126, 36, 58, 63 and 12. These are Solanum dulcamera (Woody Nightshade), Conium maculatum (Hemlock), Galium aparine (Cleavers), Hedera helix (Ivy) and Arum maculatum (Lords and Laidies). These are all woodland species, primarily found at Box End Kempston and Brook Farm.

Axis 1 therefore represents the habitat change from open grassland to closed woodland.

The vast majority of species on axis 3 are clumped around a central point; all the missing species not plotted are found in this group. The species found elsewhere in two lines heading in a south-easterly and north-easterly direction do not show any distinct pattern. This axis cannot be explained in terms of known environmental variables.

The Axis 1 v Axis 4 plot appears similar to the axis 1 v 2 species ordination diagram, although the species composition is different. The main north/south gradient starts at the bottom with 50, 46, 102, 40 and 44. These are Equisetum arvense (Common Horse-tail), Deschampsia cespitosa (Tufted Hair-grass), Polygonum persiaria (Common Persicaria), Crepis sp. (Hawk's-beard) and Dactylorchis fuchsii (Common Spotted Orchid). From this group and from the rest of the species there does not appear to be any apparent environmental reason for this gradient.

From these results from the square quadrats it is apparent that axis 1 represents the transition from open grassland through scrub/grassland mix to closed woodland. Axis 2 shows succession along the time series with respect to the open grassland habitats only. Axes 3 and 4 cannot be explained in terms of known environmental gradients.

6.7. Transects

6.7.1. Introduction to Transects.

Consider a single environmental gradient which could be a long, even, uninterupted slope of a mountain. The slope is occupied by communities that include many species of plants, animals and saprobes. These species have evolved in relation to one another and they influence one anothers' populations, some of which would be competing and will have evolved in such ways that competition is reduced by niche differentiation.
Species may be distributed in relation to one another and the relevant communities in one of the following ways:

i Competing species, including dominant plants exclude one another along sharp boundaries. Other species evolve towards close association with the dominants and towards adaptations for living with one another. There thus develops distinct zones along the gradient, each zone having its own assemblage of species adapted to one another and giving way at a sharp boundary to another assemblage of species adapted to one another. The zones thus represent well-defined, relatively discontinuous kinds of communities.

ii Competing species exclude one another along sharp boundaries but do not become organised into groups with parallel distributions.

iii Competition does not, for the most part, result in sharp boundaries between species populations. Evolution of species towards adaptation to one another will, however, result in the appearance of groups of species with similar distributions. These groups characterise different kinds of communities, but the communities integrate continuously.

iv Competition does not usually produce marked boundaries between species populations and evolution of species in relation to one another. It does not produce well-defined groups of species with similar distributions. Centres and boundaries of species populations are scattered along the environmental gradient.

Each species is distributed in its own way, according to its own genetic, physiological and life-cycle characteristics and its way of relating to both physical environment and interactions with other species; hence no two species are alike in distribution.

The broad overlap and scattered centres of species populations along a gradient imply that most communities intergrate continuously along environmental gradients, rather than forming distinct clearly separated zones (either environmental discontinuity or disturbance by fire, felling, etc. can of course produce discontinuities between communities[98].

6.7.2. Methods

The random method of vegetation sampling is an essential practice for statistical purposes. It gives an estimate of variance within each site. However, if there are any environmental gradients present, for example down a slope, these will not be evident from the results of random sampling.

Thus, in order to investigate whether any environmental gradients were apparent at some of the sites, transects were set up, usually down a slope towards the pit bottom or the flooded area.

The transect line was chosen to be at right angles to the pit wall and a tape was laid flat on the ground. If the slope was longer than 30M then the process was repeated. Every 4M (or some other suitable distance), a 0.5 x 0.5M quadrat was placed on the ground with 25cm either side of the transect line. The species present within the quadrat were recorded and an estimate of their percentage cover was made.

In this manner, any environmental gradients could be detected as well as giving additional information about the species present at the sites studied.

This was carried out at four sites in Rookery; at sites aged three years, six years, ten years and sixteen years. These sites were chosen as they were most likely to show gradients caused by the slope.

The results are plotted in Figures 6.7 - 6.10.

None of the transects, surprisingly show any apparent environemt gradients, but they do give a good indication of the early stages of succession on callow.

Tripleurospermum martimum cf. ssp. inodorum (Scentless Mayweed) is one of the most important early colonisers as are Cirsium arvense (Creeping Thistle) and Tussilago farfara (Coltsfoot).

Tripleurospermum maritimum quickly loses its dominating role, and by six years Picris echioides (Bristly Ox-tongue) and Senecio erucifolius (Hoary Ragwort) assume dominance.

Tussilago farfara (Coltsfoot) becomes dominant at ten years, although it is present from earlier on. Picris echioides and Senecio spp.are still present at this time in lesser quantities.

By sixteen years of age Medicago lupulina (black Medick), Arrhenatherum elatius (Oat-grass) and Agrostis stolonifera (Fiorin) become dominant with several other species colonising from this stage.

These results are comparable with the 1980 survey of Rookery[24]. In that survey, transects were made on a two year old and a fourteen year old surface. The vegetation cover on the two year old slope was very patchy with any environmental gradient being hardly noticeable. It was thought that the reasons for this were variations in pH and moisture content along the transect. These variations were found to be localised and did not represent an overall gradient. It was noticed that the vegetation cover increased with increasing distance away from the origin. It was thought that this was caused by a more stable environment being provided in the centre of the pit; the slope flattens out and mass movement of the callow is not so great.

FIGURE 6.7 TRANSECT ON 3 YEAR OLD CALLOW MOUND

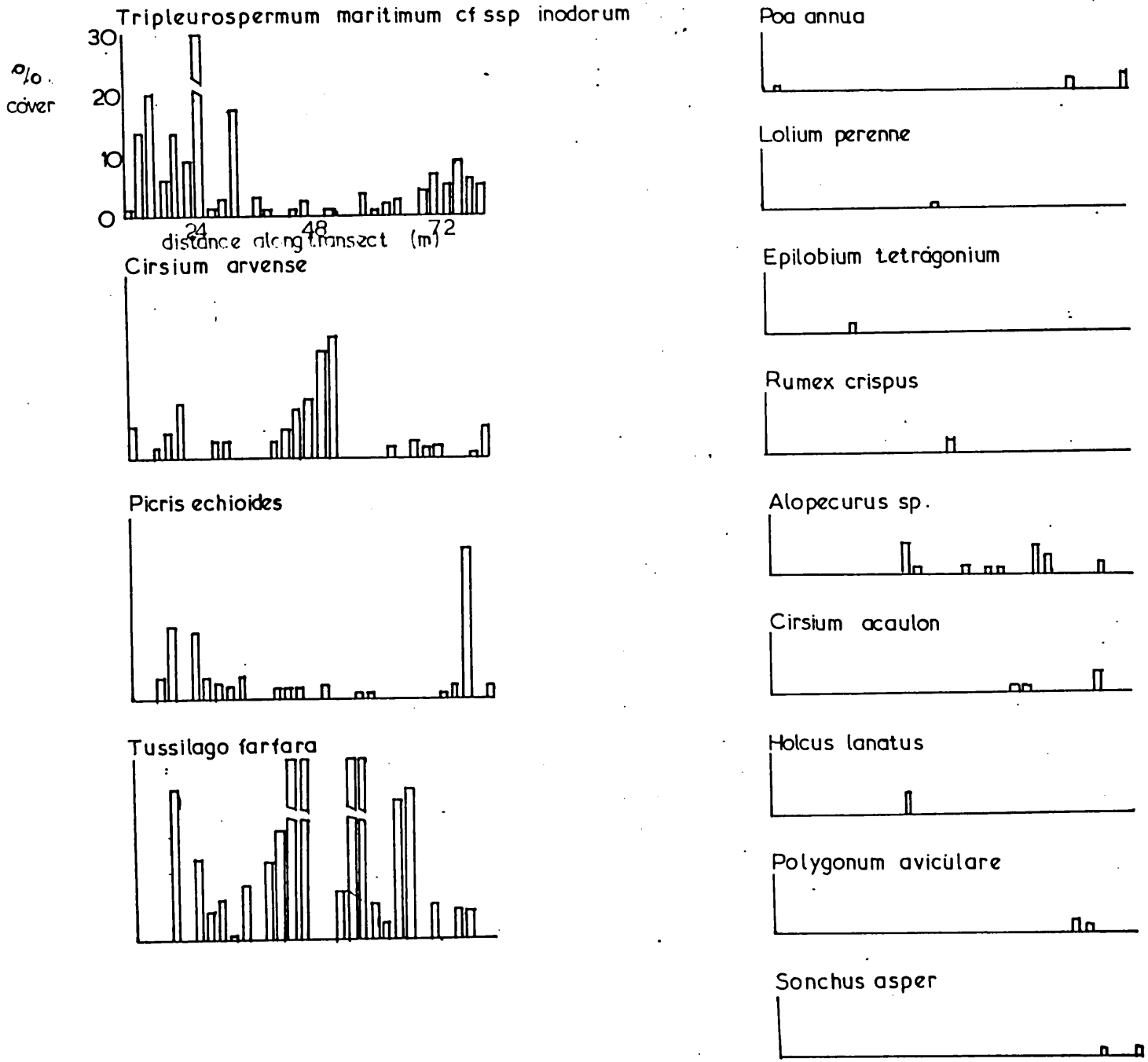


FIGURE 6.8 TRANSECT ON 6 YEAR OLD CALLOW MOUND

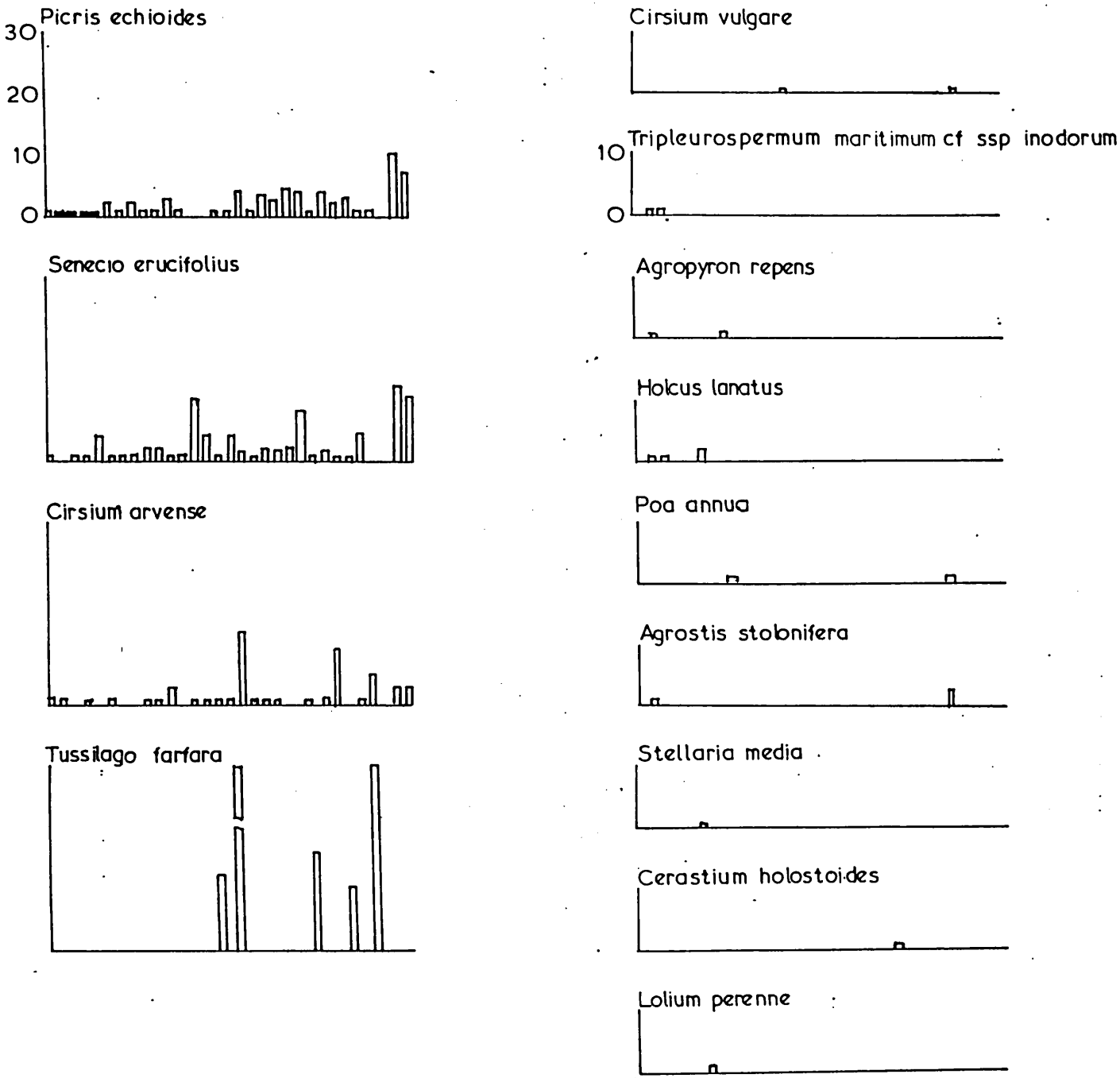


FIGURE 6.9 TRANSECT ON 10 YEAR OLD CALLOW MOUND

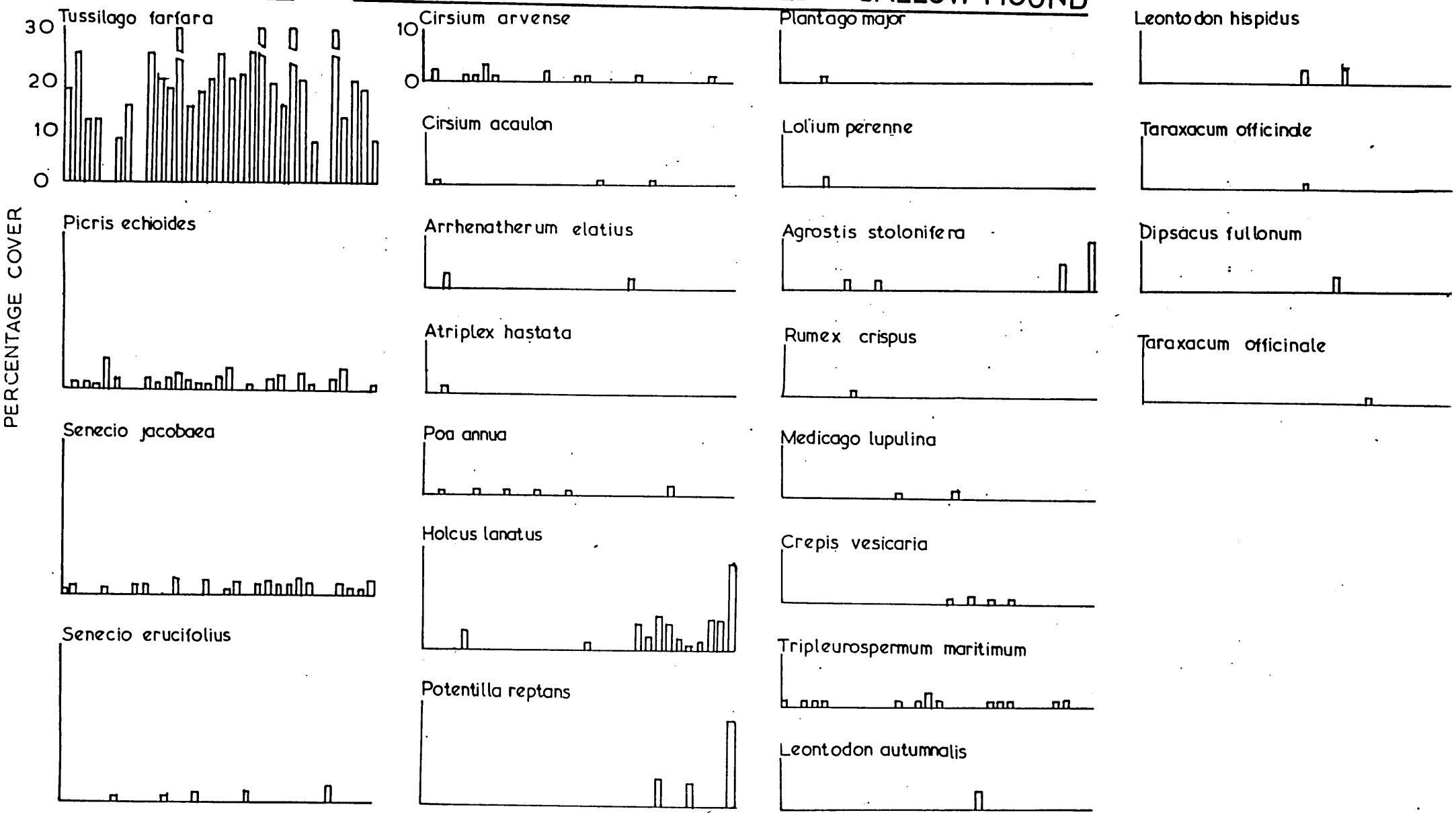
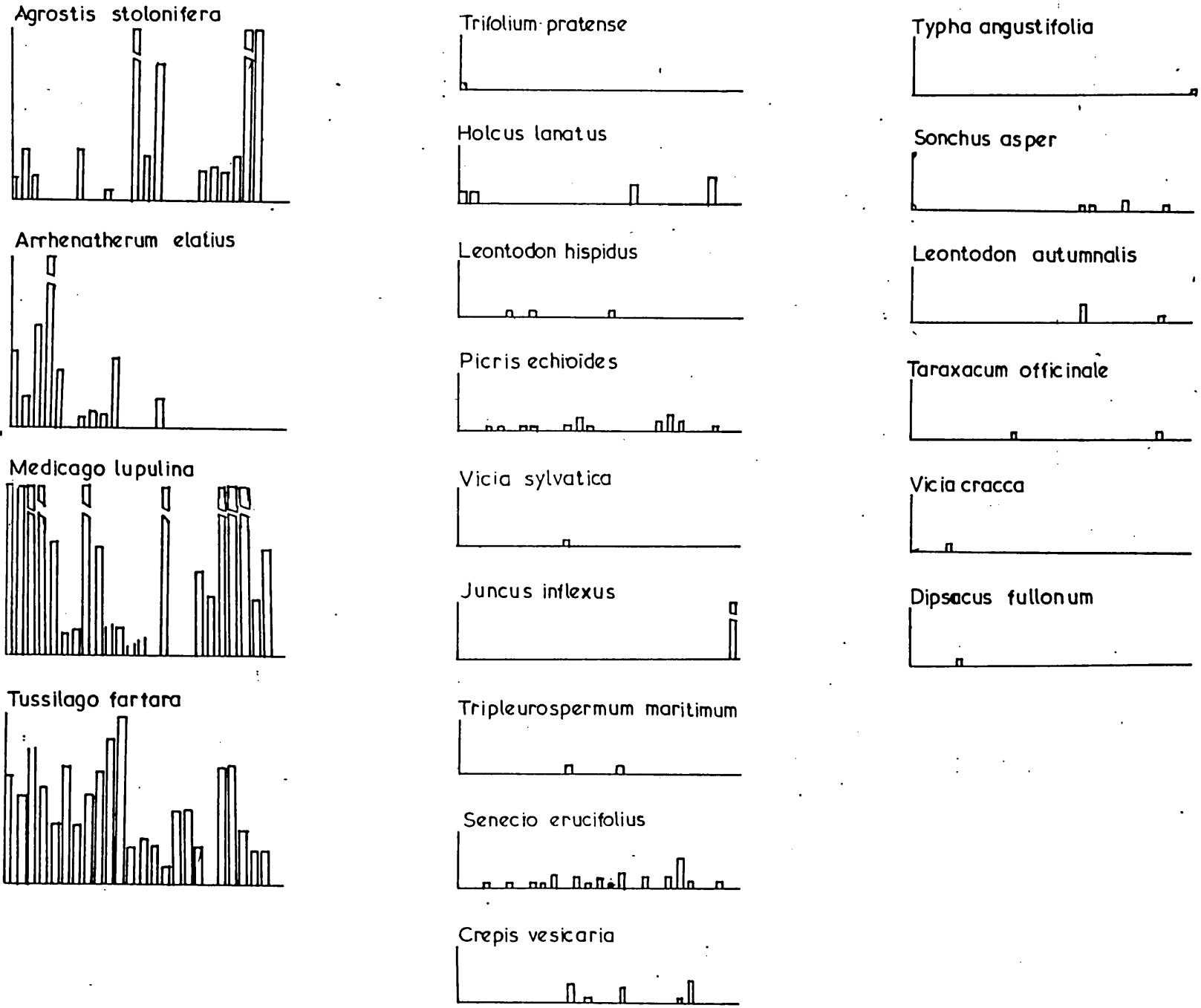


FIGURE 6.10 TRANSECT ON 16 YEAR OLD CALLOW MOUND



The transect on the fourteen year old slope during the 1980 study showed that Agrostis stolonifera (Fiorin) was the dominant species. Agropyron repens (Couch-grass) and Medicago lupulina (Common Melilot) and Tussilago farfara (Coltsfoot) were common. Apart from the solitary clump of Juncus inflexus (Hard-rush) at the end of the transect, representing a small pool at the bottom of the pit the environmental gradient was hardly noticeable.

6.8. Species Diversity Indices

For any particular group of S species, the number of individuals in the ith species, Ni as a proportion, pi of the total number of individuals,

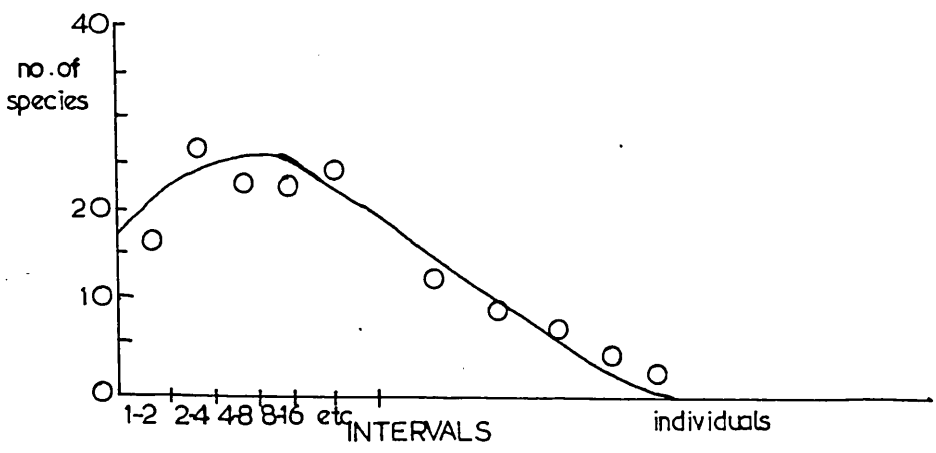
$N = \Sigma Ni$

$pi = Ni/N$[108]

This information may then be displayed on a graph of relative abundance versus rank, as shown in Figure 6.11, where "rank" is defined as the relative position of a species with respect to the other species when their relative abundance is considered. Thus, species rank 1 is the most abundant, species rank 2 is the second most abundant etc. If two species share the same relative abundance, they share the same rank, and in this instance, the next rank is omitted from the series.

Figure 6.11. Lognormal Distribution of Relative Abundances of Diatom Species in a Sample Taken From an Undisturbed Community in Ridley Creek Pennsylvania.

The Abundances are Plotted as Logarithms to the Base Two[156]



Once the community consists of a relatively large and heterogenious assembly of species, the observed distribution of species relative abundance (S(N)) is almost always lognormal, i.e. there is a bell-shaped gaussian distribution in the logarithm of the species abundance. Given a largish group of species it is likely that their relative abundances will be governed by the interplay of many independent factors. It is in the nature of the equations of population dynamics that these several factors should compound multiplicatively and the Central Limit Theorem applied to such a product of factors implies a log-normal distribution. That is, the log-normal distribution arises from products of random variables, and factors that influence large and heterogenous assemblies of species tend to do so in this fashion[108].

A useful classification, due to Whittaker[109] is:-

α - diversity: the diversity of species within a community or habitat.

β - diversity: a measure of the rate and extent of change in species along a gradient, from one habitat to another.

γ - diversity: the richness in species of a range of habitat's in a geographical area; it is a consequence of the alpha diversity of the habitats together with the extent of the beta diversity between them.

α and γ diversity are thus qualities that simply have magnitude and could be described by a scalar. β diversity in contrast is analagous to a quality that requires both magnitude and direction to characterize it fully (a vector). Their descriptions therefore require different approaches.

When a flora is sampled it is found that a few species are represented by a lot of individuals and a large number of species by few individuals. These relative abundances must be considered to represent the basic pattern of niche utilisation in thecommunity or area.

If diversity data are collected a graph similar to figure 6.12 may be prepared. Eventually the curve virtually flattens out to a value which is considered to represent total species (ST) for the habitat or area. This is the species equilibrium[110]. If the survey time is prolonged the curve will continue to creep upwards as new species are added to the flora by colonisation and others may be lost by extinction. The number ST is a straightforward measure of diversity but it can only be found by a complete survey. During the time of the survey (if prolonged) the relationship between the cumulative sample of individuals (Σ N) and the number of species (Σ S) is variable and is dependent upon the sample size.

The data may also be considered in their totality and if the log cover values (or log abundance) of each species are plotted against rank, the plot will approximate to a straight line. Such straight line plots emphasise that the ratio {species number (S): abundance of individuals (N)} relationship has two features.

i Species richness - the total number of species present in the area (ST).

ii Equitability or evenness - the pattern of distribution of the individuals between the species (a sample of 100 individuals representing ten species could consist of ten individuals of each (extreme equitability) or, at the other extreme ninety one individuals of one species (the dominant) and one of each of the other nine.

A variety of models have been proposed to estimate the relationship between abundances and species diversity indices.

One of the simpler non-parametric dominance indices is the Berger-Parker Dominance Index. It is simple, both mathematically and conceptually, expressing the proportion of the total catch that is due to the dominant species (whose abundance = N max):-

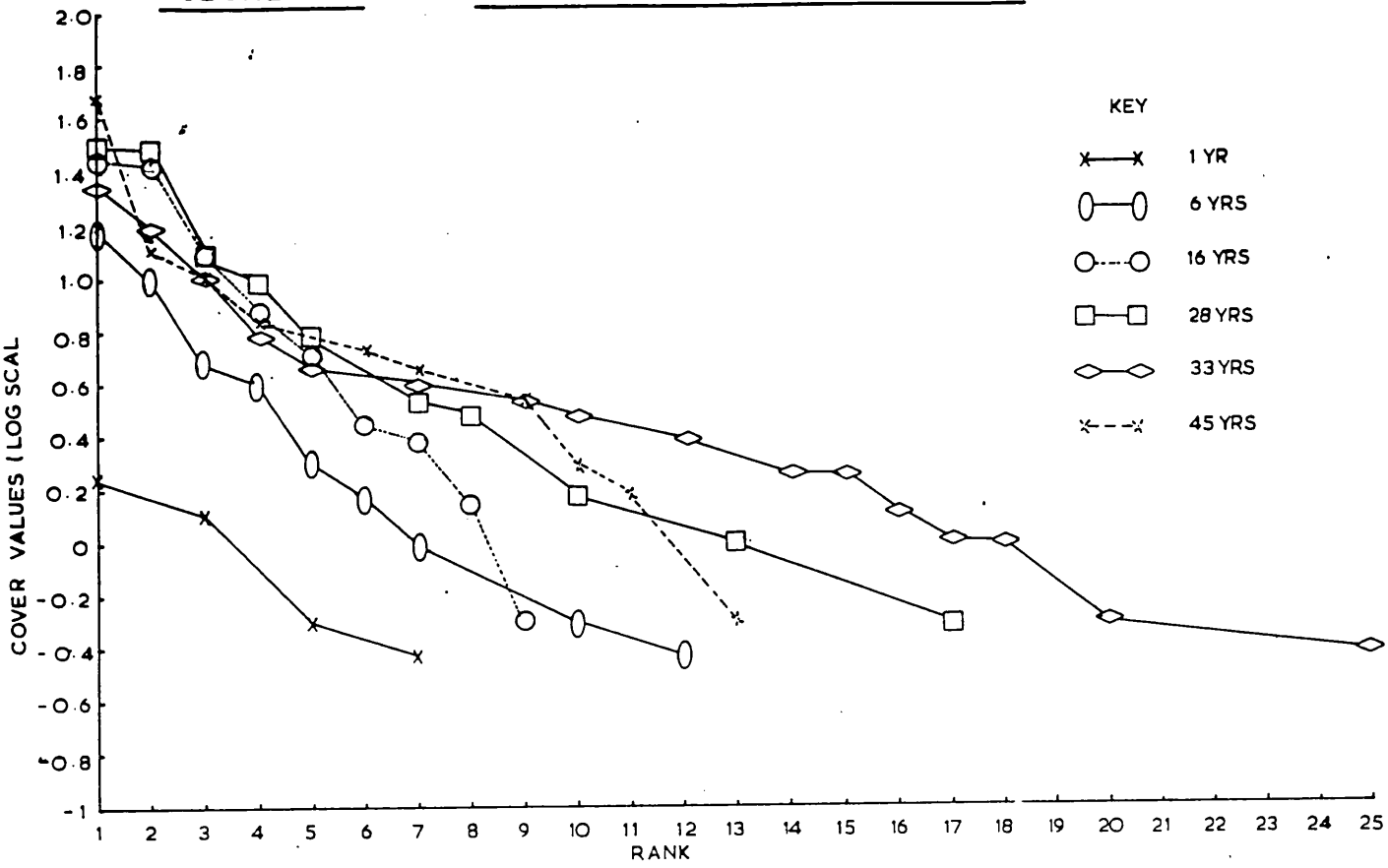
$d = N_{max} / NT$

Where d = diversity index

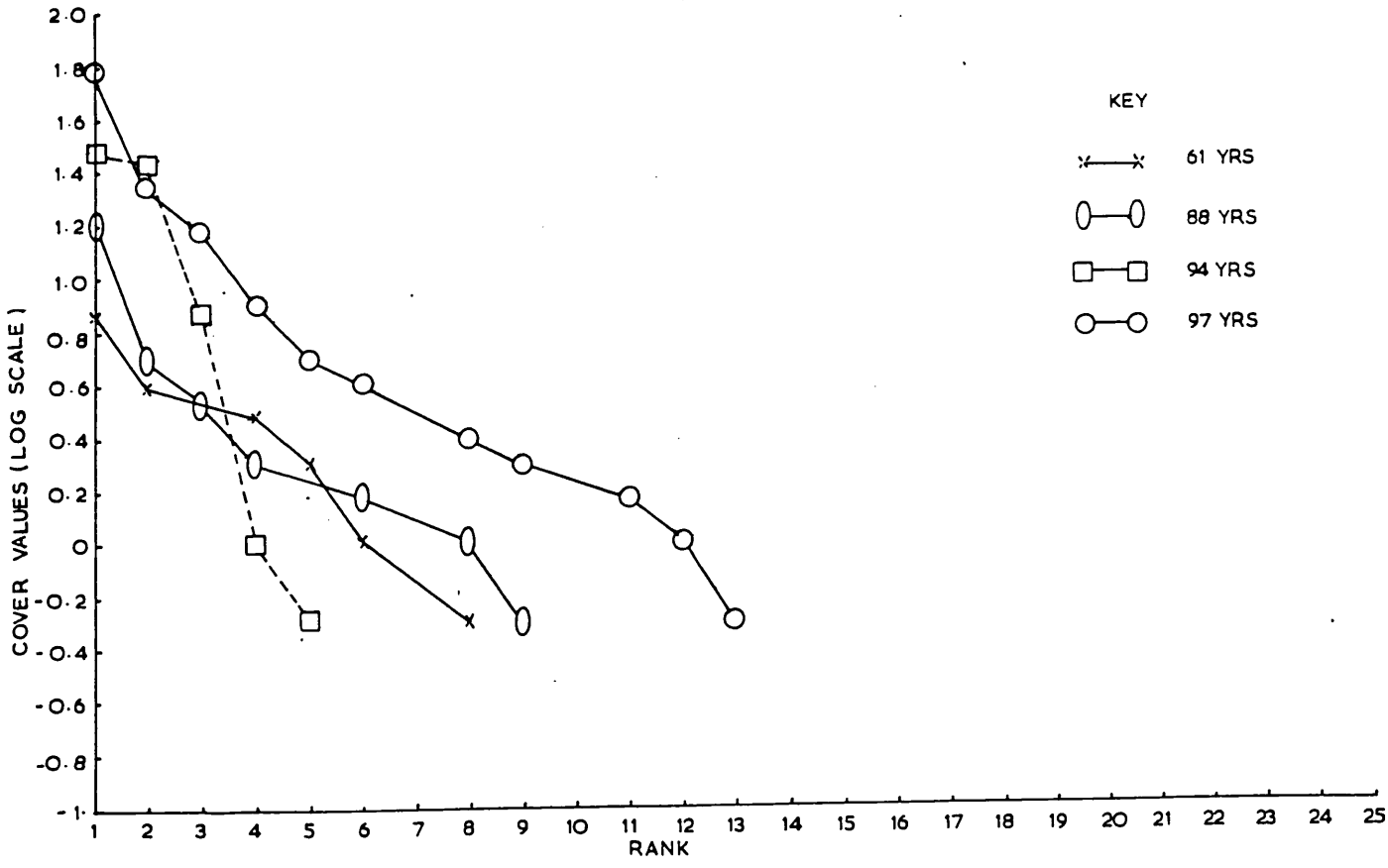
N max = percentage cover due to dominant species.

NT = total percentage cover of all species[111].

FIGURE 6.12 DOMINANCE DIVERSITY CURVES a. 1-45 YEARS



b. 61–97 YEARS



This equation was used to fit the data from the percentage cover values and the results are shown in Table 6.7. The dominance indices are plotted against age of the site. This is shown in Figure 6.13.

6.8.2. Results of Diversity Analyses

One of the attributes of mature ecosystems is a high species diversity. This fact is well documented (e.g. Margalef[112]).

It might therefore be thought that the oldest sites would have the highest indices of diversity and the greatest ST (total number of species) values.

There is no relationship however, between diversity index and age of sampling site; the correlation coefficient, r = 0.166, which is not significant.

The β diversity is concerned with the change in species diversity from habitat to habitat and the comparison of the quantitative and qualitative make up of different communities; it is a measure of change, of differences (or similarity). A direct approach to β indices, and the one used here is to compare separate diversity indices.

Point quadrat analyses gave data showing that the ST (total number of species) is not at its maximum level as indicated by the difference between the point quadrat results and those of the square quadrats. (ST values quoted in Table 6.7. are for Square Quadrat results).

The dominance diversity curves are shown in Figure 6.12. Six sites were chosen as representative of the first age range (under 45 years) and all the older sites are plotted.

Had all the points been plotted in an ideal manner, the result would be a straight line. Any deviations from a straight line indicate non-normality of data. (Southwood[113] suggests that any deviations from straightness may be caused by migrant species "en passage").

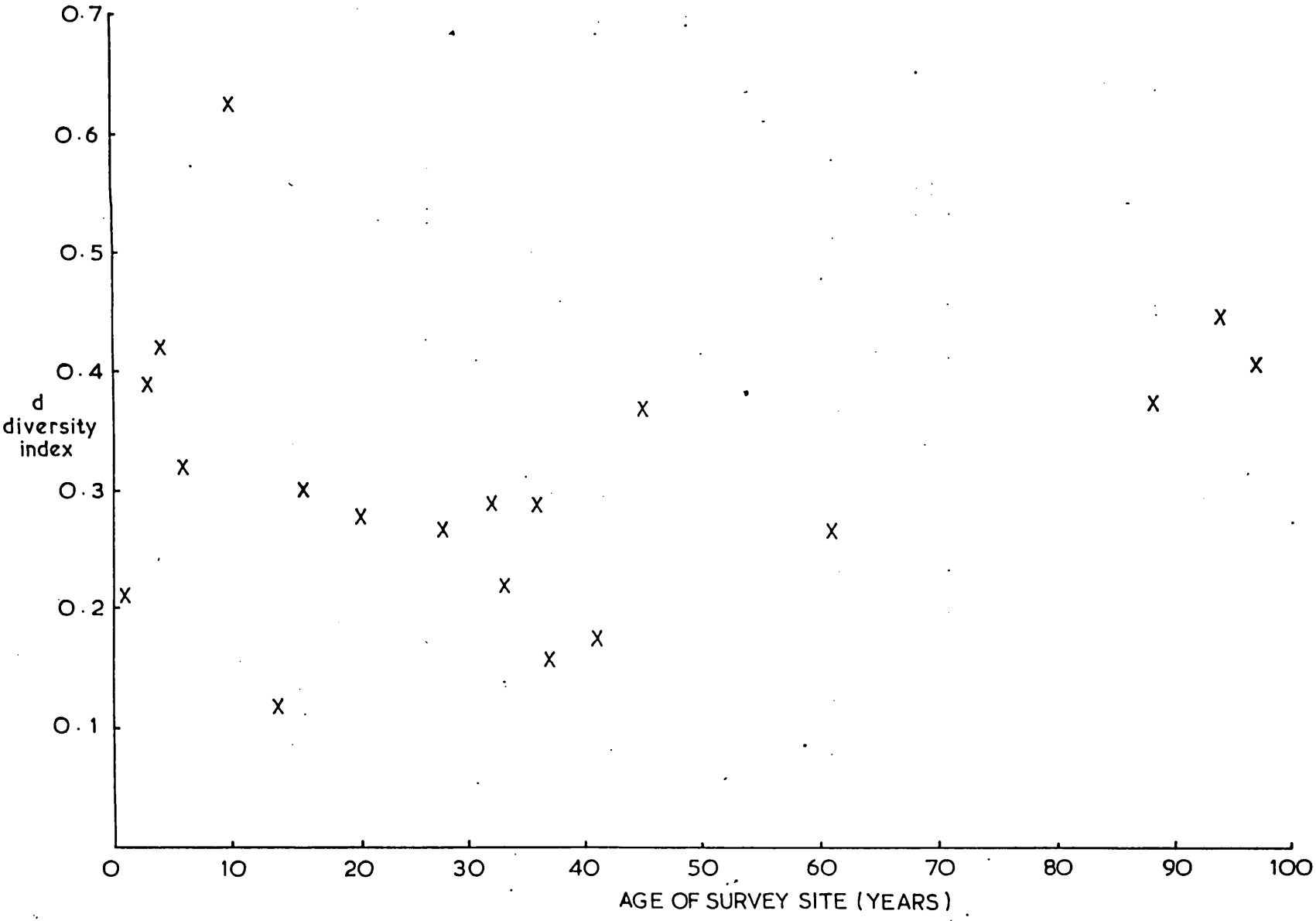
Table 6.7. Berger-Parker Diversity Indices

Site No.	Age of Site (Yrs)	St*	% Cover of Dominant**	Total % Cover	d
1	1	11	1.8	8.7	0.21
2	3	15	22.0	55.7	0.39
3	4	15	34.0	80.5	0.42
4	6	18	15.0	47.6	0.32
5	10	13	34	54.4	0.625
6	16	19	28	94.1	0.30
7	14	14	8.5	71.0	0.12
8	21	18	32.0	111.5	0.28
9	28	21	31	113.7	0.27
10	32	30	38	129.6	0.29
11	37	26	24	150.1	0.16
12	41	21	28	151.3	0.18
13	45	22	48	129.0	0.37
14	33	37	23	102.5	0.22
15	36	32	37	127.2	0.29
16	61	16	7.5	27.0	0.27
17	88	20	16	42.0	0.38
18	94	6	30	66.5	0.45
19	97	21	61	148.0	0.41

* Calculated from Square Quadrat Results.

** Calculated from Point Quadrat Results.

FIGURE 6.13 BERGER-PARKER DOMINANCE INDICES



These results confirm previous theories that the age series chosen does not show continuous succession. The different methods of excavation and callow dumping cause a break at the 45-61 year junction. However, after 61 years a second series is formed. The species diversity decreases at this break. The different methods of working the pits have given rise to a different type of habitat and therefore the species diversity curves are not indicative of an ideal successional series, they highlight the discontinuity.
The curves show a progressive increase in evenness and richness up to 45 years of age. Species number is lowest in the one year old plot; also the forty five year old plot gives a result which is lower than expected.

It was expected that the Coronation Pit sites would not have as high a diversity index as may be considered likely for its age due to the thin narrow nature of the sites and also the remoteness from possible seed sources.
The thirty three year old site in Bletchley has the greatest diversity index in the series.
The sites aged sixty one years onwards do not conform to the expected pattern of increasing richness with age.
The Berger-Parker Dominance Indices are plotted in Figure 6.13. There is no relationship between dominance index and age.
The 1980 study[24] showed that L-Field had the highest diversity index in the series then studied, caused by vertical as well as horizontal heterogeneity.

6.9. Differences Between the Two Different Aspects at Bletchley

As stated earlier, the sloping banks of Brickfields I (Bletchley, Jubilee Pit) are orientated in both a north-easterly and south-westerly direction. During sampling the orientation of each of the randomly placed quadrats was noted.

Table 6.8. A Comparison of the Percentage Occurrence Values from the North and South Facing Slopes at Jubilee Pit

(Bracketed figures are Point Quadrat Results)

Species	South Facing		North Facing	
Dactylis glomerata	64	(4.5)	60	(3.5)
Leontodon hispidus	82	(24)	92	(22)
Agrostis stolonifera	14	(3)	12	(2)
Plantago lanceolata	66	(5)	54	(3.5)
Lotus corniculatus	74	(16)	84	(9)
Senecio jacobaea	26	(2)	32	(1)
Achillea millefolium	90	(12)	82	(8.5)
Arenaria leptoclados	54	(1)	70	(1.5)
Festuca ovina	70	(17.5)	70	(13.5)
Equisetum arvense	70	(8)	54	(4)
Crepis sp.	6	(0.5)	4	(-)
Agrostis tenuis	4	(-)	2	(-)
Leontodon taraxacoides	2	(-)	-	(-)
Tussilago farfara	44	(3)	34	(3)
Senecio erucifolius	28	(-)	36	(-)
Silaum silaus	44	(-)	24	(-)
+ Trisetum flavescens	24	(1)	2	(-)
Daucus carota	54	(5.5)	64	(2.5)
Crataegus monogyna	52	(3.5)	40	(1.5)
Prunella vulgaris	20	(2.5)	14	(1)
+ Phleum bertolonii	10	(0.5)	-	(-)
Deschampsia caespitosa	54	(5)	30	(2)
Cirsium acaulon	10	(-)	12	(1)
Leontodon autumnalis	14	(0.5)	14	(1.5)
+ Chrysanthemum leucanthemum	42	(3.5)	24	(1)
Potentilla reptans	10	(0.5)	6	(0.5)
Hypocheiris radicata	4	(-)	2	(-)
+ Engeron acer	14	(0.5)	32	(1)
Plantago major	4	(-)	6	(0.5)
Heiracium pilosella	26	(7.5)	28	(4)

+ Marks those species which are more abundant on the north facing slopes.

Table 6.8. (continued)

	South Facing		North Facing	
Rosa canina	20	(0.5)	14	(0.5)
Rubus fruticosus	6	(0.5)	4	(1)
Poa pratensis	2	(-)	-	(-)
Trifolium pratense	8	(0.5)	2	(-)
Heracleum spondyleum	2	(-)	2	(-)
Blackstonia perfoliata	10	(-)	12	(-)
+ Holcus lanatus	12	(0.5)	4	(-)
+ Lotus tenuis	4	(-)	-	(-)
Cirsium arvense	10	(0.5)	6	(0.5)
Centaurea nigra	6	(-)	0	(-)
Carlina vulgaris	2	(-)	4	(-)
+ Heiracium spp.	6	(-)	14	(1)
+ Medicago lupulina	12	(2)	-	(0.5)
Arrhenatherium elatus	18	(5)	12	(1)
Festuca rubra	2	(-)	-	(-)
Stellaria media	2	(-)	-	(-)
Juncus inflexus	2	(2)	-	(-)
Agropyron repens	2	(-)	-	(-)
Ranunculus acris	2	(-)	-	(-)
Rosa sp.	8	(-)	-	(-)
Cerastium arvense	2	(-)	-	(-)
Melilotus officinalis	2	(-)	-	(-)
Gallium verum	2	(-)	2	(-)
Sambucus nigra	4	(0.5)	-	(-)
Bromus ramosus	4	(1.5)	-	(-)
Trifolium repens	2	(-)	6	(-)
Poa trivialis	2	(-)	2	(-)
Agrimonia eupatoria	2	(-)	-	(-)
Prunus spinosa	2	(-)	-	(-)
Cynosirus cristatus	2	(-)	-	(-)
+ Taraxacum officinale	4	(-)	18	(-)
Bellis perennis	2	(-)	-	(-)
Carex flacca	2	(-)	2	(0.5)
Phragmites communis	2	(-)	-	(-)
Crataegus oxycantha	2	(-)	2	(-)
Chamaenerion angustifolium	-	(-)	2	(-)
Festuca arundinacea	-	(-)	4	(0.5)

+ Marks those species which are more abundant on the north facing slopes.

The percentage occurrence of each species according to its aspect is noted in Table 6.8. The aspect of the slopes appeared to have little effect on the species composition.

Some of the less common species were found on one side only, but there was no overall trend. Some species were more common on south facing slopes, for example Trisetum flavescens (Yellow Oat-Grass) and Chrysanthemum leucanthemum (Ox-eye-Daisy) and Holcus lanatus (Yorkshire Fog). A few species are more abundant on the north facing slope, for example Erigeron acer (Fleabane) and Taraxacum officinale (Dandelion).

6.10. Discussion

The points at which invading species are able to enter the successional series can be accurately determined from these analyses. Table 6.9. shows a list of selected trees, shrubs, grasses and legumes found at the various sites. Some of the larger tree species may not have been found in a quadrat, but their presence was noted and is incorporated into this table.

An interesting feature throughout this survey is the lack of legumes in sites under sixteen years of age. Grasses are important early colonisers of the clay pits and remain important throughout most of the series.

A variety of the naturally occurring species are of significance for agricultural and reclamation uses. A number of the naturally occurring grasses are of major agricultural significance, for example Dactylis glomerata (Cock's - foot), the fescues and Lolium perenne (Perennial Rye-grass).

Results from ordination show that an age related continuum is apparent, but also other variables (not always quantifiable ones) are responsible for bringing about change in the clay pit flora.

An ideal age series would show increasing diversity, cover values etc. with age. These trends are not closely followed in the age series studied; patterns of colonisation related to age are however apparent from this study.

Age is therefore not the only variable to bring about change in the vegetation series.

The two sites at Bletchley are more diverse than the rest of the age series; the distance from the rest of the sites and the different seed banks available may be partly responsible for this.

There is little continuity at the 45-61 year junction. The majority of species found at the younger sites now disappear and new species appear in the study. This is probably caused by the difference in working methods at these sites giving rise to a different type of habitat.

The use of transects in the clay pits, following probable gradients show that actual vegetation gradients are not apparent at the sites studied.

The two different aspects at Bletchley Jubilee Pit Callow Mound do not differ significantly in their vegetation composition.

Many of the extracted axes in the ordination studies could not be related to any of the measured soil variables. Reasons for changes in vegetation pattern cannot therefore be considered to be totally quantifiable. Therefore any attempts at imitating environmental conditions to bring about the "right micro environment" for a community of species found at any stage in the series, would probably fail.

Table 6.9. SELECTED SPECIES LIST IN THE SUCCESSION SERIES

1) TREES AND SHRUBS

	AGE OF SITE AT TIME OF SURVEY (YEARS)																		
	1	3	4	6	10	14	16	21	28	32	33	36	37	41	45	61	88	94	97
Acer pseudoplatanus (Sycamore)																	✓	✓	
Crataegus monogyna (Hawthorn)									✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Crataegus oxycantha (Midland Hawthorn)					✓				✓	✓	✓					✓			
Fraxinus excelsior (Ash)																	✓	✓	
Prunus spinosa (Blackthorn)											✓								
Populus alba (White Poplar)																		✓	
Populus sp. (Poplar sp.)														✓					
Quercus rober (Pedunculate Oak)															✓		✓		
Rosa canina (Dog Rose)											✓	✓				✓	✓	✓	✓
Rosa sp. (Rose sp)											✓	✓							
Rubus fruticosus agg. (Blackberry)											✓	✓							
Salix alba (White Willow)																✓	✓	✓	✓
Salix caprea (Great Sallow)																✓	✓	✓	
Salix cinerea (Fen Sallow)																	✓		
Salix fragilis (Crack Willow)																✓	✓		
Salix viminalis (Common Osier)																		✓	
Sambucus nigra (Elder)											✓					✓	✓		
Ulmus procera (English Elm)															✓		✓	✓	
Malus sylvestris (Crab Apple)																	✓	✓	
Pinus sylvestris (Scots Pine)																	✓		

Table 6.9. (continued)

SELECTED SPECIES LIST IN THE SUCCESSION SERIES

2) GRASSES	AGE OF SITE AT TIME OF SURVEY (YEARS) 1	3	4	6	10	14	16	21	28	32	33	36	37	41	45	61	88	94	97
Agropyron repens (Couch Grass)		✓	✓	✓		✓	✓	✓	✓										
Agrostis canina (Velvet Bent)																	✓		
Agrostis stolonifera (Creeping Bent)		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓	✓		
Agrostis tenuis (Common Bent)													✓						
Alopecurus geniculatus (Marsh Foxtail)	✓																		
Allopecurus myosuroides (Meadow Foxtail)	✓	✓																	
Arrhenatherum elatius (False Oat-grass)			✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓				
Bromus erectus (Upright Brome)									✓										
Bromus ramosus (Smooth Brome)											✓						✓		
Catapodium rigidum (Hard Poa)							✓												
Dactylis glomerata (Cock's-foot)							✓	✓	✓	✓	✓	✓	✓	✓	✓				
Deschampsia cespitosa (Tufted Hair-grass)						✓					✓	✓							
Festuca arundinacea (Tall Fescue)						✓		✓	✓	✓	✓	✓	✓	✓	✓				
Festuca ovina (Sheeps Fescue)											✓	✓							
Festuca pratensis (Meadow Fescue)						✓							✓						
Festuca rubra (Red Fescue)										✓	✓	✓	✓	✓	✓	✓			
Holcus lanatus (Yorkshire Fog)		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Lolium perenne (Perennial Rye-Grass)			✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓				
Phalaris arundinacea (Reed Canary Grass)												✓							✓
Phleum bertolonii (Lesser Cats Tail)											✓								
Poa annua (Annual Meadow Grass)	✓	✓		✓	✓	✓													

Table 6.9. (continued) SELECTED SPECIES LIST IN THE SUCCESSION SERIES

	AGE OF SITE AT TIME OF SURVEY (YEARS)																		
	1	3	4	6	10	14	16	21	28	32	33	36	37	41	45	61	88	94	97
2) GRASSES (continued)																			
Poa angustifolia (Narrow-leaved Meadow Grass)									✓										
Poa compressa (Flattened Meadow Grass)														✓					
Poa pratensis (Smooth Meadow Grass)								✓		✓	✓		✓	✓					
Poa trivialis (Rough Meadow Grass)			✓							✓	✓					✓		✓	✓
Trisetum flavescens (Yellow Oat Grass)																✓			
3) LEGUMES																			
Lotus corniculatus (Bird's Foot Trefoil)							✓		✓	✓	✓	✓	✓	✓	✓				
Lotus tenuis (Narrow-leaved Trefoil)											✓								
Lathyrus nissolia (Grass vetchling)										✓			✓	✓					
Lathyrus pratensis (Yellow Meadow Vetchling)										✓		✓	✓	✓	✓				
Medicago lupulina (Black Medick)			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				
Melilotus officinalis (Ribbed Melilot)								✓	✓	✓	✓	✓	✓	✓	✓				
Melilotus altissima (Yellow Melilot)																			✓
Trifolium pratense (Red Clover)			✓						✓	✓	✓	✓	✓		✓				
Trifolium repens (White Clover)							✓	✓	✓	✓	✓	✓							
Vicia angustifolia (Narrow-leaved Vetch)						✓		✓	✓	✓			✓	✓	✓				
Vicia cracca (Tufted Vetch)								✓	✓	✓									
Vicia sylvatica (Wood Vetch)							✓												

7. FIELD TRIALS

7.1. Introduction

Commonly used soil tests for available nutrients may not provide valid results when used on mine wastes, so greenhouse and field studies of plant growth on spoils are used to evaluate the ability of common soil tests to determine plant available macronutrients.

Thus analytical (chemical and physical) procedures will provide information which can be used to estimate the potential of the waste material as a growing medium. They do not necessarily have to provide valid results which can be directly related to plant-available nutrients.

Therefore greenhouse and field trials serve as a two-fold test:-

(a) Evaluating the potential of the material as a growing medium.

(b) Evaluating the validity of nutrient analyses.

7.2. Sites

Two sites were chosen in the Marston Vale, one at Elstow in the centre of the pit, the other on callow at Brogborough Hill old refuse site. Their location is shown in Figure 4.3.

The site at Elstow was an area of callow approximately 30M long by 20M wide which had been cleared of all vegetation by April 1982. The site was originally sloping but was bulldozed to give a flat substrate. The area was surrounded on three sides by dense scrub and a track on the fourth.

The chosen area at Brogborough was a strip of callow on top of refuse 100M long by 30M wide. During the summer of 1982 the whole of the site was treated in the following way:-

i Discing, rolling, cultivation and rolling. (Sequence repeated three times across the whole area).

ii Subsoiling. The disrupting effect of a subsoiler is show n in Figure 7.1.

Plates 7.1. and 7.2. show Brogborough landfill site before and after cultivation.

iii All of the site, excepting the 30M x 100M experimental strip was seeded with perennial ryegrass in September 1982.

7.3. Selection of Species.

7.3.1. Introduction

One of the commonest components of all reclamation schemes is a grass cover, usually containing a legume. In Britain, which has a very restricted range of plant species, there are over 140 different species of grass and about 70 different species of clover and other legumes found growing in grassy places.

The grasses and legumes of Britain are adapted to the British moist temperate climate. There are as many different types of species as there are environments but it is their adaptation to soil conditions that matters. They are classified in this manner in Table 7.1. Most of the species are readily available commercially since they are used for agricultural purposes, but there are a few which are not readily available since they have no place in agriculture. These species may be important in particular situations.

Within each species there are usually many cultivars, varieties with different characteristics of hardiness, winter greenness, adaptation to soil and climate etc.

Legumes are a crucial component in almost all grass mixtures because they contribute and maintain adequate nitrogen supplies and ensure the build up of an adequate capital of organic nitrogen in the newly forming soil. They reduce or eliminate the need for aftercare treatment of nitrogen by increasing the amount of mineralisable nitrogen.

FIGURE 7.1. THE DISRUPTING EFFECT OF A SUBSOILER[127]

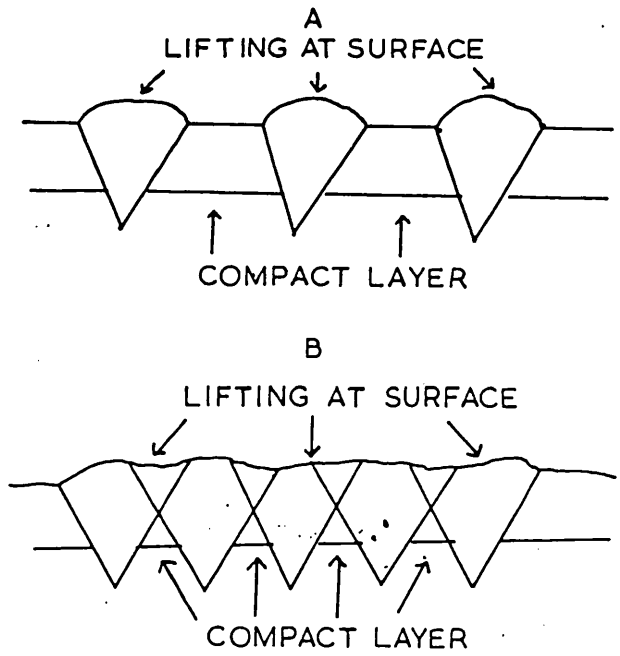


PLATE 7.1 BROGBOROUGH HILL SITE BEFORE AND AFTER CULTIVATION

a May 1982



PLATE 7.2

b May 1983



Table 7.1.

Grass Species Particularly Suitable for Derelict Land in Temperate Regions

Grass Species	Fertility Demand	pH Tolerance	Drought Tolerance	Temperature Tolerance	Cultivars
Agrostis gigantea (red top)	M	NC	M	CW	Few
Agrostis stolonifera (creeping bent grass)	M	NC	L	CW	Few
Agrostis tenuis (bent grass)	L	AN	M	CW	Many
Alopecurus pratensis (meadow foxtail)	M	NL	M	CW	Few
Dactylis glomerata (cocksfoot)	H	NC	M	CW	Many
Deschampsia caespitosa (tufted hairgrass)	M	NL	M	CW	Wild species
Deschampsia flexuosa (wavy hairgrass)	L	A	H	CW	Wild species
Festuca arundinacea (tall fescue)	H	NC	L	CW	Many
Festuca ovina (sheep's fescue)	L	ANC	H	CdCW	Few
Festuca pratensis (meadow fescue)	M	NL	M	CW	Few
Lolium perenne (Perennial rye-grass)	M	NL	M	CW	Many
Phleum pratense (timothy)	M	NL	M	CW	Many
Poa compressa (Canada blue grass)	L	ANC	H	CdCW	Many
Poa pratensis (smooth-stalked meadow grass)	L	ANC	H	CdCW	Many
	(low, medium or high)	(acidic, neutral or calcareous)	(low medium or high)	(cold, cool or warm)	

If there is no great drainage problem, it might be worth considering lucerne as a crop for mowing; in this case adequate P_2O_5 and K_2O plus the innoculation of the seed are most important."

Martindale[117] of the Ministry of Agriculture, Fisheries and Food believed that for cheapness, versatility, production and potential for success on heavy clay land the ryegrasses feature highly.

It may be worthwhile initially sowing a short term mixture which will generate some soil activity, allow further soil settling and perhaps draining before the final permanent grass-sward is sown.

For this purpose the following mixture has been used:-

	$kg.ha^{-1}$
Cropper Perennial Ryegrass	20
Talbot Perennial Ryegrass	12
Scots Timothy	3
Grasslands Huia White Clover	3
	38

In some circumstances Italian or Hybrid ryegrasses have been used as pioneer crops, for example RVP Italian ryegrass alone or in mixtures with Angusta Hybrid at a total seeding rate of 50kg/ha.

If it is feasible to use one seeding where more permanent ryegrass in association with clover and timothy can be used, the following mixture would be suitable for a heavy clay soil for a long term cutting and grazing regime:-

	$Kg.ha^{-1}$
Frances perennial ryegrass	11
Talbot perennial ryegrass	11
Melle perennial ryegrass	11
Motim timothy	5
Blanca white clover	3
	41

Usually, the most valuable legumes are those that are used in agriculture since they have high rates of nitrogen fixation. Most productive legumes presently available require reasonably high levels of calcium and phosphorus for growth and nitrogen fixation.

Legumes are only valuable if they possess their appropriate strain of Rhizobium bacteria. In soils where the species has already been growing, the appropriate Rhizobium will already be present. But in soils being formed out of wastes or other difficult material there may not be or there may only be a strain inefficient at fixing nitrogen. The proper Rhizobium may be attached to the legume seed, but this cannot be relied upon and the seed should be innoculated with the correct Rhizobium culture[3].

The first principle that applies to the design of seed mixtures is the choice of a ley that does not contain many different species which will compete and only the more aggressive types will survive. To maintain the content and the balance of the ley over a number of years it should be simple and made up of grasses that head over a narrow period. After heading, the digestibility of a grass decreases by about half a per cent a day. Because of this its feed value drops, and if complex mixtures are used with a wide range of heading dates, whenever they are cut or grazed there will be a number of components with feed value little better than barley straw.

7.3.2. Species Mixes Suitable for Use on Callow.

Advice of the choice of suitable species and mixtures was sought from Liverpool University Department of Botany; the Ministry of Agriculture, Fisheries and Food; Wye College Department of Environmental Studies and Country Planning and the Grassland Research Institute.

Bradshaw[114] stated that if the aim is restoration to agriculture, then standard agricultural species are the most appropriate, even on heavy clay, i.e. Lolium perenne (Perennial Rye-grass), Festuca pratensis (Meadow Fescue),

Phleum pratense (Timothy), Trifolium repens (White Clover), Trifolium pratense (Red Clover). They would have to be tailored to the agricultural use, for example hay or grazing and the appropriate cultivars. These species would only be appropriate if the overburden is of a reasonably good quality.

If the aim is just a vegetation cover and the overburden is a very heavy structureless clay, the choice would have to be species that cope with the conditions. These include Dactylis glomerata (Cocksfoot), Festuca arundinacea (Tall Fescue) and Medicago sativa (Lucerne).

Buckley suggested that the commonest species colonising Weald, London and Gault Clays in the Wye College area are Agrostis canina (Brown Bent-grass), Agrostis stolonifera (Fiorin), Deschampsia caespitosa (Tufted hair-grass) and Holcus lanatus (Yorkshire Fog) with Dactylis glomerata (Cocksfoot), Festuca pratensis (Meadow Fescue), Lolium spp. (Ryegrass) and Phleum pratense (Timothy) if the fertility is reasonable. Red clovers also do well[115].

Donaldson[116] of the Grassland Research Institute said "Assuming that the overburden is not separated into topsoil and subsoil the seed bed would be expected to have a low seed content so that the sown mixture should not have too much competition to contend with. The conditions would be similar to new road verges on the same formation: given appropriate P_2O_5 and K_2O dressing a conventional perennial ryegrass/white clover mixture has donw well on such sites. For general purposes, addition of Timothy would be beneficial, so a suitable mixture would be:-

	$kg.ha^{-1}$
Perennial ryegrass e.g. Melle	20
Timothy e.g. S48	5
White Clover - Huia	2
Wild White Clover - Kent or S184	0.5
	27.5

If however the reclaimed area is to be used for amenity purposes then an interesting development has been to try to establish pure stands of creeping red fescue, varieties S59 or Merlin.

The seed mixture which was used in the 1980 greenhouse trials[24] was designed for heavy clay soils for no specific purpose other than providing a quick and heavy grass cover. The mixture was as follows:-

	%
Rough Stalked Meadow Grass Dasas	10
Red fescue	20
Perennial Rye-grass S24	30
Timothy Goliath	20
Red Clover	20

Another factor which was of importance when selecting suitable seed mixtures was availability. This did not however cause any difficulties as J. Pickard and Co. (Seed Merchants) Ltd. were able to supply exact specifications.

During the first progress meeting of the project, held at London Brick Products Offices in Stewartby, it was decided that the emphasis of field and greenhouse trials should be on restoration to agricultural purposes. Thus the seed mixtures were chosen for this purpose. A listing of the six seed mixes used is shown in Table 7.2. Also three crops were grown; oil seed rape, winter wheat and winter barley.

7.3.3. Details of Species and Strains Used.

Grasses.

1. Perennial Ryegrass (Lolium Perenne)

Perennial ryegrass is by far the most widely sown grass in British agriculture. Some varieties are very persistent and are well suited for use in long leys and for establishing permanent grassland. Other varieties grow well for 2 or 3 years but are less persistent so are suitable only for short leys. Early varieties normally head in mid May whereas the late varieties head in mid June.

Table 7.2. Grass Seed Mixtures used in the Project

Westerwolds Ryegrass	40%
Red Clover - Broad Red	28%
Timothy - Motim	30%
White Clover	2%
	100%
Lucerne (Innoculated)	83%
Meadow Fescue	17%
	100%
Adas Recommended Short Term Ley	
Perennial Ryegrass Cropper	52%
" " Talbot	32%
Timothy - Goliath	8%
White Clover Grasslands Huia	8%
	100%
Adas Recommended Long Term Ley	
Perennial Ryegrass Frances	27%
" " Talbot	27%
" " Melle	27%
Timothy - S.48.	12%
White Clover Grasslands Huia	7%
	100%
Mid Season Productions - Grazing/Hay Cuts	
Perennial Ryegrass Melle	7%
Meadow Fescue S.215	54%
Cocksfoot S.26	23%
Timothy - S.48	12%
White Clover Grasslands Huia	4%
	100%
Rough Stalked Meadow Grass Dasas	10%
Red Fescue	20%
Perennial Ryegrass S.24	30%
Timothy Goliath	20%
Red Clover	20%
	100%

To give its best, ryegrass demands high soil fertility for the tendency in all strains is to be low in productivity and to run to stem when soil fertility is low. On the other hand, some pasture strains will stand considerably lower levels of soil fertility than will commercial strains. This is probably due to the fact that commercial types, being more erect are eaten out more quickly than the most prostrate leafy strains.

a) Aberystwyth S24.

This strain has been bred for its leafiness. In general type and conformation it is similar to Irish ryegrass which it has superceded. It starts its growth early in Spring and provides a heavy crop of nutrients both as hay and pasture. Under pasture conditions S24 persists better than commercial ryegrass. S24 makes good growth in the Autumn and is superior to commercial and New Zealand ryegrasses in this respect in British climates[119]. It is recommended for situations where its extreme earliness of spring growth is especially required. However, it has relatively low yields, persistence and winterhardiness when compared with other more recently developed recommended varieties[118].

b) Cropper.

This is one of the very early and early varieties recommended for general use. It is close to the average for the very early and early group in yield, persistence and winter hardiness.

c) Frances.

This variety gives high yields under both early and very early managements, particularly in the second half of the year.

d) Talbot.

This is an intermediate variety which is persistent with good yields in the second harvest year when cut for conservation.

e) Melle.

This is a late variety recommended for general use. It has very good persistence and high yields particularly in late summer and autumn.

Dry matter yields, persistence and winter hardiness as classified by the National Institute of Agricultural Botany are shown in table 7.3.

Table 7.3. Perennial Ryegrass Varieties Used in Trials.[118]

Dry matter yields are expressed as a percentage of the total 1st harvest year field of Aberystwyth S24.

Time of Flowering	Cropper Early	Frances Early	Aberystwyth S24 Early	Talbot Intermediate	Melle Late
Heading Date (Days after 1st April)	45	46	44	63	74
Simulated Grazing Yield First Harvest Year Total (100 = 11300 kg.ha^{-1})	102	106	100	102+	106+
2nd Harvest Year Total	83	85	78	-	88
Conservation Yield First Harvest Year Total (100 = 15600 kg.ha^{-1})	97	102	100	101+	102+
Second Harvest Year Total	81	85	78	93	89
Persistence (0-9)	6.5	7.0	5.5	7.0	9.0
Winter Hardiness (0-9)	6.5	6.0	5.0	7.0	7.0
Year First Listed	1971	1977	1968	1973	1968

+ Talbot and Melle yields are based on those obtained for S23, an intermediate heading variety where:

First Harvest Year Total, 100 = 11200 kg.ha^{-1}

Conservation: First Harvest Year Total, 100 = 14500 kg.ha^{-1}

2. Westerwolds Ryegrass

Varieties of westerwolds ryegrass are annuals. When sown in spring or summer they will flower during the sowing year which distinguishes them from the biennial Italian ryegrass. Westerwolds ryegrass is useful when high production is required within 3-6 months of sowing[118]. Vines[120] reports that Westerwolds ryegrass can be sown as a nurse crop on the poorer clays and chalk soils. It grows quickly and suppresses weeds such as charlock or broad-leaved dock in the first year and provides a green cover straight away.

3. Timothy (Phleum pratense).

Traditionally, timothy has been regarded as a late grass and one particularly suited to hay conditions. The newer leafy strains, high-tillering and winter-green, have made it possible to look upon timothy as a grazing plant and for it to take a prominent place in special purpose seed mixtures where the design is to produce feed at specific times of the year. Timothy does not compete well with ryegrass in a general purpose mixture but makes an excellent companion plant with meadow fescue on the one hand and with the legume on the other[119].

a) Motim.

This is an intermediate variety recommended for general use. It gives high yields in the first harvest year.

b) Aberystwyth S48.

This is a late variety which gives good persistence but is late in spring growth.

c) Goliath.

This is an early timothy variety which gave promising results in National List trials but the National Institute for Agricultural Botany states that data are too limited for a decision on provisional recommendations[118].

Motim and Aberystwyth S48 dry matter yields and persistence are given in table 7.4.

Table 7.4. Recommended Timothy Varieties Used in Trials

Dry matter yields are expressed as a percentage of the total first harvest year yield of Aberystwyth S48.

Time of Flowering	Motim Intermediate	Aberystwyth S.48 Late
Heading Date (Days after 1st April)	78	86
Simulated Grazing Yield		
First Harvest Year Total (100 = 8900 kg.ha^{-1})	107	100
Conservation Yield		
First Harvest Year Total (100 = 10600 kg.ha^{-1})	111	100
Second Harvest Year Total	104	98
Persistence (0-9)	7.0	8.0
Year First Listed	1974	1968

4. Cocksfoot (Dactylis glomerata).

Cocksfoot produces high yields in late summer and is suitable for use as autumn keep in November and December. It is commonly used as a special purpose grass on the drier free draining soils in the south-east. Early varieties of cocksfoot normally head in early May, the late varieties are about two weeks later. Most varieties have good winter hardiness but some of the newer varieties have suffered damage in cold winters.

a) Aberystwyth S26.

This is low yielding in spring and low in the first harvest year yields but 2nd harvest year yields have been average[118]. It is a recommended late variety.

5. Meadow Fescue (Festuca pratensis)

Meadow fescue is occasionally sown in a simple mixture with white clover but is more often used in association with timothy or as a companion grass to lucerne because it is less aggressive than ryegrass or cocksfoot. Once established, meadow fescue grows well under dry conditions and makes a major contribution to timothy/meadow fescue leys in midsummer. Early varieties head in mid-May about ten days earlier than the late varieties which normally head at the end of May.

a) Aberystwyth S215.

This variety shows a good combination of yield, earliness and persistence[124].

6. Red Fescue (Festuca rubra).

This finds its greatest usefulness in agriculture on hill and marginal lands while certain strains have an obvious usefulness as a basis of lawn mixtures. This is a more usual component of hill reclamation. In low-land agriculture none of the red fescues can be regarded as first rate grasses for the summer period. However, one strain, S59, produces a wealth of green leafage during the autumn months which retains its winter greenness.

7. Rough-Stalked Meadow Grass (Poa trivialis).

This is not a particularly desirable grass in agricultural terms but it retains its greenness throughout winter and grows very slowly even in the depths of a normal winter.

Legumes.

8. Red Clover (Trifolium pratense).

Red clover accounts for about 21% by weight of the herbage legume seed used in this country and white clover for about 54%. The rest consists of alsike (6%), Lucerne (5%) and other herbages legumes of minor importance (14%)[121].

a) Broad Red.

This variety is one of the early red clovers, which are earlier in spring growth and earlier to flower than late red clovers. They normally produce two main cuts and a small autumn cut. Approximately 50% of the annual yield is produced in the first cut.

9. White Clover (Trifolium repens).

White clover is used mainly in grazing leys for its high nutritive value, as a source of nitrogen for grass growth, and as a good preparation for arable cropping. Heavy applications of nitrogen associated with intensive grazing systems usually cause a reduction in the contribution of white clover, but this reduction varies with variety. The large leaved varieties are generally more tolerant of applied nitrogen than the small leaved clovers.

a) Grasslands Huia.

This is a medium small leaved clover, which is intermediate between the small leaved varieties (which often originate from old pastures) and the medium large leaved clovers.

The small leaves tend to be associated with persistance although the relationship is not a linear one. This variety is susceptible to Sclerotinia trifoliorum (Clover Rot) which is more commonly found in Eastern England.

10. Lucerne (Medicago sativa).

Lucerne is mainly grown as a crop for cutting either for silage or hay. There are normally 3 or 4 cuts taken each year at intervals of about six weeks.

The plant has been grown as a crop since its introduction in the seventeenth century, but, until recently, the total acreage under Lucerne has been relatively small.

Crops.

11. Oil Seed Rape.

In recent years the world has seen a dramatic rise in the demand for edible oils and proteins. Previously, much of this was met by soya beans and to a lesser extent by ground nuts and sunflowers. As none of these crops are commercially viable in the U.K., and there has been an increased demand for oil from homegrown oilseed rape the area grown has risen dramatically. This is shown in Table 7.5.

Table 7.5.

Area Planted with Oil Seed Rape (England and Wales).

Year	ha. planted
1972	7000
1974	25000
1976	48000
1978	65000
1979	74000
1980	79000

It is the only oilseed or protein crop within the EEC which has an intervention price, guaranteeing a return competitive with other crops.

It is also a useful crop for wild oat control, and gives an excellent preparation and re-entry for wheat.

The crop can be grown under a wide range of conditions and although it grows better on heavier soils it will do well on moisture retentive soils which have good drainage. It involves the same basic machinery as cereals and its low labour requirement allows it to integrate well on many farms.

The grower must decide whether to grow the winter or spring sown crop. The advantages and disadvantages are summarized below.[122]

Winter Rape

Advantages	Disadvantages
Higher seed yield	Must be sown by mid-September
Higher oil content	Liable to pigeon damage in late winter
Early harvest before most cereals	Harvest may clash with winter barley and early grass seed crops
Allows cheap control of some perennial grasses and annual weeds	

Spring Rape

Advantages	Disadvantages
Can be sown 7 days after treating the ground for wild oats	Lower seed yield
	Lower oil content - may not always reach contract standard of 40%
	Preparation of suitable seed bed difficult on heavy land
	More costly and difficult weed control

Most of the oil is used in the manufacture of margarines and cooking fat. Work in the 1960's showed that diets containing a high content of erucic acid, which is found in rape oil, resulted in heart lesions of experimental animals. This created concern and induced plant breeders to develop varieties with low erucic acid content. Now the intervention prices apply only to varieties of low erucic acid[123].

a Jet Neuf.

This variety is resistant again stem canker and has a high resistance to lodging.

12. Winter Wheat.

True winter wheats and barleys need a cold period to become vernalised and to proceed from the vegetative to the reproductive phase. Many varieties can be sown during early spring with a reasonable chance of success provided the field conditions are satisfactory. However the yield potential of such crops is likely to be lower than the potential of spring varieties sown at the same time.

Although sowing after the latest safe date can sometimes be successful, complete crop failure can occur and it is safer to use a spring variety.

a) Avalon.

This is a high yielding winter wheat, recommended for general use by the National Institute of Agricultural Botany. It has a high ease of mill rating, and moderately high bread making quality. It has short, very stiff straw and good resistance to brown rust.[124]

13. Winter Barley

a Sonja.

This is a two-row barley with stiff straw. It is susceptible to brown rust and net blotch. It is not as high yielding as other varieties for example, Gerbel and Igri but is recommended for general use.[124]

7.4. The Rabbit Problem

Soon after sowing, it was apparent that rabbit grazing was one of the main problems at Elstow site, as the area was surrounded by dense hawthorn scrub on three sides. Bedfordshire Planning Department arranged for a rabbit-proof fence to be erected around the site. It was put up on the 23rd. and 24th September 1982 (12 weeks after sowing), together with some trip wires along the back wall of the plots.

A plan of Elstow site, after all the field trials were established is shown in Figure 7.2.

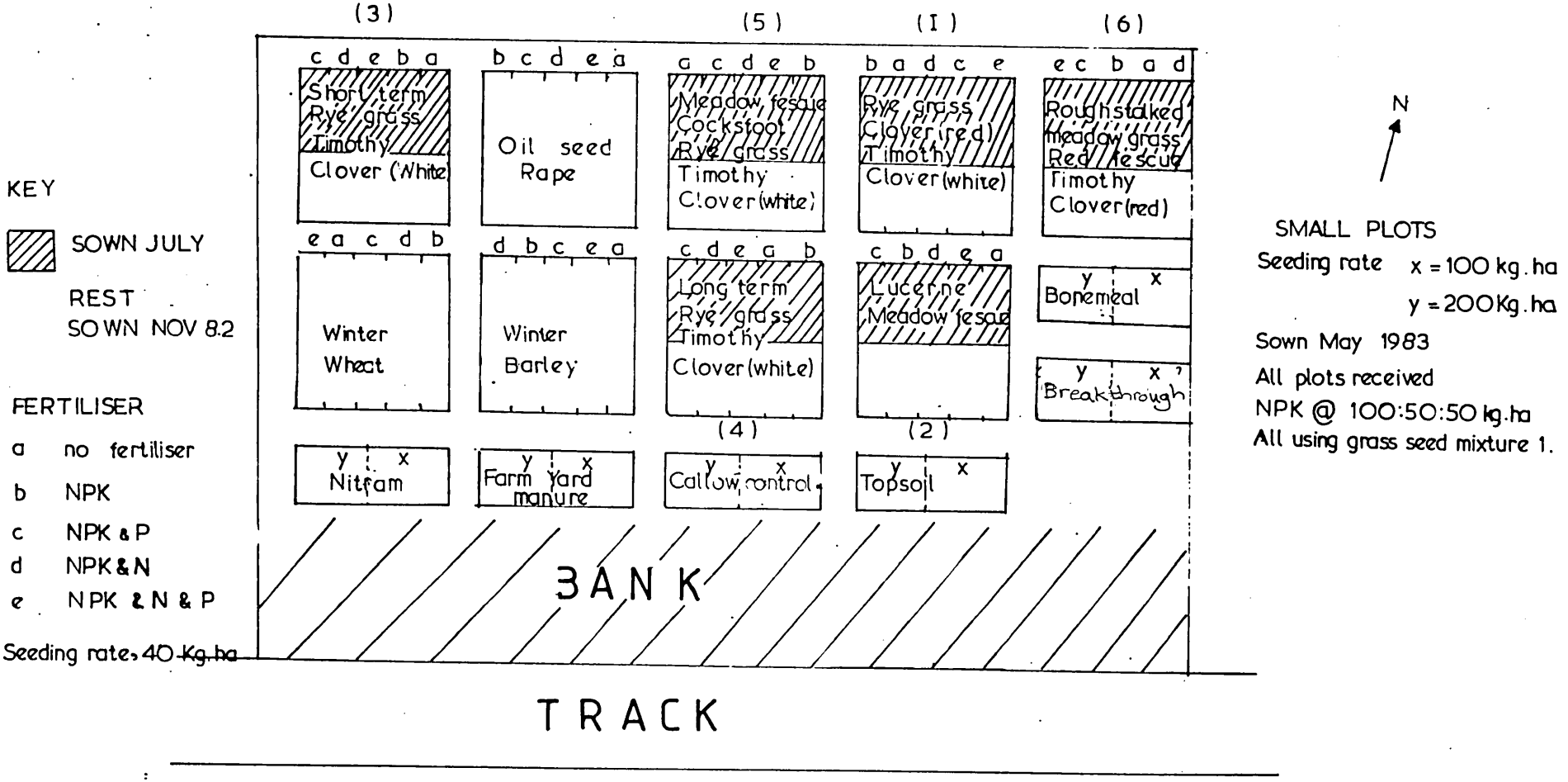
7.5. Experimental Design

i Yield Curve Experiments at Brogborough.

Using small plots (50cm x 50cm) the optimum levels of N and P_2O_5 fertilisers were to be investigated. These have previously been found to be the main factors limiting growth. The trials were to take the form of a four block fully randomised experiment.

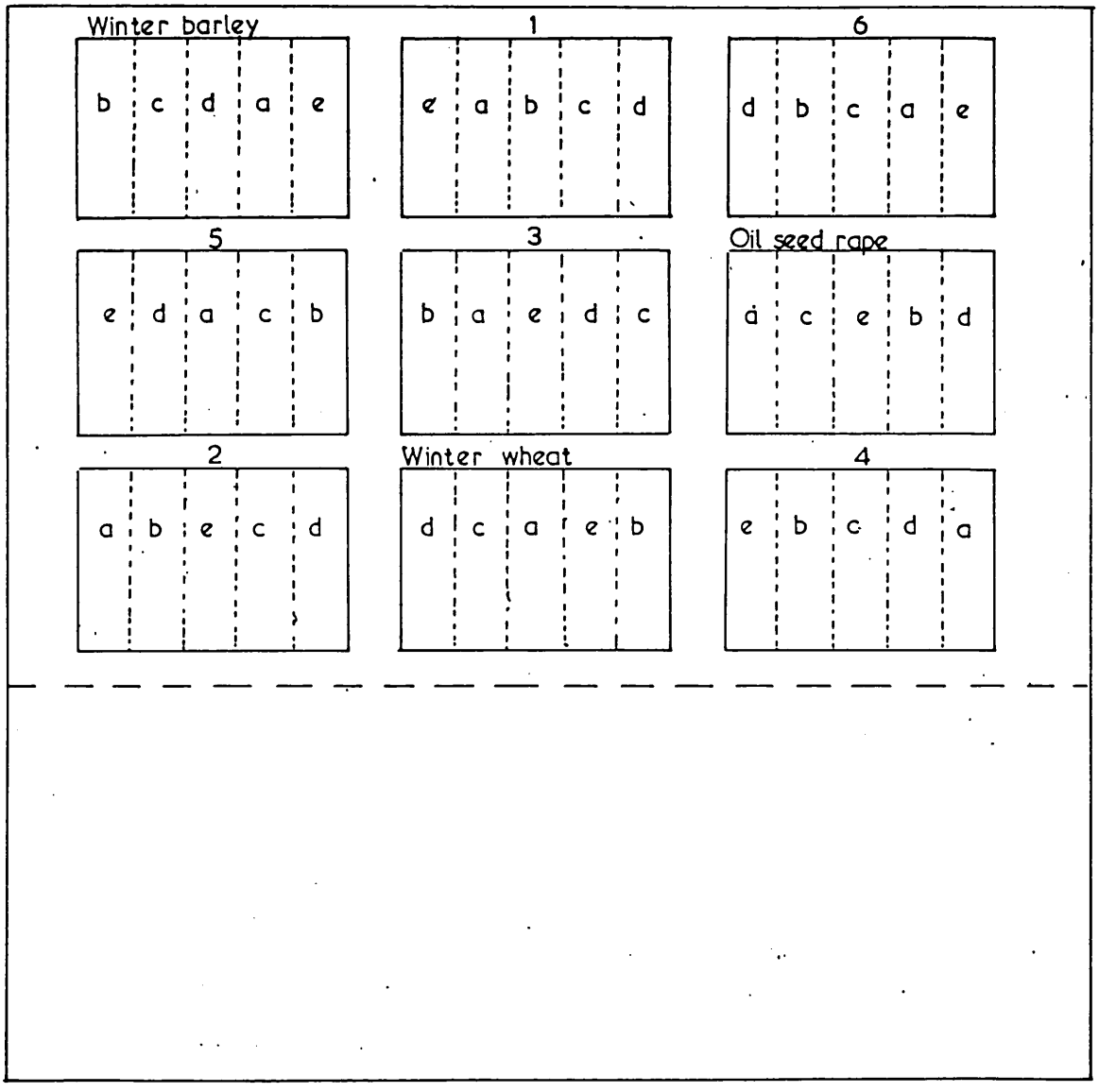
Due to difficulties later on in the project these could not be set up.

FIGURE 7.2 VEGETATION TRIALS AT ELSTOW



AUGUST 1983

FIGURE 7.3 CALLOW PORTION OF FIELD TRIALS AT BROGBOROUGH.



Seeding rate=40 kg.ha

0 5 10 metres

SCALE

PLATE 7.3 THE PROBLEMS OF RUTTING, COMPACTION AND INACCESSIBILITY ON A CLAY SURFACE. BROGBOROUGH NOV. 1982



PLATE 7.4 RUTTING CAUSED BY TRACKED VEHICLES



ii Plots 7.5M x 5.0M (5M x 5M at Elstow), divided into five strips. Compound NPK fertiliser was applied in a factorial type experiment together with additional applications of N and P. The rates of application were:-

NPK = 100:50:50 (N:P:K) $kg.ha^{-1}$

N = 200 $kg.ha^{-1}$ as nitram top dressing

P = 100 $kg.ha^{-1}$ as bomemeal. This also incorporates an additional 17.5 $kg.ha^{-1}$ N

It was hoped to replicate these experiments on

a) Callow at Brogborough

b) Top soil at Brogborough

c) Farm Yard Manure at Brogborough

d) Callow at Elstow.

Due to the difficulties of preparing the site at Brogborough, all sowing had to be delayed until November 1982. Sowing was then only possible on the callow plot as shown in Figure 7.3.

The plots at Elstow were split so that the six grass/legume plots could be partly sown in summer 1982; the rest of the sowing to be concurrent with Brogborough sowing. The summer plots at Elstow were sown on the 2nd July 1982.

A list of the grass/legume seed mixtures chosen for trials is shown in Table 7.2. The seeding rate was 40 $kg.ha^{-1}$ throughout. The nitram was applied on the 23rd. August 1982 (seven and a half weeks after sowing). The N.P.K. and Bonemeal was applied three days before sowing. The summer sown material was hand sown and the seeds and fertilisers were raked in.

The November sowing took place at both Elstow and Brogborough on the 5th and 8th November 1982. This was the earliest date that was available for seeding, due to delays caused by land preparation. The callow at that time was saturated and thixotropic. Poaching occurred. The callow was too wet for the seed to be raked in or drilled in rows.

The lucerne/meadow fescue mix sown at Elstow in the summer had failed due to the lucerne seeds not being viable. The whole of the Elstow lucerne/meadow fescue plot was re-seeded in November using a new batch of innoculated lucerne.

The winter wheat, barley and oil seed rape plots were sown on the 5th November 1982. The wheat and barley failed at both sites; no seeds germinated. Because of this a second attempt at growing these crops was made at Elstow in May 1983, when the wheat and barley plots were re-fertilized and re-seeded on the 9th May. This was the earliest date during the spring when the ground was dry enough to be workable.

Results showed that the Elstow plots managed to overcome the initial difficulties caused by late seeding, early frosts and waterlogged ground whereas those at Brogborough did not.

The N and P strips at Elstow were refertilized in May 1983 to avoid regression occurring.

iii Small Scale Organic Waste Trials at Elstow.

During Autumn 1982, a small plot of callow/farm yard manure mix was set up as shown in Figure 7.1., together with a small plot of topsoil of unknown origin. Other small scale trials set up in Spring 1983 included the use of Bonemeal, Nitram, Breakthrough and a callow control. Seeding of these plots took place in May 1983.

One seed mixture was used throughout:-

Westerwolds Rye-grass	40%
Red Clover - Broad Red	28%
Timothy - Motim	30%
White Clover	2%

Two seeding rates were used:-

X = 100 $kg.ha^{-1}$

Y = 200 $kg.ha^{-1}$

All plots received NPK fertiliser at a rate of 100:50:50 $kg.ha^{-1}$

Rates of application were as follows:-

Bonemeal @ 1000 kg.ha^{-1} (twice normal applications)

= 200 kg.ha^{-1} P_2O_5 and 35 kg.ha^{-1}N.

Breakthrough @ 1340 kg.ha^{-1} (Recommended Rate).
This is a soil Conditioner. Its marketing information reads:-
"Cuts out heavy digging - just rake it in. The natural soil conditioner. Murphy Breakthrough brings the structure of all soils, even the heaviest clay into peak condition for plant growth without heavy digging. It works by aggregating the fine colloidal particles opening up heavy clay soils and binding together light sandy soils resulting in a fine tilth.

It contains magnesium, calcium and a wealth of trace elements"

Topsoil — Approximately 15cm deep over the plot when applied in Autumn 1982. Since then it had settled and acquired a dense cover of grasses and broadleaved weeds. Applications of Murphy's Tumbleweed Weedkiller did not have the desired effect. The plot was dug on 24th May 1983 to remove weeds and prepare the site for seeding. During digging some soil was lost and also a mixing of the soil and callow was inevitable.

Farm Yard Manure — A layer of about 15cm in depth was applied. This was well mixed before seeding.

7.6. Results

7.6.1. NPK Factorial Experiments at Elstow and Brogborough

First Monitoring of Trials

23rd. August 1982. Summer sown Plots at Elstow.

A subjective assessment of growth was carried out. Grass seed mixture number 3 (Adas Recommended Short Term Ley) appeared to be the fastest to establish and had the greatest greening over effect. Seed Mixtures number 2 (Lucerne and Meadow fescue) and number 5 (Mid Seasons Production - Grazing/Hay Cuts including Meadow fescue and Cocksfoot) both seemed to be the slowest to establish. It was later realised that the first batch of lucerne was not viable. In all mixtures the clovers were the slowest to establish.

Second Monitoring of Trials

March 1983. Both Elstow and Brogborough Sites.

The callow was still wet at both sites and waterlogged in places, especially the oil seed rape plot at Elstow. The oil seed rape at both sites showed a

high germination rate and continued to grow during the winter. The lucerne had germinated but had a high percentage of loss at both sites. It was thought that it was either killed by frosts or eaten by pigeons. The grass/legume plots had established at Elstow, but not at Brogborough. The winter wheat and barley failed at both sites.

Subjective Assessment of Cover of Plots at Elstow

17th May 1983.

Any attempts at random sampling methods for assessing cover at this stage would have damaged the plots. An estimate of percentage cover and an assessment of individual species was required before re-application of fertiliser to the N and P strips of the grass/legume plots.

Estimates of percentage cover were made by eye, and are thus highly subjective. Results can be seen in Table 7.6.

Elstow Plots Harvest. August 1983

The large plots at Elstow were assessed for percentage cover and species composition at the beginning of August[+]. Weed species were also recorded where possible. The results of this extensive monitoring are shown in tables 7.7 and 7.9.

During the second week of August all the grass/legume mixtures were harvested on a split plot design. The wheat and barley plots at Elstow, resown in May were harvested on the 24th August. All material was dried at 60°C in an air circulation oven for 24 hours and then weighed. Results, converted to grams per square metre are shown in Table 7.8. The oil seed rape had all died by early summer. The small plots at Elstow were left for harvesting later in the year.

The seed mixtures and crops had all failed at Brogborough.

[+]by means of randomly located point quadrats.

Table 7.6. Subjective Assessment of Cover at Elstow, 17th May 1983

Plot 1. Westerwolds Rye-Grass, Red Clover, Timothy, White Clover

% Cover

	Summer Sown	Winter Sown
A - No T	10	5
B - NPK	17.5	15
C - NPK + P	17.5	27.5
D - NPK + N	27.5	37.5
E - NPK + N + P	22.5	30

Plot 2. Lucerne/Meadow Fescue

	Winter Sown
A - No T	3.5
B - NPK	11.5
C - NPK + P	10
D - NPK + N	11
E - NPK + N + P	7.5

Plot 3. Short Term Adas Recommended Ley. Perennial Rye-Grass, Timothy, White Clover.

	Summer Sown	Winter Sown
A - No T	12.5	2
B - NPK	35	19
C - NPK + P	62.5	18
D - NPK + N	47.5	20
E - NPK + N + P	55	27.5

Plot 4. Long Term Adas Recommended Ley. Perennial Ryegrass, Timothy, White Clover.

	Summer Sown	Winter Sown
A - No T	5	5
B - NPK	27.5	22.5
C - NPK + P	18	17.5
D - NPK + N	30	17.5
E - NPK + N + P	30	32.5

Table 7.6. (continued)

Plot 5. Mid Seasons Production - Grazing/Hay Cuts.
Meadow Fescue, Cocksfoot, Perennial Ryegrass, Timothy, White Clover.

	Summer Sown	Winter Sown
A - no T	5	2
B - NPK	20	15
C - NPK + P	15	12.5
D - NPK + N	37.5	22.5
E - NPK + N + P	37.5	27.5

Over all of this plot Cocksfoot was dominant with perennial ryegrass subsidiary. Unlike Westerwolds Ryegrass this strain is prostrate, the culms are not erect. Clover was absent.

Plot 6. Rough Stalked Meadow Grass, Red Fescue, Timothy, Red Clover

	Summer Sown	Winter Sown
A - NOT	5	5
B - NPK	12.5	30
C - NPK + P	12.5	30
D - NPK + N	52.5	22.5
E - NPK + N + P	45	37.5

Red fescue was the dominant species.

TABLE 7.7. ELSTOW PLOTS: PERCENTAGE COVER. AUGUST 1983.

1 % COVER

(a) MIXTURE 1: Westerwolds Ryegrass

	A:-		B:NPK		C:NPK+P		D:NPK+N		E:NPK+N +P		% in orig. mixture
	S	A	S	A	S	A	S	A	S	Aut	
TOTAL % COVER	41	40	49	49	59	65	59	68	74	86	100
PERENNIAL RYEGRASS	24	19	25	39	21	45	26	35	41	57	40
RED CLOVER-BROAD RED	11	5	7	9	10	7	6	1	18	3	28
TIMOTHY-MOTIM	3	8	17	2	22	13	25	33	17	52	30
WHITE CLOVER	1	0	0	0	2	0	0	0	0	0	2
OTHERS	2	9	5	4	8	8	10	3	10	5	0

(b) MIXTURE2: Lucerne/Meadow Fescue

	A	B	C	D	E	%
	A	A	A	A	A	
TOTAL % COVER	44	58.5	59.5	59.5	88	90
LUCERNE	2.5	6	3	4	6	20
MEADOW FESCUE	35	38	50.1	50.5	74.5	80
OTHER	6	17.5	6.5	4.5	8.5	0

(c) MIXTURE 3: ADAS Recommended Short Term Ley

	A		B		C		D		E		
	S	A	S	A	S	A	S	A	S	A	o/c
TOTAL % COVER	62	53	96	89	98	96	99	95	100	100	
PERENNIAL RYEGRASS	47	44	90	81	96	83	99	61	99	97	84
TIMOTHY-GOL IATH	3	2	1	9	4	19	5	34	4	37	8
WHITE CLOVER-GRASSLAND HUIA.	6	0	23	2	35	9	5	1	5	1	8
OTHER	8	7	2	4	7	12	0	13	0	2	

(d) MIXTURE 4: ADAS Long Term Ley

	A		B		C		D		E		
	S	A	S	A	S	A	S	A	S	A	
TOTAL % COVER	65	56	85	71	88	98	86	97	96	99	100
PERENNIAL RYEGRASS	60	51	82	68	83	83	81	81	95	77	81
TIMOTHY - S48	3	1	2	1	4	17	5	21	8	23	12
WHITE CLOVER	1	0	2	0	1	0	0	0	0	0	7
OTHER	1	4	1	2	0	5	0	3	0	6	0

(e) MIXTURE 5: Mid Seasons Production - Grazing/Hay Cuts

	A		B		C		D		E		
	S	A	S	A	S	A	S	A	S	A	
TOTAL % COVER	39	40	55	54	61	60	82	85	88	98	100
PERENNIAL RYEGRASS	26	31	27	34	24	30	25	52	35	30	7
MEADOW FESCUE	2	0	2	0	3	0	0	4	0	3	54
COCKSFOOT	10	4	24	14	34	23	53	23	52	68	23
TIMOTHY	0	0	0	0	0	0	0	8	1	1	12
WHITE CLOVER	0	0	0	0	0	0	0	0	0	0	4
OTHER	1	5	2	6	2	9	5	5	4	4	0

(f) MIXTURE 6: Own Mixture

	A		B		C		D		E		
	S	A	S	A	S	A	S	A	S	A	
TOTAL % COVER	35	40	65	59	75	67	72	86	82	96	100
ROUGH STALKED MEADOW GRASS	0	0	3	9	2	3	3	1	1	12	10
RED FESCUE	0	10	4	4	21	13	5	46	21	27	20
PERENNIAL RYEGRASS	34	24	51	42	43	28	56	35	56	68	30
TIMOTHY	0	5	3	2	3	15	7	43	14	45	20
RED CLOVER	1	0	7	2	8	4	3	2	4	1	20
OTHER	2	1	0	9	5	8	3	2	4	5	0

Oil Seed Rape Plot

	A		B		C		D		E	
	S	A	S	A	S	A	S	A	S	A
TOTAL % COVER	25		15		26		34		23	
O.S.R.	0		0		0		0		0	
OTHER	25		15		26		34		23	

Wheat Plot

	A		B		C		D		E	
	S	A	S	A	S	A	S	A	S	A
TOTAL % COVER	14		44		17		29		10	
WHEAT	7		6		1		5		1	
OTHER	7		40		16		25		9	

Barley Plot

	A		B		C		D		E	
	S	A	S	A	S	A	S	A	S	A
TOTAL % COVER	25		31		30		28		32	
BARLEY	0		0		0		1		0	
OTHER	25		31		30		27		32	

Table 7.8.

ELSTOW PLOTS: HARVEST AUGUST 1983

1) WESTERWOLDS RYEGRASS/RED CLOVER/TIMOTHY/WHITE CLOVER

	SUMMER	AUTUMN
A NOT	48.8	37.2
B NPK	165.8	110.6
C NPK + P	318.7	202.2
D NPK + N	274.8	241.7
E NPK + N + P	278.9	404.1

G/M^2 DRY WT.

2) LUCERNE/MEADOW FESCUE

	ALL RESOWN AUTUMN '82
A NOT	73.3
B NPK	66.8
C NPK + P	97.4
D NPK + N	114.4
E NPK + N + P	153.0

3) ADAS SHORT TERM LEY. RYEGRASS/TIMOTHY/WHITE CLOVER

	SUMMER	AUTUMN
A NOT	10.3	14.2
B NPK	237.8	129.4
C NPK + P	411.0	300.9
D NPK + N	401.1	325.5
E NPK + N + P	519.1	482.6

4) ADAS LONG TERM LEY. RYEGRASS/TIMOTHY/WHITE CLOVER

	SUMMER	AUTUMN
A NOT	56.0	10.8
B NPK	193.4	90.9
C NPK + P	175.8	243.5
D NPK + N	144.6	277.7
E NPK + N + P	303.5	386.2

Table 7.8. (continued)

5) MID SEASONS PRODUCTION/GRAZING HAY CUTS. RYEGRASS/MEADOW FESCUE/ COCKSFOOT/TIMOTHY/WHITE CLOVER.

		SUMMER	AUTUMN
A	NOT	38.3	16.3
B	NPK	66.2	44.6
C	NPK + P	121.6	96.0
D	NPK + N	207.4	168.8
E	NPK + N + P	262.4	219.7

G/M^2

6) ROUGH STALKED MEADOW GRASS/RED FESCUE/RYEGRASS/TIMOTHY/RED CLOVER.

		SUMMER	AUTUMN
A	NOT	30.6	26.2
B	NPK	104.9	25.0
C	NPK + P	208.0	87.4
D	NPK + N	173.7	244.4
E	NPK + N + P	348.6	348.6

WHEAT

		WT.STRAW	WT.SEED
A	NOT	3.5	0.1^{+}
B	NPK	3.1	1.3
C	NPK + P	1.4	0.04^{+}
D	NPK + N	3.3	1.6
E	NPK + N + P	1.8	0.6^{+o}

G/M^2

+ lodged and/or shattered during the thunderstorm on 23/
o eaten by pigeons

BARLEY

		WT STRAW	WT SEED
A	NOT	7.4	0.2
B	NPK	12.3	-
C	NPK + P	7.0	-
D	NPK + N	15.2	-
E	NPK + N + P	10.2	-

Table 7.9.

Number of Invading Species/Plot

(a) Westerwold's Ryegrass

	treatment A		B		C		D		E	
	summer/autumn sown plot S	A	S	A	S	A	S	A	S	A
Melilotus officinalis	x	x		x	x		x		x	
Senecio jacobaea	x	x			x		x			
Picris echioides	x	x	x	x	x	x	x	x	x	
Cirsium arvense		x		x		x				
Cirsium vulgare					x	x				
Rumex crispus		x				x			x	
Convulvulus arvensis		x			x				x	
Festuca rubra		x		x						
Medicago lupulina		x		x						x
Crataegus monogyna			x	x			x		x	x
Agrostis stolonifera		x	x	x		x	x			x
Plantago major			x							
Epilobium hirsutum						x				
Sonchus asper		x	x	x			x			x
Plantago lanceolata				x						
Matricaria maritima					x		x	x	x	
Atriplex hastata					x		x	x	x	
Epilobium angustifolium			x		x					
Holcus lanatus									x	
Rosa canina						x				
Cerastium holostoides						x				
Polygonum aviculare									x	
Daucus carota										x
Total no.	3	10	6	9	8	8	8	3	9	5

Table 7.9. b.

2. Lucerne/Meadow Fescue

	A		B		C		D		E	
	A	S	A	S	A	S	A	S	A	S
Potentilla reptans	x									
Cerastium holostoides	x			x						x
Picris echioides	x	x		x	x	x				x
Cirsium arvense										x
Chrysanthemum leucanthemum	x									
Rumex crispus		x								
Lactuca serriola		x								
Alopecurus sp.		x								
Trifolium pratense		x								
Lolium perenne		x								
Melilotus officinalis			x	x						
Matricaria maritima			x	x						
Agrostis stolonifera	x		x	x	x	x	x	x	x	x
Poa annua				x						x
Daucus carota				x	x					
Polygonum aviculare				x					x	x
Senecio jacobaea		x		x					x	
Holus lanatus							x	x		
Plantago major									x	
Chamaenerion angustifolium									x	
Atriplex hastata									x	
Atriplex patula										x
	5	7	3	9	3	2	2	2	6	7

Table 7.9.c.

3. Adas Recommended short term Ley.

	A		B		C		D		E	
	S	A	S	A	S	A	S	A	S	A
Picris echioides	x	x	x							x
Polygonum persicaria	x	x								
Melitotus officinalis	x	x	x	x	x	x	x			
Crataegus monogyna	x		x							
Agrostis stolonifera	x	x		x		x	x		x	
Rumex crispus	x								x	
Holcus lanatus	x	x			x	x	x	x	x	
Potentilla reptans		x								
Poa trivialis		x							x	
Cerastium holostoides		x								
Rosa canina			x							
Festuca rubra			x							
Sonchus asper			x		x					
Senecio jacobaea					x					
Cirsium arvense					x					
Medicago lupulina					x					
Epilobium hirsutum									x	
Atriplex hastata									x	
	7	8	6	2	6	3	3	1	5	1

Table 7.9. d.

4. Adas Recommended long term Ley.

	A		B.		C		D		E	
	S	A	S	A	S	A	S	A	S	A
Crataegus monogyna	x	x		x						
Cirsium arvense		x								x
Sonchus asper		x	x	x						
Senecio jacobaea		x					x			
Rumex crispus		x				x				x
Picris echoides		x	x	x		x	x	x		
Potentilla reptans		x		x	x					x
Plantago major		x								
Rosa canina				x						
Matricaria martima						x		x		
Poa pratensis						x				
Cirsium vulgare						x				
Poa trivialis						x		x		x
Melilotus officinalis						x				
Festuca pratensis										x
	1	8	2	5	1	7	2	3		5

Table 7.9.e.

5. Mid Seasons Production: Grazing/hay cuts.

	A		B		C		D		E	
	S.	A	S	A	S	A	S	A	S	A
Matricaria martima	x			x				x		
Atriplex hastata	x									
Medicago lupulina	x					x				
Melilotus officinalis	x			x		x				
Picris echioides	x	x	x	x	x		x	x	x	
Agrostis stolonifera	x	x			x	x	x	x		
Polygonum aviculare	x				x					
Festuca rubra	x			x		x		x		x
Senecio jacobaea		x	x							
Sonchus asper		x					x	x	x	x
Crataegus monogyna		x	x			x	x			
Holcus lanatus			x							
Potentilla reptans				x						
Epilobium angustifolium					x					
Rosa canina	x				x					
Cirsium vulgare					x					
Senecio vulgare					x					
Tussilago farfara							x			
Cirsium arvense						x		x		
Polygonum persicaria						x				
	9	5	4	5	7	7	5	6	2	2

Table 7.9.f.

6: Own Mixture.

	A		B		C		D		E	
	S	A	S	A	S	A	S	A	S	A
Melilotus officinalis	x		x	x			x			
Agostis stolonifera	x				x	x	x	x		x
Crataegus monogyna		x		x	x			x		
Daucus carota		x								
Plantago major		x		x		x				
Picris echioides		x		x	x	x	x			
Poa annua				x						
Senecio jacobaea					x				x	
Sonchus asper					x				x	x
Rumex crispus					x			x		
Prunella vulgaris							x			
Trifolium repens							x			
Matricaria martima								x		
Bromus sterilis		x							x	
Plantago lanceolata									x	
	2	5	1	5	6	3	5	4	4	2

Table 7.9.g.

Wheat:

	A	B	C	D	E
Agrostis stolonifera	x	x	x	x	x
Melilotus officinalis	x		x	x	x
Picris echioides	x	x	x	x	x
Polygonum aviculare	x	x	x	x	x
Equisetum arvense	x			x	
Matricaria maritima	x	x	x	x	
Senecio jacobaea	x	x	x	x	x
Tussilago farfara	x	x	x	x	x
Rosa canina	x		x	x	
Sonchus asper	x	x	x	x	x
Plantago lanceolata	x				
Rumex crispus	x	x	x	x	
Arrhenathenum elatius	x				
Cirsium arvense		x	x	x	
Sonchus arvensis		x			
Chamaenerion angustifolium		x	x		
Cerastium holostoides		x			
Catapodium rigidum		x			
Senecio vulgaris		x	x	x	x
Atriplex hastata		x	x	x	
Poa annua		x	x		
Epilobium hirsutum		x			x
Timothy grass		x			
Lolium perenne		x	x		
Plantago major			x		x
Cirsum vulgare		x	x		x
Potentilla reptans				x	
Poa trivialis				x	
Fagopyrum esculentum					x
Festuca pratensis					x
Crataegus monogyna			x		
Medicago lupulina			x		
Trifolium pratense			x		
Convulvulusarvensis				x	
Polygonum persicana					x
Chrysanthemum leucanthemum					x

Table 7.9.h.

Barley:

	A	B	C	D	E
Wheat	x	x	x	x	
Plantago major	x		x		x
Agrostis stolonifera	x	x	x	x	x
Senecio jacobaea	x	x	x	x	x
Timothy grass			x	x	
Melilotus officinalis	x	x	x		x
Lolium perenne	x	x	x	x	
Daucus carota	x	x			
Sonchus asper	x				
Polygonum aviculare	x	x	x	x	x
Cirsium arvense	x		x		x
Matricaria maritima	x	x			
Polygonum persicaria	x	x	x	x	
Crataegus monogyna	x				
Tussilago farfara	x	x			x
Poa annua	x	x			x
Medicago lupulina	x		x		
Cirsium vulgare	x	x			x
Festuca rubra	x			x	
Rumex crispus	x				x
Bromus sterilis	x	x	x	x	x
Picris echioides	x	x		x	x
Epilobium hirsutum	x	x	x		x
Senecio erucifolius					x
Leontodon autumnalis	x				
Convulvulus arvensis		x	x		
Equisetum arvense	x	x			x
Poa trivialis		x	x		x
Rosa canina		x	x		
Sencio vulgaris		x		x	
Prunella vulgaris		x			
Atriplex hastata		x			
Agropyron repens		x			
Chamaenerion angustifolium		x			
Holcus lanatus					x

Table 7.9.i.

Oil Seed Rape:

	A	B	C	D	E
Wheat	x	x		x	
Sonchus asper	x	x	x		x
Polygonum aviculare	x			x	x
Rumex crispus	x	x	x	x	x
Festuca rubra	x			x	x
Agrostis stolonifera	x	x	x	x	x
Tussilago farfara	x	x	x		x
Rosa canina	x	x		x	
Picris echioides	x	x		x	x
Holcus lanatus	x	x	x	x	x
Melilotus officinalis	x	x		x	x
Plantago major	x			x	
Polygonum persicaria		x	x		x
Cirsium arvense		x			x
Epilobium angustifolium		x			
Festuca ovina		x			
Alopecurus myosurides		x	x		
Crataegus monogyna		x	x		
Senecio jacobaea		x	x		
Potentilla reptans		x		x	x
Poa annua		x		x	
Cirsium vulgare		x			
Arenaria leptoclados	x				
Chamaenerion angustifolium			x	x	
Matricaria maritima		x			

Elstow Small Plots Harvest

The results of the small scale trials set up at Elstow in May 1983 and harvested in October 1983 were as follows:-

Plot	Seeding Rate ($kg.ha^{-1}$)	$G.M^{-2}$ Harvest
Nitram	100	132.3
Nitram	200	226.5
Bonemeal	100	23.6
Bonemeal	200	32.6
Callow Control	100	85.4
Callow Control	200	68.7
Breakthrough	100	10.1
Breakthrough	200	102.5
Farm Yard Manure	100	40.9
Farm Yard Manure	200	82.4
Topsoil	100	120.5
Topsoil	200	106.7

In order to find out whether an increase in the seeding rate from 100 - 200$kg.ha^{-1}$ significantly increased yields, a paired t-test was carried out on the results. The t-value = 0.865, which is not significant. That is, in these trials a doubling of the seeding rate did not increase yields significantly.

It is also apparent that the addition of the soil conditioner Breakthrough is not as beneficial as the addition of Nitram fertiliser.

7.7. Discussion

Burrows[125] studied root growth of clover on compacted colliery spoil. He stated that under severe compaction in the field the roots of established seedlings are confined to the upper few centimetres of the soil. In this position they are exposed to extremes of climate, are susceptible to dessication and are unlikely to survive. Even in conditions which favour survival, compaction severely reduces above ground growth.

Unlike problems associated with the chemical properties of spoils, those of compaction can be avoided by sensible handling of the material. For example, the timing of recommencing operations after rain periods could be critical to successful revegetation.

In the formation of tips, there is no compaction other than by the mass of material coming to rest above,[126] (unless the tips are compacted mechanically).

Compaction reduces the amount of pore space in soils. The important point is that the pores which are lost are the large ones which permit the free passage of air and water through the soils. Thus a compact layer of soil holds up water, prevents air getting into the soil and also stops roots penetrating through it.

Soils which compact most easily are those of silty texture or weakly developed structure or are low in organic matter (e.g. subsoils) and especially soils which are moist. The moisture content of a soil is critical as regards compaction. Dry soils are fairly resistant but the degree of compaction caused by the same pressure increases greatly as the soil becomes moist. The greatest compaction is caused in the soils which are at or around field capacity. Thus it is vital to handle soils only when they are dry to avoid compaction. Compaction also depends on the pressure applied; less compaction is caused by tracked vehicles than wheeled vehicles.[127]

Problems of methane generation on landfill sites in relation to their effect on vegetation are not well documented. Some sites can have serious difficulties with foul leachates and/or gaseous emissions from the fill.[127] From the results

of the main Brogborough Hill London Brick Farms Section ryegrass seeding, it appears that methane generation does not cause serious problems to crops at this site. This may be due to the thickness of the callow cap over the site. Brogborough Hill site is shown in Plates 7.1. and 7.2.

There were localised problems of methane bubbling into small pools during Spring 1983. The areas so affected were small, as shown in Plate 7.5. A problem which occurred throughout the two year project was the inaccessibility of the callow during a large part of the year and the crucial timing necessary in order to achieve satisfactory soil management. Soil treatment of any kind when the ground was wet caused rutting, compaction or pouching. This in its worse state meant that the ground has to be left until the following summer.

Through experience it has been found that mis-management of the clay when it is wet causes time losses of up to nine months. An example of the inaccessibility of the callow was during the 9th - 12th May 1983, when the Brogborough Hill refuse site was still not accessible without causing pouching, after a wet winter. The trials at Elstow were waterlogged in places at that time, although the areas of waterlogging were shrinking.

It was undoubtedly the combination of a waterlogged seed-bed and the late sowing that caused the failure of all the trials at Brogborough.

Although the sowing time at Elstow was the same as Brogborough, the conditions were not so poor and the grass/legume mixtures survived. The percentage seed loss through poor conditions was not investigated, but initial observations suggested it was high. It therefore appears that in a normal seed population a proportion are hardier than the rest. It is this hardy fraction that is able to survive in adverse conditions as shown at Elstow.

Because conditions were so much worse at Brogborough, it is likely that the endurances required by seedlings were beyond those available.

The Summer sown grass/legume mixtures were slow to establish. This is not surprising as the first few weeks were very dry. The rainfall in the months following seeding was 15.1mm for July 1982 and 42.8mm for August 1982. During

PLATE 7.5 A SMALL POND AT BROGBOROUGH SITE BUBBLING BECAUSE OF METHANE



PLATE 7.6 A SOLITARY BARLEY PLANT AT ELSTOW



this period the callow dried out and cracked into a mosaic like pattern.
The clovers were all slow to establish and contributed little towards the overall cover until towards the end of the summer in 1983. The lucerne had a high germination rate, but later regressed. Towards the end of the monitoring period it began to increase in cover and biomass, as indicated in Tables 7.7 and 7.8.
By Spring 1983, the beneficial effect of the fertilisers was apparent, although at this stage few trends were evident.
In Plot I (Westerworld's Rye-grass) the highest percentage cover was obtained by the application of additional nitrate fertiliser on top of the NPK application. Whereas in Plot III (the short term A.D.A.S. ley) the addition of bonemeal, supplying extra phosphate gave the highest percentage cover. In Plot V(the Mid-Seasons Production Mix with Cock's-foot), the highest percentage cover at that time was obtained by both nitram and bonemeal applications on top of the general purpose NPK.
The differences in cover due to different seeding times were still evident by May 1983 in plots III, V and VI. The percentage covers in the other plots had more or less evened out.
The final percentage cover figures before harvesting were more scientifically obtained by random quadrat analysis. One hundred point quadrats were randomly positioned in each sub plot, and the species touching the quadrat were recorded so that both percentage cover and species abundance could be monitored.
Mixture I.
The application of NPK with N and P gave highest cover values in both summer and autumn sown plots. Although the Timothy was slow to establish it provided a high percentage cover in terms of percentage seeds by weight in the original mixture. The red clover also provided a significant percentage cover.
The cover occupied by invading species was ten per cent or less. The white clover had a low percentage in the original mixture and did not contribute much towards cover.

FIGURE 7.4 ELSTOW PLOTS PRE-HARVEST MONITORING

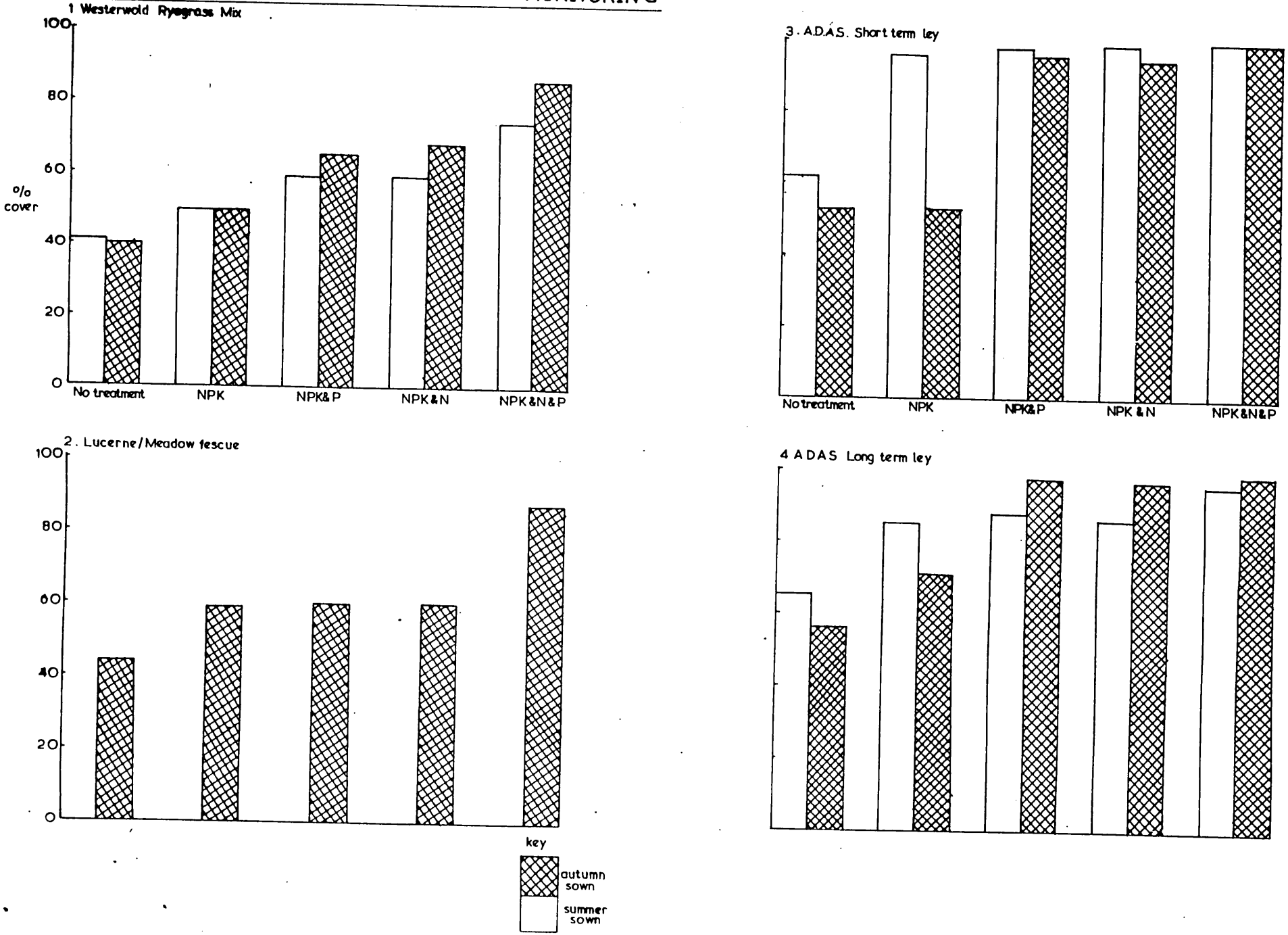
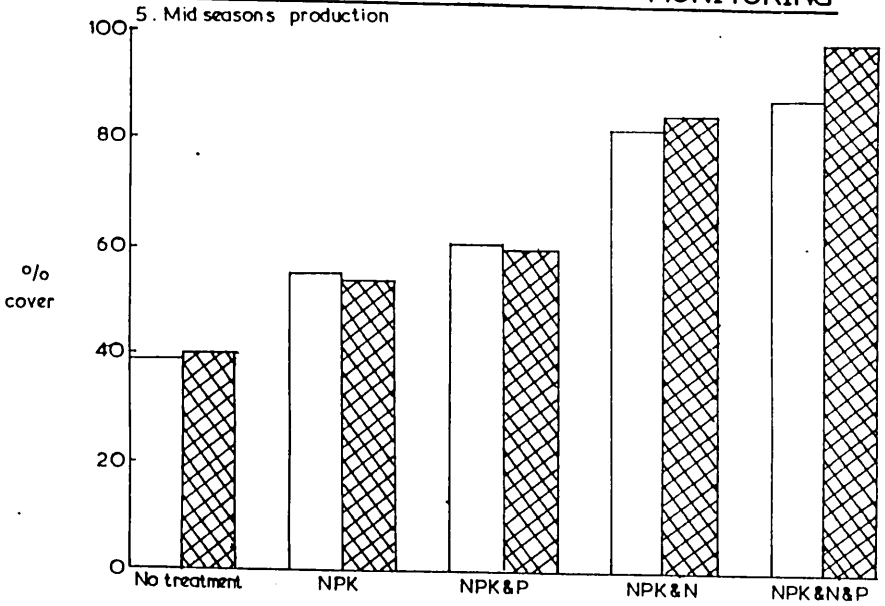


FIGURE 74 ELSTOW PLOTS PRE HARVEST MONITORING



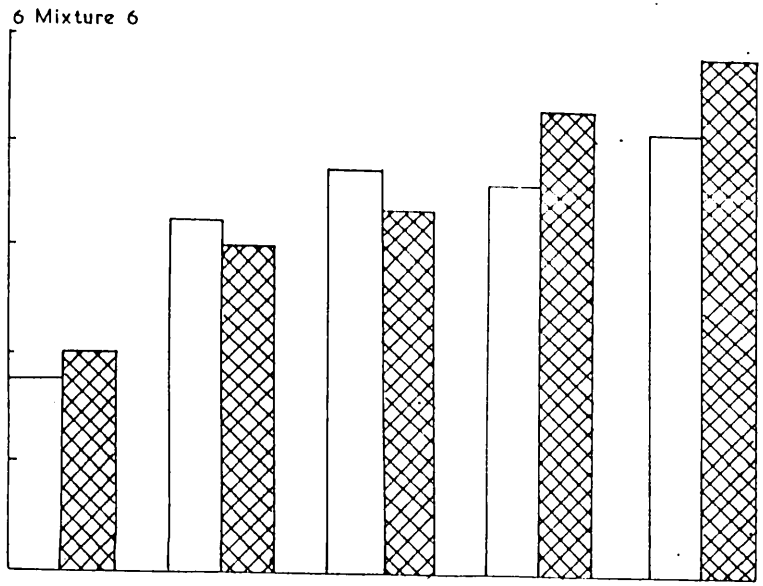
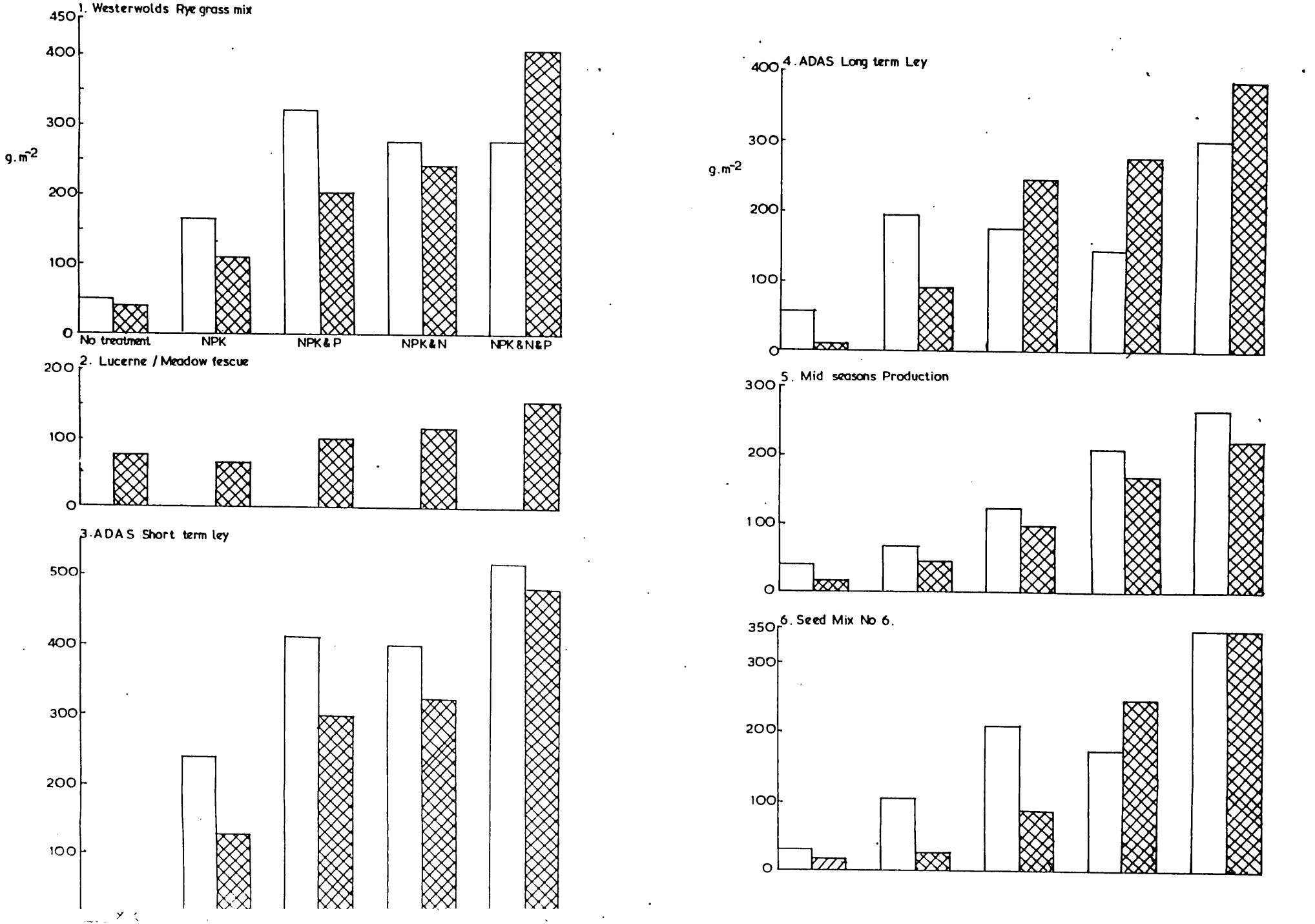


FIGURE 7.5 ELSTOW PLOTS HARVEST



Mixture II.

All the lucerne/meadow fescue plot was resown in November 1982. The highest cover value was obtained by application of NPK with N and P. The lucerne had begun to grow well after a slow start. The percentage cover figures do not really reflect this. The additional cover achieved by the application of fertiliser is almost entirely achieved by meadow fescue.

Mixture III.

This seed mix based on ryegrass gave a high percentage cover when NPK fertiliser was added. The performance of the Timothy was highly variable, its highest cover was recorded in the autumn sown, NPK and N plots. The Grassland's Huia white clover also gave variable results, its maximum cover being recorded in the summer sown NPK + P plot.

Mixture IV.

This mix based on ryegrass and timothy gave high percentage cover results throughout, dominated by the ryegrass. The timothy did better in the autumn sown plots. The white clover did not contribute much towards the cover.

Mixture V.

The ryegrass gave a higher percentage cover value throughout than its original percentage in the seed mixture. The meadow fescue did not do well, contributing between 0-4% total cover, although it was 54% of the original mixture. The white clover was not apparent. The timothy was out-competed by the cock'sfoot. Overall the Cock'sfoot achieved the most benefits from the additional fertiliser applications.

Mixture VI.

Without fertiliser applications perennial ryegrass was the dominant species. The timothy contributed a high percentage cover, especially in the autumn sown plots. The red fescue contributed around the right percentage cover according to its original content in the seed mix.

Oil Seed Rape/Wheat/Barley.

The total percentage cover for these plots is surprisingly high when the biomass of the actual crops are taken into account. The oil seed rape all died during the early spring 1983, although it had successfully germinated. The wheat and barley plots also gave poor results, the majority of the cover being provided by invading species.

A.D.A.S. recommended long term ley and seed mix VI (own mixture) were the best at surpressing weed species invading from the surrounding area.

Harvest Results.

Mixture I.

(Westerwolds Ryegrass).

Without any fertiliser treatment, very low yields were obtained. Applications of NPK increased yields, but additional applications of N and P also improved yield in the autumn sown plots. The highest yield in the summer sown plot was obtained by NPK + bonemeal.

Mixture II.

(Lucerne/Meadow Fescue).

These yields were low in comparison with the other mixes. The highest yields were obtained with NPK + N + P. The lucerne was very slow to establish.

Mixture III

(ADAS Short Term Ley).

Without fertiliser treatments very low yields were obtained. This mix gave highest yields overall. When fertilisers were added, giving yields of 519.1g.m^{-2} dry weight for the summer sown plot and 482.6 g.m^{-2} dry weight for the winter sown plot.

The yields of the summer sown plot are highest with NPK + P fertiliser applications. This may be due to the contribution of the clover. This was not replicated in the autumn sown plot, but neither was the high proportion of clover present.

Mixture IV.

(ADAS Long Term Ley).

This did not give such high yields as the short-term ley, but this is as expected. The long-term ley would achieve higher yields in later years. Again the summer sown plots had a higher yield in the NPK + P plot than the NPK + N plot.

Mixture V.

Very low yields were achieved without fertiliser applications. Highest yields were obtained by NPK + N + P. Total yields were only half those obtained by the A.D.A.S. Short Term Mix. Of the various species, Cock'sfoot was probably the most important in terms of biomass.

Mixture VI.

(Rough Stalked Meadow-grass/Red Fescue/Ryegrass/Timothy).

Highest yields were obtained in the summer sown plots by NPK + P then NPK + N. In the autumn sown plots, nitrogen had a greater additive effect with NPK than did phosphate. Although the yields obtained were not as high as the A.D.A.S. short-term ley, they approximately equalled the long-term ley.

The Wheat and Barley.

Those results were very poor, but this was not unexpected due to the very late seeding times.

As well as giving low yields the few surviving specimens showed signs of marginal and intercostal necrosis. They also had bluey green leaves with much drying off of the older leaves. The leaf sheaths were tinted purplish red in some specimens. There was a general lack of tillering.

These symptoms are indicative of several environmental problems, which in the case of Elstow could be wholly or partly related to

a) Nitrogen deficiency

b) Phosphate deficiency

c) Fluoride poisoning.

It is interesting to note here that wheat and barley are two of the least resistant species to fluoride pollution.

Plates 7.7. and 7.8. show Elstow field trials area in June 1983. The nitrogen deficiency causing a yellowing colour is evident in both plates, as is the beneficial effect of additional fertiliser applications. The plots in the foreground of 7.7. are the crop plots.

The highest yields achieved here are 5 190 $kg.ha^{-1}$. These compare favourably with estimated yields at Brogborough, from the L.B.C. Farms Ryegrass area. Yields there were estimated at between 3100 $kg.ha^{-1}$ and 5800 $kg.ha^{-1}$ for the first cut.

Problems with interpreting these results are partly related to the fact that no replication could be carried out as the sites at Brogborough were not available for setting up trials. By the time this was realised, it was too late to alter the experimental design.

Replication and randomisation prevent misleading chance effects being given spurious biological significance. It is a consolation that the callow is a fairly uniform material, thus heterogeneity of substrate within the site was not considered to be a major problem.

Edge effects (i.e. the close proximity of one plot to another) did not appear to be a problem, as shown in Plate 7.8.

Some of the more important results to emerge from this study therefore include:-

i. No one seed mixture out performs the others on callow.

ii. Legumes do not provide a major contribution to cover or biomass.

iii. The growing of arable crops as a pioneer cover is not recommended.

iv. An adequate grass cover can be achieved by applying phosphate and nitrate fertilisers.

v. The use of soil conditioners is not recommended.

PLATE 7.7. ELSTOW PLOTS. GENERAL VIEW. JUNE 83



PLATE 7.8 GRASS SEED MIXTURE NO 6 MAY 83



8. GREENHOUSE TRIALS.

8.1. Introduction

Pot experiments have the advantage over field trials in that they are cheaper to set up and can cover a wide range of treatments and combinations, though only over a short time scale. They are particularly valuable for testing the efficacy of fertiliser and other soil amelioration treatments.[128]

8.2. Work Previously Carried Out on Callow

One set of greenhouse trials was set up during the summer of 1980[24] using four types of growing medium - two types of callow (one from the surface and one from depth), clay soil obtained from near Brogborough II Pit and Fisons Levington Potting Compost. The callow samples were crushed using a pestle and mortar to obtain material which was suitably sized for use in pot-trials.

Five species and one seed mix were used on each substrate. They were as follows:-

(a) Phleum pratense (Timothy-Oldenwalder).

(b) Lolium perenne (Perennial Rye-Grass-N.Z. Ruanii).

(c) Poa trivialis (Rough-Stalked Meadow-grass-Dasasi).

(d) Festuca rubra (Red Fescue - Creeping Pennlawn).

(e) Trifolium pratense (Red Clover).

(f) Mixture:-

Poa trivialis	10%
Lolium perenne	30%
Festuca rubra	20%
Phleum pratense	20%
Trifolium pratense	10%

The same fertiliser regime was used for each species/seed combination on each substrate. These were as follows:-

(a) No fertiliser treatment.

(b) Ammonium nitrate at a rate of 125kg.ha^{-1}-N.

(c) Sodium hydrogen phosphate at a rate of 100 kg.ha^{-1}-P

(d) Both (b) and (c)

The nutrients were applied in solution to the soil surface of the pots approximately two weeks after germination.

63mm flower pots were used throughout. In all combinations three replicates were set up, randomised on the greenhouse bench in three blocks.

The vegetation was harvested after eight weeks. During the early stages of growth the hot dry weather in the green house affected both the germination and survival rates. Temperatures of over 34°C were recorded in the shade at times.

Average yields were converted to $g.m^{-2}$ and plotted as histograms as shown in Figure 8.1. The standard error of each set of replicates is shown as a vertical bar. The differences in yield between the various growing media were calculated using Student's t-tests, as shown in Table 8.1. It was realised at the time that three replicates could not be considered to fit the standard curve. However, the only non-parametric test considered at the time (the Rank Sum test) was not suitable due to the small amounts of data employed in each comparison.

When the nutrient deficiencies in the overburden were corrected, the differences in yield between overburden and clay soils became insignificant in most cases.

In comparison, yields of grasses on potting compost were, on the whole, significantly greater than the corresponding yields on overburden. These differences were reduced when the nutrient status of the overburden samples were increased, making the difference in yield insignificant in the majority of cases when both N and P were applied.

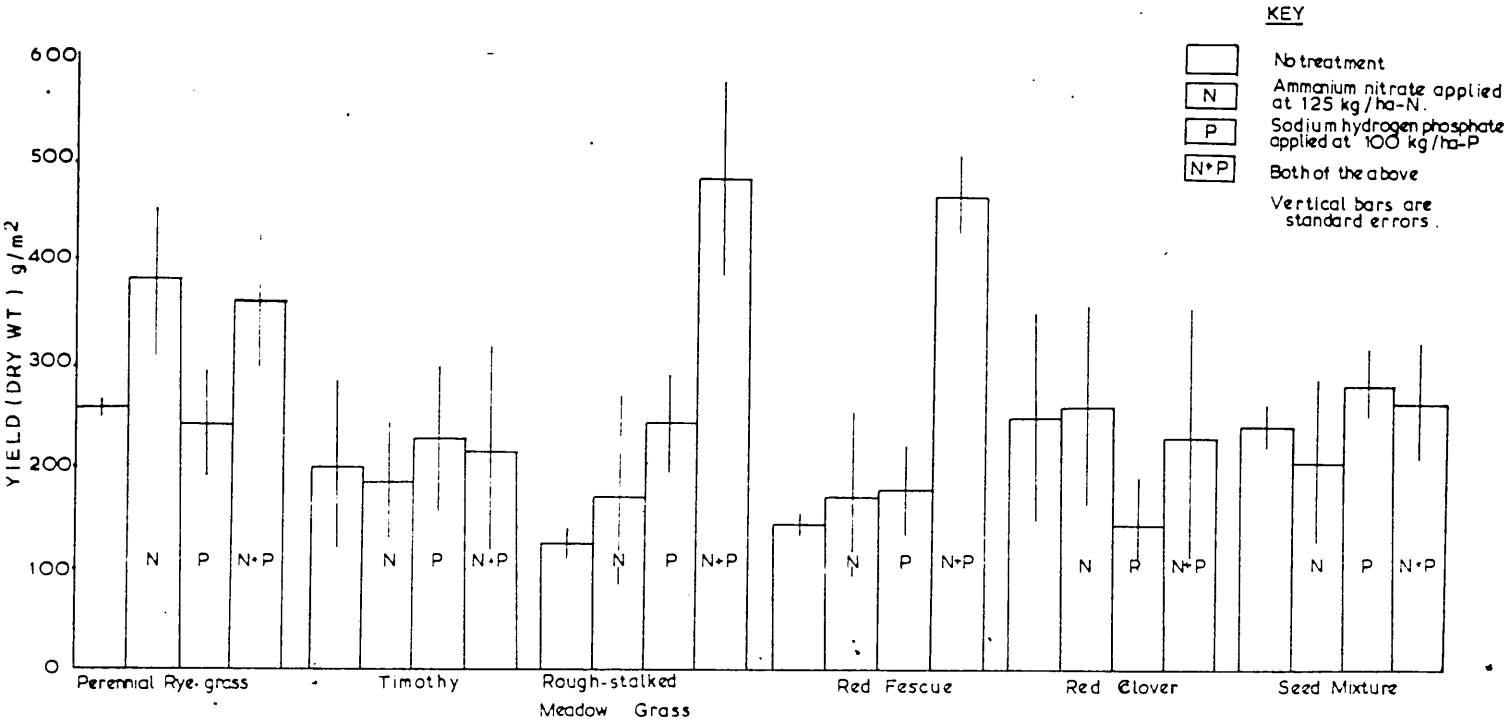
Yields were increased considerably by the application of N and P fertilisers at normal agricultural rates.

From these results, it was apparent that vegetation on orange-brown (surface) callow produced higher yields than the deeper blue callow. These differences were probably related to the difference in mineralogy of the clay, i.e. the weathered material from the surface has a higher oxidised iron content than the material from depth.

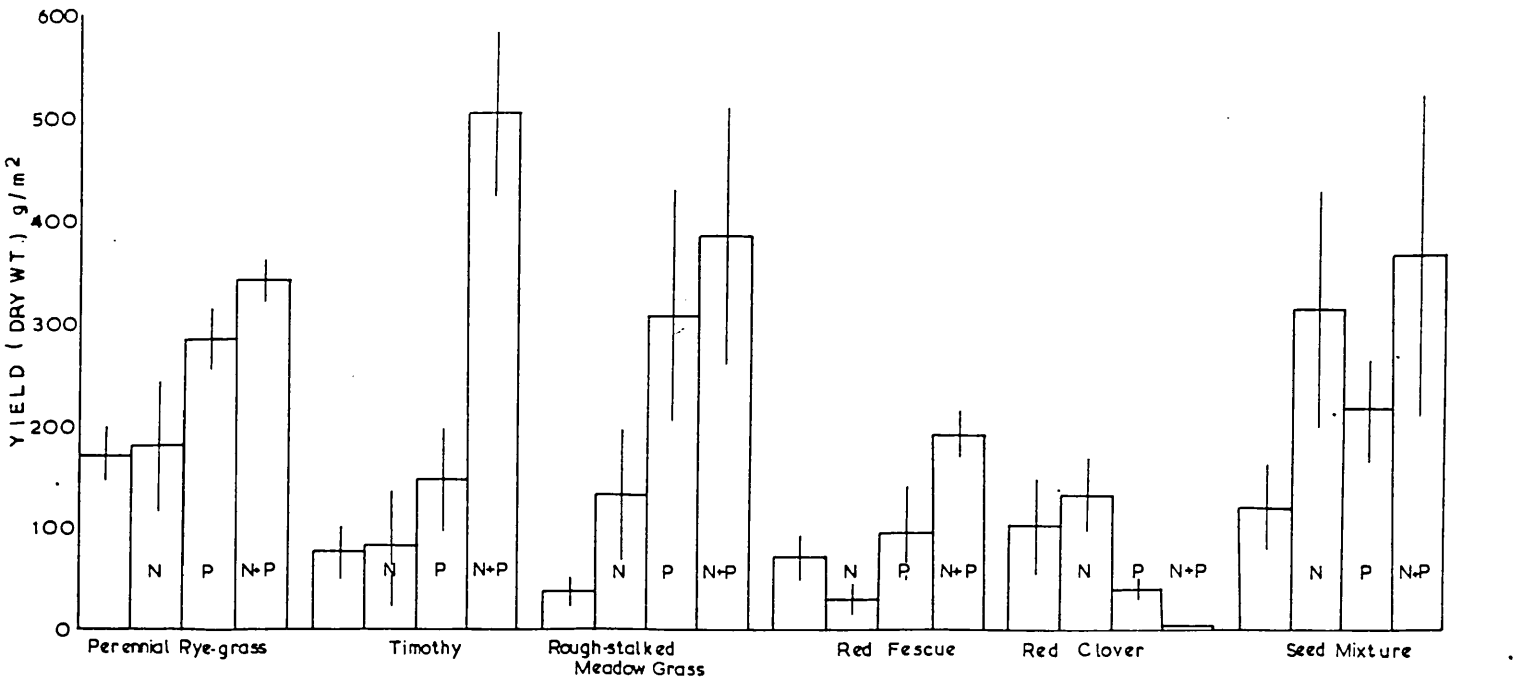
FIG 8.1

AVERAGE YIELDS IN GREENHOUSE EXPERIMENTS

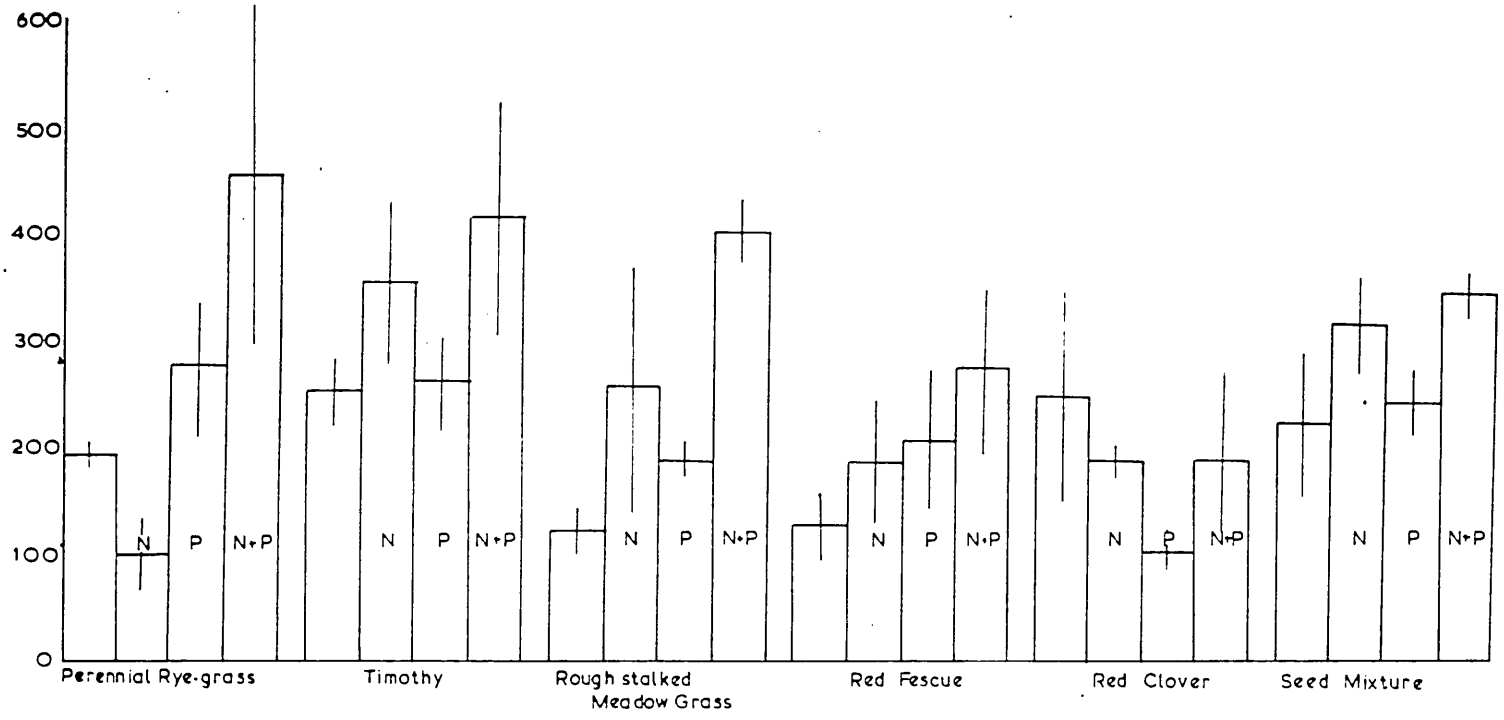
(a) Overburden from near the surface



(b) Overburden from depth



(c) Clay Soil from the Marston Vale



(d) Fisons Levington Compost.

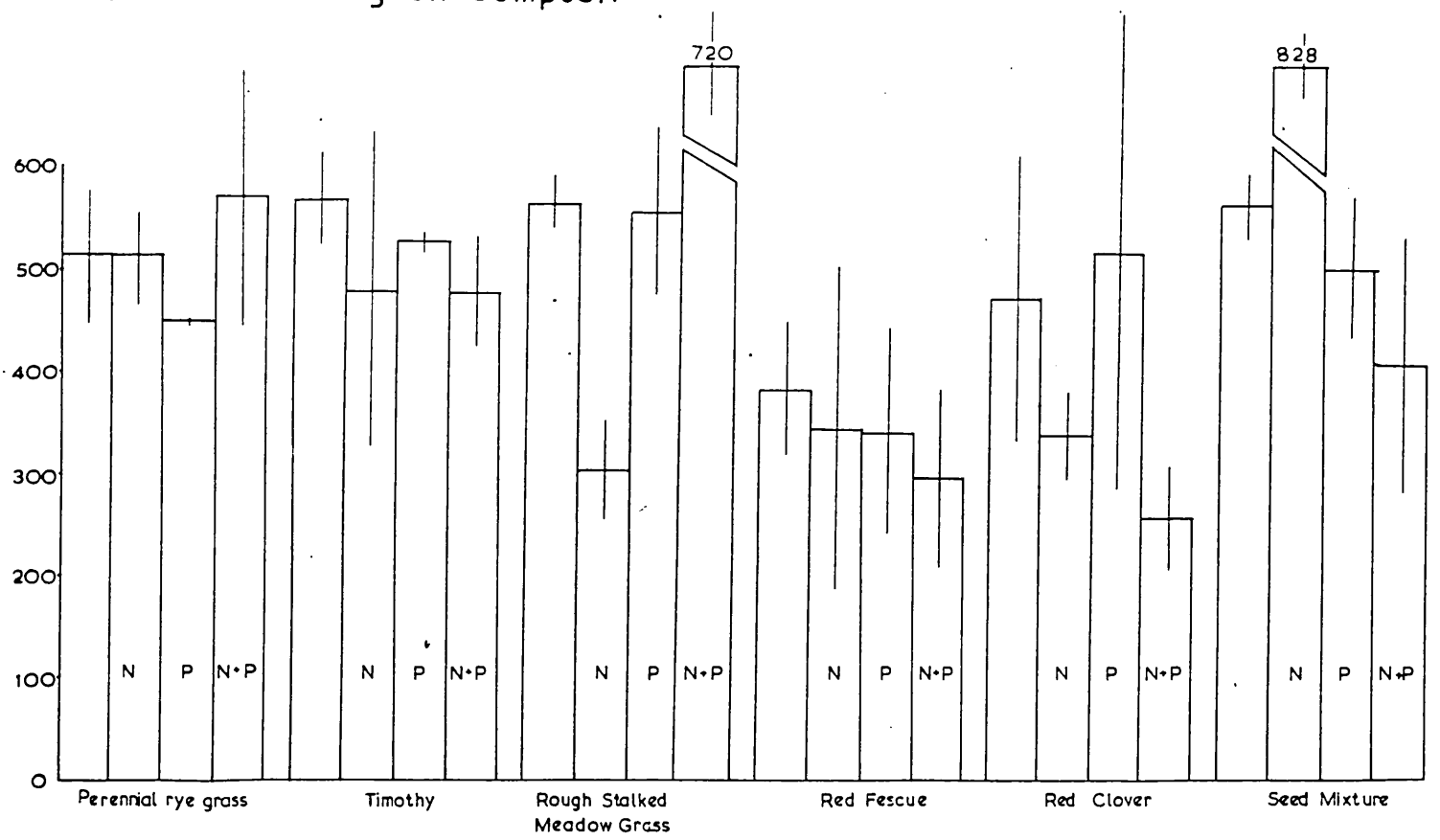


Table 8.1 Results of t-tests to Find Whether ther is a Significant Difference in Yield between Potting Compost and Overburden

(a) Potting Compost and Overburden from Depth

Species	No Treatment	N	P	N+P
Lolium perenne	****	***	****	N.S.
Phleum pratense	****	**	****	N.S.
Poa trivialis	****	*	N.S.	*
Festuca rubra	****	N.S.	*	N.S.
Trifolium pratense	*	**	N.S.	****
Seed Mixture	****	***	**	N.S.

(b) Potting Compost and Overburden from the Surface

Species	No treatment	N	P	N+P
Lolium perenne	***	N.S.	***	N.S.
Phleum pratense	***	N.S.	***	*
Poa trivialis	****	N.S.	**	*
Festuca rubra	***	N.S.	N.S.	N.S.
Trifolium pratense	N.S.	N.S.	N.S.	N.S.
Seed Mixture	****	****	**	N.S.

Table 8.1 (Cont) **Results of t-tests to Find Whether There is a Significant Difference in Yields between Clay Soil and Overburden**

(a) Clay Soil and Overburden from Depth

Species	No Treatment	N	P	N+P
Lolium perenne (Perennial Rye-grass)	N.S.	N.S.	N.S.	N.S.
Phleumpratense (Timothy)	***	*	N.S.	N.S.
Poa trivialis (Rough stalked Meadow Grass)	**	*	N.S.	N.S.
Festuca rubra (Red Fescue)	N.S.	**	N.S.	N.S.
Trifolium pratense (Red Clover)	N.S.	N.S.	**	*
Seed Mixture	N.S.	N.S.	N.S.	N.S.

(b) Clay Soil and Overburden from the Surface

Species	No Treatment	N	P	N+P
Lolium perenne	***	***	N.S.	N.S.
Phleum pratense	N.S.	N.S.	N.S.	N.S.
Poa trivialis	N.S.	N.S.	N.S.	N.S.
Festuca rubra	N.S.	N.S.	N.S.	*
Trifolium pratense	N.S.	N.S.	N.S.	N.S.
Seed Mixture	N.S.	N.S.	N.S.	N.S.

* Significant difference at P = 0.1
** Significant difference at P = 0.05
*** Significant difference at P = 0.02
**** Significant difference at P = 0.01
N.S. Not significant

The validity of using a parametric test, i.e. Student's t-test, on these results was tested in 1983. Normal probability plots, using the statistical package MINITAB, were drawn on a sample of the results. All of the plots produced deviated from a straight line. It was therefore considered that the data did not come from a normal population.

A more suitable test for the results obtained, was considered to be a one-way analysis of variance, which compares the results from each group, not pairs of results as in the Student's t-test. Once a statistically significant result was obtained for a group of results, analysis was continued to find out where the difference lay within that group.

In order to achieve this, the method of Tukey was applied (Modified by Snedecor[129]).

The test was made by computing a difference, D, which is significant at the 5% level, then comparing D with a $(a - 1)/2$ sample differences in the experiment.

D is the product of Sx and a factor Q taken from Tukey's tables.

a = number of treatments to be compared.

$$Sx = \frac{\text{mean square (error)}}{\text{no. of replicates}}$$

In this way, significant differences within the group tested by the one-way analysis of variance could be distinguished.

A summary showing results of all the one-way analyses of variance and results of Tukey's Tests of Comparisons Among all Means is shown in Table 8.2.

It was found that the effect of fertiliser treatments on yields were only significant in certain combinations. The effects were not invariably significant. There is no set pattern throughout the table, the significant results being scattered throughout the four substrates. Red clover was the only species which did not show a significant increase in yield with fertiliser applications on at least one substrate.

Table 8.2. One Way Analyses of Variance and Tukeys Tests Applied to the 1980 Greenhouse Trial Results. To Investigate Whether Fertiliser Treatments Increase Biomass in Greenhouse Trials.

Soil Type	Species	F Value	Significance	Differences by Tukey's Test
Potting Compost	Perennial Ryegrass	0.47	N.S.	
	Timothy	0.17	N.S.	
	Rough-Stalked Meadowgrass	9.20	< 0.01	4>2; 1>2
	Red Fescue	0.1	N.S.	
	Red Clover	0.55	N.S.	
	Mix	6.07	<0.05	4>2
Clay Soil	Perennial Ryegrass	2.98	N.S.	
	Timothy	1.08	N.S.	
	Rough-Stalked Meadowgrass	3.81	N.S.	
	Red Fescue	1.04	N.S.	
	Red Clover	0.76	N.S.	
	Mix	1.71	N.S.	
Top Overburden	Perennial Ryegrass	1.64	N.S.	
	Timothy	0.05	N.S.	
	Rough-Stalked Meadowgrass	4.39	< 0.05	4>1
	Red Fescue	9.57	<0.01	4>1;4>2;4>3
	Red Clover	0.31	N.S.	
	Mix	0.33	N.S.	

Table 8.2. (continued)

Soil Type	Species	F Value	Significance	Difference by Tukey's Test
Bottom Overburden	Perennial Ryegrass	4.48	< 0.05	4>1
	Timothy	12.69	< 0.01	4>1;4> 2;4>3
	Rough-Stalked Meadowgrass	2.84	N.S.	
	Red Fescue	5.5	< 0.01	4>2
	Red Clover	3.71	N.S.	
	Mix	1.13	N.S.	

+Key

1 = No treatment
2 = Nitrate Fertiliser @ 125 $kg.ha^{-1}$-N
3 = Phosphate Fertiliser @ 100 $kg.ha^{-1}$-P
4 = Both nitrate and phosphate.

In all cases apart from one, it was the application of both nitrogen and phosphate fertilisers that gives highest yields.

One result which did not fit in with trends was that of Rough-Stalked meadow-grass on potting compost. Higher yields were obtained in the "no-treatment pots" than in the nitrate pots.

Interaction is a term given to the type of effect which the factorial experiment is designed to detect. Its presence destroys the additivity of the main effects.

It is measured by the difference between two differences; that is by the failure of two differences to be the same.

In this case, it was desirable to find out whether there was any interaction between species and fertiliser regime. In order to compute this a two-way analysis of variance (A.O.V.) was used. The results of this analysis is shown in Table 8.3.

It was found that there was no interaction between the two variables (seed type and nutrient status).

8.3. Summer 1982 Trials

8.3.1. Methods

The first set of trials established during the project were ones replicating the field trials at Elstow and Brogborough. All sixgrass seed/legume mixtures were used on three substrates.

i Callow from Elstow

ii Top soil collected from the edge of Quest Pit.

iii Callow from Elstow mixed with farm-yard manure at a rate of 10-15g.pot^{-1} (dry weight) which is equal to 450 - 680 kg.ha^{-1}.

The same five fertiliser treatments were used.

Table 8.3. A.O.V. Table To Investigate the Interaction Effects between Seed Types and Nutrients.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Sig.
Main Plots					
Mixtures	5	308183	61637	0.74	N.S.
Blocks	2	334393	167197	1.99	N.S.
Main plot error	10	836890	83689	-	
Sub Plots					
Nutrients	3	198062	66021	4.56	<0.05
Nutrients & seed	15	316254	21082	1.46	N.S.
Error	48	694611	14471	-	

i No fertiliser

ii NPK at 100:50:50 $kg.ha^{-1}$

iii NPK at 100:50:50 $kg.ha^{-1}$ and nitram at 200 $kg.ha^{-1}$ N

iv NPK at 100:50:50 $kg.ha^{-1}$ and bonemeal which supplied 100 $kg.ha^{-1}$ P and 17.5 $kg.ha^{-1}$ N.

v NPK at 100:50:50 $kg.ha^{-1}$ and both nitram and bonemeal as in iii and iv.

The additional nitrate was applied as a top dressing four weeks after germination. Sowing rates were increased to 100 $kg.ha^{-1}$.

Five replicates of each seed mixture/substrate/fertiliser amendment were set up. The pots were arranged in a five block randomised experiment. This was so both inter and intra group comparisons could be made.

The trials were set up in July and harvested nine weeks later. Germination and growth in the first few weeks did not prove to be as good as in the 1980 trials. The lucerne/meadow fescue results were not included in the final results as the lucerne seeds were later found to be not viable. Seed mortality was high in all seed mixtures as they were subjected to moisture stress during the early stages of growth. The late sowing combined with the fast drying conditions were most likely responsible for this.

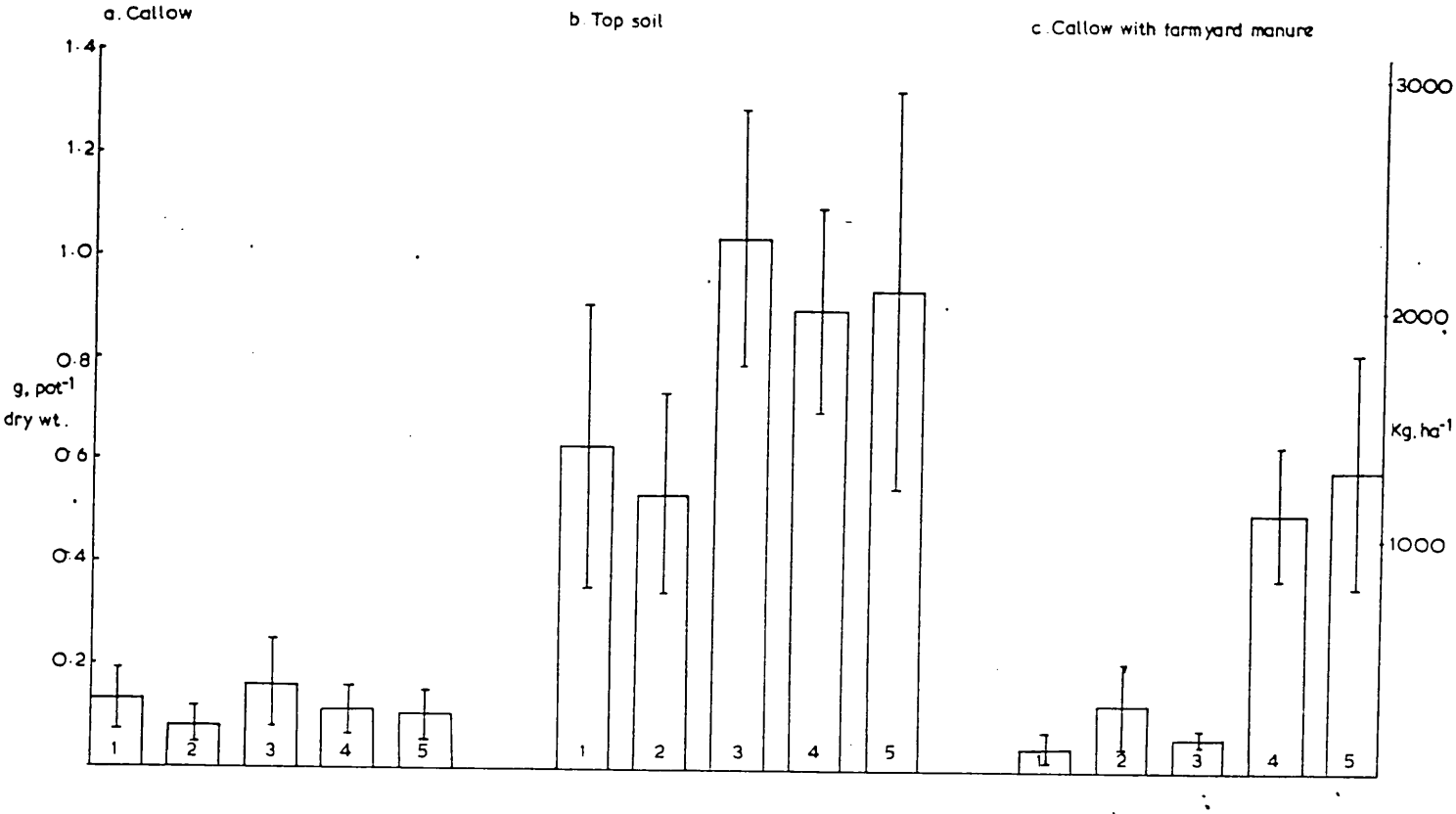
8.3.2. Results

Dry weight yields for the five seed mixtures are shown in Figure 8.2. Vertical bars represent standard errors. The differences between yields on top soil and those on callow are self evident.

In order to determine whether the fertiliser treatments promote growth in the five seed mixtures on the three different substrates, a series of one way analyses of variance was carried out. Results are shown in Table 8.4. The only seed mixture/substrate combination where the fertiliser treatments had a statistically significant effect was Westerwolds Ryegrass mix on callow

FIGURE 8.2 YIELDS FROM FIRST SET OF GREENHOUSE TRIALS

SEED MIX 1



SEED MIX 3

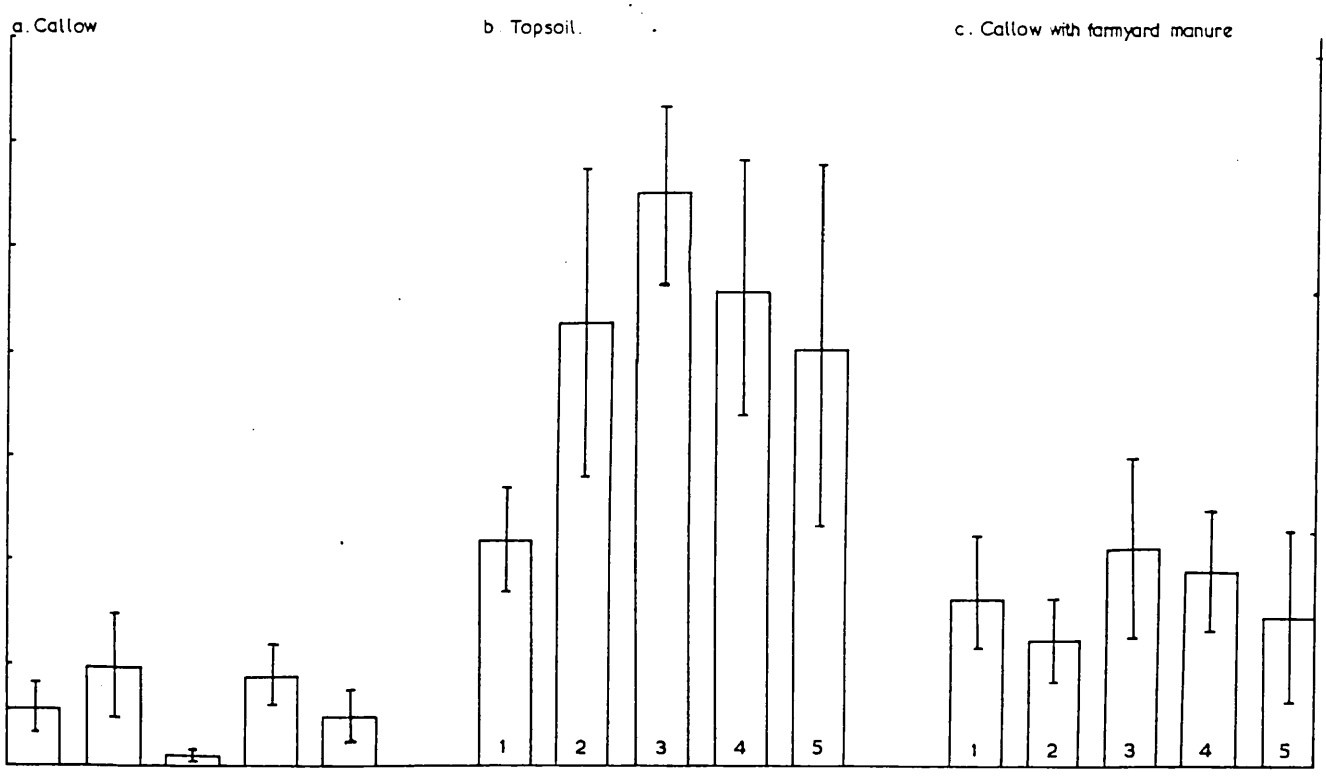
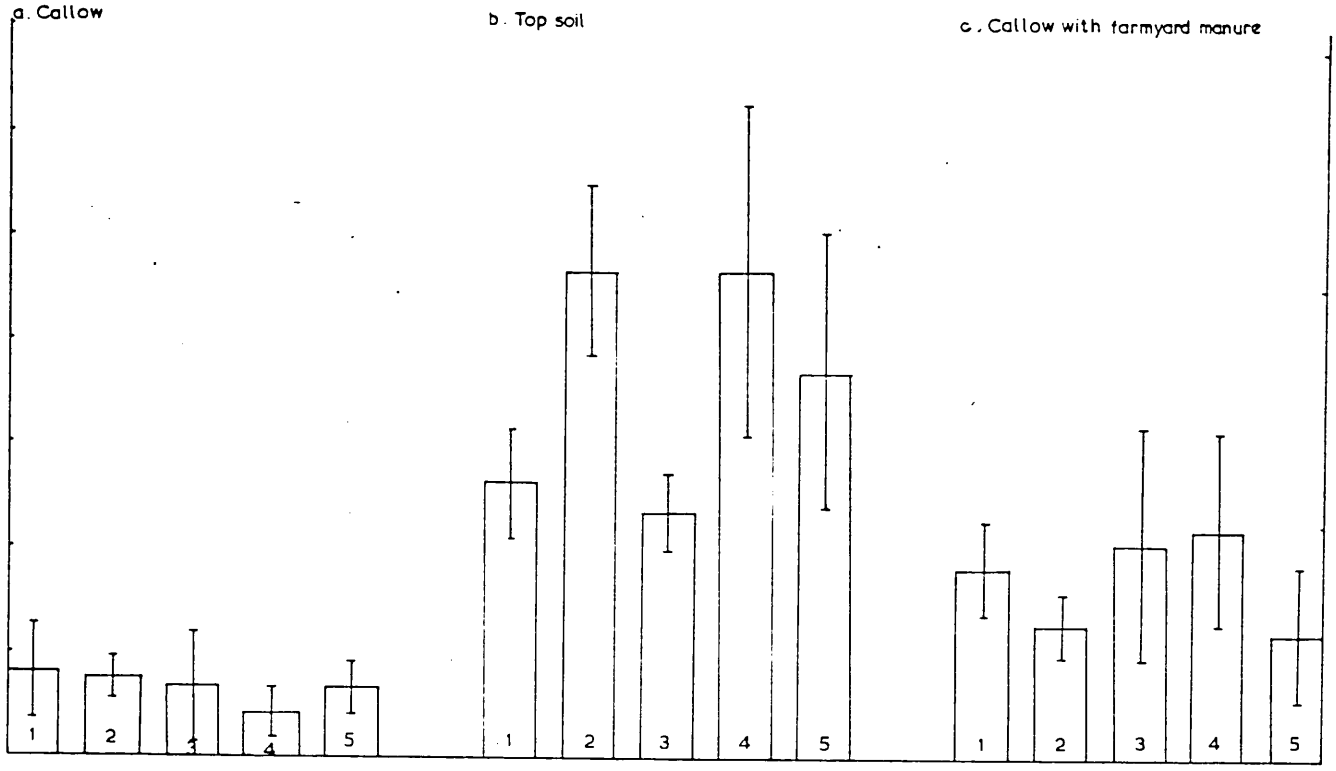


FIG 8.2 (Cont.)

SEED MIX 4



SEED MIX 5

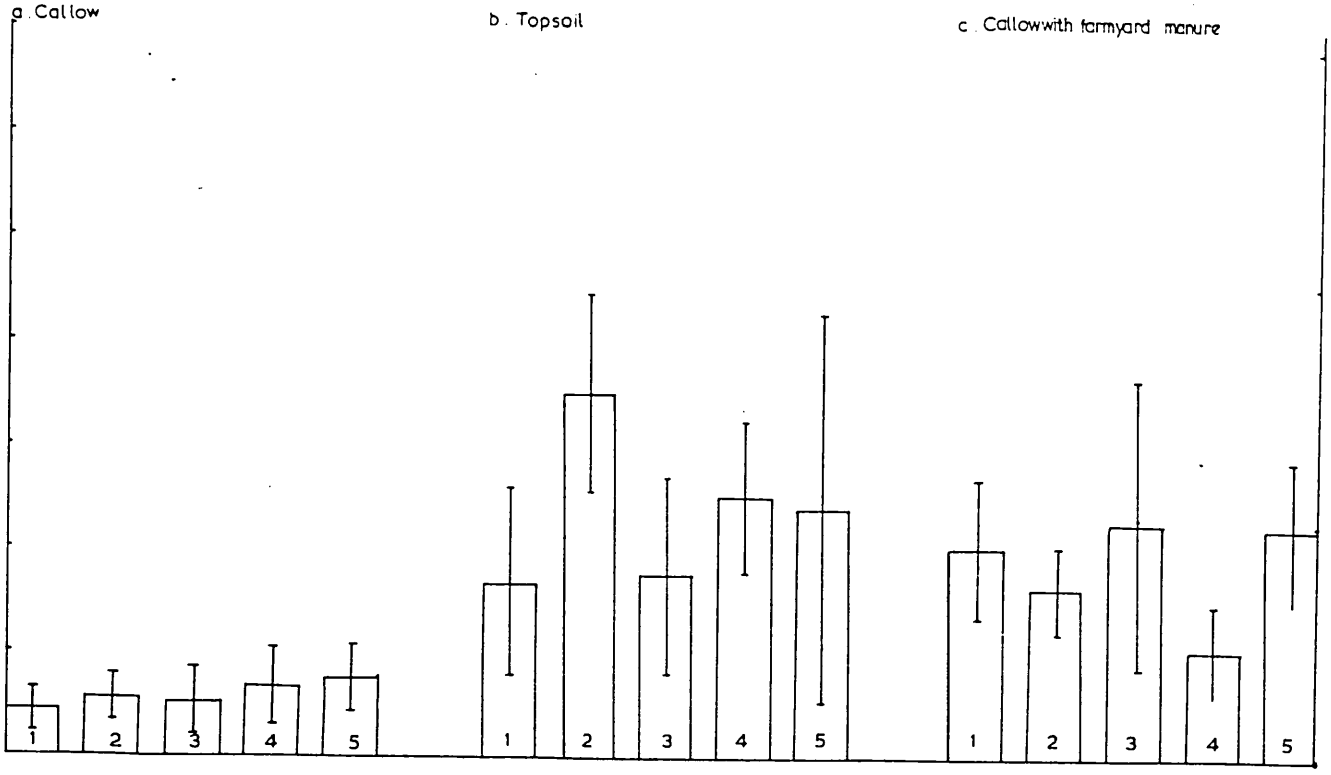


FIG 8.2 (Cont)

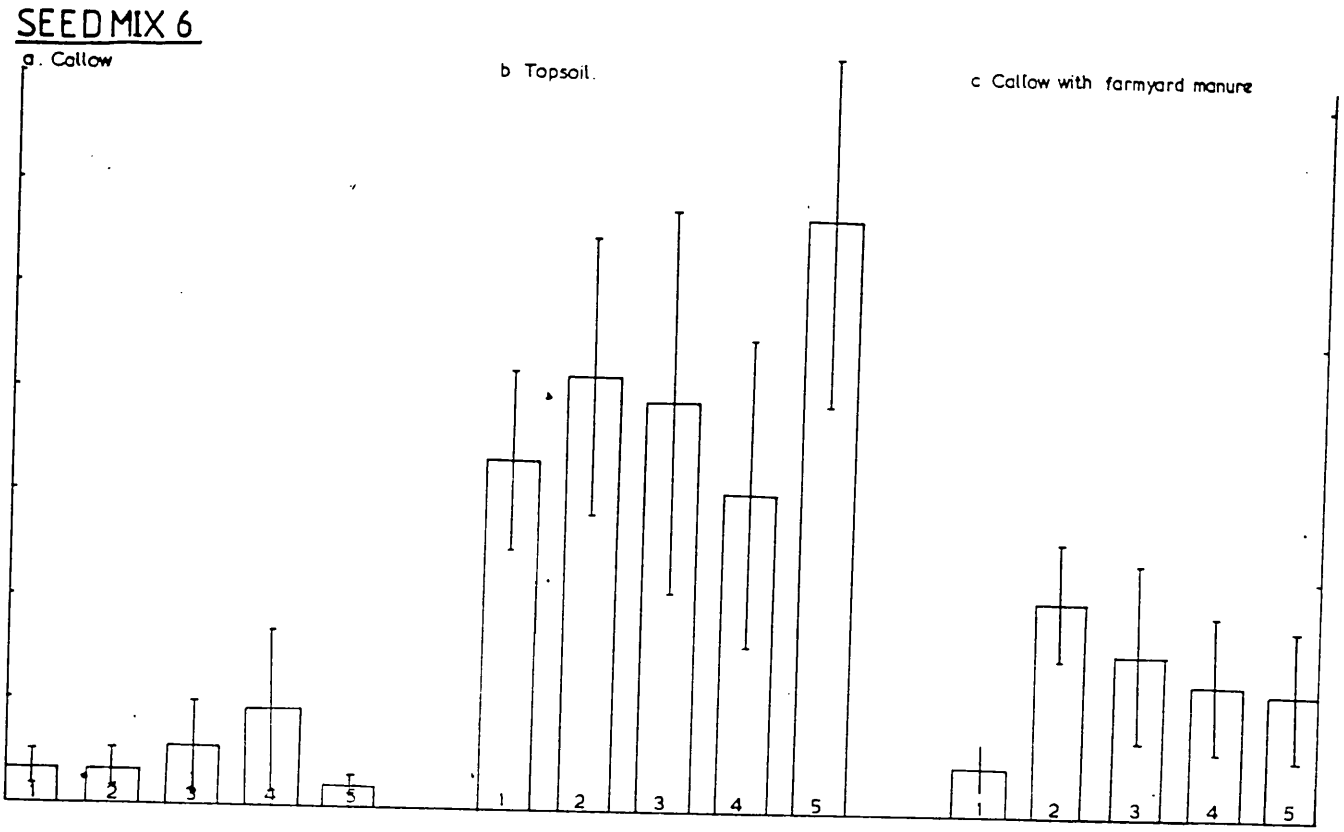

SEED MIX 6
a. Callow
b Topsoil.
c Callow with farmyard manure
1
2
3
4
5
1
2
3
4
5
1
2
3
4
5

Table 8.4. To Determine Whether Addition of Fertiliser Promotes Growth in the five Seed Mixtures on Three Substrates.

1. CALLOW SEED MIX	F VALUE	PROBABILITY
1. Westerwolds Ryegrass	0.23	N.S.
3. A.D.A.S. Short Term	1.27	N.S.
4. A.D.A.S. Long Term	0.16	N.S.
5. Mid Seasons Grazing/ Hay Cuts	0.18	N.S.
6. Own Mix	0.45	N.S.

2. TOP SOIL SEED MIX	F VALUE	PROBABILITY
1. Westerwolds Ryegrass	0.63	N.S.
3. A.D.A.S. Short Term	0.76	N.S.
4. A.D.A.S. Long Term	0.60	N.S.
5. Mid Seasons Grazing/ Hay Cuts	0.40	N.S.
6. Own Mix	0.44	N.S.

3. CALLOW WITH FARM YARD MANURE SEED MIX	F VALUE	PROBABILITY
1. Westerwolds Ryegrass	5.45	<0.01
3. A.D.A.S. Short Term	0.32	N.S.
4. A.D.A.S. Long Term	0.36	N.S.
5. Mid Seasons Grazing/ Hay Cuts	0.33	N.S.
6. Own Mix	0.87	N.S.

mixed with f.y.m. In all the other combinations the addition of nitram and/or bonemeal did not have a significant effect.

Tukey's Test of all Comparisons Among Means was applied to investigate where the differences occurred. The differences were as follows:-

NPK + N + P > NPK + P > NPK > NPK + N > No treatment

The next question which needed to be answered was whether or not some seed mixtures gave higher yields on callow than others. In order to test this a two-way A.O.V. was carried out. The F value produced = 0.36, which was below the critical level of 3.01 for $\alpha = 0.05$. Therefore there is no evidence that seed mixtures vary in their yields on callow in these conditions.

A similar test was carried out to find out whether some seed mixtures gave higher yields on callow mixed with f.y.m. The f value = 0.62, thus again there was no evidence that seed mixtures vary in their yields on callow mixed with f.y.m. in moisture stress conditions.

When the same test was applied to the top soil results, the resulting F value = 3.39, which gave a significant result at the $p < 0.05$ level. The difference was investigated by the application of Tukey's test; it was found that Seed Mix 3 (A.D.A.S. Short Term) gave significantly higher yields than seed mix 5 (Mid Seasons Production/Grazing/Hay Cuts).

In order to test whether the addition of f.y.m. to callow improved yields over those of callow alone, a test of comparisons of paired results was needed.

The data were plotted on a normal probability curve to investigate normality. The plots showed that the results were not normally distributed therefore the use of a non-parametric test was advisable.

The test chosen was Wilcoxon's Two Sample test cited in Wallis, Allen and Roberts[130], the results of which are shown in Table 8.5.

Table 8.5. Results of Wilcoxon's Two Sample Test

Seed Mix	Probability
1. Westerwolds Rye-grass	N.S.
3. ADAS Short Term Ley	$p < 0.05$
4. ADAS Long Term Ley	$P < 0.05$
5. Mid Seasons Production	$P < 0.05$
6. Own Mix	$P < 0.05$

Thus from this set of greenhouse trials it is evident that in an out-of-season sowing, the addition of farm yard manure to the callow promotes growth in four out of five of the seed mixes. Westerwold's rye-grass mix was the only one which did not respond to the addition of f.y.m.

A two way A.O.V. table for this set of greenhouse trials is shown in Table 8.6. It is interesting to note that the only significant factor in this table is the "block" position, i.e. the position on the greenhouse bench gives the most significant results.

8.3.3. Summary of Results

i Results were poor overall, due to moisture stress causing poor germination rates.

ii Apart from this, results give some idea of the possible outcomes resulting from out-of-season sowing.

iii Using one-way A.O.V.'s it was evident that the addition of fertilisers to five different seed mixes on three different substrates did not have significant effects on yields in the majority of cases. The only significant result was that of Westerwold's Rye-grass on callow with f.y.m. In this one significant result a Tukey's Test of Comparisons Among all Means showed that NPK + N + P > NPK + P > NPK > NPK + N > no treatment

iv The data are not normally distributed.

v A two way A.O.V. showed that the five seed mixtures varied in their yields on top-soil $F = 3.39$, $p < 0.05$.. Tukey's Test showed that the A.D.A.S. short

Table 8.6.

ANALYSIS OF VARIANCE TABLE OF GREENHOUSE EXPTS. ON CALLOW

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Main Plots				
Mixes	4	0.0776	0.0194	0.257
Blocks (Replicates)	4	3.7103	0.9276	12.30++
Main plot error	16	1.2064	0.0754	
Sub Plots				
Nutrients	4	0.0201	0.0050	0.215
Nutrients & Mixes	16	0.1844	0.0115	0.49
Sub-plot error	100	2.3230	0.0232	

Interaction is not significant, neither is the nutrient treatment or the seed mixture. The only parts that are significant $F = 12.30$, $P < 0.01$; are the blocks, i.e. position on bench is more important than nutrient treatment or species mix.

term ley gave higher yields than the Mid Seasons Production on top-soil; there were no differences among the other means.

vi There are significant differences between yields on callow and those on callow mixed with f.y.m.

vii A two-way A.O.V. (with replicates combined to give a mean) showed that there was no difference between the five seed mixtures grown on callow or callow mixed with f.y.m.

viii Four out of five of the seed mixes gave higher yields when the callow was mixed with f.y.m. than on bare callow alone.

ix There was no interaction between nutrients and seed mixes. The position on the greenhouse bench was a significant factor affecting yields, for example the block of experimental pots nearest the south facing wall may have dried out the quickest.

x Moisture stress during, or just after germination may have caused great losses in biomass.

xi The organic material and the moisture retaining properties of f.y.m. may have given rise to a less stressful environment to seedlings.

8.4. The Second Set of Greenhouse Trials

8.4.1. Objectives and Experimental Design

These were based on the following assumptions:-

i Both nitrogen and phosphate deficiencies had previously been shown to limit growth on callow. Given good sowing conditions, it was known that applications of fertilisers increase yield[24].

ii Germination in out-of-season sowing gave poor results as shown in the previous greenhouse trials. Yields from experiments sown out-of-season were not significantly improved by fertiliser applications in the majority of cases. The main limiting factor was water availability and the effect of direct heat on germination.

iii Yields from out of season sowing in greenhouse experiments were improved by the addition of farm yard manure to the callow. This may have been due to the water retaining properties of the straw content rather than the fertilising properties.

The next objectives were considered to be:-

i To determine whether nutrient deficiencies were limiting factors on a wider variety of seed mixtures than those used in 1980.

ii To establish whether soil stabilisers would increase germination rates in drought conditions. Stabilisers are intended to form a crust over the soil, increasing the likelihood of successful establishment of seed sown out of season: the experiment was to ascertain whether this was the case. In order to establish the most seriously limiting macronutrients, fertiliser treatments were applied as mono-nutrient applications.

Callow was dug from the border of the Quest Pit Site for this experiment. The experimental design was as follows:

N	=	Ammonium nitrate	@	125 $kg.ha^{-1}$-N
P	=	Super phosphate	@	100 $kg.ha^{-1}$-P
K	=	Sulphate of Potash	@	125 $kg.ha^{-1}$-K

Treatments

1. No additions
2. P,K
3. N,P
4. N,K
5. N,P,K
6. N
7. P
8. K
9. NPK with soil stabiliser SFB 20

10. NPK with soil stabiliser Vinamul 3277

11. NPK with soil stabiliser Verdyol

12. NPK with soil stabiliser Huls 801

13. NPK Control

Groups of pots 9-13 were separated from the rest and subjected to drought conditions.

The experiments were carried out using

a. ADAS Recommended Short Term Ley Mix

b. Lucerne/Meadow Fescue (A New Batch)

c. Mid Seasons Production Mix.

d. Winter Wheat

Four replicates of each seed mix/fertiliser regime were set up, arranged in four randomised blocks on the greenhouse bench. Seeds were sown on 15th March 1983 and were harvested six and a half weeks later, except the winter wheat which was allowed to continue to grow.

The winter wheat experiments germinated and grew well in the first few weeks. Then they were transferred to an outside greenhouse on the roof of the Botany Building. Despite regular watering they later died.

The harvested material was dried in an air circulation over @ 60°C for four days. The results are the averages of four replicates of each treatment.

8.4.2. Details of Soil Binders Used.

i SFB20

This was obtained from Steetley Chemicals Ltd., Chemical Specialities Apex Works, Willowbank, Uxbridge. Its price in 1973 was £1130 per tonne. It is a dispersion of a vinyl acetate-ethylene co-polymer in water. This is emulsified by small quantities of a non-biodegradable surfactant and preserved by formalin. The approximate constituents are:-

	%
Vinyl acetate co-polymer	54.0
Surfactant	1.0
Formalin	0.1
Water	44.9

The liquid was diluted to a 50:1 water: binder ratio and applied at a rate of 340 $l.ha^{-1}$ which was its recommended application rate as a grass seed stabiliser on reclaimed land.

ii Vinamul 3277

This liquid was stated to "dry to give a clear colourless, non-tacky film that holds the grass seed and other ingredients in place until the seedlings are established". The binders action lasts for 5-6 weeks. It is a water based, synthetic resin dispersion specially developed as a soil stabiliser for grassing difficult areas.

Vinamul was diluted to a 40:1 water: binder ratio and was applied at a rate of 1200 $l.ha^{-1}$.

iii Verdyol Soil Binder.

This binder has a solids content of 23%. Its pH value is 4-5 and its specific gravity is 1.03. Its predominant particle size is 0.5 - 2 μ.

Verdyol was diluted to a 1:1 water:binder ratio and was applied at a rate of 20-50 $ml.m^{-2}$.

iv Huls 801

This was applied at full strength at a rate of 500 $l.ha^{-4}$. The only details that were available on the binder were that it is a synthetic product.

8.4.3. Results

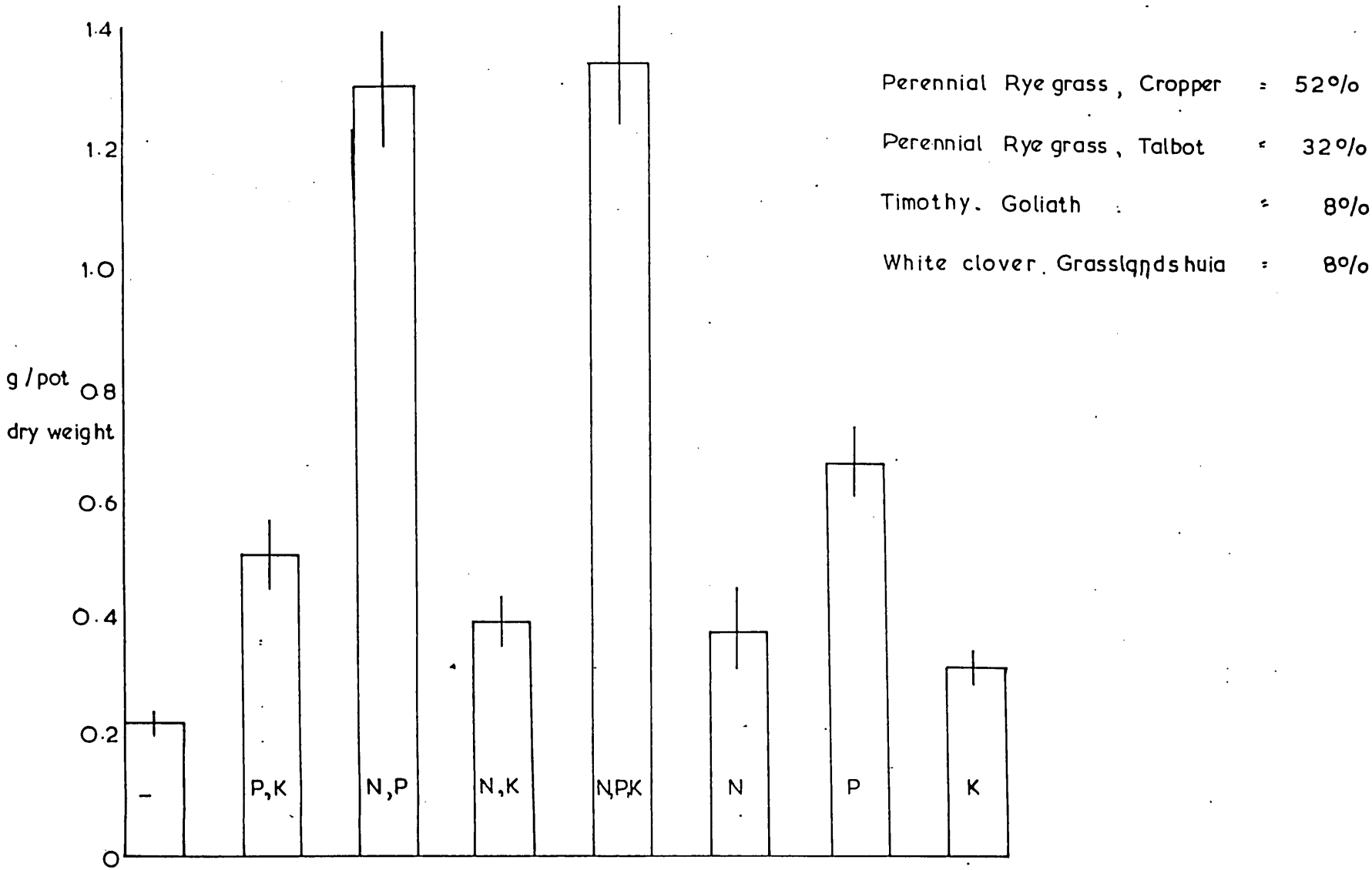
All the soil binder experiments failed. The winter wheat germinated and grew well in the first few weeks, then it regressed, with mottled leaves which later suffered from marginal necrosis. No tillering occurred and anthesis was not reached. The plants later died.

The results of the three seed mixes are plotted in Figure 8.3.

The most important points from these figures are itemised below:-

i All three seed mixes gave similar results. The grazing/hay cuts mix gave the highest yields.

FIG 8.3 ADAS RECOMMENDED SHORT TERM LEY



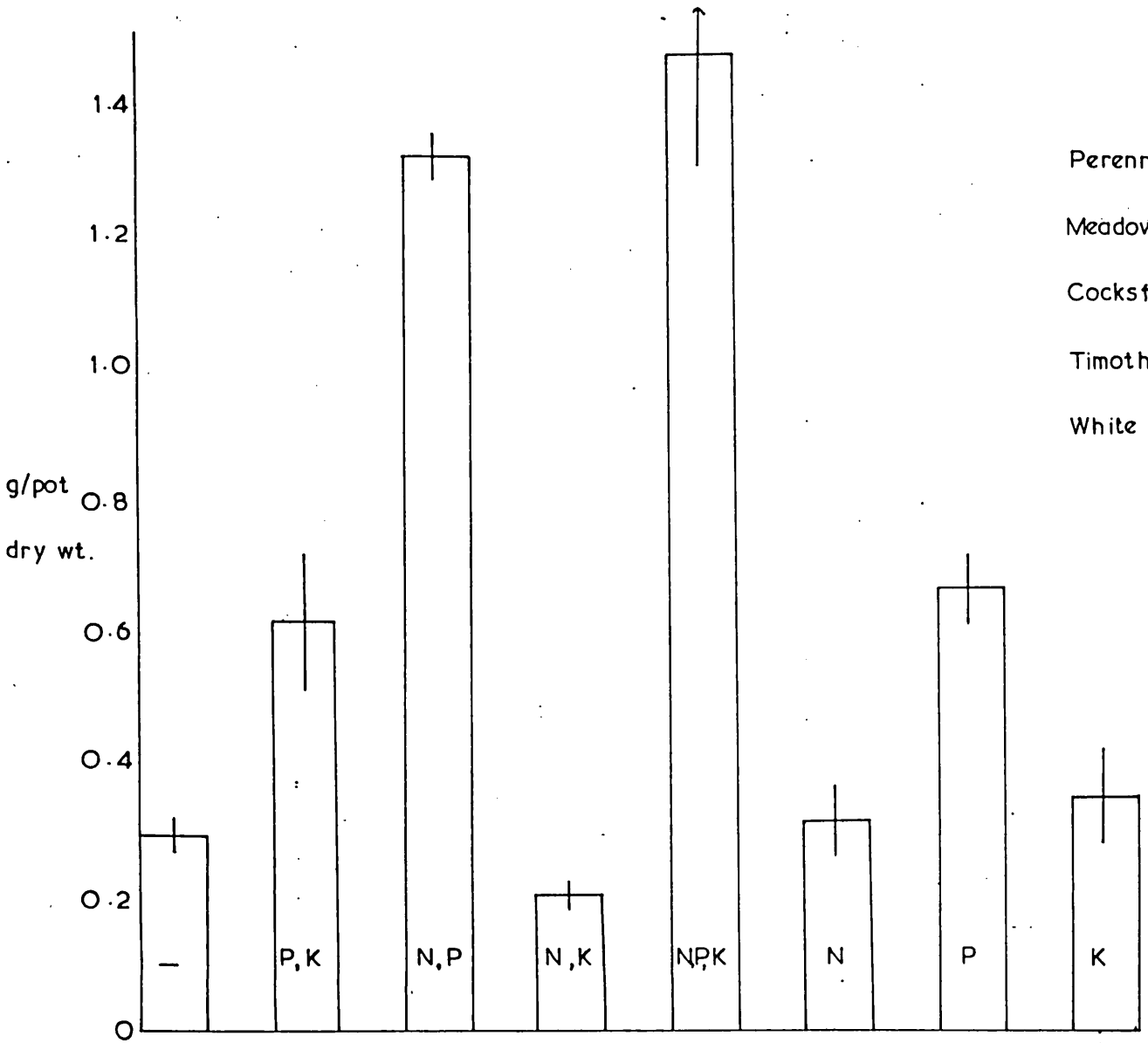
Perennial Rye grass, Cropper = 52%

Perennial Rye grass, Talbot = 32%

Timothy. Goliath = 8%

White clover. Grasslands huia = 8%

FIG 8.3 MID SEASONS PRODUCTION - GRAZING / HAY CUTS



Perennial Ryegrass, Melle = 7%

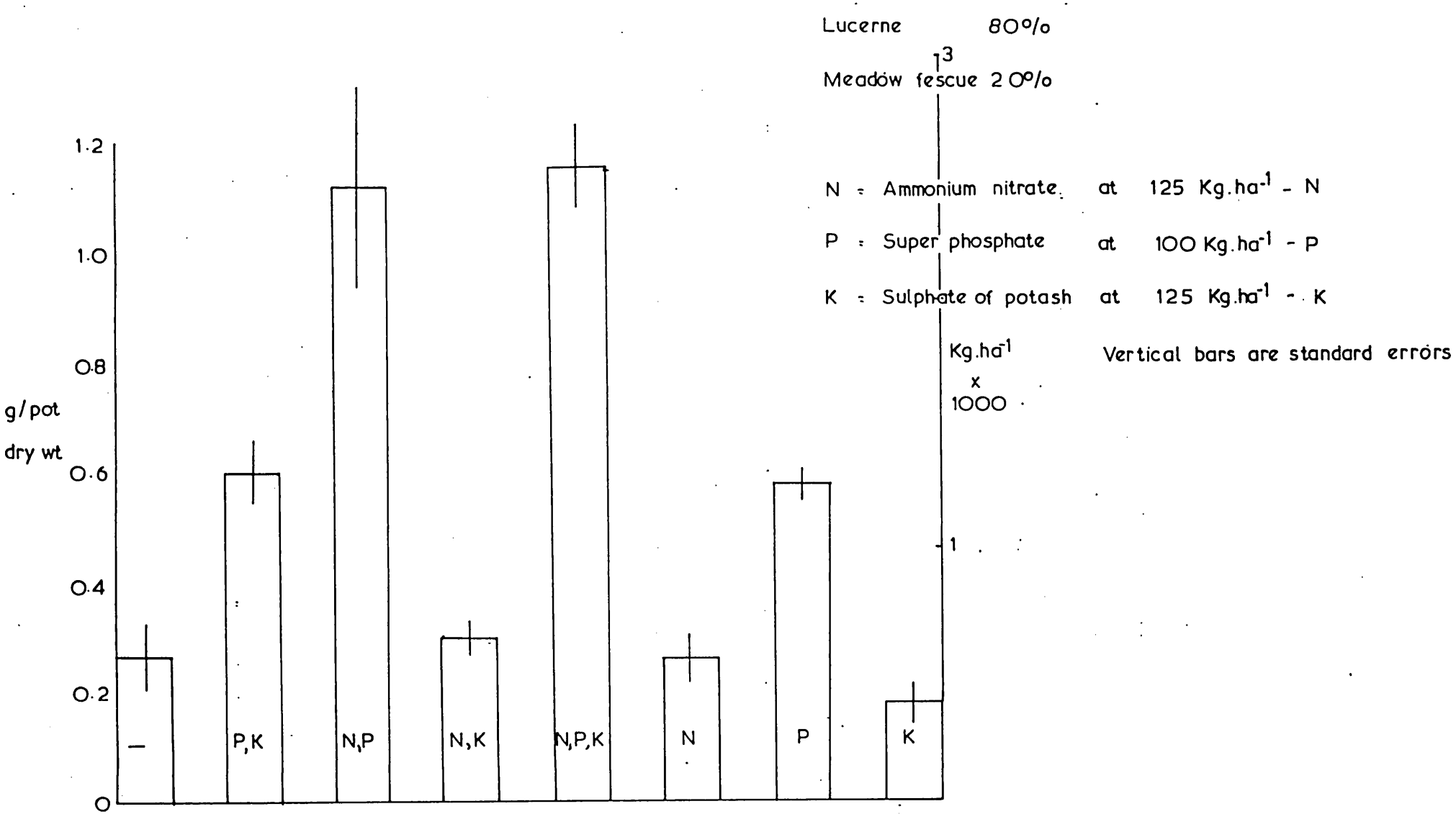
Meadow fescue S215 = 54%

Cocksfoot S 26 = 23%

Timothy S48 = 12%

White clover, Grasslands huia = 4%

FIG 8.3 LUCERNE / MEADOW FESCUE



ii The lucerne and clovers did not contribute to the overall results. Lucerne was present in a small number of pots but its contribution towards total biomass was negligible.

Despite this, the meadow fescue made up for the loss of productivity.

iii Phosphate deficiency was found to be the limiting factor. When applied in mononutrient applications phosphate doubled yield.

iv Nitrate applications did not generally have much effect on their own or when applied with potassium.

v When applied with phosphate, nitrate has its greatest effect and vice versa. It appears that N and P applications act synergistically to promote growth.

8.5.4. The Third Set of Greenhouse Trials

It was thought that one of the possible reasons for the failure of the previous soil-binder experiments was due to the age of the binders and their unknown, limited life. It was understood that they deteriorate with time.

One more attempt at investigating the potential of a soil binder was made. Fresh stocks of binder were obtained from the suppliers. Essbinder is of vegetable origin, dissipates after about 8 months in the soil, therefore it does not build up in the soil with successive applications. It is very soluble in water, and is mixed at a 1:1 Binder:Water ratio before application. Its recommended application rate is 50 $g.m^{-2}$.

Two seed mixtures were used; Meadow fescue/lucerne and the Westerwolds Rye-grass mixture, at a rate of 100 $kg.ha^{-1}$. Fertiliser was applied to all the pots at a rate of

N @ 125 $kg.ha^{-1}$
P @ 100 $kg.ha^{-1}$
K @ 125 $kg.ha^{-1}$

All pots were well watered and then Essbinder was applied to half of the pots. These were then subjected to drought conditions.

Results were poor, no germination occurred in the Essbinder pots and germination and growth were low in the control pots.
Again, this was thought to be due to the extreme temperatures experienced in the greenhouse in the summer.
From these results and the previous experiments it appears that soil binders would not aid out-of-season germination or growth.

8.6. Discussion

From the various batches of greenhouse trials several points become evident.

i The use of soil-binders to alleviate drought conditions cannot be recommended from these results.

ii No one seed mixture out performs the others on callow.

iii Sown at the correct time of year a suitable grass seed/legume mix will germinate and give good yields provided the nutrient status is improved.

iv The most limiting nutrient in the callow is phosphate. This agreed with previous results showing that the phosphate level in the callow was below detectible limits. It is therefore of prime importance that the phosphate balance of the callow is improved.

v Phosphate and nitrate fertiliser applications are recommended for maximum yields. Standard agricultural rates of application based on poor soils are sufficient to ensure yields are improved.

vi Although there was previously found to be a high total nitrogen level in the callow, it appears that most of this is not "plant-available" and thus high levels of additional nitrogen fertiliser applications are recommended.

vii Legumes do not perform well on callow. They are slow to establish in greenhouse trials and do not contribute significantly towards yield. Red Clover does better than white; lucerne, although slow to establish

and therefore of little significance in pot trials, did contribute towards the total cover in field trials during the second year of growth.

9. CONCLUSIONS AND RECOMMENDATION

The purpose of this study was to assess the potential of the "callow" overburden as a growing medium in reclamation schemes. The practical aspects of the project included three components.

The first of these was a study of the natural vegetation of callow over an extensive age range. Sites were located in Bedfordshire and Buckinghamshire.

A study such as this, using a number of scattered, independent sites is dependent upon the sites being similar in all respects except age. As was shown in the chapters on Callow Analysis and Natural Vegetation, some of the results from some of the chosen sites do not comply with the trends expected from a successional series.

The vegetation of any man-made surface must be partly or wholly dependent upon the local seed source. Thus, the distance between the survey sites, the varying natural seed sources and the types of surrounding habitat, would all influence the deviations from the expected successional trends.

Results from transects, species lists and complex ordination studies show that succession in these habitats is not a simple linear process but is highly dependent upon a variety of other factors, some of which could not be identified.

Plants colonise the callow rapidly after its dumping. Thistles dominate for a short time in the early stages (usually around the four year age range) but these are quickly replaced by other dominant species. Grasses and herbs are important early colonisers.

The preponderence of legumes, but only in the mid-late stages of succession may be closely linked to their poor results in both greenhouse and field trials using freshly excavated callow. The governing factor for legume

establishment, in a soil-less medium, is that there are no bacteria to innoculate the root nodules. Legumes would only invade the natural plant communities once sufficient bacteria have been built up in the callow. This could explain the greenhouse results. However, it does not explain the field trials where the legume seed was innoculated. Presumably poor sowing conditions over-rode the presence of bacteria in this case.

The species type one selects for reclamation are rarely (if ever) those which are pioneer colonisers. One is in fact trying to jump several stages in succession, by choosing grass/legumes as opposed to the pioneer species such as Tussilago (Coltsfoot) and Cirsium spp. (Thistles).

The second component of the practical work carried out was callow analysis. A variety of changes in the callow have been monitored and where those changes were age-related, obvious trends were apparent. For example, the speed of organic matter build-up was noted; its content doubles every thirty to fifty years.

Loss-on-ignition results could be related to the total nitrogen content of the callow. If these experiments had to be repeated on callow, it would be easier, cheaper and faster to make estimates of Total Nitrogen from L.O.I. results rather than to undergo a series of more complex Kjeldahls analyses.

The high levels of nitrogen found in the callow did not necessarily reflect the "plant-available-nitrogen". This was because of the fossilised organic content of the clay. Thus "total-nitrogen" results are misleading and should not be read as "plant-available-nitrogen".

Salt levels and conductivity of the callow decreased with age. This may have been due to the leaching of soluble salts through the soil profile. Potassium and Calcium levels were high; these are not likely to be limiting to plant growth.

Phosphate levels in the callow were very low - below detectible limits. This is of central importance when considering callow as a growing medium for future reclamation schemes. Thus, for any types of plant growth, unless phosphate levels are increased by the application of fertilisers, phosphate deficiency is likely to cause growth problems.

The data from natural colonisation was analysed by ordination methods, in order to establish whether any links could be made between species composition and chemical/physical properties of the callow. Many of the extracted axes from the ordination studies could not be related to any of the measured soil variables. Therefore, changes in vegetation at the sites studied could not be considered to be totally explicable. The analyses carried out during this project did not provide a complete picture of the callow. Therefore, immitating only those factors which were studied might result in failure, if a single species or collection of species were required.

Ordination results from the point quadrats showed that the age of the sites and water content of the callow could be related to two of the extracted axes. Axis four was the most representative of the age series and Axis one was related to moisture content. The other two axes could not be explained.

Ordination results from the square quadrats showed that only axes one and two could be related to any measured variables. Axis one represented the transition from open grassland through scrub/grassland mix to closed woodland. Axis two showed succession along the time series with respect to the open grassland habitats only.

The vast wealth of species found in the clay pits is indicative of the importance that should be placed on these man-made, semi-natural habitats. They should not be considered solely as derelict land devoid of any use in their current state, but should be seen as a vast complex of habitats providing a valuable resource as a refuge for the wildlife in the area. There might be some value in allowing more of the pits to colonise naturally,

to provide nature reserves. Coronation Pit is the obvious choice for conservation because of its diverse habitats, easy access and usefulness as a site for studying succession and species diversity.

The third part of the project was concerned with growth trials in the greenhouse and in the field. Although only agricultural purposes were considered these recommendations would also be applicable to other after-uses, for example forestry or amenity grassland.

Standard agricultural seed mixes such as those recommended by ADAS for use on heavy clay soils provide good ground cover and give relatively high yields.

The growth of a grass/legume is preferential to the growth of crops in the initial years after establishing the callow, due to higher yields, better ground cover and more reliable results.

The problems of low phosphate and plant-available nitrate levels in the callow are of crucial importance and need to be rectified before seeding takes place. Broadly speaking, standard agricultural rates recommended for soils with very low nutrient standards were satisfactory.

The legumes did not do well in either field or greenhouse trials. However, if given another growing season the lucerne in the field trials would have been established as a major contributor to the total yield of that site. Lucerne appears to give marginally better results than the clovers.

If only a short-term-ley is required, a ryegrass based mix, such as that suggested by A.D.A.S. is recommended. Owing to the poor results of the clovers, an alternative would be the ryegrass monoculture as used by LBC Farms; using high applications of NPK and Nitram fertilisers.

Additional applications of a phosphate-based fertiliser, for example, bonemeal, are also recommended.

There are soil conditioners, such as Breakthrough and Claycure intended to improve clay soils. However, the use of such formulations showed no measurable additional benefits, let alone results which could justify their costs.

The sowing and treatment of leys on callow is highly time dependent. It is essential that all ground preparations and top dressing applications are carried out when the moisture content of the clay permits. It would seem sensible, therefore, that requirements such as planning consent conditions should allow flexibility of sowing times. The use of a winter sown ley appears to assist in overcoming these problems and is recommended.

Trials indicate no increase in yields when vastly increased seeding rates are used. The normal rates of 40 $kg.ha^{-1}$ employed in this research seem satisfactory.

Organic matter, for example farmyard manure aided aeration of the clay in the greenhouse trials and improved out-of-season-sown yields. The organic matter helped to aggregate the clay particles therefore improving drainage and aeration.

The use of soil-binders to aid out of season sowing was not successful, and is therefore not recommended on the basis of these results.

Problems associated with the toxic effects of methane generation do not appear to be significant at Brogborough. This may be due to the depth of the clay cap. This should be treated as an important criterion when covering a land-fill site.

The overall conclusions from this project are therefore two fold:

a) Some areas of callow have developed naturally and ecologically diverse flora and it might therefore be beneficial in any strategic land reclamation plan to identify actual or potential areas of conservation value and to consider their protection and, perhaps, enhancement.

b) Callow as a material for land restoration, whether for capping over land fill or otherwise, has marked disadvantages in terms of water relationships, which restrict the ability to conduct farming operations. Despite this, with careful management, callow is shown to be a very satisfactory medium for grassland establishment, subject to enhancement of phosphate and nitrate regimes.

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APPENDIX I

GUIDELINES FOR THE HANDLING, STORAGE AND REPLACEMENT OF SOILS DURING THE CLAY EXTRACTION AND LAND RESTORATION PROCESS AND THE SUBSEQUENT AFTER CARE OF REINSTATED LAND[1]

Introducton

1. Although significant improvements in land restoration techniques have taken place during the last 15-20 years there have still been many instances of schemes which, on completion, have experienced serious problems relating to cultivation and fertility or even total failure.

2. The process of land restoration may be sub-divided into four main stages, at each of which soil is vulnerable to a variety of damaging or debilitating problems.

   (1) Removal and storage of soils and overburden.

   (2) Filling.

   (3) Contouring.

   (4) Replacement of soils.

3. The initial and final stages relating to the handling, storage and replacement of soils are considered here since, in any scheme aimed at restoring agricultural production, it is the degree of care and treatment given to the final 3 feet of delicately structured material which will largely control the level of future agricultural productivity.

The Importance of Soil

4. Soil comprises the complex biologically active surface layers formed from the weathering and breakdown of parent rocks.

5. Its particular value derives from the arrangement of sand, silt, clay particles and accumulated organic material which in a well developed soil create a structure containing voids and fissures ideally suited for the germination, establishment and growth of plants.

Soil Texture and Soil Structure

6. Texture and structure are two of the main characteristics of soil which can be used to assess its value for agricultural use.

7. Unlike soil texture, which describes the relative proportion of sand, silt and clay constituting the mineral fraction of soil and which is unaltered by normal agricultural practice, soil structure can be damaged or destroyed when cultivation or earthmoving operations are undertaken in wet conditions.

8. Soil structure refers to the manner in which the individual soil particles of sand, silt and clay are joined together into larger compound units known as peds. In well developed soil the structure is characterised by the presence of voids and spaces between the crumbs which can be filled with air, other gases or water from which roots obtain moisture and nutrients.

9. Structure is developed in soil by weathering and mechanical cultivations, and is stabilised by the action of clay particles, humus and plant roots.

10. Organic matter, much of which is derived naturally by the incorporation of the remains of dead animals and plants, is an important component of soil. It has important physical properties such as increasing the water retention capacity and is itself rapidly colonised by many micro-organisms such as fungi and bacteria.

11. These micro-organisms encourage the breakdown and decomposition of organic matter to the important structureless but complex brown material known as humus and, in addition, secrete gummy substances around themselves which help to build individual soil particles into crumbs.

Soil Profile: Topsoil and Subsoil Layers and Overburden

12. In addition to texture and structure a further important characteristic of well developed soil is the presence of recognisable sequences of layers or horizons together comprising the soil profile.

13. In terms of its importance for agricultural use the soil available for exploitation by crop roots is sub-divided into topsoil and subsoil, each of which have distinctive qualities.

14. The topsoil is the darker coloured surface layer usually about 15-30cm in depth. It invariably has a higher humus content and is more biologically active than the underlying layers. It also contains most of the mineral nutrients required for crop growth.

15. It is principally the size and stability of the soil structural units which distinguish it from subsoil. Without a good structure, the value of the topsoil is much impaired and problems of poor crop growth are likely. The higher proportion of humus in the topsoil helps to promote stability in the soil crumbs, which enables them to withstand the mechanical pressures imposed by machinery, cultivating implements, livestock and rainfall.

16. The zone directly beneath the topsoil, the subsoil, may extend to a depth of 3 ft. or more. It has a lower humus content than topsoil. Plants obtain their moisture requirement in summer from this zone, and a stable well formed permeable structure is one of the essential requirements for plant root development.

17. In clay soils the natural physical structure often consists of long columns or prisms of soil between which water, air and roots can move. If the spaces between the columns are sealed for example by the compressing or smearing effects of machinery, the value of the subsoil to the crop is reduced since roots air and water can only enter with difficulty.

18. The zone lying between the subsoil and the workable mineral deposit is known as the overburden. Normally it has no commercial value but it must be removed before working of the mineral deposit can commence. If it is of suitable quality, and correctly handled, it may be used in subsequent restoration. In certain circumstances it would be considered for development as a growing medium, for example an old site where no soil was retained.

19. Where adequate topsoil and subsoil exists, the overburden is normally retained for replacement above the top layer of fill.

Soil Damage - Problems Related to Mineral Extraction and Land Restoration

20. The damage and disturbance which are most commonly experienced as a result of soil handling and storage during mineral extraction and subsequent restoration are compaction and loss of soil profile.

(1) **Compaction and The Importance and the Role of Organic Matter**

21. Without doubt compaction and the resultant loss of soil structure is the major single cause of restoration failure.

22. Once compaction reduces or eliminates the pores, fissures and channels vital for the passage of air, water and nutrients then the healthy and vigorous root growth necessary for the retention and development of soil structure is also reduced.

23. The principle cause of compaction is the compression of soil particles by heavy earthmoving equipment during the stripping or replacement stages of soil handling or under the excessive weight of overlying material during storage.

24. The degree of compaction caused during any of these operations depends upon the ability of soil structural units to withstand such pressures which in turn depends upon the quantity of organic material and water present in the soil. The presence of organic matter within a well structured granular soil give its structure stability by providing it with resilience. Up to a given moisture content a well structured soil will deform slightly under pressure and then return to its original state on release due to the elastic, cushioning properties of the organic material lying between the soil particles.

25. However, there comes a point at which continued addition of water to the soil causes saturation of the organic material and a consequent temporary reduction or loss of its elastic properties. If soil is subjected to pressure whilst in this wet state it will deform without subsequently returning to its original condition and the soil structure will be seriously damaged or lost.

(2) **Loss of Soil Profile**

26. For the purposes of agricultural cultivation the critical layers of the soil profile are those of the topsoil and subsoil which as a result of their respective structures and composition provide the stability required by soil to enable it to withstand the mechanical pressures imposed by machinery, livestock and rainfall and provide growing crops with their essential moisure and nutrient requirements.

27. If either layer is diluted by mixing then its physical properties will become altered, and, in the case of topsoil this will normally result in a decrease of its humus and organic matter content and stability of the soil.

28. Similarly, replacement of the soil layers in other than their original positions will prevent them from performing their particular function in the crop growth process.

Requirement for Optimum Reinstatement of Soil Structure and Profile

29. To enable the optimum reinstatement of site soils to take place during the restoration process it will be apparent from the preceding discussion that certain characteristics or elements of soil composition and structure must be retained at all costs and these are outlined below:

(1) Dilution of the organic rich topsoil layer by other material, particularly subsoil, must be prevented since the relative reduction in organic material content seriously reduces the structure and stability of the soil.

(2) Handling of all soil material, and most particularly the delicately structured topsoil, should only take place in dry conditions when the included organic material is capable or providing maximum protection to the inherent structure.

(3) Reinstatement of the separate topsoil and subsoil layers in their correct sequence is essential if their distinctive properties and structures are to be utilised by growing plants or crops.

30. It cannot be over-emphasised that prevention of damage to an existing well structured soil is infinitely preferable to subsequent attempts at repairing such damage once incurred.

31. The development of a stable soil structure takes place over extremely long periods of time, normally measured in tens of years and, once destroyed, its recreation if possible at all, would require patient and time consuming treatment, cultivation and aftercare.

32. Furthermore, once lost, the reattainment of original levels of fertility and productivity cannot be ensured.

Soils of the Marston Vale

33. The preceding sections discuss the principles involved in retaining and re-establishing soil structure and profile during the land restoration process.

34. In attempting to formulate the best practise for handling and reinstatement of these soiltypes, developed on the Oxford Clay, it is necessary to understand their particular characteristics of composition, texture and structure.

35. The major clay bearing areas of the low lying Marston Vale are dominated by the important group of non-calcareous gley soils which are formed on the Oxford and Ampthill Clays with some drift admixture.

36. This group is known as the Rowsham Association of which the Rowsham series is the most widespread. The soils commonly consist of imperfectly to poorly drained clay loams or sandy clay loams where sand has been washed down from the Greensand.

37. These heavy soils suffer from waterlogging in winter and cracking in summer, cultivations have to be carefully timed and artificial drainage is essential if the best use is to be made of the land.,

38. A tilth suitable for drilling is often difficult to obtain and they are most suited to grassland farming for which they were traditionally used although winter wheat has now replaced grass as the principal crop.

39. The soils are most commonly graded as 3b by the Ministry of Agriculture, Fisheries and Food agricultural land grade classification although small areas of both 3a and 3c grade are also encountered.

40. The principle reason why these clay soils are unable to achieve the higher yields or wider crop diversity necessary for higher grading relates to the difficulties and limitations of cultivation resulting from their fine texture. As we have seen texture is a reflection of the relative quantities of sand, silt and clay particles and since these particles each have different physical and chemical properties then soils having different mixes of particles can vary considerably in their overall properties. Hence, a soil composed of sand and gravel is very free draining and retains few plant nutrients whilst a clay soil may drain badly and become almost totally impervious to water if compressed yet retain nutrients because of its ion exchange properties.

41. A fertile loam soil with a well developed structure has an active microbial population about 50% solids, 20% air and 30% water at field capacity. In such a soil the particles are normally characterised by a crumb structure and without this a soil composed of fine particles can quickly become massive with a very high bulk density and almost impervious to root growth, water and oxygen.

42. The fine texture clay soils of the Marston Vale are therefore highly dependent upon the maintenance of their existing soil structure for their agricultural value and will consequently suffer considerably if that structure is destroyed.

43. In order, therefore, to protect the particularly vulnerable qualities of existing site soils from irreparable damage during handling and subsequent restoration and enable their most beneficial reinstatement the following guidelines have been drawn up to indicate those measures to further this aim.

44. Without doubt the best techniques for preventing the deterioration of soils, particularly topsoil, is progressive restoration in which soil layers are stripped ahead of the working face and replaced behind on the prepared surface of the worked out extraction area. This might take place with or without filling, depending upon circumstances, but in either case, the receiving surface would be appropriately graded or contoured to provide satisfactory drainage.

45. The progressive restoration concept has major advantages when compared to the traditional approach of post-working restoration. These may be summarised as follows:

(a) It eliminates the need for dual handling of soils thus reducing the likelihood of physical damage by compaction, smearing etc.

(b) It eliminates the need for storage of soils in heaps which may cause both physical damage and often, more seriously, the creation of anaerobic conditions. Anaerobic conditions result in a considerable reduction in available nitgogen and prevent the production by microorganisms of the organic gums which help confer stability on soil structure.

(c) It often enables the utilisation of plant and machinery already available on site for both extraction and restoration operations.

The Guidelines

1. Prior to any work starting on the stripping of soil layers, a soil survey should be undertaken to determine the depth, texture, structure and drainage characteristics of the topsoil and subsoil.

2. Conditions for soil handling: all soil handling operations should only be carried out under dry conditions when the soil materials are sufficiently dry to be handled without damage to their structure. Soil handling operations should cease during and immediately after heavy rainfall and at any time when the cumulative effects of rainfall are considered likely to render the soil vulnerable to damage by handling. Soil handling operations should only resume when the material has had sufficient opportunity to dry.

   N.B. Drainage characteristics vary from one soil type to another and precise soil handling requirements should be determined by laboratory analysis together with information obtained from the soil survey.

3. Topsoil, subsoil and callow should be stripped and replaced (or, in appropriate circumstances, stored) separately and at no time should they be subjected to conditions which might lead to their mixing or contamination.

4. Appropriate machinery for soil handling operations should be used at all times to prevent or minimise compaction. Soil stripping is normally undertaken by motor scrapers which should be of the elevating type in order to produce a shatter of the soil and to avoid polishing of the scraped soil surface.

   A preferable alternative to the use of motor scrapers is the removal of soil by wheeled or tracked loaders working in combination with dump trucks enabling soil layers to be lifted direct without first being traversed and compacted by the loader.

5. Restoration schemes, wherever possible, should be progressive making provision for the lifting of undisturbed soil layers and their immediate replacement on areas of the site awaiting final restoration.

6. Storage of topsoil and subsoil should only take place where immediate replacement as part of a progressive restoration scheme is not possible.

   Soils should be placed in low heaps not to exceed a height of 2 1/2 metres and should be stored for the minimum period of time, which,

49. The methods and techniques appropriate to an after care programme are in fact, essentially "normal" agricultural practices although they may require modification in their execution and most particularly in their timing to ensure that maximum benefit acrues to the re-developing soils.

50. The general principles upon which an after care programme might be drawn up for a reinstated site might include:

1. Grass should usually be established as soon as possible after reinstatement to aid in the regeneration of soil structure. It is the best crop for this purpose as the fine roots help to create stable soil aggregates while the sward protects the surface against rain.

2. All cultivations should only be carried out under dry conditions when the soil is friable to prevent further damage by compaction or smearing.

3. Soils should be regularly analysed for pH and nutrient status and deficiencies corrected by appropriate treatment to ensure availability of nutrients of levels to sustain the planned cropping programme and maintain pH within the range 5.0-7.5.

4. Subsoiling should be carried out at regular intervals (not normally less than once every 2 years) both to improve the percolation of water and assist roots to penetrate the subsoil.

5. Careful management is essential to ensure that grazing stock are kept off the land whenever it is wet, even during the summer. In the early years the poorly structured soils may have poor drainage and are extremely susceptible to poaching by livestock. Dairy cattle in particular are the worst offenders because of their weight and frequent movement.

6. The provision of effective drainage is particularly important on restored sites where the absence of structure in the reinstated soils render them highly vulnerable to damage.

   As a temporary measure on materials of low permeability drainage can be achieved through the provision of suitable gradients which enable natural, run-off to open ditches. However, as a longer term solution it is normal practice to instal a permanent tile or plastic pipe underdrainage system.

   It is important in the case of sites which have been subject to filling that this operation should not be carried out until complete settlement of the site has occurred. This will normally be about 2-5 years after completion of filling.

   A settled depth of 1 metre of topsoil plus subsoil is the minimum depth required for the installation of an effective piped underdrainage system, in order to avoid pipes coming into contact with the fill material. However, on unfilled sites, where the depth of returned topsoil and subsoil is less than 1 metre, pipes may be placed in the underlying material of the pit base.

wherever possible, should not exceed one year.

Soil stored in heaps for greater lengths of time can be provided with a grass cover crop to minimise erosion.

Weed growth should be controlled on storage heaps to keep them weed free and all necessary steps should be taken to destroy weeds at early stages of growth.

Storage heaps shall be managed to avoid vehicles, machinery and other plant traversing them during their formation, removal or replacement.

7. During the replacement of subsoil and topsoil compaction can be eliminated if a dump-truck/hydraulic excavator (back acter) combination is used working from the surface of the fill and replacing subsoil and topsoil in strips so that none of the reinstated layers are traversed by the machinery.

Compaction can be reduced where scrapers are used by:

(i) Starting replacement at the farthest point from the subsoil/topsoil source so that the scraper hauls over the surface of the fill and not over the replaced subsoil and topsoil layers.

(ii) Replacement taking place in narrow strips, each successive layer being laid by the machine running in the wheelmarks of the previously spread layer. This should ensure that the soil between the wheelmarks remains in a loose and free draining condition.

(iii) Using a subsoiler at right angles to the direction of spreading after the subsoil has been spread, and again after the topsoiling has been completed.

Where subsoil and topsoil replacement is to be carried out by scrapers then the above procedure should be carried out as standard practice.

8. After the replacement of topsoil the land should be cultivated, fertilised and otherwise treated for such a period, not normally to exceed five years, in a manner necessary to secure its restoration so as to be fit for use as agricultural land.

After Care

46. The principal purpose of the "after-care" period following reinstatement of site soils is to re-establish a good soil structure.

47. The importance of this period in aiding the recuperation of reinstated soils cannot be overemphasised and needs as much care and attention as reinstatement itself.

48. This importance has been recognised in the Town and Country Planning (Minerals) Act 1981 which enables mineral planning authorities to impose after care conditions on planning permissions where these are granted subject to restoration conditions.

APPENDIX II

Statistical Significances

The object of statistics is to provide a method for assessing the validity of the evidence, by introducing a value for the probability in each situation. In other words, what are the odds that the results of an experiment are merely due to chance, a fluke if you prefer the term.

The word "significant" is used, but it sounds more important than what it means. There are three levels of significance commonly used, or levels of confidence, expressed as 5%, 1% and 0.1% to indicate that the result could have occurred by chance 1 in 20 times, 1 in 100 or 1 in 1000. The one in 20 is usually accepted as "significant" (and the P, or probability value is also given, $P < 0.05$).

A test of significance (and it must be specified which one: 't' test, chi-square, variance or others) is essentially a rule for deciding, from examination of the data, whether or not to reject a hypothesis that has been set up. The rule or guide is made to satisfy two conditions that are clearly desirable:

1. Hypotheses that are true shall be rejected only very occasionally.
2. Hypotheses that are false shall be rejected as often as possible.

The level of statistical significance attained measures the uncertainly involved in taking, say, an apparent difference between two treatments as real. Hence,

Not statistically significant at the 10% level.	=	data are consistent with no (or zero) contrast. The new treatment is no better than the old.
Statistically significant at or near the 5% level.	=	data give good evidence that there is a true contrast (or difference) between treatments.

Statistically significant at or near the 1% level.	=	data give strong evidence that the true contrast is not zero and that, you're on to something!

It must be emphasised that statistical significance is not the same as technical importance.

The Mean

Suppose that n measurements have been taken on the variate under investigation, and these are donated by $X_1, X_2, \ldots, X_n$. The arithmetic mean of the observations is given by

$$\bar{X} = \frac{X_1 + X_2 + \ldots\ldots X_n}{n} = \sum_{i=1}^{n} \frac{xi}{n}$$

In everyday language we say that $\bar{x}$ is the average of the observations.

Variance

The sample variance S^2 of n observations, $x_1, x_2 \ldots x_n$, is given by

$$S^2 = \frac{(X_1 - \bar{X})^2 + (X_2 - \bar{X})^2 + \ldots + (X_n - \bar{X})^2}{(n-1)}$$

$$= \sum_{i=1}^{n} \frac{(xi - \bar{X})^2}{n-1}$$

Standard Deviation

The standard deviation s of the sample is obtained by taking the square root of the variance.

$$S = \sqrt{\sum_{n=1}^{n} \frac{(X_i - \bar{X})^2}{n-1}}$$

Standard Error

If random samples, size n, were to be taken from a distribution with mean μ and standard deviation σ, then the sample means would form a distribution having the same mean μ but with a smaller standard deviation given by $\sigma / \sqrt{n}$.

The quantity $\sigma / \sqrt{n}$, which is the standard deviation of the sampling distribution of $\bar{X}$, is often called the standard error of $\bar{X}$ to distinguish it from the standard deviation, σ, of the original distribution. As n increases $\sigma / \sqrt{n}$ decreases and this confirms the intuitive idea that the more observations taken, the more accurate will be the sample mean.

Correlation Coefficient

When measurements are made simultaneously on two variables, neither of which are controlled, i.e. they are both random variables, their correlation can be calculated:- Let us suppose that n pairs of measurements (x_1, y_1) are made on two random variables x and y. The observed correlation coefficient is given by:-

$$r = \frac{(x_1 - \bar{x})(y_1 - \bar{y})}{\sqrt{\{[\Sigma (x_1 - x)^2] \; [(y_1 - y)^2]\}}}$$

Student's t-test

When comparing two different methods, it often happens that experiments are carried out in pairs. Thus it is the difference between each pair of measurements which is of interest.

Generally we have k pairs of measurements x1j, x2j (j = 1,2...k) which are independent observations from populations with means $\mu_1 j$, $\mu 2j$. The null hypothesis is that each pair of means is equal.

Ho : $\mu_1 j = u_2 j$ (for all j)

Then the differences

dj = x1j - x2j (j = 1 .... k)

will be a sample, size k, from a population with mean zero. Furthermore, if the populations are approximately normally distributed, the differences will also be approximately normally distributed. If the observed average difference is denoted by $\bar{d}$ and the standard error of the observed differences by Sd then the standard error of $\bar{d}$ is given by

Sd / $\sqrt{k}$ By applying a t-test, by calculating the test statistic:-

$$t = \frac{\bar{d}}{sd/\sqrt{k}}$$

If Ho is true, the distribution of t will be a t distribution with (k - 1) degrees of freedom, as the estimate s_d is calculated from k differences.