- CHAPTER 2 -
EXPERIMENTAL STUDY SITE: LUSTY HILL FARM

We spray the fields and scatter
The poison on the ground
So that no wicked wild flowers
Upon our farm be found.

John Betjeman (1906-1984) From *Harvest Hymn*

SUMMARY

1. Lusty Hill Farm is located in south-east Somerset, UK. The land holding is approximately 11 hectares, and has been managed as a Private Nature Reserve since 1992, assisted by Countryside Stewardship funding. The site overlies Oolitic 'Corn Brash' limestone, the soil is essentially Brown Earth with neutral pH. Most of the site is composed of agriculturally improved mesotrophic grassland, with only small patches of the pre-improvement, species-rich grassland remaining. These remnants have the closest affinity to the MG5 *Centaureo-Cynosuretum cristati* community type.

2. LHF seems to have no great claim to antiquity. The entity of 'Lusty Hill Farm' is probably a 19^{th} century agglomeration. Earliest records suggest the land of Lusty Hill was originally all rough grassland. By 1734, the pasture of the western half had been turned into a large area of "arrable". By the late 19^{th} century most of the arable lands were converted back to grassland.

3. Applications of inorganic fertilisers on LHF have been far less than surrounding farms, and were started as late as the 1960s. The treatments included early spring applications of "nitro-chalk" for "early bite", and biennial applications of "complete" (20:10:10 NPK) fertiliser. Most of the grassland was used for hay making rather than the ubiquitous silage, and it was only in the period 1983-6 that big-bag "haylage" was harvested. The only field (concerning the present study) that was not ploughed and resown was Paddock (Plot 3).

4. Three fields from the landholding w

5. ere chosen by *a priori* selection (botanical observations) to represent a gradient of apparent agricultural improvement: from the most improved, Wheatstubble (MG6), through to Paddock (MG6) and Clayground (MG6). To broaden the spectrum to include typical intensively managed grassland, "The Griffins" (MG7 *Lolium* ley) was leased from the neighbouring dairy farm. A further patch of remnant unimproved, species-rich grassland Bitham Wells (Plot 5) was negotiated for study as a reference community. Within the four improved fields, a homogenous area of land was demarcated as an experimental plot, with dimensions 60-m x 30-m (1800-m^2). Each plot was then in turn divided into three discrete management treatment subplots, with dimensions 20-m x 30-m (600-m^2)

6. To provide a monitoring baseline from which to evaluate the effects of the various experimental treatments, grassland community and diversity aspects were surveyed in 1994 using point-quadrat frames; surveys of peak biomass were also undertaken in 1994; and soil chemistry analyses in 1995. Three fields from the landholding were chosen by *a priori* selection (botanical observations) to represent a gradient of apparent agricultural improvement, scaled from: Plot 1 with highest productivity (848gm^{-2} peak biomass) and lowest species richness (22 spp., *H'* score 0.587); through to Plot 4 with lowest productivity (474gm^{-2} biomass), and highest species richness (34 spp., *H'* score 1.093).

7. In 1995, soil pH was similar throughout the subplots. Total N and organic matter traced a bell-shaped curve, peaking in Plot 3, the only improved field not ploughed in the last 50 years. Both phosphorus and potassium significantly followed the improvement gradient, with very high levels in Plot 1 (P 102ppm K 548ppm), and lowest in Plot 4 (P 13ppm; K 235ppm).

8. Application of multivariate statistics further demonstrated the plot and subplot gradient of improvement. Cluster analysis sorted the subplots with the primary division at only 16% similarity between the improved subplots (1-4) and the species-rich Plot 5; the secondary division at 23% between the subplots of Plot 1, and the older, less improved swards (Plots-2-4). The pattern of subplots along axis-1 in the DCA scattergram again demonstrated the significance of the improvement gradient, as well as indicating within-plot homogeneity before management treatments started.

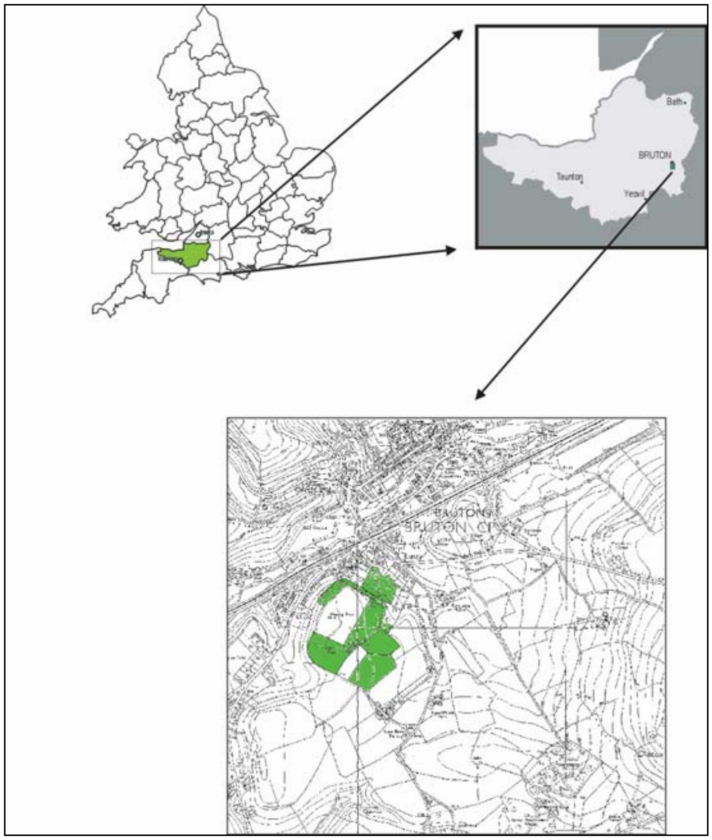
Keywords: Lusty Hill Farm, landscape history, MG5 *Centaureo-Cynosuretum*, inorganic fertilisers, hay making, agricultural improvement, gradient, baseline data, productivity, species-richness, NPK, multivariate statistics, homogeneity.

INTRODUCTION

Lusty Hill Farm is located in southeast Somerset, U.K. (51^{o} 06' N 2^{o} 28' W; National Grid Reference ST 679 338) (see **Figure 2.01**). The land holding is approximately 11 hectares, and has been managed purely as a Private Nature Reserve (Davies & Davies 1998) since its acquisition by the author's parents in 1992. The site overlies Oolitic *Corn Brash* limestone and the soil is essentially a Brown Earth (Trudgill 1989) with neutral pH. Most of the site is composed of agriculturally improved mesotrophic grassland (Mountford *et al* 1994) with only small patches of the pre-improvement, species-rich grassland remaining. These remnants have the closest affinity to the MG5 *Centaureo-Cynosuretum cristati* community type under the U.K. National Vegetation Classification Scheme (Rodwell 1992). The other main habitat type on the reserve is secondary woodland, of which the oldest parts probably date to mid-late 19th century.

Recognition of the site's potential for research into the botanical restoration of agriculturally improved grassland was recognized during initial botanical observations after the site was bought in 1992. Intensive dairy grasslands mostly managed as impermanent leys – regularly herbicided, ploughed and reseeded, surround Lusty Hill Farm. In contrast, most of LHF was managed for hay production up until its dissolution as a working farm in 1986. The fields were unevenly, and only moderately fertilised with inorganic fertilisers. The unintentional result was that some semi-natural interest still remained on the farm (Davies 1992; MAFF 1998). Furthermore, it was apparent that individual fields had undergone differing degrees of agricultural improvement over the last 40 years, and that the lack of homogenous intensification meant that comparative restoration studies could be made between grassland communities (Davies *et al* 1999).

Figure 2.01 Geographical location of Lusty Hill Farm within the UK.



PAST AND PRESENT LAND USE

Lusty Hill Farm seems to have no great claim to antiquity. The land specifically relating to Lusty Hill was only first mentioned in survey of the demesne lands of Bruton in 1713: "*One close of Pasture call'd Lusty Hill cont. 20 acres, now let for 13/10/00.*"

A slightly later survey mentioned the lease of:

"*One tennant and garden in the high street, 4 acres of arable whereof 2 acres is inclosed near…upon Lusty Hill plaine 1 acre of saunders near the same place. Lease 23 Sept: 1717. James Millard + Rose his wife.*"

However, the first possible mention of Lusty Hill as a farm is an entry in a later survey of manor and demesne lands of Bruton:

"*A new Erected house on the waste at Lusty by lease dated 22 sept: 1718. John Hole (aged 50), Matthew Smith (35) and Stephan Smith (30).*" and "*A new Erected Barn with a Barton on the Waste at Lusty by lease dated 1718.*"

The next reference to the land of Lusty Hill is noted in 1734:

"*Leased in 1729 One close of pasture, but now Arrable, call'd Lusty Hill cont. 20 Acres let for £24.*"

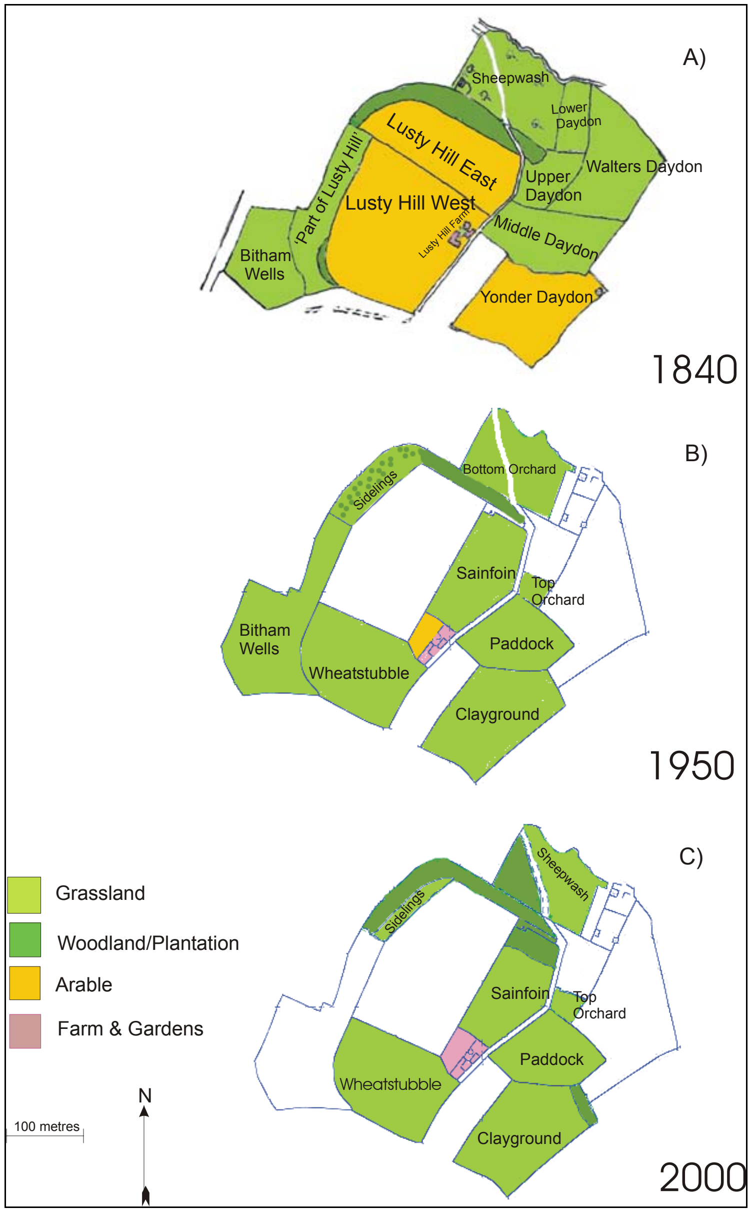
Some 30 years later there is another mention in the manorial court record concerning the land holding of Lusty Hill:

"*The Particular of the Estate at Bruton – not to be leased.*" "*John Griffin – Lusty Hill & Lands 30 acres.*"

Further court records from the 1760s show that Elizabeth Hole (aged 63), widow of John Hole owned several acres of land near Lusty Hill, of which one field was called Long Daydon. In 1783, the records also show that William Hole, younger son of William Hole of Kilmington, owned the same land area as Elizabeth Hole had two decades earlier. In a Survey of the Manor of Bruton (1805) Mr Lebbeus Trimby was recorded as owning lands amounting to a then huge 246-acres, which included parts of the present land holding: "*Lusty Mead; Sheep Wash (pasture), and arable fields at Lusty*." Overall, the evidence suggests that the Farm had not been consolidated as a unitary entity until the mid-19th century. The primary documents establishing the historical land use of the Farm are from the Bruton Parish Map of 1838, and an estate valuation for the owners – (the late) William, Richard and Harry Hole (**see Figure 2.02a**), in 1840.

The farm sale poster, used as a frontispiece for the thesis, was also printed at this time. Mention of Lusty Hill Farm was only made in the 1841 Tithe Map because the Farm was valued as 'Tithe-free', and thus the area was left blank on the map (Bennett 1840). Though the Hole family probably sold the farm in the 1840s, they seem to have been involved with the farming of the land until the end of the 19th century, and thus were central to the management of Lusty Hill for at least 5 generations. The Smith family then took over until John Stroud bought the property in 1920 for approximately £900 after having fought in the Western Front trenches of WW1. The family had previously been shopkeepers in Bruton before the war. David (John's son) and Mary Stroud took over the running of the small dairy farm until the sale of the milk quota in 1986, and the sale of

Figure 2.02 Historical land use maps of Lusty Hill Farm.



most of the farm holding (excluding Bitham Wells and part of the Sidlings) in 1992 to the Davies family, who have managed the property for nature conservation up to the present.

All the fields studied in this project, except Plot 1, have been documented as part of Lusty Hill Farm, though as indicated, the entity of 'Lusty Hill Farm' is probably a 19th century agglomeration. The land-holding and land use history is therefore complicated and difficult to divulge properly (Owen Davies pers. comm.). The mention of "Lusty Waste" in 1718 may indicate that the eastern half of the land up until 1838 at most (**see Figure 2.02a**), may have been unenclosed rough grazings for common livestock usage (Dyer *et al* 2000). The western half of the hill was probably the 20-acre "close" mentioned in the 1713 demesne survey. Thus, at the time of the earliest records, the land of Lusty Hill was probably all grassland. Building of a house, barn and barton on Lusty Hill in this period may be evidence for the start of the piecemeal enclosure of Lusty waste (Dyer *et al* 2000). By 1734, the pasture of the western half had been turned into a large area of "arrable", probably in the same configuration as described in the Parish Map of 1838. Thus common grazing was probably still the main land use of the eastern half, while the western side was down to plough land. This may explain why the hedge on the eastern side of the track (probably originally a sheep drove road to the waste) leading up to the farm seems older in species-richness and bank size than the west side, which was possibly grubbed out when the fields were turned to arable in the 19th century. The 1805 "Survey of the Manor of Bruton" indicates that the land use of Lusty Hill by the beginning of the 19th century was very much mixed, with meads, pasture and arable juxtaposed. The first mention is also made of a particular, and extant field name, "Sheepwash[1]" (**Figure 2.02a**), though this field was part of a much larger land holding under Lebbeus Trimby. Detailed information, however, on the land ownership and usage only goes back to the Bruton Parish Map of 1838 and the valuation document of 1840. This indicates that, though peripheral fields have been lost, the actual landholding as far as area has changed little in the intervening years until the local school (Sexey's School, Bruton) bought the large central *hill* area for a playing field in 1920 Otherwise, field boundaries and cropping patterns have altered to a fair degree. In 1838 the western half of Lusty Hill was still under arable cultivation. However, Lusty Waste was fully enclosed and a large part of this was under arable production, possibly converted from grassland during the early 19th century due to economic pressures of the Napoleonic War (Thirsk 2000). By the late 19th century, the repeal of the Corn Laws led to an agricultural depression, especially in arable production. Together with increasing urban demand for milk, this triggered the conversion of arable lands back to grassland, particularly in the West Country (Davies & Davies 1997; Dyer *et al* 2000). Clayground (formerly Yonder Daydon) was probably reverted to pasture in this period, and the arable fields of East and West Lusty were split and converted to meadow/pasture fields in the early 20th century. The conversion of Sheepwash and Upper

[1] The remnant of the *Sheepwash* dipping pool still survives.

Daydon to orchard-pasture for combined grazing-cider production probably also occurred in this general period[2]. Paddock (formerly Middle Daydon), and Top Orchard (formerly part of Upper Daydon) most likely have at least two centuries of management continuity as grassland. The area of Top Orchard was recorded as part of Lusty Hill Farm in 1840, though became detached in the intervening 90 years, only to be reunited in the 1930s after a land swap (D. Stroud pers. comm.) The grassland with the most continuous land use history and probably least disturbed is Bitham Wells. This field has for certain been grassland since 1840, and may never have been ploughed due to the steep gradient. There is no evidence of lynchets or orcharding earthworks (Rackham 1986), and it would not be remiss to suggest that it was all unimproved ancient grassland up to WWII, with a long history of sheep grazing until dairying took over in the 19th century. Unfortunately, whilst not ploughed and reseeded, inorganic and organic fertilisers have been applied to the majority of the field (60% of the area) for the last 35 years in order to boost dairy production. Since the owners sold up their milk quota in 1986, grazing pressure has been minimal, initially with cattle, and latterly with very short periods - less than three weeks - of *ad hoc* sheep grazing. Over the last 10 years, the lower part of the field has been treated with slurry for hay production, though luckily the species-rich upper slope has been spared. However, grazing neglect is slowly but insidiously destroying the conservation interest as surely as fertiliser applications.

Management regimes from 1920 to 1992

For most of the last 75 years[3], the grasslands of LHF have been farmed semi-intensively for dairy production. Lusty Hill Farm, although probably quite a reasonable landholding before 1900 (Walker, 1911), gradually become a comparatively small enterprise as time went on and land was sold. By the 1980s when the previous owners sold their milk quota, its 35 acres and 22 cows was very small in comparison with its neighbours (Stirling 1996). Overall farm production was equally modest (David Stroud pers. comm.), though few attempts were made to further intensify the management of the grasslands. Through most of the last century, the soil fertility of the fields was enhanced with farmyard manure alone. Applications of inorganic fertilizers have been far less than surrounding farms, and

[2] Tree ring counts of remnant apple trees which have recently blown over indicate establishment in the 1870s.
[3] Information in this section was compiled from interviews with Mr & Mrs Stroud who owned the farm up to July 1992: and from research undertaken by Dr Owen Davies.

were started in the 1960s. Treatment included yearly early spring spreading of "nitro-chalk" for "early bite", and biennial application of "complete" (20:10:10 NPK) fertiliser after hay cropping. Most of the grassland was used for hay making rather than the ubiquitous silage, and it was only in the period 1983-6 that big-bag "haylage" was harvested. During World War 2 only Sainfoin was ploughed, and the greatest disturbance event affecting the majority of the grasslands in the last 50 years was the ploughing up and reseeding of most of the fields in 1965. The only field (concerning the present study) that was not ploughed and resown was Paddock (Plot 3). This field was habitually used as winter standing for the cows. The attempt at agricultural renovation was, however, not entirely effective in creating grass/clover swards, as herbicide was not used, and the action was not followed up with intensive treatment with inorganic fertilisers. Although species richness and diversity were clearly severely reduced, and species such as *Primula veris* were deleted from the swards (D. Stroud pers comm.), a certain degree of species re-colonisation has taken place over the years so that there is now little difference between the ploughed and unploughed grasslands in terms of species assemblages (e.g. Paddock and Clayground). The principle difference between treatments is that the unploughed grassland – Paddock - has a greater build up of organic matter, which is also positively related to total nitrogen levels (**see Figures 2.08b & 2.08c**). Also the only remaining patches of *Centaurea nigra* and *Primula veris* occur in this unploughed grassland, indicating, in particular, that *Centaurea nigra*, though a common constituent of many semi-natural habitats, is especially susceptible to such gross disturbance, and cannot easily regenerate after intensive agricultural improvement practices (Grime *et al* 1988).

The crucial aspect of this small farm for the present study is the relative degrees of grassland improvement. All the grassland except The Sidelings (**see Figures 2.02a and 2.02b**) have been subjected to levels of agricultural improvement, and this has in turn greatly affected the vegetational composition. The reason why Plot 1 is the most improved grassland is clear from the intensive short-term ley management regime. What is not so clear is why the Lusty Hill Farm fields differ so much in productivity and soil fertility. The most likely reason, and accepted to a degree by the former owner, is that proximity has played a part in management, so that the fields closest to the homestead received most fertiliser applications, and the fields further away the least. This was noted as a common (though thoroughly disapproved of) feature of Somerset grassland management by L. Dudley Stamp (1938).

The grassland was grazed almost continuously from August to April, though the cows were kept in during very wet weather and extreme cold conditions. The fields for hay production were generally shut up at the end of April. This comprised nearly 90% of the land holding. The grass was then cut preferably by mid June, though on average cutting started at the end of June/early July. Occasionally, because of bad weather, cutting was pushed back to August. Plot 2 (Wheatstubble) produced the largest crop, with Plot 4 (Clayground) producing the least. In some years, Clayground was only used for hay production, as it could not sustain spring and/or autumn grazing as well. On average 1800 small bales were produced from the 32 acres of grassland, and in a good year 2000. After the hay had been harvested, the cows were put straight back on the aftermath to glean the hay remnants and to manure the stubbles. It was also important to put them on quickly after cutting because the farm holding was so small that it was essential to move the cows off the grazing blocks as soon as possible. From the sale of the milk quota in 1986 to the farm sale in 1992, supplementary income was generated from production of suckler beef cattle.

Changes to management since acquisition as a nature reserve

Since acquiring the Farm, the property has been managed with primary regard to enhancing wildlife diversity (Davies 1992). The wildlife value of the property is not considered of biotic interest for formal designations such as a Site of Special Scientific Interest or County Wildlife Site. However, there are semi-natural, species-rich patches remaining, and these are locally important (Davies 1992). Otherwise, the habitat restoration potential has been appreciated within the Private Nature Reserve Network (Davies & Davies 1998). The management and restoration of the property has also been supported with Countryside Stewardship funding (MAFF 1998). The secondary woodland habitats are mostly managed with limited intervention to allow natural structural diversity, though a section is managed with coppicing. New woodlands have been initiated through planting and natural regeneration. The hedges are being renovated through coppicing, laying and gapping-up. Because grassland habitats make up most of the reserve, the greatest attention has been applied to restoring their biodiversity (Davies 1992). As mentioned earlier, the intermediate intensity of agricultural management of these grasslands allowed species-rich patches to survive. Within this context, early evaluation for habitat restoration potential seemed strong (Davies 1992). Invertebrate interest compared to surrounding farmland also increased the restoration potential. Populations of indicator species such as Common Blue *Polyommatus icarus*, Large Skipper *Ochlodes venata* and Marbled White *Melanargia galathea* were present, and have expanded markedly since the transfer of the land to nature conservation in 1992. These previously very common species are now effectively deleted from the majority of agricultural grassland habitats due to intensive grassland management (Thomas & Lewington 1991).

The running of the grasslands of Lusty Hill Farm has been reconstituted from the previous agricultural base, to align with nature conservation criteria (Battershill & Gilig 1996; Bignal & McCracken 1996; MAFF 1998; SSDC 1998, 1999). This means that land management is undertaken on a compartment-by-compartment basis. The compartments mostly follow the historic field delineations outlined in **Figure 2.02c** (Bennett 1840; Davies 1992). This management structure enables the development of greater habitat variation and diversity. In primary terms, the grasslands can be divided into the general management patterns of pasture and meadow. Wheatstubble (excluding the research Plot) is managed as pasture (Crofts & Grayson 1999). Clayground, Paddock, Sheepwash and Sainfoin are managed for hay production. All the grasslands except Sheepwash are managed with spring grazing, July hay cut, and aftermath grazing. Though a common feature of pre-twentieth century Somerset farming (Brenchley 1916) and of the previous owners of LHF, winter-spring grazing was frowned upon by 'scientific farmers' of the nineteenth century (Tanner 1857) as it reduced yield, especially of grasses, and meant that the hay crop was often set-back to mid- to late July (Jones 1933). The phenology of most of the meadow species thus meant that at this time of their annual cycle they had 'run-to-seed' and the crop was therefore less nutritious. Though acceptable within the generality of nineteenth-century standards, by the 1930s, farmers considered a late hay crop as unacceptable for properly productive dairy production (Jones 1933), and only suitable for horse feed (Local retired farmer pers. comm.). For conservation management there is a general necessitate to disregard the majority of mid-late 20th century farming dictums, and reinstate the antecedent methods which, though discarded, allowed for (contained) biodiversity. However, traditionalistic virtues can be combined with technological innovations, such as high-powered tractors, and PTO mounted cutting, baling and lifting technologies (Jefferson 1999).

Typical local intensive grassland management

Typical modern dairy pasturage surrounds Lusty Hill Farm. The nearest dairy unit to LHF has a land holding of approximately 300 acres, both owned and rented. Plot 1 is still owned by the Griffin family, and the milking cows used in the grazing treatments of the project are from this dairy herd. The majority portion of the field in which Plot 1 is situated is still managed by the farmer using intensive management (i.e. use of inorganic fertilisers and medium-term *Lolium perenne* leys). It is worth describing the grassland management of this neighbouring dairy farm as an example of regional grassland management methods, in order to contrast with the extensive management of LHF.

The grassland holdings of New Barn Farm[4] are roughly divided into grazed, one-cut silage and grazed, and silage grasslands, though as the swards are impermanent, the management regimes for each field unit can be annually altered, and all grasslands have a degree of cow grazing at different times of the year. All grasslands are ploughed and reseeded approximately between 7-10 years in order to renew 'worn-out' swards, i.e. swards with unacceptable levels of dicot weeds. Different seed mixtures are sown according to the primary use of the sward. Cut and grazed swards are sown with intermediate and late varieties of *Lolium perenne*, whereas the pure silage fields are sown mainly with *Lolium multiflorum* cultivars, and later oversown with clover (*Trifolium repens*) cultivars. The general fertiliser management regime for grazed fields includes 125kg/ha of PK applied between November and February; 200kg/ha of N (ammonium nitrate) in April, followed by 150kg/ha of N in June. A thorough dressing of slurried manure is applied on all fields from September to October. Slurry washings are sprayed on the grassland throughout the year. For silage fields, and limited hay production, the April N application is 250kg/ha, with 190kg/ha of N after the crop is cut. Other elements such as sulphur, magnesium and lime are applied if soil testing indicates a deficiency.

Grazed swards: once the cows are allowed out of their winter housing in April, the grazed swards are tightly strip-grazed until June. In July more extensive strip-grazing is applied until all fields are under rotational grazing from August until the cows are re-housed in October. Other management includes harrowing and rolling in April before grazing, topping of weeds twice during July-September, and very occasionally a resort to selective dicot herbicide treatment, depending on the infestation levels.

[4] Brian Griffin, Godminster Lane, Bruton, Somerset.

One cut silage and hay swards: there is no spring grazing and the swards are allowed to develop from October to the cut in May/June for silage, and late June for hay. After the crop has been stored, the sward is lightly grazed for a week, the fertiliser applied, and then the sward is rested for approximately 6 weeks. The fields are then brought into the grazing rotation. For pure silage fields, the May cut is followed by a further cut in July, and if weather conditions are not droughty, then another cut in September.

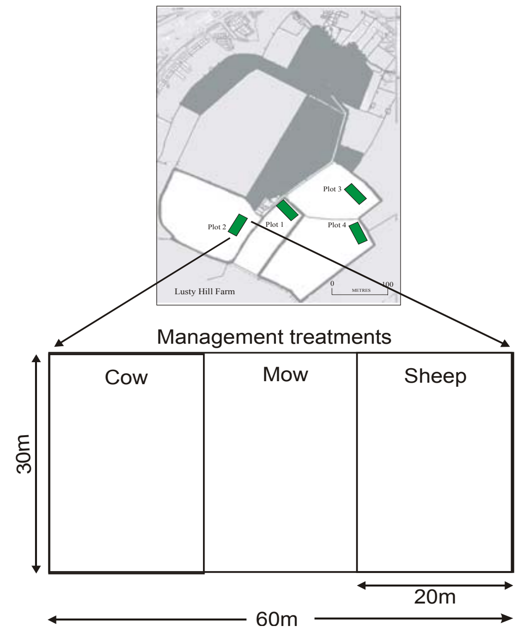
It is worth noting that with a downturn in dairying profitability, the farm holding has been undergoing rationalising management activities to reduce unnecessary costs (Mike Griffin *pers comm*.). Soil nutrient capital is monitored in order to reduce unnecessary expense on inorganic fertiliser applications. This has merited reduced annual N applications, with more integrated use of slurry/manure as organic N collateral. Thus P and K application is managed on a more selective biennial basis rather than previous *carte blanche* annual usage. This management turnabout is due to the identification of huge soil reserves as a consequence of previous over-application (Eco-Ag Ltd 1997; Brady & Weil 1999). The turning out of cows from housing earlier in the spring, and leaving out later in the autumn reduces concentrate feed costs. Grassland cropping management is also altered to accommodate longer-term plough and reseed regimes, with previously short-term leys being succeeded by medium-term, and occasionally permanent swards.

EXPERIMENTAL PLOT SET-UP

As already inferred, it was apparent from preliminary vegetation surveys of 1992-3 that the individual fields of Lusty Hill Farm differed in their vegetation composition and structure probably due to inconsistencies in grassland husbandry. Three fields in particular seemed to show exclusive vegetation characteristics, which marked them apart (**see Figure 2.02c** and **Table 2.02**). Wheatstubble seemed to be the most productive sward with a high dominance of grass species especially *Lolium perenne*, and also high abundance of *Trifolium repens*. Paddock seemed to have a greater diversity of grass species, though chiefly marked out by a particularly high *Holcus lanatus* cover. Clayground superficially seemed to be the least agriculturally improved, with a shorter, sparser sward, with a higher forb component, and the presence of *Ranunculus acris* and *Leucanthemum vulgare*, which were not apparent in the other fields. Therefore, these fields were chosen through *a priori* selection to represent a minimum gradient of apparent agricultural improvement levels - Wheatstubble, Paddock through to Clayground. However, to maximise the ecological differentials in the study, and to demonstrate a more robust ecological gradient, a patch of land was leased from the neighbouring intensive dairy farm (Griffins Field - Plot 1). This sward was sown in 1989 as a medium term *Lolium perenne* grazing ley. No legumes or forbs were sown with the *Lolium-Poa trivialis* grazing mixture, and the field was treated with industry standard levels of inorganic fertilisers. A further patch (Bitham Wells – Plot 5), which was part of Lusty Hill Farm until the farm sale in 1992, was negotiated for study as a reference community (White & Walker 1997), as it is an unimproved, species-rich remnant. Probably due to the steepness of the slope, the thinness of the soil and the previous uncommitted attempt to intensify grass production, this patch survived improvement measures.

In order to establish experimental research plots, homogenous areas of grassland were chosen within each of the five fields. In Griffins, Wheatstubble, Paddock and Clayground **(see Figures 2.01 and 2.02c**) 60-m x 30-m (1800-m^2) areas were measured, and the corners of the rectangular plots marked out with round timber fencing stakes. These enclosures were numbered 1, 2, 3 and 4 respectively. Electric fencing insulators were attached to each post so as to be able to enclose whole plots in energised electric fencing wire to manage grazing exposure. This was a necessary measure so that whole plots could be shut up during the hay-growth period. Each plot (except Plot 5) was, in turn, also divided into three discrete management treatment subplots using further fencing stakes (**Figure 2.03**). These equal-area (600-m^2) paddocks were randomly allocated to accept sheep, dairy cow or mowing management treatments in the pre- (*spring*), and post- (*aftermath*) hay cut periods. Electric fencing netting was applied around the perimeter of each of the designated sheep plots during grazing periods to prevent the

Figure 2.03 Plot locations and design.



escape of stock. These three cropping treatment regimes were applied over an infrastructure of species-enhancement techniques evaluated throughout the majority of the thesis. Plot 5 (25-m x 6-m), already being diverse and species-rich, was not treated to the full range of treatments and analyses, but used as a reference and target community as far as the attempted restoration of the other species-depauperated grasslands (Parker 1995; White & Walker 1997). As noted previously, over at least the last 10 years, this grassland has been subject to low grazing pressure, and general management neglect by the owners. In order to prevent the sward deteriorating completely unchecked, the author has attempted to stem successional pressures through mowing and raking from 1998 onwards.

Table 2.01 sets out the plot and subplot numbering system used to identify the grassland areas throughout the thesis.

Table 2.01 Field plot/subplot synonyms.

Field name	Plot Number	Subplot numbers
Griffins	1	1 – 3
Wheatstubble	2	4 – 6
Paddock	3	7 – 9
Clayground	4	10 – 12
Bitham Wells	5	13

PRELIMINARY SITE VEGETATION DESCRIPTION

During 1994, the first year of experimental treatments, it was crucial to gather baseline data to provide a starting point from which to measure the impacts of the experimental treatments. Without these analyses, clearly there would have be limited empirical means with which to assess the validity of the longer-term methodologies employed in the restoration research. To this end, the grassland vegetation was surveyed using a point-quadrat frame as described in detail in **Chapters 3** and **4**. The subsequent datasets were then statistically analysed using widely used descriptive and multivariate techniques (Fowler *et al* 1998; Kent & Coker 1992). The first soil census was conducted later than desired in the spring of 1995 when funds became available.

Table 2.02 contains summary descriptions of the management histories of the fields within which the experimental plots are situated, including NVC community affinities (Rodwell 1992). In association, **Table 2.03** presents basic quantifications of diversity, productivity and major chemical soil characteristics[5] as measured in 1995. These details provide the bases from which the possible floristic developments due to restoration treatments can be compared (Parker 1995). As noted above, in order to increase the treatment variables, the research was conducted on both a plot and subplot foundation.

Table 2.02 Quantification of agricultural histories of grasslands involved in research.

Plot No.	NVC Community Type (Rodwell 1992)	Improvement level /inorganic fertilizer input	Year last ploughed and reseeded	Last year of artificial fertiliser application
1	*Lolium perenne - Poa trivialis* ley grassland	High	1989	1993
2	*Lolium perenne-Cynosurus cristatus* grassland	Medium	1965	1985
3	*Lolium perenne-Cynosurus cristatus* grassland	Medium	pre 1945	1985
4	*Lolium perenne-Cynosurus cristatus* grassland	Low	1965	1985
5	*Cynosurus cristatus-Centaurea nigra* grassland (reference site)	No fertilizer	probably never	never

Table 2.03 Diversity and productivity characteristics of research grasslands.

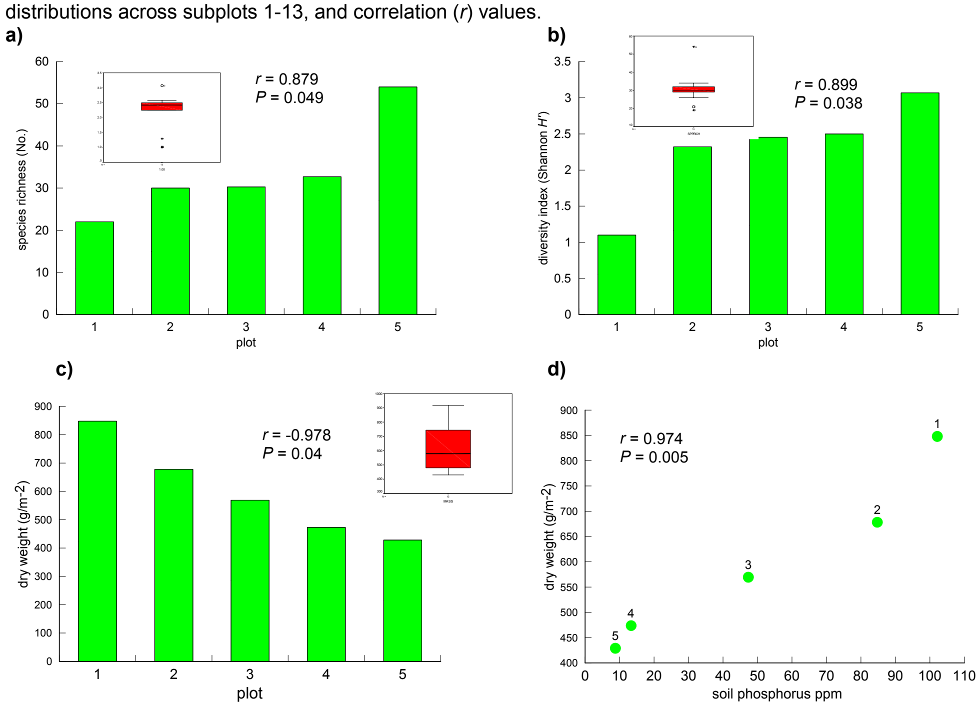
Plot	Species richness (No.)	Shannon diversity index (H')log e	Biomass/ productivity (g m^{-2})	Soil Analyses				
				pH	OM %	N %	Pppm	Kppm
1	22	1.20	847.7	7.3	21	0.72	102.2	548
2	31	2.46	679.7	7.3	24	0.93	84.8	460
3	32	2.54	569.2	7.1	30	1.11	47.4	233
4	34	2.55	473.6	7.3	24	0.86	13.4	235
5	54	3.07	429.0	7.4	20	0.71	8.8	160

Table 2.04 is comprised of total species lists collated for each of the subplots (1-13) in two surveys carried out in June 1994. This was compiled as elementary comparative baseline data, and to assess whether management treatments other than species

[5] Analytical Laboratory, Reading University.

introductions facilitated increases in species-richness over time. **Figure 2.04a** shows that species number was lowest in Plot 1, increasing but levelling across Plots 2-4, and then significantly higher for Plot 5, with a complement of 54 species.

Figure 2.04 Graphs **a-c** demonstrate the significance of the plot improvement gradient in terms of **a)** species-richness (No.); **b)** Shannon diversity index (*H*'); **c)** and phytomass (g dry matter/m^{-2}). Chart **2.04d** shows the relationship between starting phytomass and soil phosphorus; data labels refer to plots. Also included are box plots to indicate data distributions across subplots 1-13, and correlation (*r*) values.



The prominence of the gradient is supported by the significant *r* correlation result. A similar relationship is also apparent from plotting Shannon Diversity Index scores (*H*') and peak phytomass (negative), against the plot gradient (**Figures 2.04b & 2.04c**). Importantly, as shown in **Figure 2.04d**, dry weight phytomass as measured by samples taken from each subplot in June 1994, very closely follow the gradient of soil phosphorus (r = 0.974; P = 0.005), indicating that P was a highly significant factor in controlling grassland productivity.

Table 2.03 Species inventories recorded for each subplot in 1994.

Subplot 1	Subplot 2	Subplot 3	Subplot 4	Subplot 5	Subplot 6	Subplot 7	Subplot 8	Subplot 9	Subplot 10	Subplot 11	Subplot 12	Subplot 13
Agrostis stolonifera *Allium vineale* *Anthriscus sylvestris* *Arum maculatum* *Bellis perennis* *Brachythesium rutabulum* *Cerastium fontanum* *Cirsium arvense* *Cirsium vulgare* *Convolvulus arvensis* *Dactylis glomerata* *Festuca arundinacea* *Galium aparine* *Geranium dissectum* *Lamium album* *Lamium purpureum* *Lolium perenne* *Poa annua* *Poa pratensis* *Poa trivialis* *Rumex obtusifolius* *Taraxacum officinale* *Trifolium repens* *Urtica dioica* *Veronica persica* *Vicia sativa*	*Agrostis stolonifera* *Allium vineale* *Anthriscus sylvestris* *Brachythesium rutabulum* *Bromus hordeaceus* *Cirsium arvense* *Cirsium vulgare* *Dactylis glomerata* *Galium aparine* *Geranium dissectum* *Lamium purpureum* *Lolium perenne* *Poa annua* *Poa pratensis* *Poa trivialis* *Rumex obtusifolius* *Stellaria media* *Taraxacum officinale* *Trifolium repens* *Urtica dioica* *Veronica persica*	*Agrostis stolonifera* *Allium vineale* *Anthriscus sylvestris* *Bromus hordeaceus* *Cirsium vulgare* *Convolvulus arvensis* *Dactylis glomerata* *Elytrigia repens* *Geranium dissectum* *Holcus lanatus* *Lamium purpureum* *Lolium perenne* *Poa annua* *Poa pratensis* *Poa trivialis* *Rumex obtusifolius* *Stellaria media* *Taraxacum officinale* *Veronica persica*	*Achillea millefolium* *Agrostis stolonifera* *Alopecurus pratensis* *Arrhenatherum elatius* *Bellis perennis* *Brachythesium rutabulum* *Bromus hordaceus* *Cerastium fontanum* *Cirsium arvense* *Cirsium vulgare* *Convolvulus arvensis* *Cynosurus cristatus* *Dactylis glomerata* *Festuca arundinacea* *Festuca rubra* *Geranium dissectum* *Heracleum sphondylium* *Holcus lanatus* *Lolium perenne* *Phleum pratense* *Plantago lanceolata* *Plantago major* *Poa annua* *Poa trivialis* *Ranunculus bulbosus* *Rumex acetosa* *Rumex obtusifolius* *Taraxacum officinale* *Trifolium pratense* *Trifolium repens* *Urtica dioica*	*Achillea millefolium* *Agrostis stolonifera* *Alopecurus pratensis* *Arrhenatherum elatius* *Bellis perennis* *Bromus hordaceus* *Cerastium fontanum* *Cirsium arvense* *Cirsium vulgare* *Convolvulus arvensis* *Cynosurus cristatus* *Dactylis glomerata* *Festuca arundinacea* *Festuca rubra* *Galium aparine* *Geranium dissectum* *Heracleum sphondylium* *Holcus lanatus* *Lolium perenne* *Phleum pratense* *Plantago lanceolata* *Poa annua* *Poa trivialis* *Ranunculus bulbosus* *Rumex acetosa* *Rumex obtusifolius* *Taraxacum officinale* *Trifolium pratense* *Trifolium repens* *Urtica dioica*	*Achillea millefolium* *Agrostis stolonifera* *Alopecurus pratensis* *Arrhenatherum elatius* *Bellis perennis* *Bromus hordaceus* *Cerastium fontanum* *Cirsium arvense* *Convolvulus arvensis* *Cynosurus cristatus* *Dactylis glomerata* *Festuca arundinacea* *Festuca rubra* *Geranium dissectum* *Heracleum sphondylium* *Holcus lanatus* *Lolium perenne* *Phleum pratense* *Plantago lanceolata* *Poa annua* *Poa pratensis* *Poa trivialis* *Ranunculus bulbosus* *Rumex acetosa* *Rumex obtusifolius* *Taraxacum officinale* *Trifolium pratense* *Trifolium repens* *Urtica dioica*	*Agrostis stolonifera* *Alopecurus pratensis* *Arrhenatherum elatius* *Bromus hordaceus* *Centaurea nigra* *Cerastium fontanum* *Cirsium arvense* *Convolvulus arvensis* *Cynosurus cristatus* *Dactylis glomerata* *Elytrigia repens* *Festuca arundinacea* *Festuca rubra* *Geranium dissectum* *Heracleum sphondylium* *Holcus lanatus* *Lolium perenne* *Phleum pratense* *Plantago lanceolata* *Poa annua* *Poa trivialis* *Ranunculus bulbosus* *Ranunculus ficaria* *Rumex acetosa* *Rumex obtusifolius* *Taraxacum officinale* *Trifolium pratense* *Trifolium repens* *Trisetum flavescens* *Urtica dioica*	*Agrostis stolonifera* *Alopecurus pratensis* *Arrhenatherum elatius* *Bromus hordaceus* *Cerastium fontanum* *Cirsium arvense* *Convolvulus arvensis* *Cynosurus cristatus* *Dactylis glomerata* *Elytrigia repens* *Festuca arundinacea* *Festuca rubra* *Geranium dissectum* *Heracleum sphondylium* *Holcus lanatus* *Lolium perenne* *Phleum pratense* *Plantago lanceolata* *Poa annua* *Poa trivialis* *Ranunculus bulbosus* *Ranunculus ficaria* *Rumex acetosa* *Rumex obtusifolius* *Taraxacum officinale* *Trifolium pratense* *Trifolium repens* *Trisetum flavescens* *Urtica dioica*	*Achillea millefolium* *Agrostis stolonifera* *Alopecurus pratensis* *Anthriscus sylvestris* *Arrhenatherum elatius* *Bellis perennis* *Bromus hordaceus* *Centaurea nigra* *Cerastium fontanum* *Cirsium arvense* *Convolvulus arvensis* *Cynosurus cristatus* *Dactylis glomerata* *Festuca arundinacea* *Festuca rubra* *Geranium dissectum* *Heracleum sphondylium* *Holcus lanatus* *Lolium perenne* *Phleum pratense* *Plantago lanceolata* *Poa annua* *Poa trivialis* *Primula veris* *Ranunculus bulbosus* *Ranunculus ficaria* *Rumex acetosa* *Rumex obtusifolius* *Taraxacum officinale* *Trifolium pratense* *Trifolium repens* *Trisetum flavescens* *Urtica dioica*	*Agrostis stolonifera* *Alopecurus pratensis* *Arrhenatherum elatius* *Avenula pubescens* *Bellis perennis* *Brachythesium rutabulum* *Bromus hordaceus* *Cerastium fontanum* *Cirsium arvense* *Convolvulus arvensis* *Cynosurus cristatus* *Dactylis glomerata* *Festuca arundinacea* *Festuca rubra* *Geranium dissectum* *Heracleum sphondylium* *Holcus lanatus* *Leucanthemum vulgare* *Lolium perenne* *Phleum pratense* *Plantago lanceolata* *Poa annua* *Poa trivialis* *Ranunculus acris* *Ranunculus bulbosus* *Ranunculus ficaria* *Ranunculus repens* *Rumex acetosa* *Rumex obtusifolius* *Taraxacum officinale* *Trifolium pratense* *Trifolium repens*	*Agrostis stolonifera* *Alopecurus pratensis* *Arrhenatherum elatius* *Bellis perennis* *Brachythesium rutabulum* *Bromus hordaceus* *Cerastium fontanum* *Cirsium arvense* *Convolvulus arvensis* *Cynosurus cristatus* *Dactylis glomerata* *Festuca arundinacea* *Festuca rubra* *Geranium dissectum* *Heracleum sphondylium* *Holcus lanatus* *Lathyrus pratensis* *Leucanthemum vulgare* *Lolium perenne* *Phleum pratense* *Plantago lanceolata* *Poa annua* *Poa trivialis* *Ranunculus acris* *Ranunculus bulbosus* *Ranunculus ficaria* *Rumex acetosa* *Rumex obtusifolius* *Taraxacum officinale* *Trifolium pratense* *Trifolium repens* *Urtica dioica*	*Agrostis stolonifera* *Alopecurus pratensis* *Anthriscus sylvestris* *Arrhenatherum elatius* *Bellis perennis* *Brachythesium rutabulum* *Bromus hordaceus* *Cerastium fontanum* *Cirsium arvense* *Convolvulus arvensis* *Cynosurus cristatus* *Dactylis glomerata* *Festuca arundinacea* *Festuca rubra* *Fissidens bryoides* *Geranium dissectum* *Heracleum sphondylium* *Holcus lanatus* *Leucanthemum vulgare* *Lolium perenne* *Lotus corniculatus* *Phleum pratense* *Plantago lanceolata* *Poa annua* *Poa trivialis* *Ranunculus acris* *Ranunculus bulbosus* *Ranunculus ficaria* *Rumex acetosa* *Rumex obtusifolius* *Taraxacum officinale* *Trifolium pratense* *Trifolium repens* *Trisetum flavescens*	*Achillea millfolium* *Agrimonia eupatoria* *Agrostis stolonifera* *Anacamptis pyramidalis* *Anthxanthum odoratum* *Arrhenatherum elatius* *Helictotrichon pubescens* *Bellis perennis* *Briza media* *Bromus hordeaceus* *Carex flacca* *Centaurea nigra* *Centaurea scabiosa* *Cirsium acaule* *Convolvulus arvensis* *Cynosurus cristatus* *Dactylis glomerata* *Daucus carota* *Festuca arundinacea* *Festuca rubra* *Heracleum sphondylium* *Hieracium pilosella* *Holcus lanatus* *Hypochoeris radicata* *Knautia arvensis* *Lathyrus pratensis* *Leontodon autumnalis* *Leontodon hispidus* *Leucanthemum vulgare* *Linum catharticum* *Lolium perenne* *Lotus corniculatus* *Luzula campestris* *Medicago lupulina* *Ophrys apifera* *Phleum pratense* *Pimpinella saxifraga* *Plantago lanceolata* *Plantago media* *Poa trivialis* *Polygala vulgare* *Primula veris* *Prunella vulgaris* *Pseudoschleropodium purum* *Quercus robur* *Ranunculus acris* *Ranunculus bulbosus* *Sanguisorba minor* *Senecio jacobea* *Taraxacum officinale* *Thymus polytrichus* *Tragopogon pratensis* *Trifolium pratensis* *Trisetum flavescens*

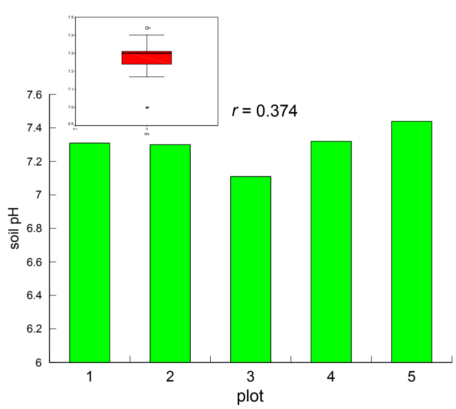
Applying Al Mufti *et al*'s (1977) and Grime's (1979) standing crop (including litter) productivity parameters of 350-750 g/m^{-2} to determine optimum species richness, Plot 1 clearly had dry matter levels above the conservation-desired intermediate levels (Hodgson 1989), whereas, in 1994, all the other sward measurements indicated productivities potentially sympathetic to floristic restoration.

Pre-treatment soil parameters

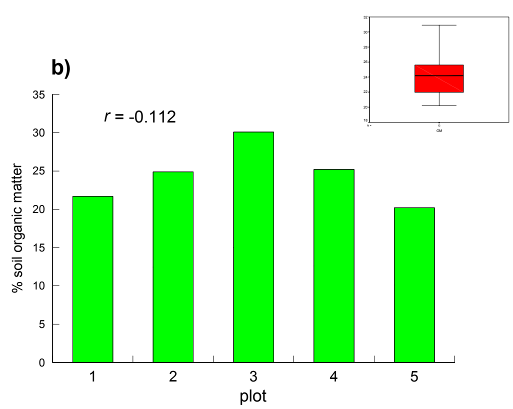
Soil pH was essentially similar throughout the plot gradient in 1995. However, Plot 5 had the highest pH, probably a representative of the thin soil/turf facilitating higher soil/subsoil mixing, allowing calcium (from Oolite) to raise percentage base saturation of the soil clay-colloidal complex (Brady & Weil 1999). This is suggested by the 1998 soil survey in which pH and calcium content positively significantly correlate (r = 0.578; P = 0.038). Plot 3 had notably lower pH (**Figure 2.05a**) probably due to the humic acids developed by the significantly higher soil organic matter. This factor is evinced by **Figures 2.05b-c**, which demonstrate a bell-shaped curve for both organic matter and total nitrogen across the prescribed plot gradient. Both percentage organic matter and percentage total nitrogen were inextricably linked (r = 0.996; P = 0.000). Plot 1 (Subplots 1-3) is a medium/long-term ley, and usually ploughed on a 7-10 year cycle. Such regular ploughing prevents the build-up of soil organic matter and total nitrogen, as both are released in available or leachable form once the turf is broken up. Plot 3 has not been ploughed in living memory and has the highest organic matter/total nitrogen build-up of the agriculturally improved fields. Ironically, Plot 5 (Subplot 13) has probably never been ploughed, though due to its steep slope, the soil has always been thin, and organic matter has not been able to accumulate compared to a level terrain.

Figure 2.05 Column charts indicating trends in plot data: **a)** pH; **b)** organic matter; **c)** nitrogen; **d)** potassium; and **e)** phosphorus. Also included are box plots to indicate data distributions across subplots 1-13.

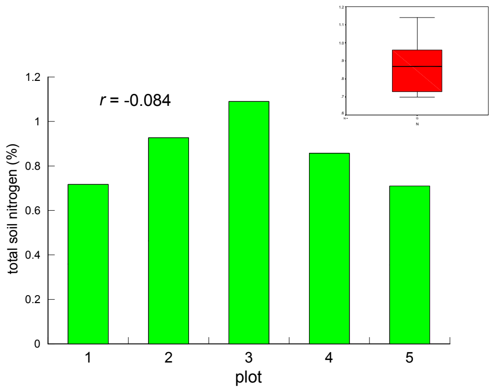
a)



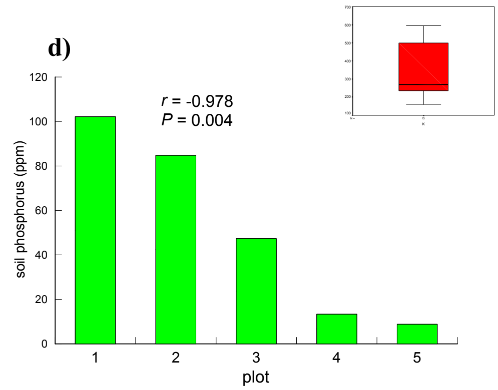
b)



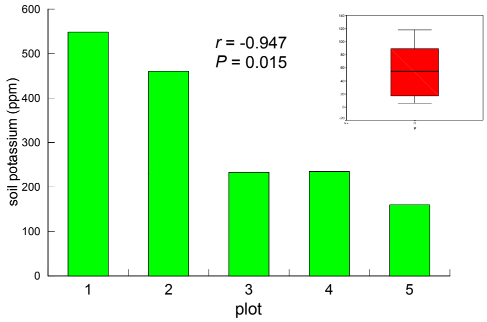
c)



d)



e)



Figures 2.05d-e show that both phosphorus and potassium levels significantly followed the improvement gradient. In addition, following MAFF RB209 (2000) fertiliser guidelines, the levels of both elements are very high; high enough that even under intensive management it is good practice to halt fertiliser applications until levels are substantially depleted. This is a crucial observation as high residual soil K, and P in particular, are considered very detrimental to attempting grassland restoration (Berendse *et al* 1992; Mountford *et al* 1994; Kirkham *et al* 1996). Both nutrients are relatively immobile soil constituents (Brady & Weil 1999), and it may take many years of cropping without replacement for these elements to become depleted. Most evidence suggests that the depletion of these soil macronutrients is essential for increasing plant species-richness (Hopkins *et al* 1999; Jones & Hayes 1999; Critchley *et al* 2002).

Grassland community classification

As well as the species lists, cover-abundance data was collected in the same period using point-quadrat surveys (Grieg-Smith 1983). The methods and results are described in more detail in **Chapter 4**, but some preliminary descriptive results are presented in this chapter in order to demonstrate the pre-treatment agricultural improvement gradient. Also, in order to understand the vegetational developments – whether positive or negative - associated with restoration management, application of a range of analytical techniques was mounted so as to develop a preliminary baseline for future comparison. In order to evaluate the pre/initial restoration status of the grasslands, a number of multivariate techniques were applied. The principle methods used were Cluster Analysis (Kovach 1998), Detrended Correspondence Analysis (Kovach 1998), and TWINSPAN (McCune & Mefford 1997).

Figure 2.06 Dendrogram of cluster analysis results for subplot field layer data.

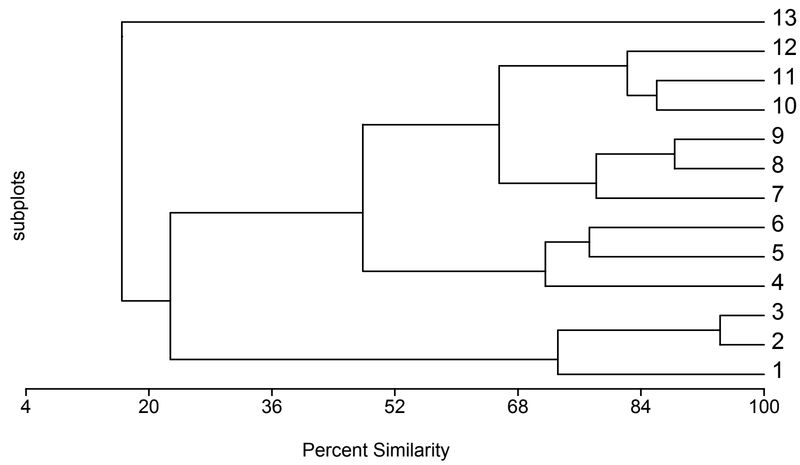
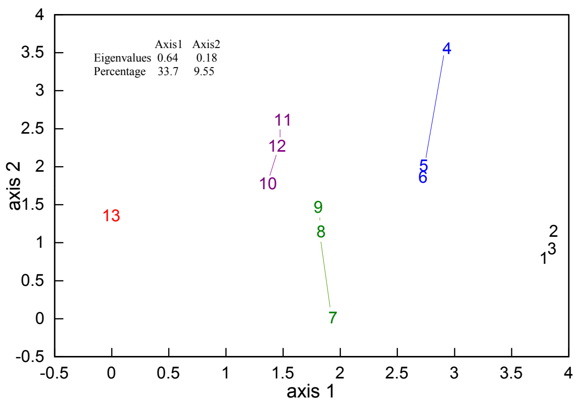


Figure 2.06 is a cluster analysis classification dendrogram applying percent similarity to describe the relationships between subplots based on the 1994 floristic data. The primary division at only 16% similarity was between the improved subplots (1-4) and the species-rich Plot 5; the secondary division at 23% between the subplots of Plot 1, and the older, less improved swards (Plots-2-4). This supports the initial presumption on which the restoration project was founded. In point of fact, the whole sequence is also supported by the classification, though the perfect ranking of subplots along the vertical axis is probably little more than numerical serendipity A similar picture is demonstrated by the DCA analyses. In **Figure 2.07** the subplots are also closely clustered in continuity with their respective plots, and in a sequence along axis-1 in accordance with the cluster analysis.

Figure 2.07 Scattergram of DCA results of subplot 1994 field-layer data.



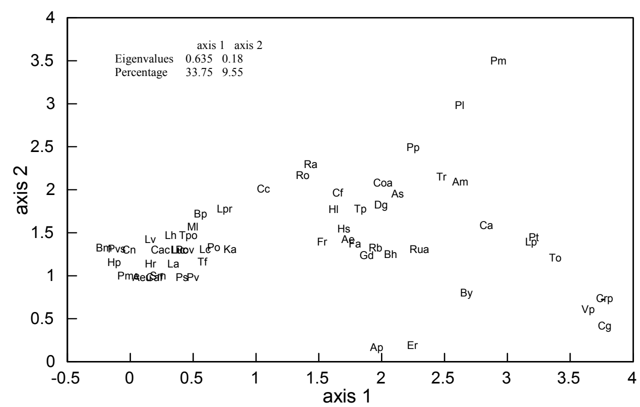
Two-way indicator species analysis (TWINSPAN) (Hill 1979; McCune & Mefford 1997) was applied to the 1994 field-layer data to ordinate the grassland communities in accordance with the analytical methodology used by the National Vegetation Classification (Rodwell 1992; Kent & Coker 1992). The computer-generated two-way table produced by TWINSPAN is presented as **Table 2.05**. The basic first level of the dichotomised species key, cleaves between the improved and unimproved communities. However, it is the third level that has the most evaluative power. The first group is primarily made up of weedy

```
Two-Way Ordered Table Fieldlayer Data
1994

                         1111
                1234567890123

   21  Elytrigi  --2---41-----  000000
   14  Ceras gl  1------------  000001
   18  Crepis    1------------  000001
   35  Lolium p  5555554333331  000001
   44  Poa spp   555434322111-  000001
   58  Veron pe  1------------  000001
   17  Convolvu  1-1-23---2231  00001
   53  Taraxacu  5222221111-11  00001
   10  Bromus    -11112222111-  0001
   16  Cirs arv  11--1211111--  0001
   56  Trifol r  -1-333111211-  0001
   39  Phleum    ---221--1221-  001000
   42  Plant ma  ---4---------  001000
    4  Alope pr  ---11-31--1--  001001
   24  Geran di  ----11111-1--  001001
   50  Rumex ac  -----2111-1--  001001
   13  Ceras fo  ---1--1--111-  00101
   25  Heracleu  ------112111-  00101
   48  Ran acri  ---------333-  00101
   51  Rumex ob  ---------1-1-  00101
    3  Agros st  -115554444441  0011
    5  Arrhen e  ---1114443141  0011
   20  Dactylis  --14434443342  0011
   22  Fest aru  ---1113322121  0011
   28  Holcus    1--1213434442  010
   41  Plant la  ---421-11---1  010
   55  Trifol p  ---1131112212  010
    1  Achil mi  ---12---1---1  011
   19  Cynosuru  ---11-1-13323  011
   23  Fest rub  ---1324333234  011
   49  Ran bulb  ---111111---1  011
   30  Lathyrus  -----------11  100
   31  Leucanth  ----------112  100
   57  Trisetum  ------1111-13  100
    6  Helicto   ---------1--3  10100
    2  Agrim eu  ------------1  10101
    9  Briza     ------------3  10101
   11  Carex     ------------4  10101
   12  Centau n  ------------1  10101
   15  Cirs aca  ------------2  10101
   26  Pilosell  ------------2  10101
   27  Hypochoe  ------------1  10101
   29  Knautia   ------------1  10101
   32  Leont au  ------------1  10101
   33  Leont hi  ------------2  10101
   34  Linum     ------------3  10101
   36  Lotus     ------------2  10101
   37  Luzula    ------------1  10101
   38  Medicago  ------------1  10101
   40  Pimpinel  ------------1  10101
   43  Plant me  ------------1  10101
   45  Polygala  ------------1  10101
   46  Primula   ------------1  10101
   47  Prunella  ------------1  10101
   52  Sanguiso  ------------1  10101
   54  Thymus    ------------1  10101
    7  Bellis    ---1--------1  1011
    8  Bryophyte 311---------2  11

                0000000000001
                000111111111
                   000111111
```

Table 2.05 Out-put of TWINSPAN analysis of 1994 subplot field layer data.

species allied with MG7. The second group contains the bulk of productive, bulky MG6 species. Groups three and four have no clear precedent, though the fact that *Cynosurus cristatus* and *Festuca rubra* are allied suggests a community attaining features of MG5. Finally, group six cleaves off *Lathyrus pratensis*, *Leucanthemum vulgare* and *Trisetum flavescens*. Judged by NVC classifications, these are key indicators of restoration success. Increasing abundances of these species suggests successional transition from MG6 to MG5 *Lathyrus pratensis* sub-community (Rodwell 1992). It is worth noting, however, that the reference community (Plot 5) does not fit neatly into any of the MG5 sub-communities. To some extent these ordered results also support the same general precedent demonstrated by the other multivariate analyses, that the initial first-order appraisal of pre-restoration vegetation sequence was essentially correct. The use of DCA ordination presents a more complex picture.

Figure 2.08 Scattergram of DCA species ordination results.



The DCA species scatter along axis-1 (**Figure 2.08**-see species abbreviations in footnote[6]) has a similarity to the first divisional level of TWINSPAN (**Table 2.05**). Ruderal-intermediate CSR species (Grime *et al* 1988) are presented as generally spread more to the right of the graph, typified on the far right by *Veronica persica*, *Cerastium glomeratum* and *Crepis capillaris*. The more stress-tolerant species (Grime *et al* 1988) usually associated

[6] Ae=*Arrhenatherum elatius*; Aeu=*Agrimonia eupatoria*; Am=*Achillea millefolium*; Ao=*Anthoxanthum odoratum*; Ap=*Alopecurus pratensis*; As=*Agrostis stolonifera*; Bh=*Bromus hordeaceus*; Bm=*Briza media*; Bp=*Bellis perennis*; Bs=*Brachypodium sylvaticum*; Bst=*Bromus sterilis*; By=Bryophytes; Ca=*Cirsium arvense*; Cac=*Cirsium acuale*; Caf=*Carex flacca*; Cc=*Cynosurus cristatus*; Cf=*Cerastium fontanum*; Cg=*Cerastium glomerata*; Cn=*Centaurea nigra*; Coa=*Convolvulus arvensis*; Crp=*Crepis capillaris*; Dg=*Dactylis glomerata*; Er=*Elytrigia repens*; Fa=*Festuca arundinacea*; Fr=*Festuca rubra*; Gd=*Geranium dissectum*; Hl=*Holcus lanatus*; Hp=*Helictotrichon pubscens*; Hr=*Hypochoeris radicata*; Hs=*Heracleum sphondylium*; Hse=*Hordeum secalinum*; Ka=*Knautia arvensis*; La=*Leontodon autumnalis*; Lc=*Lotus corniculatus*; Lh=*Leontodon hispidus*; Lic=*Linum catharticum*; Lp=*Lolium perenne*; Lpr=*Lathyrus pratensis*; Luc=*Luzula campestris*; Lv=*Leucanthemum vulgare*; Ml=*Medicago lupulina*; Pl=*Plantago lanceolata*; Pme=*Plantago media*; Pm=*Plantago major*; Po=*Pilosella officinarum*; Pp=*Phleum pratense*; Ps=*Pimpinella saxifraga*; Pov=*Polygala vulgaris*; Pt=*Poa trivialis*; Pv=*Prunella vulgaris*; Pvs=*Primula veris*; Ra=*Ranunculus acris*; Rb=*Ranunculus bulbosus*; Ro=*Rumex obtusifolius*; Rr=*Ranunculus repens*; Rua=*Rumex acetosa*; Sm=*Sanguisorba minor*; Tf=*Trisetum flavescens*; Tp=*Trifolium pratense*; Tpo=*Thymus polytrichus*; To=*Taraxacum officinale*; Tr=*Trifolium repens*; Vp=*Veronica persica*; Vs=*Vicia sativa*

with unproductive, species-rich grasslands are heavily clustered to the left of the chart. In broad terms, this pattern can be interpreted as a gradient of species indicative of grassland improvement level. Species associated with intensive grassland-leys to the right of axis-1 (Plot 1); agriculturally improved grassland species occupying the central axis-1 locus (Plots-2-4); and species associated with unimproved diverse conditions clustered to the left of axis-1 (Plot 5).

LIMITATIONS OF EXPERIMENTAL DESIGN ON STATISTICAL ANALYSIS AND PREDICTIVE POWER

Most European grassland restoration studies utilise cropping treatments centred on mowing, sometimes integrated with sheep grazing (Wells 1971: Gibson *et al* 1987; Oomes 1992; Smith & Rushton 1994; Stampfli & Zeiter 1999; Huhta *et al* 2001). Mowing is the easiest cropping treatment as defoliation can be simply manipulated by hand. However, introducing sheep into an experimental design complicates practicalities as plots have to be larger, stock fencing used, and general shepherding skills are required for their welfare (Bacon 1990). Though sheep are relatively small farm animal stock, moving them is time consuming, and maintenance requires constant vigilance. Even so, whilst mowing and sheep grazing may reflect a considerable proportion of pastoral management in Britain, large areas of grassland are under cattle husbandry (Stoate 1996). Introducing bovine stock to any grassland experiment requires a great increase in design scale to accommodate these bulky animals (Crofts & Grayson 1999). To use lactating dairy cows, which require milking twice a day, places even more, perhaps too many restrictions on experimental design (Bacon 1990). Though considered in the early stages of the project, it was clear that in both financial and manpower terms, to set-up a fully factorial randomised experimental framework (Fowler *et al* 1998) using a dairy herd as the primary management treatment was beyond the limited resources available to the study and even those available to funded ecology research institutions. As far as the author is aware, no grassland restoration experiment incorporating lactating cows has been documented in a peer-reviewed journal. However despite the restrictions imposed on the experimental design by the incorporation of lactating cows as a treatment, it is vital that attempts are made to assess their role and influence on grassland restoration.

LHF is situated in a predominately dairying landscape (Rodwell 1992). To ignore the impact of dairy cows on restoration would be to ignore the historical and present ecology of the area (Stoate 1995). As LHF is adjacent to an amenable and co-operative dairy farmer (Brian Griffin), and because the field containing Plot 1 is owned and managed by this neighbouring farmer, and the grass keep of the fields containing Plots 2-4 already let to the same farmer (within Countryside Stewardship restrictions; DEFRA 2001), this presented the scarce opportunity to incorporate lactating cows into a grassland restoration research project. However, such a strategy also meant that complex randomised experimental designs could not be applied. In addition, the design was further restricted by the inclusion of comparative management treatments – mowing and sheep grazing. Thus, the four plots were divided into three (randomised) management treatment subplots of mowing, sheep grazing, and cow grazing. It was clear to the author from the start, and backed up by subsequent critiques (K. Thompson & P. Buckley pers. comm.), that this simple design clearly restricts the statistical analyses that can be applied, and the due inferences and predictions that can be satisfactorily made. Within this background, it is requisite at this stage to underline certain statistical peculiarities of the experimental design, and what they mean for data interpretation.

The first major statistical concern is with the gradient of plots/subplots with respect to data analysis. The improvement gradient of plots 1-5, key to the experiment, was initially chosen on an observational basis, though later substantiated with soil and vegetation analyses as presented in this Chapter. However, each improved grassland plot (plots 1-4) were randomly divided into the three management treatments, thus overall providing monitoring datasets for 12 subplots along the elected gradient. Unfortunately, because the subplots are essentially a function of the imposed treatment within an initially homogenous grassland plot, it is necessarily inappropriate (K. Thompson & P. Buckley pers. comm.) to use the subplots to increase the informative value of the gradient with respect to variation within plots, and overall power increase of the statistical tests through reductions in degrees of freedom (Waite 2000). The second area of concern is intimately related to the above mentioned experimental design simplification. Although the plots are randomly divided into three treatment subplots, this is essentially 'pseudoreplication' (Hurlbert 1984; Sokal

& Rohlf 1995; Waite 2000) because management treatment is not fully randomised throughout each plot; that is, all of the treatment sampling derives from one area of each plot. The reason for this problem, as mentioned previously, is that in order to incorporate large herbivores such as commercial lactating cows, it was not possible to have second or third tiers of randomisation within each plot. This in effect means that there is only one fixed management treatment within each plot, and although samples are taken randomly within each of the treatment subplots, this amounts to little more than pseudoreplication in the eyes of any statistician. Therefore, the main constraint to interpretation is that whilst statistical inferences can be made, it would be inappropriate to make unsupported generalisations from the ensuing results (Sokal & Rohlf 1995; Waite 2000).

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