Cyfoeth Naturiol Cymru
Natural Resources Wales

Conservation management of species-rich grasslands in the Elan Valley, Radnorshire

M.J. Hayes & R.A. Lowther

Natural Resources Wales Evidence Report No: 8

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Contents

List of Figures

List of Tables

1. Crynodeb Gweithredol

Mae Cwm Elan, sydd yng nghanolbarth Powys, yn cynnwys rhai o'r enghreifftiau pwysicaf a chyfoethocaf o laswelltiroedd mesotroffig heb eu gwella yng Nghymru. Mae'r rhan fwyaf o'r rhain yn ddolydd wrth odrau'r ucheldir ac yn gyfoethog iawn o rywogaethau. Mae'r rhan fwyaf erbyn hyn wedi'u dynodi yn Safleoedd o Ddiddordeb Gwyddonol Arbennig (SoDdGAau) oherwydd eu harwyddocad cenedlaethol. Er mwyn helpu diogelu dyfodol y safleoedd pwysig hyn sefydlwyd Prosiect Dolydd Cwm Elan yn 2004 i geisio rheoli'r glaswelltiroedd llawn rhywogaethau presennol ac, efallai, eu hehangu. Roedd y prosiect yn cael ei reoli a'i weithredu gan bartneriaeth rhwng Ymddiriedolaeth Cwm Elan, Cyfoeth Naturiol Cymru (Cyngor Cefn Gwlad Cymru ar y pryd) ac ymgynghorwyr ecolegol annibynnol.

Prif amcan y prosiect oedd darparu cyngor penodol ynghylch safleoedd a hefyd gyngor ar gyfer eu rheoli'n ecolegol gynaliadwy er mwyn helpu i gadw'r dolydd godrau'r ucheldir hyn, sy'n bwysig ac yn arbennig yn rhanbarthol. Yn benodol, roedd angen penderfynu ar faint o faetholion fyddai ei angen i'w hadfer yn ddolydd lle gellid tyfu a lladd gwair yn ôl y dulliau traddodiadol, ac, yr un pryd, gadw'r o amrywiaeth presennol o flodau. I gyflawni hyn, cynhaliwyd treialon maes efelychol i benderfynu sut y byddai grŵp cynrychiadol o ddolydd Cwm Elan yn ymateb i daenu gwahanol symiau o dail buarth a / neu galch, o ran cemeg y pridd, cynhyrchu gwair a newidiadau yn amrywiaeth y rhywogaethau.

Dangosodd canlyniadau profion monitro'r pridd yn y tymor hir dystiolaeth glir fod y pridd yn dod yn gynyddol fwy asidig ar bob un o'r safleoedd ar y dolydd oedd yn cael eu hastudio, gymaint felly fel ei bod yn annhebyg y bydd y cymunedau presennol o lystyfiant yn cael eu cynnal. Mae hynny'n dangos fod angen ail sefydlu'r ymarfer traddodiadol o chwalu calch o dro i dro. Rhag amharu ar y cydbwysedd presennol o rywogaethau, awgrymir chwalu digon o galch ar y dolydd i gael pridd gyda ph o tua 5.5. Mae'r canfyddiad hwn yn codi pryderon y gallai safleoedd eraill yn yr ardal sy'n gyfoethog mewn rhywogaethau ac sydd angen pridd eithaf niwtral i'w cynnal hefyd fod o dan fygythiad gan fod eu pridd yn asideiddio'n gynyddol. Mae hefyd yn dangos mor bwysig yw cynnal profion pridd yn ehangach.

Dangoswyd hefyd fod taenu ychydig o dail yn ysbeidiol yn bwysig er mwyn cael pridd digon ffrwythlon i gynnal y cymunedau o blanhigion o dan sylw a hefyd roi cnwd o wair mwy derbyniol. Tua 12 tunnell o dail yr hectar bob dwy flynedd oedd y raddfa fwyaf addas ar gyfer rhai o'r dolydd, er y byddai graddfa is o 12 tunnell bob tair blynedd yn well ar gyfer safleodd wedi hen sefydlu ac sydd wedi datblygu llawer mwy o amrywiaeth o rywogaethau. Dagnoswyd y byddai taenu mwy o dail na'r uchod yn niweidilol, drwy annog gormod o dyfiant mewn rhai planhigion ar y dolydd a fyddai'n gorchuddio gormod ar y tir. Arweiniodd taenu tail a chalch ar gynnydd derbyniol yn swm y gwair a dylai hynny wneud y dolydd yn fwy deniadol yn amaethyddol, o ran y tebygolrwydd o allu ail sefydlu cynaeafu gwair a chael porthiant gaeaf da ar gyfer stoc.

Amcan arall oedd ystyried y cyfleoedd sylweddol sydd yng Nghwm Elan i ymestyn, adfer a chysylltu rhywogaethau ar ddarnau o laswelltir sy'n gyfoethog o rywogaethau drwy amrywio porfeydd cyfagos sydd wedi'u lled wella. I gyflawni hyn, dechreuwyd ar reolaeth adfer ar nifer o safleoedd a gafodd eu nodi fel rhai lle'r oedd diffyg maetholion a strwythur porfa addas. Cafodd y rhain eu monitro i ganfod natur, graddfa a pha mor lwyddiannus oedd adfer y dolydd drwy ail goloneiddio naturiol. Dagnosodd gwaith monitro ar y safleoedd ar ôl eu hadfer arwyddion hynod obeithiol y gellid datblygu cyfoeth o rywogaethau o ganlyniad i ail goloneiddio naturiol gan rywogaethau dolydd cynhenid. Roedd presenoldeb gweddillion poblogaethau o rywogaethau yn y dolydd, y tu fewn a'r tu allan i'r safleoedd a ddewisiwyd, a hefyd fod yna gymaint o amodau da o ran y pridd a'r hinsawdd, y gallai'r safleoedd hyn yn hawdd ymateb yn gymharol gyflym i reolaeth adfer addas. Er enghraifft, roedd rhai safleoedd eisoes yn dangos cymaint o gyfoeth o ran rhywogaethau nes eu bod bron yn cyfateb i'r dolydd cyfagos sy'n SoDdGa (er heb bresenoldeb rhai o'r rhywogaethau dolydd prinach) ar ôl dim ond 10 mlynedd o reoli. Gellid disgwyl y byddai hynny'n cymryd degawdau lawer mewn ardaloedd gyda phridd gwell ond â llai o rywogaethau. Mae ymdrech wreiddiol a mwy uchelgeisiol i wella amrywiaeth y rhywogaethau mewn porfa asidig, dlodaidd o ran rhywogaethau ger dôl niwtral, drwy chwalu calch, gwella strwythur y borfa ac ychwanegu hadau drwy wasgaru gwair cyn ei gynaeafu yn dechrau dangos arwyddion cynnar o lwyddiant, ond mae'n amlwg angen rhagor o amser i ddatblygu. Yn ogystal â bod yn gynefinoedd defnyddiol eu huanain, mae’r safleoedd hyn sydd wedi'i hadfer yn gamau ecolegol ar gyfer rhywogaethau mudol a choloneiddio. Maen nhw hefyd yn gallu bod yn barthau byffer pwysig i amddiffyn y caeau cyfoethog iawn mewn rhywogaethau sydd, at ei gilydd, yn fychan ac yn hynod wasgaredig.

Roedd gwaith arall yn canolbwyntio ar adfer safleoedd sydd eisoes yn y SoDdGA lle’r oedd darnau o laswelltir o ansawdd da yn cael eu bygwth gan redyn a phrysgwydd. Llwyddodd rhaglen o reoli rhedyn a phrysgwydd drwy eu torri bob blwyddyn (gyda thorrwr ffust) a thynnu'r rhedyn â llaw i wella’n sylweddol faint ac ansawdd rhywogaethau ar borfeydd cyfoethog o rywogaethau ar safleoedd penodol, er y byddai’n rhaid parhau â hyn i ddal i gael y canlyniadau.

Y cam rhesymegol nesaf ar gyfer y prosiect yw gweithredu argymhellion ar gyfer safleoedd penodol, o ran cadwraeth a rheolaeth adferol, yn ogystal â monitro’r pridd a'r planhigion i fesur eu llwyddiant.

Gellid ymestyn canlyniadau’r prosiect hwn hefyd, yn ddelfrydol, i safleoedd eraill yn yr ardal y byddai'n bosibl eu hadfer. Byddai'r setiau cynhwysfawr o ddata sydd eisoes wedi'u cynhyrchu yn rhoi gwybodaeth amhrisiadwy sut y mae porfeydd o’r fath yn ymateb i wahanol ffyrdd o'u rheoli. Mae yna lawer o gyfleoedd ychwanegol ar gyfer hyfforddi, arddangos a chynnal diwgyddiadau cyhoeddusrwydd ynghylch rheolaeth gadrwaethol y cynefinoedd hyn, rhai gwych ond sy’n gynyddol o dan fygythiad.

2. Executive Summary

The Elan Valley, in mid-Powys, includes some of the most important and richest examples of unimproved mesotrophic grasslands in Wales. The majority of these are highly species-rich upland-fringe meadows that are now mostly designated as Sites of Special Scientific Interest (SSSIs) due to their national significance. In order to help safeguard the future of these important sites the Elan Valley Meadow Project was initially set up in 2004 to address both the management of the existing species-rich grasslands and their potential expansion. The project was managed and implemented by a partnership between the Elan Valley Trust, Natural Resources Wales (Natural Resources Wales) (formerly Countryside Council for Wales; CCW) and independent ecological consultants.

The primary objective of the project was to provide site-specific and ecologically sustainable management advice to help conserve these important and regionally distinct upland-fringe meadows. Specifically there was a need to determine what levels of nutrient inputs are required to enable reinstatement of traditional hay making practices while still conserving existing high levels of floristic diversity. To this end a long-term replicated field trial was undertaken to determine how a representative group of the Elan Valley meadows respond to different inputs of farmyard manure (FYM) and/or lime in terms of soil chemistry, herbage productivity and changes in species diversity.

Results from long term monitoring of soils in the trial showed clear evidence of progressive soil acidification at all meadow sites studied and at a level that is unlikely to sustain the present vegetation communities, and thus highlights the need to reinstate the traditional practice of periodic liming. It is recommended that to prevent any potentially negative impacts on the present species balance that the meadows are limed with the aim of achieving a soil pH of circa. 5.5. This finding raises concerns that other circum-neutral species-rich sites in the locality could also be at threat from increasing soil acidification and highlights the need for wider soil testing.

Light intermittent applications of FYM were also shown to be an important traditional input for maintaining appropriate levels of fertility capable of sustaining the desired plant communities together with providing a more acceptable hay crop. For some meadows the most appropriate rate of FYM inputs was shown to be circa. 12t/ha every two years, although a lower rate of 12t/ha every three years would be more advisable for the long established sites that have developed particularly high levels of species diversity. Rates of FYM applied at higher rates than the above were shown to be detrimental by excessively promoting the growth of some individual meadow components and resulting in undesirable cover levels of undesirable species. Inputs of FYM and lime resulted in acceptable increases in hay yields and as such should make the meadows more agriculturally attractive, both in terms of the likelihood of successfully re-instating hay-making operations and supplying high quality winter forage for livestock.

A further objective related to the considerable opportunities in the Elan Valley for patch expansion, restoration and linkage of species-rich grasslands by diversification of adjoining semi-improved swards. In this regard, a number of previously identified sites with low nutrient status and appropriate sward structure were entered into a period of restoration management and monitored to characterize the nature, rate and success of meadow reversion primarily by natural re-colonisation. Monitoring of the restoration sites showed highly promising indications of developing species richness purely through natural re-colonisation by indigenous meadow species. The presence of remnant populations of meadow species both within and adjacent to selected sites, together with the prevalence of highly amiable edaphic and climate condition shows that these sites are very well able to relatively rapidly respond to suitable restoration management. For example, some sites are already showing levels of species richness starting to approach that of adjacent SSSI meadows (albeit without the presence of some rarer meadow species) within just 10 years of appropriate management, a situation that would be expected to take many decades in areas with more nutrient-rich, species-impoverished conditions. A novel and more ambitious attempt to improve the species diversity of a species-poor acid pasture adjacent to an existing neutral meadow, by liming, ameliorating sward structure and seed addition via green hay strewing, is starting to show early indications of success but clearly needs more time to develop. As well as these newly restored sites acting as useful habitats in there own right, as ecological ‘stepping stones’ for migrating and colonising species, they can also serve a very important role as buffer-zones to help protect the existing mostly small and fragmented highly species-rich fields.

Other work focused on the rehabilitation of existing SSSI sites where high quality stands of grassland were being threatened by bracken and scrub encroachment. A programme of bracken and scrub control by annual cutting (flail-mowing) and hand pulling of bracken was shown to have a significant benefit on the extent and quality of species-rich grassland at specific sites, although this management will need to be continued to achieve lasting results.

The logical next step for the project is to implement the site specific recommendations in terms of conservation and restoration management, together with further soil and botanical monitoring to gauge their success.

Findings from this project should also, ideally, be extended to other potentially suitable restoration sites in the locality with the comprehensive dataset already generated offering invaluable insights into how such grasslands respond to different managements. There are also considerable further opportunities for training, demonstration and publicity events concerned with the conservation management of these outstanding yet increasingly threatened habitats.

3. Foreword

The Elan Valley, on the lower eastern flanks of Elenydd in mid-Powys, includes some of the most important and richest examples of unimproved mesotrophic and acid grasslands in Wales (Stevens *et al*. 2010). These highly species-rich grasslands are distributed among seven clusters of upland-fringe hay-meadows spread over a 20 km stretch of the valley at an altitude between 260 and 420 m. The stands are situated in a series of adjacent sites, on slopes above the valley's four reservoirs where long-standing restrictions on the usage of fertilisers and herbicides have limited the extent of agricultural improvement. They support a distinctive flora, including uncommon or local species such as great burnet *Sanguisorba officinalis*, mountain pansy *Viola lutea*, wood bitter-vetch *Vicia orobus* (for which the Elan Valley is perhaps the key area in Britain), greater butterfly-orchid *Platanthera chlorantha* and fragrant orchid *Gymnadenia conopsea*. In terms of the National Vegetation Classification (NVC) plant communities these grasslands predominately support a distinctive 'Welsh upland fringe' form of the *Lathyrus pratensis* sub-community of the *Cynosurus cristatus-Centaurea nigra* grassland (MG5a) and as such are now mostly designated as Sites of Special Scientific Interest (SSSIs) due to their national significance. The overall aim of this project was to address both the management of the existing species-rich grasslands and their potential expansion, as well as some small-scale supporting studies. The project was managed and implemented by a partnership between staff of the Elan Valley Trust, Natural Resources Wales (formerly CCW) and independent ecological consultants. Overall the project comprised of five specific objectives with an initial report summarising the progress and results achieved between 2004 and 2009 published in 2010 (Hayes and Lowther 2010). Between 2009 and 2013 three of the main project objectives concerning the practicalities of managing and expansion/restoration of specific meadow sites were continued with results and recommendations for future meadow management from across the whole 10 years of the project presented in this report.

Overall, the project findings are expected to have broader applicability in Wales and the rest of the UK to lowland grassland management and restoration, both within special sites and in the wider countryside, including agri-environment schemes. Through a series of annual meadow visits and training events the project is also helping to demonstrate best practice on managing and restoring species-rich grasslands for interested parties and the general public.

4. Rehabilitation of Existing Species-rich Grassland – FYM Trial

4.1. Introduction

This objective of the project was associated with a number of changes in grassland management that have occurred in the Elan Valley over recent decades that may be having significant effects on the grasslands in terms of both their agricultural and conservation value. Generally declining yields due to reduced inputs of farmyard manure (FYM) and possibly lime, has resulted in some of the meadows no longer being harvested in the traditional manner. There is a recent tendency for fields just to be topped-over in late summer and for toppings to be left *in situ*. Also, some traditional hay-meadows are now being cut for big-bale silage without the more prolonged hay-making process which involves various drying and turning operations (with resultant seed-shedding etc). Prolonged periods of such practices are likely to disrupt the flowering and seeding patterns of forb and grass species with largely unpredictable consequences for future species balance and diversity. The maintenance of unimproved meadows is dependent upon maintaining an optimum level of generally low soil fertility. Excessive and prolonged divergence either above or below this optimum range may, in time, also lead to losses of diversity. Limited amounts of FYM are permitted within many of the SSSI agreements but general lack of availability (due in part to the reduction in cattle numbers in the Valley) has resulted in little actual FYM being applied in practice in recent years.

Generally the traditional management of hay-meadows involves occasional inputs of nutrients at appropriate levels in order to maintain acceptable levels of herbage yield. However, on an individual site basis there are often problems in defining what the 'traditional managements' were and also on deciding which operations may be beneficial or detrimental from a nature conservation standpoint. Specifically for the Elan Valley meadows there is a need to determine whether lime and/or farmyard manure inputs are required to restore the production of a hay crop and if so what levels are appropriate to sustaining a hay cropping regime while yet maintaining high levels of floristic diversity. To help address these questions a multi-site small-plot field trial was set up to assess the effects of FYM and lime applications on a selection of Elan Valley meadows. In practice this involved applying a range of potential suitable nutrient rates over nine years and assessing their effects on soil nutrient levels, yields and quality of harvested herbage and key features of floristic composition and diversity. The ultimate aim was to formulate sustainable fertility management advice for the specific sites studied and for wider implementation at other suitable meadows in the region. This project objective builds on a parallel DEFRA/CCW/NE-funded multi-site investigation of nutrient additions to hay-meadow grassland (e.g. Kirkham *et al*. 2008 & Kirkham *et al*. 2014) by focusing on treatments directly relevant to the sustainable management of the Elan Valley hay-meadows.

4.2. Methodology

4.2.1. Experimental Design

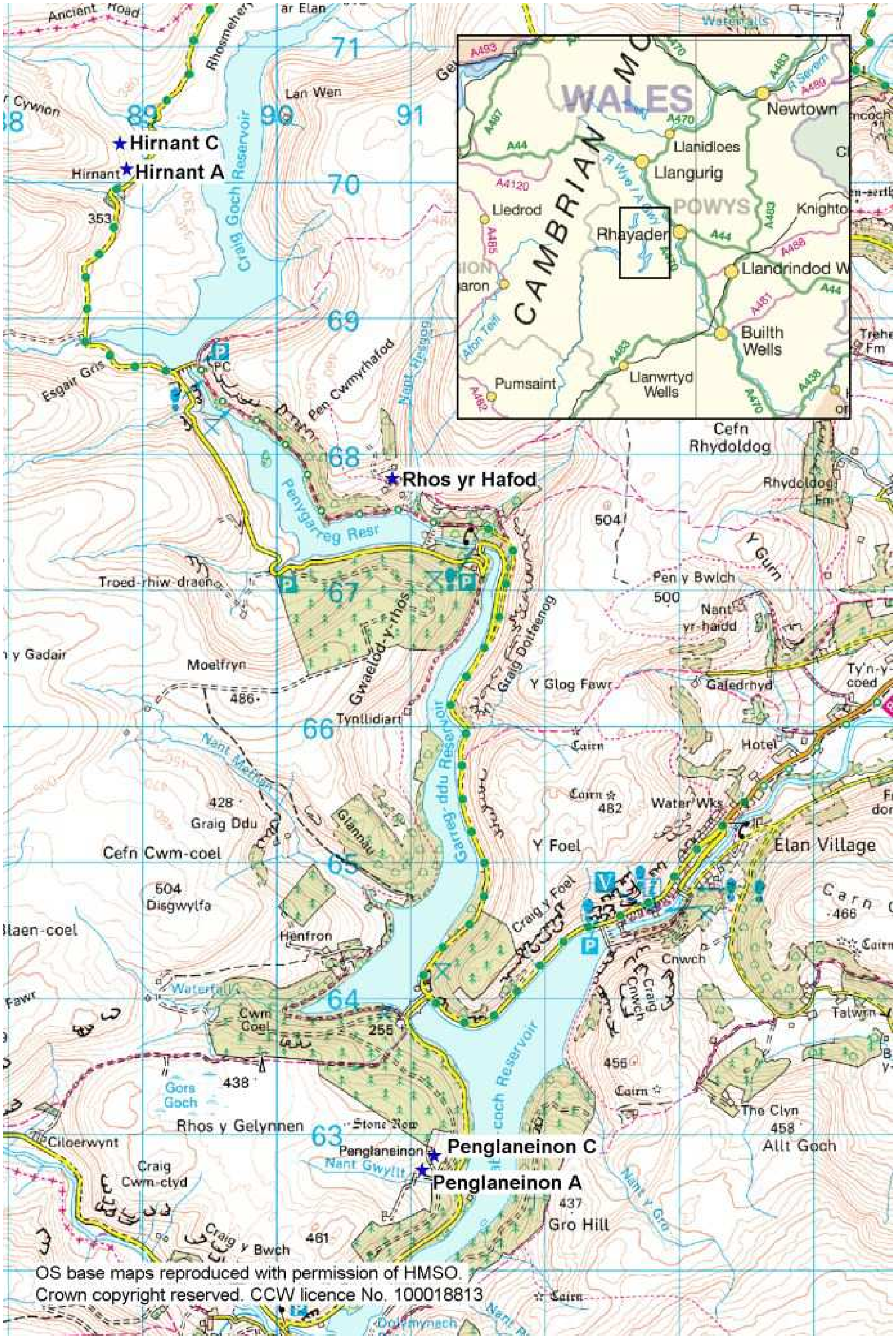
The experimental plots for investigating the application of varying levels of farmyard manure and lime were initially established during autumn 2004. The experiment consisted of a randomised block design of 6 nutrient application treatments in five replicate blocks (sites). The five sites were established in separate meadow enclosures at three different holdings (**Figure 1**): two at Hirnant, two at Penglaneinon and one at Rhos yr Hafod. Four of the sites were located within homogeneous stands of species-rich MG5a grassland, while one of the Hirnant sites was sited within an area of less species-rich MG6 grassland undergoing meadow restoration management. The individual enclosures were selected to be representative of the range of meadows present within the Estate including long-established highly species-rich examples (such as those at Penglaneinon and Rhos yr Hafod) together with examples supporting less well developed communities and the more semi-improved enclosure situated at Hirnant (see below for detailed site descriptions). Such a range of meadow types were chosen so that both 'general' management prescriptions could be formulated for other similar upland-fringe meadows in the region and also so that 'detailed site specific data' could be gathered for the individual meadows selected. Individual plots were 5 x 7 m with each treatment plot surrounded by a 5m untreated 'buffer-zone'. The nutrient treatments consisted of three applications rates: **Nil FYM** (untreated control) and cattle-derived farmyard manure rates applied at either 12 t/ha every year (**High FYM** rate) or at 12 t/ha applied every 2 years (**Low FYM** rate). Each of the above treatments were combined either with or without an initial lime (**L**) application with the objective of raising the soil pH of limed plots to c. 6.0, making six treatment combinations in total. At the two Penglaneinon enclosures only, an additional treatment was included consisting of a low rate (12 t/ha applied every 2 years) of sheep manure (**Sheep FYM**), again either with or without lime application, making eight treatment combinations at those sites. This latter treatment did not serve as part of the overall experimental design but was added to just two sites to help evaluate the potential for using sheep-based manure as an alternative, potentially more readily available, source of nutrients within the Estate.

Summary of main treatments:

FYM type			Cattle		Cattle		†Sheep	
Application rate	Nil		Low (12 t/ha every 2 years)		High (12 t/ha every year)		Low (12 t/ha every 2 years)	
Limed (to pH 6.0)	+	-	+	-	+	-	+	-

† **=** sheep-derived FYM treatments applied at the 2 Penglaneinon fields only and therefore not part of main experimental design.

Figure 1. Locations of the five meadow sites used in the FYM trial.



The lime, in the form of ground limestone, was applied on two separate occasions to relevant plots firstly at the outset of the trial during spring 2005, followed by a smaller follow-up application in October 2009. The rates of lime applied to individual plots were calculated after first determining soil pH levels within the uppermost 0-7.5cm soil horizon of relevant plots. To achieve the required target of pH 6.0 for relevant treatments different rates of lime were applied depending on base-line values i.e. where initial soil pH values were in the range 5.3-5.49 lime was applied at a rate equivalent to 2.5 t/ha, where initial levels were in the range pH 5.5 to 5.69 lime was applied at 2.0 t/ha and where initial levels were 5.7-5.8 lime was applied at 1.5t/ha. Details of actual rates of lime applied to specific plots are presented in **(Appendix 1).**

Manures were all sourced locally within the Elan Valley and applied to relevant plots in the early spring either annually or every other year between 2005 and 2013. Throughout the experimental period fields were managed traditionally with spring grazing, followed by a late summer hay-cut (usually at the end of July or August) and aftermath grazing thereafter.

4.2.2. Individual Site Details

(taken from original Project Scoping Study; Hayes & Sackville-Hamilton 2001)**:**

PENGLANEINON A (Field ref: PEN A) Nat. Grid ref: SN912628
SSSI-designated hay-meadow of highly species-rich MG5a grassland with scattered patches of MG5c. Frequent high cover of Vicia orobus and Sanguisorba officinalis. Not known to have been ploughed (vestiges of organic turf mat implies no cultivation over last century). No fertiliser or lime inputs since 1993. FYM is permitted under SSSI agreement (@5 t/ha/yr) but none recently applied due to lack of availability. No other fertiliser or lime inputs permitted. Up until 1996 a traditional hay crop was taken in mid-Aug., since when herbage has usually been just topped and left in situ due to declining herbage growth. Yield now estimated to be more than 50% down compared to previous fertilised years. Soils are free-draining brown podzolic soils of Manod series.
(N.B.This site has recently been nominated as the ‘Coronation Meadow’ for the county as an outstanding example of flower-rich grassland.)

PENGLANEINON C (Field ref: PEN C)
SSSI-designated hay-meadow adjacent to PEN A above with slightly poorer quality MG5a vegetation with only scattered patches of Vicia orobus and Sanguisorba officinalis. The lower slopes of this field grade into more acidic U4c vegetation with occasional Viola lutea, Betonica officinalis. Past and current management same as for PEN A.

RHOS YR HAFOD D (Field ref: RYH) Nat. Grid ref: SN909678
SSSI-designated hay-meadow of highly species-rich MG5a grassland.
Past management details uncertain but hay-crop not regularly taken prior to the start of the FYM trial due to lack of growth. Species-diversity thought to be declining. Soils predominately free-draining brown podzolic soils of Manod series.

HIRNANT A (Field ref: HIR A) Nat. Grid ref: SN889701
More recently SSSI designated hay-meadow of moderately species-rich MG5a grassland notable for the widespread dominance of Leontodon hispidus (Hairy hawkbit) and Trisetum flavescens (Yellow oat-grass). Field was reportedly ploughed in 1988 in preparation for re-seeding but was not actually re-seeded. Subsequent entry into ESA scheme in 1995 (as Tier 2 Hay-meadow) has facilitated return of diversity to SSSI quality (notified in 2000). Historically used to receive annual applications of both compound fertiliser and FYM. More recently fields have been cut for big-bale silage. For the first 5 years of the ESA agreement the original tenant was granted derogation to apply organic based fertiliser (15:7:7) at 125 kg/ha/yr. Soils predominately typical brown earths of Denbigh series, grading into slightly darker (peaty) soils at northern end of meadow.

HIRNANT C (Field ref: HIR C) Undesignated more semi-improved generally species poor meadow adjacent to HIR A above. Originally mapped as 'improved grassland' prior to 2000 for ESA purposes but has recently been undergoing restoration management with rapidly developing levels of diversity.

4.2.3. Assessments

Initial baseline levels of soil pH and soil macro-nutrients for each individual plot were assessed by taking soil samples in January 2005. Eight individual soil cores (0-7.5cm depth) were taken from each plot and bulked to produce a single sample per plot. Cores were sealed in polythene bags and returned to the Analytical Laboratory of the Institute of Biological, Environmental and Rural Sciences (IBERS) where they were air-dried for 7 days. Resultant dried samples were then milled to remove stones and analysed for the following nutrient determinations: pH (in water), organic matter (loss on ignition), available phosphate (Olsen P) and exchangeable base cations sodium, potassium, calcium and magnesium (Exch. Na, K, Ca, Mg respectively). Repeat analyses of the same soil determinations were also conducted in 2008 and 2013 using the same procedures. For the final soil sampling of plots in April 2013 additional determinations of the soil micronutrients manganese (Mn), sulphur (S), copper (Cu), zinc (Z) and boron (B) were also carried out. Plots were re-sampled to monitor changes in soil pH during November 2005 (following the first liming treatment) and thereafter every April up until 2013. The chemical composition (macro-nutrients and pH) of representative samples of the manures applied to plots were also assessed annually.

Botanical monitoring of individual experimental plots was carried out during mid-summer (usually mid-July) each year between 2005 and 2013 within three permanently marked 1 x 1 m quadrats per plot. Monitoring involved visual estimates of percentage cover of all plant species, bare ground and litter. Average sward heights were also recorded for each quadrat at the time of botanical monitoring.

Annual dry matter hay yields were estimated from each experimental plot just prior to the time of hay-cutting from within 4 randomly located $25m^2$ quadrats/plot. Herbage was harvested at a cutting height of c.4 cm above ground level, being the average cutting height of most conventional cutter bar and agricultural mowers, and samples kept cool until oven drying at 80^0 c for 8 hours prior to recording dry matter weights. On three occasions during the course of the experiment (2005, 2008 and 2013) sub-samples of oven dried harvested hay from each plot were milled in preparation for the following chemical analysis and herbage quality determinations: DOMD (digestible organic matter content), %N, %P, %K, %Ca, %Mg and %Na.

4.2.4. Data Analysis

In addition to the individual soil, herbage and species derived variables listed above a number of separate composite response variables were also calculated to help further assess the relative effects of the treatments on vegetation quality. These included calculations of total vascular species richness and numbers of forb species per quadrat together with the proportions (%) of total vegetation accounted for by forbs, grasses, and MG5 i.e. (mesotrophic) grassland positive indicator (PI) species. These were calculated for individual years and also averaged out for all years of the study to overcome the large annual fluctuations in vegetation cover resulting from the periodic nature of the nutrient treatment applications and annual weather conditions. Modified MG5 positive indicator (PI) species were identified after Kirkham *et al*. 2008 and Robertson & Jefferson 2000 from lists used for monitoring the condition of grassland SSSIs and thus allow any potential changes in overall meadow quality to be quantified. (For the purpose of this study the locally occurring, yet nationally scarce species, *Vicia orobus* was added to the list of MG5 PI species (JNCC 2004).

Another very useful method of detecting for any comparative shifts in the general fertility and vegetation quality of such grassland communities is by use of ‘weighted Ellenberg N indices' (N-scores). Individual Ellenberg N values are mainly derived from extensive survey data (Ellenberg 1988; Hill *et al*. 1999) and thus can provide an additional general indicator of soil fertility as directly related by plant composition present within plots. Such N scores were calculated for each quadrat as the mean indicator value averaged over the plant species present, weighted according to the proportional contribution of each species to total vegetation cover. This was only done for plant data collected in 2008 and 2013 so that enough time had elapsed for any treatments effects to become apparent and also to see if there was any evidence for shifts in the relative nutrient status of treatments over the final five year period of monitoring. The values are based upon a nine point scale: species with an N index of 1 are associated with very nutrient-poor habitats, with N index 9 indicating extremely nutrient-rich conditions. Thus, for example, in this situation, any evidence of progressive increases in N-scores could signify increases in the overall presence of species associated with raised soil nutrient conditions and vice versa with any observed decrease in average N-score.

Effects of six main treatments (3 FYM rates, each with plus or minus lime) were then examined for each soil, herbage quality and vegetation response variable using general analysis of variance (ANOVA), Genstat Version 10. Separate analyses were carried out for the variables obtained for each individual site, individual years and for all sites and years combined within a single analysis as a randomised block design with each of the meadow sites representing a block in the analysis. Results from the additional Sheep derived FYM treatments incorporated at the two Penglaneinon sites where not included in the statistical analyses and are presented for comparative purposes only where appropriate.

4.3. Findings

4.3.1. Soil Monitoring

Full results obtained from monitoring the soil pH for all individual plots and sites are presented in **Table 1**. At the outset of the experiment in 2005 the uppermost 7.5 cm of soils of all fields were shown to be weakly acid with mean pH values for individual sites ranging from 5.3 at the RYH site to 5.8 at HIR A, with the two Penglaneinon sites having intermediate pH values of circa. 5.5 Addition of lime to relevant experimental plots achieved the desired effect of maintaining a statistically significant difference in soil pH between limed and unlimed treatments over the course of the experiment i.e. averaged over all years and sites, limed plots had a mean pH of 5.7 compared with a pH of 5.3 for unlimed plots (**Table 1; Figure 2)**.

The most striking finding from monitoring pH levels over the course of the experiment was the extent of progressive acidification observed on unlimed control plots, which when averaged for all five meadow sites, amounted to a total drop in pH of 0.57 over the eight years of monitoring (equivalent to a 0.07 mean decline in pH per year). By the end of the monitoring period in 2013 this progressive acidification had resulted in soils in most unlimed plots reaching around pH 5 and in the case of the PEN C and RYH sites dropping below the 5.0 level to 4.9 and 4.8 respectively. Only soils on the unlimed plot at HIR A, which had the highest initial pH value, maintained a relatively neutral pH of 5.4 by the end of the monitoring period. Soil acidification in the Elan Valley is probably largely due to the acidic nature of the underlying geology coupled with the rapid nutrient leaching effects of such a hill-land climate, although the acidifying effect of atmospheric nitrogen deposition may also be significant (Maskell *et al*. 2010). If soil acidification was to continue at a similar rate **(Figure 3),** there are likely to be serious implications for the meadows in terms of maintaining both acceptable levels of hay production and desirable levels of floristic diversity. For example, theoretically all five sites could reach pH values below 5 within three more years with some sites, such as RYH, PEN C and HIR C, approaching acidity levels of around 4.5. The application of FYM showed a slight tendency to raise mean soil pH, although this only reached a statistically significant level on one occasion during 2010.

Table 1. Summary of results for soil pH (0 - 7.5 cm depth) monitored from the FYM trial plots between 2005 and 2013.

Fields	Treatments	pH								
		Jan 2005	Nov 2005	April 2007	April 2008	April 2009	April 2010	April 2011	April 2012	April 2013
PenA	Nil FYM -lime	5.57	5.70	5.56	5.88	5.48	5.13	5.03	5.07	5.08
	Nil FYM +lime	5.51	5.67	5.65	5.75	5.58	5.42	5.40	5.38	5.85
	Low FYM -lime	5.62	5.96	5.61	5.91	5.49	5.29	5.18	5.18	5.35
	Low FYM +lime	5.65	6.09	5.79	5.57	5.64	5.59	5.58	5.31	5.73
	High FYM-lime	5.43	5.63	5.56	5.99	5.37	5.13	5.10	5.11	5.32
	High FYM +lime	5.67	6.14	5.96	5.49	5.75	5.61	5.70	5.50	5.84
	Sheep FYM -lime	5.78	5.78	5.78	5.84	5.43	5.40	5.46	5.26	5.63
	Sheep FYM +lime	5.53	5.37	5.53	5.76	5.55	5.68	5.62	5.39	5.83
	Field Mean	*5.60*	*5.79*	*5.68*	*5.77*	*5.54*	*5.41*	*5.38*	*5.28*	*5.58*
PenC	Nil FYM -lime	5.37	5.52	5.17	5.50	5.15	4.95	4.72	4.79	4.95
	Nil FYM +lime	5.65	6.08	5.86	5.92	5.39	5.43	5.40	5.37	5.70
	Low FYM -lime	5.69	5.73	5.62	5.77	5.31	5.50	4.99	5.00	5.20
	Low FYM +lime	5.49	6.11	5.98	6.14	5.56	5.73	5.68	5.49	5.77
	High FYM-lime	5.49	5.71	5.52	5.63	5.31	5.19	5.03	4.99	5.19
	High FYM +lime	5.44	5.93	5.63	5.97	5.62	5.58	5.51	5.45	5.86
	Sheep FYM -lime	5.43	5.45	5.45	5.54	5.29	5.09	4.94	4.94	5.14
	Sheep FYM +lime	5.45	5.37	5.37	6.13	5.55	5.55	5.54	5.49	5.78
	Field Mean	*5.50*	*5.74*	*5.58*	*5.83*	*5.50*	*5.38*	*5.23*	*5.19*	*5.45*
RYH	Nil FYM -lime	5.23	5.44	5.09	5.34	5.00	4.60	4.75	4.76	4.86
	Nil FYM +lime	5.41	5.73	5.67	5.95	5.58	5.21	5.37	5.30	5.60
	Low FYM -lime	5.31	5.47	4.93	5.36	5.28	4.71	4.70	4.76	4.98
	Low FYM +lime	5.37	5.77	5.65	5.81	5.61	5.47	5.45	5.33	5.58
	High FYM -lime	5.32	5.42	5.08	5.44	5.14	4.73	4.90	4.77	4.90
	High FYM +lime	5.38	5.73	5.78	5.78	5.57	5.20	5.63	5.52	5.74
	Field Mean	*5.34*	*5.59*	*5.37*	*5.61*	*5.36*	*4.99*	*5.13*	*5.07*	*5.28*
HirA	Nil FYM -lime	5.80	5.71	5.71	5.76	5.71	5.33	5.16	5.20	5.44
	Nil FYM +lime	5.80	5.95	5.95	5.81	5.73	5.61	5.53	5.52	5.87
	Low FYM -lime	5.73	5.63	5.63	5.78	5.65	5.42	5.24	5.33	5.69
	Low FYM +lime	5.73	5.83	5.83	5.97	5.69	5.68	5.57	5.59	5.73
	High FYM -lime	5.72	5.68	5.68	5.68	5.35	5.34	5.18	5.10	5.40
	High FYM +lime	5.78	5.86	5.86	5.92	5.66	5.63	5.50	5.52	5.71
	Field Mean	*5.76*	*5.78*	*5.78*	*5.82*	*5.63*	*5.50*	*5.36*	*5.38*	*5.64*
HirC	Nil FYM -lime	5.48	5.83	5.45	6.02	5.48	5.12	5.01	4.98	5.01
	Nil FYM +lime	5.80	5.95	6.11	5.83	5.39	5.28	5.32	5.36	5.33
	Low FYM -lime	5.45	5.60	5.16	5.37	5.20	5.01	4.90	5.13	5.00
	Low FYM +lime	5.71	5.95	5.78	5.88	5.70	5.67	5.42	5.65	5.57
	High FYM -lime	5.57	5.72	5.71	5.60	5.40	5.35	5.15	5.24	5.33
	High FYM +lime	5.74	5.88	5.89	5.81	5.53	5.56	5.36	5.54	5.48
	Field Mean	*5.63*	*5.82*	*5.68*	*5.75*	*5.45*	*5.33*	*5.19*	*5.32*	*5.29*
Treatment means of all fields	Nil FYM -lime	5.49	5.64	5.40	5.70	5.36	5.03	4.93	4.96	5.07
	Nil FYM +lime	5.63	5.88	5.85	5.85	5.53	5.39	5.40	5.39	5.67
	Low FYM -lime	5.56	5.68	5.39	5.64	5.39	5.19	5.00	5.08	5.24
	Low FYM +lime	5.59	5.95	5.81	5.87	5.64	5.63	5.54	5.47	5.68
	High FYM -lime	5.51	5.63	5.51	5.67	5.31	5.15	5.07	5.04	5.23
	High FYM +lime	5.60	5.91	5.82	5.79	5.63	5.52	5.54	5.51	5.73
	l.s.d. (5% level)	0.123ns.	0.162ns.	0.236ns.	0.280ns.	0.167ns	0.169ns	0.162ns	0.143ns	0.194ns
	Unlimed plots	5.52	5.65	5.43	5.67	5.35	5.12	5.00	5.03	5.18
	Limed plots	5.61	5.91	5.83	5.84	5.60	5.51	5.49	5.46	5.69
	l.s.d. (5% level)	0.071ns.	0.094***	0.136***	0.162*	0.097***	0.078***	0.093***	0.082***	0.111***
	Nil FYM	5.56	5.76	5.62	5.77	5.45	5.21	5.17	5.17	5.37
	Low FYM	5.58	5.81	5.60	5.76	5.51	5.41	5.27	5.28	5.46
	High FYM	5.55	5.77	5.67	5.73	5.47	5.33	5.31	5.27	5.48
	l.s.d. (5% level)	0.087ns.	0.115ns	0.167ns	0.198ns	0.118ns	0.120**	0.114ns	0.101ns	0.137ns

Note: *, **, *** denote significance at the 5%, 1% and 0.1% probability levels respectively

Figure 2. Change in soil pH (0 – 7.5 cm depth) on main treatments between 2005 and 2013 (Means of all sites).

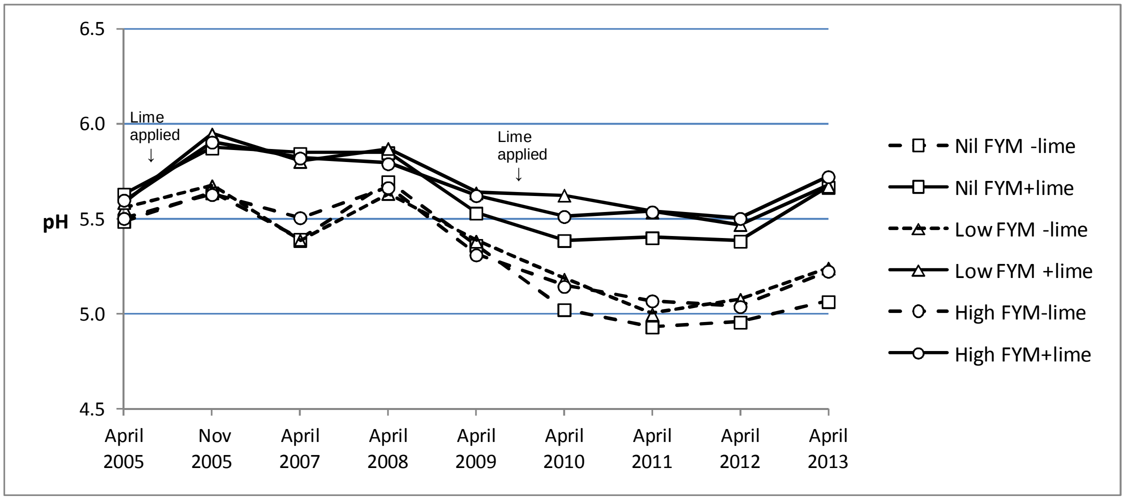
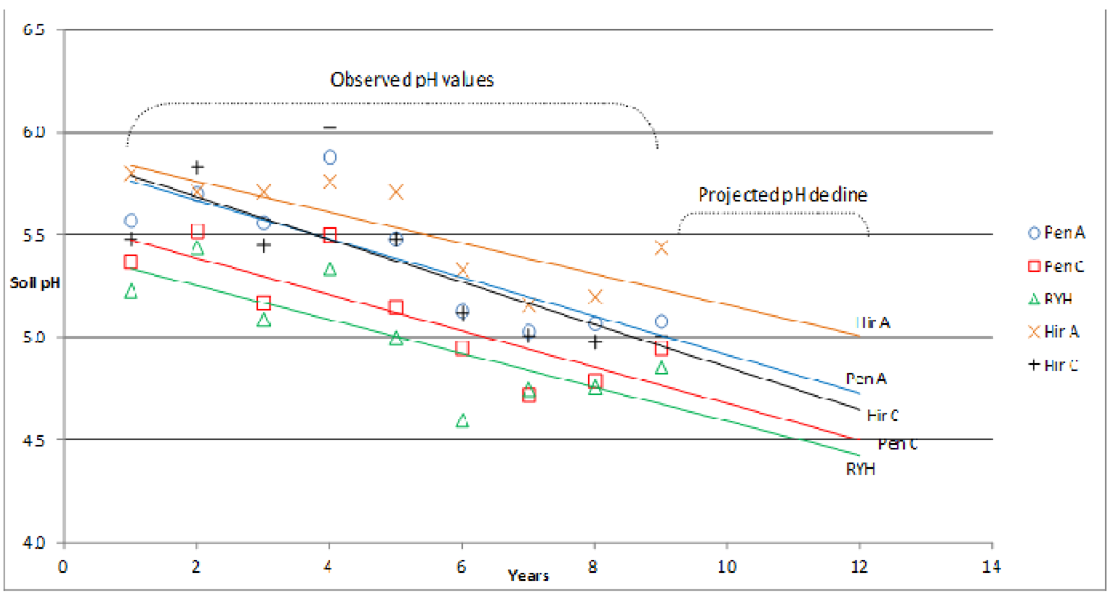


Figure 3. Trend lines for the 'actual observed' and 'projected' soil pH levels (0 – 7.5 cm depth) for untreated control plots (Nil FYM -lime) for the different field sites.



As would be expected the above differences in pH status of soils were also reflected in their exch. Ca concentrations with significantly higher levels of calcium recorded on limed compared to unlimed plots **(Table 2).** By 2013 there were also significantly higher Ca concentrations in plots that had received the High FYM rate compared with Nil FYM, although this difference was not reflected in a similarly significant difference in actual soil pH values.

As anticipated for such unimproved species-rich grasslands, monitoring levels of available phosphorus at the outset of the experiment in 2005 confirmed the presence of relatively low levels of available P for all sites. There were however some site specific variations between individual meadow sites with, for example, the fields at Hirnant A, Hirnant C and Pen A having the lowest overall P levels (DEFRA P Index 0), the RYH field having the richest P content (Index 2) and with the PEN C field having an intermediate level (Index 1).

By 2013, limed plots were shown to have significantly lower mean concentrations of available phosphorus compared to unlimed plots. Between 2005 and 2013 mean values of available P decreased from 9.8 to 5.2 mg/kg on limed plots and from 9.3 to 6.8 mg/kg on unlimed control plots. This overall trend in the reduction of available P over time is likely to be a result of general uptake by plants with the greater decrease in P content observed on limed plots being associated with the peak P fixation due to aluminium that occurs at pH 5.5. At pH 5.5 P fixation in soil by aluminium is particularly high resulting in limited phosphorus availability. At pH above and below 5.5 P fixation due to aluminium declines, with further fixation peaks occurring due to iron in very acid soils and due to calcium in alkaline soils. This relationship between soil pH and phosphorus availability has been illustrated as 'the hills and valleys of phosphorus fixation' (Soil Fertility Manual 2003).

There was little variation between fields in initial exch. K levels which remained at DEFRA K Index 2 for all fields sampled.

Levels of soil magnesium, an element which is an important for animal health, were high throughout all fields sampled and all either at or above Mg Index 3. By 2013 there were significantly higher concentrations of magnesium on unlimed plots compared with limed plots and also on plots treated with FYM compared with plots without any FYM applications.

In relation to soil micronutrients, liming resulted in significant decreases in mean concentrations of both available zinc and manganese, compared to unlimed plots **(Table 3).** This can be explained by Zn and Mn ions being more tightly bound to soil colloids at higher concentrations of soil calcium (Brady 1990).

Table 2. Summary of results for soil nutrients (0 - 7.5 cm depth) monitored from the FYM trial plots between 2005 and 2013.

Fields	Treatments	OM, %	The content of nutrients, mg/kg of soil														
			Ca			K			Mg			Na			Olsen P		
		2008	2005	2008	2013	2005	2008	2013	2005	2008	2013	2005	2008	2013	2005	2008	2013
PenA	Nil FYM -lime	13.80	549	867	760	148	210	194	141	158	175	43.5	47.0	48.9	6.46	4.29	5.61
	Nil FYM +lime	14.68	525	925	1345	225	175	141	152	207	121	63.9	47.7	55.3	7.56	6.11	4.75
	Low FYM -lime	13.51	858	1237	1014	211	165	171	172	168	186	60.5	53.8	50.7	7.24	4.46	5.12
	Low FYM +lime	14.00	616	569	1086	226	135	241	142	123	173	41.1	50.6	50.9	8.66	2.81	4.69
	High FYM -lime	14.75	506	1153	1097	160	129	185	139	141	205	47.6	43.6	54.2	8.35	3.96	6.76
	High FYM +lime	13.92	902	528	1628	354	144	131	194	139	170	54.5	48.1	51.6	8.50	4.29	4.40
	Sheep FYM -lime	13.49	804	1053	985	334	121	153	182	104	193	48.5	50.8	48.4	8.82	4.13	4.09
	Sheep FYM +lime	13.87	471	735	1530	180	129	132	128	157	151	45.9	42.4	66.6	7.72	4.13	4.58
	Field Mean	*14.0*	*654*	*883*	*1181*	*230*	*151*	*169*	*156*	*149*	*172*	*50.7*	*48.0*	*53.3*	*7.91*	*4.27*	*5.00*
PenC	Nil FYM -lime	15.65	331	235	357	259	161	252	140	99	136	40.8	29.3	37.2	10.39	8.42	7.36
	Nil FYM +lime	15.91	622	1138	1331	340	239	176	245	137	128	41.8	57.3	48.8	13.86	8.58	5.76
	Low FYM -lime	14.03	500	456	722	292	194	212	222	150	187	45.1	37.4	46.8	13.39	8.75	7.14
	Low FYM +lime	15.47	459	1645	1558	326	178	157	168	130	128	39.9	52.6	49.9	12.28	7.43	5.61
	High FYM -lime	15.04	380	538	782	303	228	229	162	169	182	38.9	48.7	48.3	15.12	9.91	8.94
	High FYM +lime	13.73	416	1259	1666	306	144	152	154	100	143	49.7	46.1	54.7	11.18	4.79	6.33
	Sheep FYM -lime	15.26	219	433	576	206	167	212	113	135	152	35.5	62.8	47.6	9.92	8.09	8.75
	Sheep FYM +lime	14.98	295	1444	1494	250	179	152	120	118	136	42.7	56.9	53.1	10.08	6.60	5.48
	Field Mean	*15.01*	*403*	*893*	*1061*	*285*	*186*	*193*	*165*	*130*	*149*	*41.8*	*48.9*	*48.3*	*12.03*	*7.82*	*6.92*
RYH	Nil FYM -lime	14.14	368	340	335	216	173	237	133	119	135	39.9	35.7	46.6	13.08	14.69	7.78
	Nil FYM +lime	14.18	432	1400	1350	244	157	153	146	126	120	42.0	43.0	56.1	12.00	7.76	6.55
	Low FYM -lime	15.22	296	343	455	271	153	197	125	123	141	36.9	27.4	42.4	13.23	12.05	14.93
	Low FYM +lime	13.85	333	1221	1235	224	131	170	127	113	129	41.2	41.0	55.1	14.62	12.05	6.82
	High FYM -lime	14.53	246	502	641	208	169	219	121	155	159	39.7	38.0	46.7	12.92	15.35	9.48
	High FYM +lime	13.80	378	1197	1496	234	137	179	130	123	147	34.5	36.7	55.8	13.54	15.85	7.42
	Field Mean	*14.29*	*342*	*834*	*919*	*233*	*153*	*193*	*131*	*126*	*139*	*39.0*	*37.0*	*50.4*	*13.23*	*12.96*	*8.83*
HirA	Nil FYM -lime	12.73	1392	1296	1309	155	116	188	151	137	153	70.4	69.6	63.5	6.15	3.97	4.47
	Nil FYM +lime	13.33	1718	1775	1820	136	130	224	152	136	164	78.5	93.3	55.5	7.69	7.59	3.66
	Low FYM -lime	13.46	1677	1587	1655	119	110	179	145	145	172	69.2	70.3	60.1	8.46	9.58	4.64
	Low FYM +lime	13.18	1333	1275	1976	147	88	222	155	114	180	69.3	50.5	74.9	6.92	2.35	4.38
	High FYM -lime	12.61	1290	1170	1712	128	99	163	147	130	188	68.1	67.7	98.3	7.85	4.94	6.15
	High FYM +lime	13.69	1471	1613	1863	172	118	200	174	160	169	82.1	79.3	69.2	10.00	3.97	5.38
	Field Mean	*13.17*	*1480*	*1453*	*1722*	*143*	*110*	*196*	*154*	*137*	*171*	*72.9*	*71.8*	*70.2*	*7.85*	*5.40*	*4.78*
HirC	Nil FYM -lime	14.26	1068	998	1136	113	142	215	97	108	128	59.5	52.5	51.4	5.08	3.16	5.45
	Nil FYM +lime	14.31	1058	1022	1560	120	105	215	86	82	120	59.1	53.2	57.6	9.09	3.32	4.09
	Low FYM -lime	14.12	636	554	948	178	141	243	117	109	164	46.9	42.0	47.4	5.64	5.92	4.19
	Low FYM +lime	15.79	1343	1774	2239	164	185	252	131	152	176	71.0	65.8	59.2	6.15	2.84	3.82
	High FYM -lime	15.68	1546	1304	2002	169	144	256	129	151	218	72.0	61.1	70.5	6.62	2.19	4.50
	High FYM +lime	15.51	1341	1282	1664	135	136	181	113	95	116	73.5	66.1	57.1	4.73	4.14	5.07
	Field Mean	*14.94*	*1165*	*1156*	*1591*	*147*	*142*	*227*	*112*	*116*	*154*	*63.6*	*56.8*	*57.2*	*6.22*	*3.59*	*4.52*

Table 2 continued. Summary of results for soil nutrients (0 - 7.5 cm depth) monitored from the FYM trial plots between 2005 and 2013.

Fields	Treatments	The content of nutrients, mg/kg of soil														
		Ca			K			Mg			Na			Olsen P		
		2005	**2008**	**2013**	**2005**	**2008**	**2013**	**2005**	**2008**	**2013**	**2005**	**2008**	**2013**	**2005**	**2008**	**2013**
Treatment means of all fields	Nil FYM -lime	742	747	779	178	160	217	132	124	146	50.8	46.8	49.5	8.23	6.91	6.13
	Nil FYM +lime	871	1252	1481	213	161	182	156	138	131	57.1	58.9	54.7	10.04	6.67	4.96
	Low FYM -lime	793	835	959	214	153	200	156	139	170	51.7	46.2	49.5	9.59	8.15	7.21
	Low FYM +lime	817	1297	1619	217	143	209	144	126	157	52.5	52.1	58.0	9.73	5.49	5.07
	High FYM -lime	793	933	1247	194	154	210	140	149	191	53.3	51.8	63.6	10.17	7.27	7.16
	High FYM +lime	902	1176	1663	240	136	169	153	123	149	58.8	55.3	57.7	9.59	6.61	5.72
	l.s.d. (5% level)	266.0ns	502.3ns	332.8ns	23.5ns	35.9ns	29.1ns	31.3ns	32.2ns	23.3ns	9.37ns	11.69ns	9.83ns	0.799ns	2.832ns	1.932ns
	Unlimed plots	776	839	995	195	156	209	143	137	169	51.9	48.3	54.2	9.33	7.44	6.83
	Limed plots	863	1242	1588	224	147	186	151	129	146	56.1	55.4	56.8	9.79	6.26	5.25
	l.s.d. (5% level)	153.6ns	290.0**	192.1***	13.6ns	20.8ns	23.7ns	18.1ns	18.6ns	13.5**	5.41ns	6.75*	5.68ns	0.461ns	1.635ns	1.115**
	Nil FYM	806	1000	1130	196	161	200	144	131	138	53.9	52.9	52.1	9.14	6.79	5.55
	Low FYM	805	1066	1289	214	148	204	150	133	164	52.1	49.1	53.7	9.66	6.82	6.14
	High FYM	848	1055	1455	178	145	189	146	136	170	56.0	53.5	60.6	9.88	6.94	6.44
	l.s.d. (5% level)	188.1ns	355.2ns	235.3*	16.6ns	25.4ns	41.1ns	22.1ns	22.8ns	16.5**	6.63ns	8.26ns	6.95*	0.565ns	2.002ns	1.366ns

Note: *, **, *** denote significance at the 5%, 1% and 0.1% probability levels respectively.

Table 3. Soil micronutrient contents (0 - 7.5 cm depth) on the FYM trial plots in 2013.

Fields	Treatments	Micro nutrients, mg/kg				
		Mn	**S**	**Cu**	**Zn**	**B**
PenA	Nil FYM -lime	51.8	15.2	0.11	4.93	0.27
	Nil FYM +lime	20.5	13.3	0.11	1.64	0.27
	Low FYM -lime	37.0	24.6	0.11	3.28	0.27
	Low FYM +lime	25.8	30.8	0.05	1.66	0.27
	High FYM-lime	32.2	17.5	0.16	3.25	0.37
	High FYM +lime	4.8	25.5	0.11	1.07	0.34
	Sheep FYM -lime	22.9	22.2	0.16	3.61	0.33
	Sheep FYM +lime	16.2	22.3	0.11	1.17	0.27
	Field Mean	*26.4*	*21.4*	*0.11*	*2.58*	*0.30*
PenC	Nil FYM -lime	40.4	20.0	0.11	6.31	0.22
	Nil FYM +lime	21.2	16.9	0.16	1.76	0.27
	Low FYM -lime	45.5	20.7	0.11	6.43	0.21
	Low FYM +lime	13.6	14.4	0.11	1.23	0.27
	High FYM-lime	42.0	21.0	0.16	5.53	0.27
	High FYM +lime	15.3	14.7	0.11	1.24	0.27
	Sheep FYM -lime	34.7	18.1	0.22	6.62	0.27
	Sheep FYM +lime	18.2	15.6	0.11	1.71	0.21
	Field Mean	*28.8*	*17.7*	*0.13*	*3.85*	*0.25*
RYH	Nil FYM -lime	105.2	21.7	0.11	6.64	0.32
	Nil FYM +lime	20.9	15.6	0.11	1.46	0.22
	Low FYM -lime	53.4	22.6	0.05	6.55	0.32
	Low FYM +lime	38.6	16.0	0.11	1.40	0.27
	High FYM-lime	105.2	20.9	0.16	6.29	0.26
	High FYM +lime	12.7	16.3	0.11	1.14	0.27
	Field Mean	*56.0*	*18.9*	*0.11*	*3.91*	*0.28*
HirA	Nil FYM -lime	42.2	12.4	0.11	1.12	0.27
	Nil FYM +lime	31.1	12.5	0.11	0.53	0.21
	Low FYM -lime	41.9	13.2	0.05	0.95	0.21
	Low FYM +lime	43.8	31.7	0.16	0.52	0.26
	High FYM-lime	38.3	25.8	0.16	1.62	0.26
	High FYM +lime	62.7	29.5	0.16	0.68	0.26
	Field Mean	*43.3*	*20.9*	*0.12*	*0.90*	*0.25*
HirC	Nil FYM -lime	56.8	22.9	0.10	2.24	0.21
	Nil FYM +lime	55.9	21.8	0.16	1.67	0.26
	Low FYM -lime	56.0	26.2	0.16	4.60	0.21
	Low FYM +lime	25.7	19.7	0.05	0.89	0.21
	High FYM-lime	23.3	28.9	0.16	1.68	0.31
	High FYM +lime	36.6	27.3	0.11	1.31	0.21
	Field Mean	*42.4*	*24.5*	*0.12*	*2.06*	*0.24*
Treatment means of all fields	Nil FYM -lime	59.3	18.4	0.11	4.25	0.26
	Nil FYM +lime	29.9	16.0	0.13	1.41	0.24
	Low FYM -lime	46.8	21.5	0.10	4.36	0.24
	Low FYM +lime	29.5	22.5	0.10	1.14	0.26
	High FYM-lime	48.2	22.8	0.16	3.67	0.30
	High FYM +lime	26.4	22.7	0.12	1.09	0.27
	l.s.d. (5% level)	12.63ns	7.30ns	0.040ns	1.61ns	0.047ns
	Unlimed plots	51.4	20.9	0.12	4.09	0.27
	Limed plots	28.6	20.4	0.11	1.21	0.26
	l.s.d. (5% level)	15.21**	4.21ns	0.023ns	0.93***	0.027ns
	Nil FYM	44.6	17.2	0.12	2.83	0.25
	Low FYM	38.1	22.0	0.10	2.75	0.25
	High FYM	37.3	22.7	0.14	2.38	0.28
	l.s.d. (5% level)	18.62ns	5.160ns	0.028*	1.140ns	0.033ns

Note: *, **, *** denote significance at the 5%, 1% and 0.1% probability levels respectively.

4.3.2. FYM Nutrient Content

The cattle and sheep manures applied to the experimental plots showed very wide variations in their pH and nutrient composition from year to year (**Appendix 2**), probably as a result of differences in their origin, age and type of storage conditions. The pH of the manures ranged from acid-neutral to alkaline with a minimum value of 5.5 for the cattle FYM applied in 2008 and maximum value of 8.5 in 2005. The K content of cattle manures applied also differed by up to two orders of magnitude, with those applied in 2007 and 2008 having particularly low values compared with the typical ranges found elsewhere. In 2006 both the K and P content of the applied cattle FYM was generally twice as high as the typical ranges found for other cattle manures. The contents of N and DM were however within the typical ranges expected throughout the whole period. As reported in earlier MAFF studies (MAFF 1994), the sheep derived manure was similar to cattle manure in dry matter and N contents but generally had lower P and K concentrations.

4.3.3. Effects of Nutrient Treatments on Dry-matter Hay Yields

Results from monitoring the annual hay yields (**Table 4**) from the untreated control plots on the five sites confirmed that under existing management these upland-fringe species-rich meadows were generally at the low end of the typical range of DM yields obtained from other unimproved semi-natural grasslands in the UK. Averaged over all years untreated plots at the different sites produced mean yields of 1.82 t ha^{-1} (Pen C), 2.03 t ha^{-1} (Pen A), 2.26 t ha^{-1} (HIR C), 2.41 t ha^{-1} (HIR A) and 2.81 t ha^{-1} (RYH). (i.e. compared with the typical range from lower lying sites of 1.5t ha^{-1} to 6.0t ha^{-1}, Tallowin & Jefferson 1999). In general hay yields varied widely over the nine years of sampling and were found to be closely associated with fluctuations in annual weather conditions and particularly with summer rainfall during the June and July period prior to harvesting **(Figure 4).** It is known that soil moisture deficiency can have a large impact on yields of such unfertilised semi-natural grasslands particularly when under conditions of low fertility, particularly soil nitrogen availability (Tallowin & Jefferson 1999)

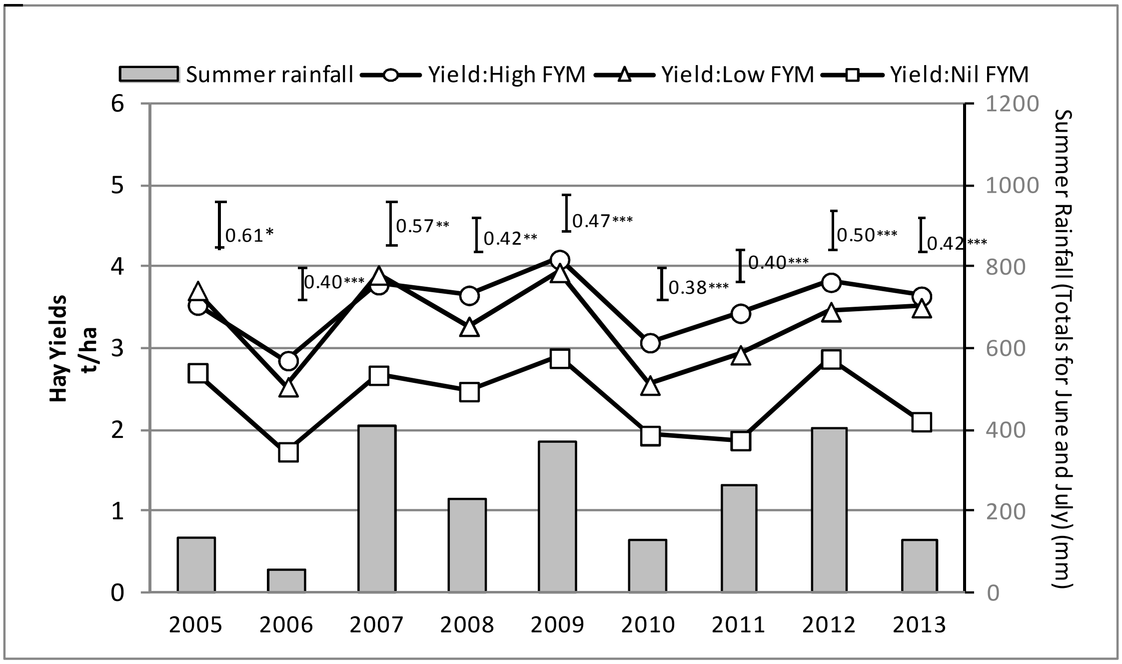
Application of FYM to plots had a significant positive effect on resulting dry matter hay yields when compared with the untreated control plots. Results of hay yields averaged over all sites **(Figure 4)** showed that treatments receiving either of the two rates of FYM had significantly higher yields compared with untreated control plots with mean increases over all years averaging 41% and 52% for the Low FYM and High FYM rates respectively. Although there was a general tendency for the High FYM rate to produce moderately higher yields than the Low FYM rate, overall this did not reach statistical significance. Applying lime also tended to produce higher yields compared with unlimed plots (c. 10% increase), although again this difference did not reach statistically significance for every season sampled.

Table 4. Summary of annual dry matter hay yields (t/ha) obtained from the FYM trial plots between 2005 and 2013.

Fields	Treatments	2005	2006	2007	2008	2009	2010	2011	2012	2013
PenA	Nil FYM -lime	2.74	1.42	1.86	2.32	2.98	1.32	1.49	2.62	1.56
	Nil FYM +lime	1.52	1.84	2.48	2.02	1.87	1.61	1.49	1.76	1.48
	Low FYM -lime	3.93	2.77	4.46	3.09	3.68	2.54	3.50	3.89	3.74
	Low FYM +lime	4.19	3.75	4.75	4.00	4.65	3.20	2.83	3.84	4.49
	High FYM-lime	2.41	2.60	3.87	3.01	3.25	2.74	3.78	4.07	3.48
	High FYM +lime	4.53	3.76	4.86	3.91	4.44	3.32	4.12	4.15	4.19
	Sheep FYM -lime	4.53	2.98	4.62	3.85	3.57	1.78	3.38	4.02	4.30
	Sheep FYM +lime	4.45	2.81	4.35	3.07	3.97	2.67	2.81	3.19	3.29
	Field Mean	*3.54*	*2.74*	*3.91*	*3.16*	*3.55*	*2.40*	*2.93*	*3.39*	*3.32*
PenC	Nil FYM -lime	2.40	0.96	2.29	1.92	1.91	1.50	1.77	2.24	1.41
	Nil FYM +lime	3.41	2.12	3.45	2.87	2.89	2.12	1.76	2.96	2.36
	Low FYM -lime	3.60	2.39	3.29	3.50	3.23	2.27	2.49	3.22	2.41
	Low FYM +lime	3.76	2.54	5.32	3.93	3.71	3.15	3.46	3.68	3.30
	High FYM-lime	3.86	2.25	3.27	3.49	3.06	2.72	3.51	3.98	3.12
	High FYM +lime	3.27	2.09	5.42	4.31	3.48	2.77	3.92	3.95	3.33
	Sheep FYM -lime	2.75	2.23	3.71	3.14	2.84	1.97	2.89	3.04	2.66
	Sheep FYM +lime	3.00	2.66	5.35	4.13	3.98	2.55	3.16	3.16	3.08
	Field Mean	*3.26*	*2.15*	*4.01*	*3.41*	*3.14*	*2.38*	*2.87*	*3.34*	*2.71*
RYH	Nil FYM -lime	4.32	1.70	3.96	1.87	4.08	1.47	1.90	3.59	2.37
	Nil FYM +lime	4.05	2.74	3.36	2.17	3.76	1.98	2.77	2.90	3.02
	Low FYM -lime	6.49	2.95	3.91	2.54	5.52	2.06	3.14	3.98	4.17
	Low FYM +lime	4.98	2.40	4.02	1.81	4.47	1.59	2.43	2.22	3.89
	High FYM -lime	5.31	3.02	3.37	2.70	4.15	2.19	2.94	3.45	4.04
	High FYM +lime	5.62	3.30	4.01	2.96	5.16	2.92	2.84	3.69	4.52
	Field Mean	*5.13*	*2.69*	*3.77*	*2.34*	*4.52*	*2.03*	*2.67*	*3.30*	*3.67*
HirA	Nil FYM -lime	2.45	1.41	1.52	2.81	3.24	2.09	1.68	4.17	2.32
	Nil FYM +lime	2.29	1.33	2.31	3.59	3.29	2.34	2.34	5.12	2.89
	Low FYM -lime	2.83	1.75	2.85	4.26	3.65	2.04	2.99	4.97	3.90
	Low FYM +lime	3.73	1.97	3.47	3.76	4.52	2.96	2.88	4.83	4.03
	High FYM -lime	3.15	2.04	2.82	3.51	4.96	3.89	3.32	4.70	4.52
	High FYM +lime	3.41	2.74	3.01	5.53	4.68	3.99	3.81	4.98	4.23
	Field Mean	*2.98*	*1.87*	*2.66*	*3.91*	*4.06*	*2.88*	*2.84*	*4.80*	*3.65*
HirC	Nil FYM -lime	2.10	1.79	3.13	2.89	2.44	2.43	2.00	1.71	1.89
	Nil FYM +lime	1.80	2.09	2.40	2.32	2.52	2.61	1.57	1.78	1.85
	Low FYM -lime	1.37	2.38	3.57	2.65	2.92	2.46	2.92	2.36	2.65
	Low FYM +lime	2.37	2.49	3.46	3.28	3.01	3.37	2.68	1.66	2.50
	High FYM -lime	2.25	3.59	3.54	3.42	3.77	3.20	2.85	2.67	2.74
	High FYM +lime	1.56	3.21	3.76	3.76	4.05	3.05	3.30	2.55	2.31
	Field Mean	*1.91*	*2.59*	*3.31*	*3.05*	*3.12*	*2.85*	*2.55*	*2.12*	*2.32*
Treatment means of all fields	Nil FYM -lime	2.80	1.46	2.55	2.36	2.93	1.76	1.77	2.86	1.91
	Nil FYM +lime	2.62	2.02	2.80	2.59	2.86	2.13	1.99	2.90	2.32
	Low FYM -lime	3.64	2.45	3.62	3.21	3.80	2.27	3.01	3.68	3.37
	Low FYM +lime	3.81	2.63	4.20	3.36	4.07	2.85	2.86	3.25	3.64
	High FYM -lime	3.40	2.70	3.37	3.23	3.84	2.95	3.28	3.77	3.58
	High FYM +lime	3.68	3.02	4.21	4.09	4.36	3.21	3.60	3.86	3.72
	l.s.d. (5% level)	0.857ns	0.565ns	0.819ns	0.602ns	0.668ns	0.541ns	0.571ns	0.706ns	0.596ns
	Unlimed plots	3.28	2.20	3.18	2.93	3.52	2.33	2.69	3.44	2.96
	Limed plots	3.37	2.56	3.74	3.35	3.77	2.72	2.81	3.34	3.23
	l.s.d. (5% level)	0.495ns	0.326*	0.473*	0.347*	0.386ns	0.312*	0.330ns	0.407ns	0.344ns
	Nil FYM	2.71	1.74	2.68	2.48	2.89	1.95	1.88	2.88	2.11
	Low FYM	3.72	2.54	3.91	3.28	3.94	2.56	2.93	3.46	3.51
	High FYM	3.54	2.86	3.79	3.66	4.10	3.08	3.44	3.82	3.65
	l.s.d. (5% level)	0.606**	0.399***	0.579***	0.425***	0.472***	0.382***	0.404***	0.499**	0.421***

Note: *, **, *** denote significance at the 5%, 1% and 0.1% probability levels respectively.

Figure 4. Dry matter yields (t/ha) for the three main FYM treatments (Nil, Low and High) from 2005 to 2013 (Means of Lime treatments and Field sites).
Summer rainfall data$ plotted on additional axis.



$ Rainfall data = Total rainfall for June and July prior to hay-cut. (Data compiled from daily rainfall measurements at Nant Gwyllt monitoring station: Data from Severn Trent Water Ltd.) (Raw data in Appendix 3)

The low rate of sheep-derived manure applied at the Penglaneinon sites tended to produce comparable yield results with the cattle-based manure of the same rate.

So in practice, application of either rate (or type) of FYM resulted in yields averaging 3.4 t ha^{-1} compared with 2.4 t ha^{-1} on untreated control plots, together with a corresponding difference in average standing leaf height (as recorded in mid-July) of 23 cm compared with 14 cm respectively. Although these yields are still not high in comparison with many other lowland unimproved meadows, they may be at levels more compatible with local agricultural requirements and could thus make the probability of reinstating traditional hay-making regimes more likely (particularly in years with good climatic growing conditions).

4.3.4. Effects of Nutrient Treatments on Hay Quality

Despite relatively low yields, the results of the chemical analysis of harvested hay carried out on three separate occasions (**Table 5**) showed that all the meadows sites consistently produced hay of high quality with levels of nutrients (Ca, K, Mg, Na and P) generally comparable with recommended levels necessary for optimal livestock performance (Tallowin and Jefferson 1999).

There were few differences found in herbage hay-quality between the different meadow sites other than herbage from the RYH site developing slightly higher phosphorus concentrations over time and HIR C, the least species-rich site, developing relatively lower magnesium and sodium contents over time compared with other sites.

In terms of treatment effects, the application of FYM and/or lime had no effect on the digestible organic matter in the dry matter (DOMD) with values remaining generally constant and at the high end of the range of D-values typically found within late-season cut unfertilised semi-natural grasslands (circa. 57% DOMD). In fact such levels were above those normally quoted for most unfertilised MG5 species-rich meadows.

Initial concentrations of phosphorus in the herbage were at adequate levels and there were further significant and progressive increases in phosphorus content over time with increasing rates of FYM applied. By 2012, under the high FYM rate, P content was above 0.18% which is considered sufficient for maximum livestock growth. Also by the 2012 sampling date, FYM applications had significantly further increased the contents of both nitrogen and sodium in the herbage.

The potassium content of herbage appeared to be directly related to the potassium content of the FYM applied during each individual year. The relatively high potassium content of FYM applied to plots in 2005 (30.8 g/kg K) resulted in significantly higher potassium levels in the herbage harvested from manured plots as compared to untreated control plots. However during the other sampling occasions in 2008 and 2012 the significantly lower K contents (0.4 g/kg in 2008 and 2.3 g/kg in 2012) of manure applied resulted in no significant differences in K content between treatments.

Results also revealed some statistically significant effects of liming on herbage quality. Not unexpectedly the addition of lime resulted in higher calcium content in the herbage at all three sampling occasions compared with herbage from unlimed vegetation. In contrast however, liming appeared to slightly reduce the magnesium content of herbage, albeit to levels still found within the typical range for MG5 grasslands.

As observed for dry matter yields earlier, the use of sheep manure as an alternative to cattle-derived manure on selected sites had no clear effect on the herbage nutrient contents measured or on herbage digestibility.

Table 5. Summary of results of the hay quality analysis of cut herbage sampled from FYM trial plots in 2005, 2008 and 2012.

Fields	**Treatments**	**Ca, %**			**K, %**			**Mg, %**			**Na, %**		
		2005	**2008**	**2012**	**2005**	**2008**	**2012**	**2005**	**2008**	**2012**	**2005**	**2008**	**2012**
	Nil FYM –lime	0.97	0.76	0.78	1.27	1.56	1.69	0.26	0.26	0.25	0.47	0.25	0.29
	Nil FYM +lime	1.01	0.87	0.98	0.83	1.09	0.93	0.27	0.22	0.21	0.50	0.35	0.51
	Low FYM –lime	0.76	0.83	0.74	1.50	1.55	1.24	0.23	0.27	0.24	0.34	0.25	0.38
	Low FYM +lime	0.70	0.72	0.68	2.28	1.84	1.88	0.23	0.22	0.20	0.16	0.19	0.25
PenA	High FYM-lime	0.78	0.67	0.74	1.51	1.35	1.02	0.26	0.26	0.26	0.43	0.33	0.47
	High FYM +lime	0.98	0.87	0.78	1.88	1.60	1.31	0.21	0.22	0.21	0.33	0.27	0.40
	Sheep FYM –lime	0.79	0.72	0.72	2.05	1.85	1.41	0.27	0.24	0.24	0.29	0.24	0.34
	Sheep FYM +lime	0.69	0.87	0.84	1.28	1.03	0.90	0.24	0.24	0.23	0.29	0.38	0.53
	Field Mean	*0.84*	*0.79*	*0.78*	*1.58*	*1.48*	*1.30*	*0.25*	*0.24*	*0.23*	*0.35*	*0.28*	*0.40*
	Nil FYM –lime	0.55	0.43	0.48	1.48	1.61	1.74	0.27	0.23	0.24	0.28	0.19	0.27
	Nil FYM +lime	0.86	0.66	0.90	1.93	1.22	1.25	0.27	0.14	0.19	0.25	0.16	0.36
	Low FYM –lime	0.50	0.49	0.50	2.02	1.60	1.34	0.23	0.24	0.21	0.35	0.29	0.40
PenC	Low FYM +lime	0.74	0.93	0.82	2.07	1.42	1.04	0.20	0.19	0.19	0.26	0.29	0.37
	High FYM –lime	0.47	0.53	0.56	2.11	1.71	1.21	0.24	0.25	0.23	0.36	0.23	0.34
	High FYM +lime	0.77	0.89	0.63	1.52	1.24	1.04	0.23	0.21	0.18	0.35	0.37	0.45
	Sheep FYM –lime	0.66	0.56	0.58	2.00	1.29	1.09	0.26	0.27	0.23	0.39	0.36	0.39
	Sheep FYM +lime	0.73	0.89	0.82	2.03	1.21	0.98	0.21	0.19	0.19	0.26	0.31	0.46
	Field Mean	*0.66*	*0.67*	*0.66*	*1.90*	*1.41*	*1.21*	*0.24*	*0.21*	*0.21*	*0.31*	*0.27*	*0.38*
	Nil FYM –lime	0.33	0.45	0.43	1.18	1.76	1.37	0.17	0.24	0.22	0.25	0.28	0.47
	Nil FYM +lime	0.41	0.78	0.87	1.41	1.73	1.07	0.15	0.20	0.20	0.28	0.33	0.44
RYH	Low FYM –lime	0.30	0.45	0.48	1.36	1.77	1.21	0.16	0.23	0.21	0.28	0.30	0.40
	Low FYM +lime	0.41	0.86	0.70	1.52	1.19	0.87	0.15	0.24	0.20	0.26	0.45	0.54
	High FYM –lime	0.36	0.49	0.46	1.43	1.68	1.31	0.17	0.24	0.21	0.28	0.34	0.47
	High FYM +lime	0.51	0.61	0.74	1.44	1.77	1.11	0.15	0.21	0.18	0.30	0.35	0.44
	Field Mean	*0.39*	*0.61*	*0.61*	*1.39*	*1.65*	*1.16*	*0.16*	*0.23*	*0.20*	*0.27*	*0.34*	*0.46*
	Nil FYM –lime	1.09	1.31	0.93	1.15	1.30	1.37	0.27	0.29	0.18	0.46	0.42	0.24
	Nil FYM +lime	1.21	1.09	0.81	0.97	1.04	1.49	0.30	0.24	0.16	0.49	0.43	0.29
HirA	Low FYM –lime	1.14	1.22	0.80	1.23	1.00	1.56	0.29	0.26	0.16	0.48	0.50	0.34
	Low FYM +lime	1.15	1.31	1.04	1.40	1.51	1.16	0.28	0.26	0.22	0.39	0.39	0.34
	High FYM –lime	1.20	1.37	0.92	1.29	1.12	1.01	0.27	0.32	0.23	0.42	0.47	0.47
	High FYM +lime	1.05	1.02	0.91	1.20	1.06	1.21	0.24	0.26	0.21	0.46	0.54	0.45
	Field Mean	*1.14*	*1.22*	*0.90*	*1.21*	*1.17*	*1.30*	*0.28*	*0.27*	*0.19*	*0.45*	*0.46*	*0.36*
	Nil FYM –lime	0.92	1.07	0.66	1.34	1.30	1.19	0.20	0.26	0.13	0.33	0.28	0.19
	Nil FYM +lime	1.08	1.04	0.74	1.12	1.23	1.19	0.18	0.20	0.11	0.36	0.38	0.18
HirC	Low FYM –lime	0.85	0.73	0.78	1.52	1.34	1.50	0.21	0.20	0.20	0.31	0.18	0.16
	Low FYM +lime	0.95	1.20	0.79	1.54	1.62	1.39	0.20	0.26	0.15	0.28	0.24	0.16
	High FYM –lime	1.02	1.16	0.89	1.55	1.40	1.71	0.21	0.26	0.19	0.36	0.39	0.26
	High FYM +lime	1.10	0.93	0.74	1.15	1.32	1.42	0.25	0.21	0.14	0.44	0.31	0.23
	Field Mean	*0.99*	*1.02*	*0.77*	*1.37*	*1.37*	*1.40*	*0.21*	*0.23*	*0.15*	*0.35*	*0.29*	*0.20*

Table 5 continued. Summary of results of the hay quality analysis of cut herbage sampled from FYM trial plots in 2005, 2008 and 2012.

Fields	Treatments	P, % 2005	P, % 2008	P, % 2012	N, % 2005	N, % 2008	N, % 2012	DOMD, % 2005	DOMD, % 2008	DOMD, % 2012
PenA	Nil FYM –lime	0.14	0.14	0.16	2.10	1.93	1.65	58.54	59.44	57.36
	Nil FYM +lime	0.14	0.14	0.13	2.00	1.79	1.57	58.19	58.85	58.48
	Low FYM –lime	0.13	0.14	0.14	2.01	1.92	1.72	55.85	58.65	55.93
	Low FYM +lime	0.12	0.13	0.14	1.95	1.86	1.80	53.68	56.76	54.82
	High FYM-lime	0.14	0.15	0.18	1.85	1.75	1.74	58.08	56.14	54.64
	High FYM +lime	0.12	0.14	0.18	1.82	1.83	1.55	56.95	57.81	56.54
	Sheep FYM –lime	0.18	0.14	0.14	1.83	1.80	1.68	52.12	56.51	56.28
	Sheep FYM +lime	0.16	0.15	0.17	2.27	1.88	1.60	53.29	57.87	55.20
	Field Mean	*0.14*	*0.14*	*0.16*	*1.98*	*1.84*	*1.66*	*55.84*	*57.75*	*56.16*
PenC	Nil FYM –lime	0.12	0.15	0.14	1.85	1.65	1.77	58.57	54.44	58.12
	Nil FYM +lime	0.13	0.16	0.16	1.88	1.87	1.82	56.13	58.05	56.66
	Low FYM –lime	0.13	0.15	0.19	1.92	1.81	1.89	55.88	57.51	55.27
	Low FYM +lime	0.14	0.17	0.15	1.97	1.78	1.76	53.48	55.86	56.07
	High FYM –lime	0.12	0.19	0.19	1.74	1.86	1.88	53.62	55.01	54.86
	High FYM +lime	0.13	0.15	0.19	2.01	1.67	1.77	55.95	57.75	47.04
	Sheep FYM –lime	0.15	0.16	0.16	1.76	1.78	1.97	53.72	55.83	59.08
	Sheep FYM +lime	0.16	0.18	0.15	2.01	1.67	1.82	54.05	56.66	55.22
	Field Mean	*0.14*	*0.16*	*0.17*	*1.89*	*1.76*	*1.84*	*55.18*	*56.39*	*55.29*
RYH	Nil FYM –lime	0.13	0.23	0.18	1.39	2.24	1.74	50.62	56.81	55.66
	Nil FYM +lime	0.13	0.19	0.16	1.47	2.34	1.93	51.80	58.73	57.86
	Low FYM -lime	0.17	0.24	0.21	1.85	2.41	1.75	62.82	55.64	55.70
	Low FYM +lime	0.16	0.27	0.25	1.73	2.26	2.02	49.65	60.53	57.79
	High FYM -lime	0.14	0.26	0.25	1.50	2.12	1.98	51.52	57.28	57.35
	High FYM +lime	0.15	0.25	0.26	1.55	2.31	1.82	49.48	57.49	55.77
	Field Mean	*0.15*	*0.24*	*0.22*	*1.58*	*2.28*	*1.87*	*52.65*	*57.75*	*56.69*
HirA	Nil FYM -lime	0.21	0.11	0.10	1.58	1.45	1.34	61.92	60.64	58.22
	Nil FYM +lime	0.15	0.13	0.13	1.65	1.35	1.26	53.39	60.77	57.05
	Low FYM -lime	0.20	0.16	0.16	1.82	1.51	1.49	60.21	59.45	56.43
	Low FYM +lime	0.15	0.13	0.12	1.70	1.45	1.42	60.62	60.64	57.15
	High FYM -lime	0.15	0.13	0.19	1.77	1.63	1.54	60.94	61.61	57.02
	High FYM +lime	0.17	0.14	0.18	1.67	1.39	1.45	60.29	56.36	56.69
	Field Mean	*0.17*	*0.13*	*0.15*	*1.70*	*1.46*	*1.42*	*59.56*	*59.91*	*57.09*
HirC	Nil FYM -lime	0.11	0.11	0.14	1.63	1.57	1.39	58.04	57.63	58.70
	Nil FYM +lime	0.11	0.12	0.11	1.57	1.49	1.39	59.27	59.61	55.30
	Low FYM -lime	0.12	0.12	0.14	1.59	1.55	1.68	56.45	57.15	56.13
	Low FYM +lime	0.13	0.12	0.16	1.69	1.50	1.74	55.70	59.50	58.36
	High FYM -lime	0.15	0.14	0.23	1.76	1.55	1.99	61.32	61.24	60.02
	High FYM +lime	0.12	0.14	0.20	1.52	1.47	1.65	57.44	57.19	57.05
	Field Mean	*0.12*	*0.13*	*0.16*	*1.63*	*1.52*	*1.64*	*58.04*	*58.72*	*57.59*

Table 5 continued. Summary of results of the hay quality analysis of cut herbage sampled from FYM trial plots in 2005, 2008 and 2012.

Fields	Treatments	Ca, %			K, %			Mg, %			Na, %		
		2005	**2008**	**2012**	**2005**	**2008**	**2012**	**2005**	**2008**	**2012**	**2005**	**2008**	**2012**
	Nil FYM -lime	0.77	0.80	0.66	1.29	1.51	1.47	0.23	0.25	0.20	0.36	0.29	0.29
Treatment	Nil FYM +lime	0.91	0.89	0.86	1.25	1.26	1.19	0.24	0.20	0.17	0.38	0.33	0.36
means of	Low FYM -lime	0.71	0.74	0.66	1.53	1.45	1.37	0.22	0.24	0.20	0.35	0.30	0.37
all fields	Low FYM +lime	0.79	1.01	0.81	1.76	1.52	1.27	0.21	0.23	0.19	0.27	0.31	0.33
	High FYM -lime	0.76	0.84	0.71	1.58	1.45	1.25	0.23	0.27	0.22	0.37	0.35	0.40
	High FYM +lime	0.88	0.86	0.76	1.44	1.40	1.22	0.22	0.22	0.18	0.38	0.37	0.39
	l.s.d. (5% level)	0.119ns	0.202ns	0.153ns	0.308ns	0.273ns	0.339ns	0.028ns	0.025*	0.029ns	0.081ns	0.087ns	0.086ns
	Unlimed plots	0.75	0.80	0.68	1.46	1.47	1.37	0.23	0.25	0.21	0.36	0.31	0.34
	Limed plots	0.86	0.92	0.81	1.48	1.39	1.22	0.22	0.22	0.18	0.34	0.34	0.36
	l.s.d. (5% level)	0.069**	0.117*	0.087**	0.178ns	0.158ns	0.196ns	0.016ns	0.015***	0.017**	0.047ns	0.050ns	0.050ns
	Nil FYM	0.84	0.85	0.76	1.27	1.38	1.33	0.23	0.23	0.19	0.37	0.31	0.32
	Low FYM	0.75	0.87	0.73	1.64	1.48	1.32	0.22	0.24	0.20	0.31	0.31	0.33
	High FYM	0.82	0.85	0.74	1.51	1.42	1.23	0.23	0.24	0.20	0.37	0.36	0.40
	l.s.d. (5% level)	0.084ns	0.143ns	0.109ns	0.218**	0.193ns	0.240ns	0.020ns	0.017ns	0.021ns	0.057ns	0.062ns	0.061*

Fields	Treatments	P, %			N, %			DOMD, %		
		2005	**2008**	**2012**	**2005**	**2008**	**2012**	**2005**	**2008**	**2012**
	Nil FYM -lime	0.14	0.15	0.14	1.71	1.77	1.58	57.54	57.79	57.61
Treatment	Nil FYM +lime	0.13	0.15	0.14	1.71	1.77	1.59	55.76	59.20	57.07
means of	Low FYM -lime	0.15	0.16	0.17	1.84	1.84	1.71	58.24	57.68	55.89
all fields	Low FYM +lime	0.14	0.16	0.16	1.81	1.77	1.75	54.63	58.66	56.84
	High FYM -lime	0.14	0.17	0.21	1.72	1.78	1.83	57.10	58.26	56.78
	High FYM +lime	0.14	0.16	0.20	1.71	1.73	1.65	56.02	57.32	56.16
	l.s.d. (5% level)	0.023ns	0.021ns	0.027ns	0.145ns	0.112ns	0.139ns	4.046ns	2.158ns	1.691ns
	Unlimed plots	0.14	0.16	0.17	1.76	1.80	1.70	57.63	57.91	56.76
	Limed plots	0.14	0.16	0.17	1.74	1.76	1.66	55.47	58.39	56.69
	l.s.d. (5% level)	0.013ns	0.012ns	0.016ns	0.084ns	0.065ns	0.080ns	2.336ns	1.246ns	0.976ns
	Nil FYM	0.14	0.15	0.14	1.71	1.77	1.59	56.6	58.50	57.34
	Low FYM	0.15	0.16	0.17	1.82	1.80	1.73	56.4	58.17	56.37
	High FYM	0.14	0.17	0.21	1.72	1.76	1.74	55.5	57.79	56.47
	l.s.d. (5% level)	0.016ns	0.015*	0.019**	0.103ns	0.079ns	0.098**	2.861ns	1.526ns	1.196ns

Note: *, **, *** denote significance at the 5%, 1% and 0.1% probability levels respectively.

4.3.5. Effects of Nutrient Treatments on Botanical Diversity & Composition

- Overall effects of nutrient treatments:

Botanical monitoring of experimental plots at the outset of the trial in 2005 confirmed the variation between the individual study fields in terms of their respective degrees of species richness and essential differences in vegetation character; an important and valuable aspect of the Elan Valley meadows in general. However when considering the main effects of the nutrient treatments averaged over all sites there were no statistically significant changes observed in any of the six nutrient treatments over the nine years of monitoring. i.e. no significant differences between treatments for total number of vascular plant species, number of forb species or number of Positive Indicator (PI) species **(Figure 5).**

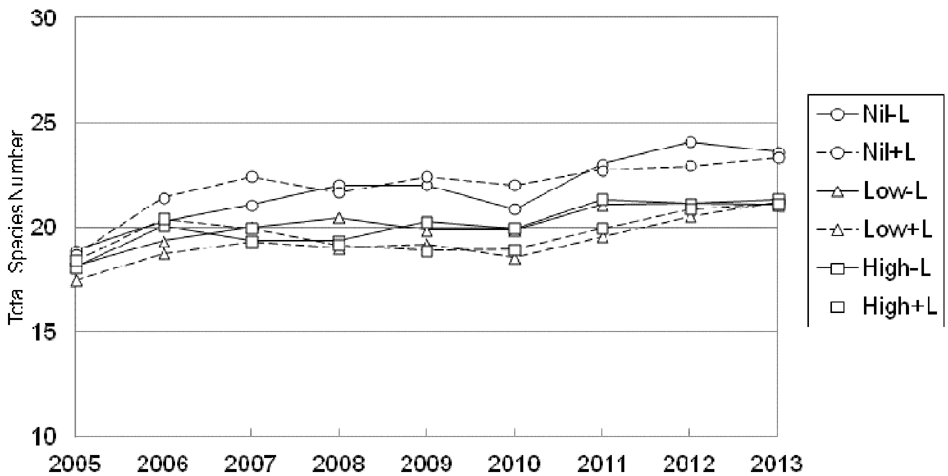
Indeed over time, species richness tended to remain at either broadly constant levels or showed slight overall increases (e.g. between 2005 and 2013 the mean number of species present increased from 18.3 species/m^2 to 20.2 species/m^2). When the number of species was averaged for all years both of the unmanured (Nil FYM) treatments had slightly more species (mean of 21.8 species/m^2) than treatments receiving FYM (mean of 19.8 species/m^2). This suggests that declining soil fertility and/or acidification in the unmanured plots is favouring the development of less competitive conditions for some species (i.e. due to reduced competition from other taller growing and/or more nutrient dependant species). The additional species present in these untreated control treatments occurred mainly at the PEN and RYH sites and primarily included either ‘acid grassland indicators’ (e.g. *Carex panicea, Danthonia decumbems, Galium saxatile, Lathyrus linifolius, Pedicularis sylvatica*) or ecologically stress-tolerant (relatively delicate) species that are only able to persist in highly infertile conditions (e.g. *Campanula rotundifolia, Viola lutea, Linum catharticum*).

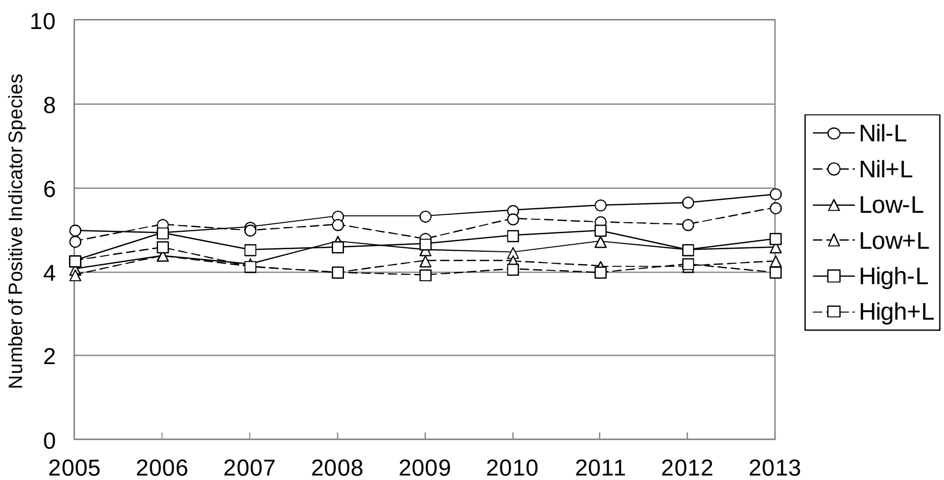
This evidence for declining fertility was further substantiated by the Ellenberg N-score analyses of the plant species present which clearly showed a trend of decreasing fertility on both of the unmanured treatments between 2008 and 2013 **(Figure 6).** In contrast, treatments receiving FYM, with or without lime, showed the opposite trend of increasing levels of fertility (i.e. increases in mean N-scores over the same period) yet, to date, without any associated significant changes in overall species richness.

In contrast to the above findings, the addition of nutrient treatments had a far more marked and important effect on the resulting overall ‘cover’ of species present. By the final year of monitoring in 2013, the low rate of FYM with the addition of lime (Low FYM+lime) had resulted in the greatest cover of both total forbs and, more importantly, the cover of positive indicator (PI) species **(Figure 7)**. Conversely the High FYM rate tended to have a significantly lower cover of PI species, with the unlimed High FYM treatment particularly increasing the total cover of legumes. In general the addition of lime had conflicting effects; where it was applied in addition to FYM it tended to increase the cover of PI species, whereas when applied without any FYM it tended to reduce the cover of PI species.

Consideration of the results for individual key species allows further insights into the effects of the nutrient applications when averaged over all sites combined **(Figure 8)**. By 2013 both of the FYM application rates had resulted in a small increase in the cover of *Holcus lanatus*, a negative indicator species associated with the loss of conservation value of semi-natural meadows (i.e. 3.5% *Holcus* without any FYM, compared to 7% with FYM); the Low FYM-lime treatment had the lowest *Holcus* cover (5.9%) of any of the manured treatments. *H. lanatus* generally tends to thrive under conditions of moderate fertility coupled with moderately acid soil conditions, particularly on moist soils. All treatments except for the untreated control plot resulted in significant increases in the cover of *Trifolium pratense* (effectively doubling the cover from c. 6% to 12%). *T. pratense* is a standard component of mesotrophic meadows and is generally beneficial in terms of both its agricultural feed value and as a good pollinator source for insects. The cover of *Trifolium repens*, a negative indicator for such meadows, was significantly higher under the High FYM-lime treatment compared to all other treatments. The control treatment (i.e. without any lime or manure addition) resulted in a significantly higher cover of *Potentilla erecta* compared to limed or manured treatments. Increases in *P. erecta* cover can sometimes indicate a shift towards more calcifugous communities which would agree here with findings from the soil analysis in that the untreated plots may be becoming too acidic for supporting the desired mesotrophic meadow community. In terms of the most prevalent positive indicator species for these upland-fringe meadows, the highest cover of *Sanguisorba officinalis, Vicia orobus, Leontodon hispidus* and *Centaurea nigra* was with the Low FYM+lime treatment. On balance this treatment appeared to create the optimum conditions for this important suite of species by maintaining relatively low fertility levels together with only moderately acid soils. Of some of the less common positive indicator species present, *Euphrasia officinalis agg*. showed greatest cover on the limed only treatment, whereas *Lotus corniculatus* had significantly higher cover on the unmanured treatments. From the above combined results of botanical monitoring from all the sites, particularly when taken together with findings from the soil nutrients, hay yields and Ellenberg N score analysis there appears to be clear evidence that in general the untreated meadows are becoming progressively more infertile and acidic. Although in the short term such conditions can result in minor increases in overall species richness (primarily by increases in acid-tolerant species), in the longer term the overall mesotrophic (neutral) character of the meadows in terms of indicative desirable species may suffer. On the other hand applying FYM at too high a rate appears to overly favour the growth of more competitive species that can also have longer term deleterious effects on the desired species balance. Overall the best compromise at these meadows between the dual need for maintaining both appropriate soil fertility/acid-neutral levels, while at the same time conserving the targeted intricate balance of floristic diversity, appears to be periodic liming with the addition of a low application of FYM, (at a rate of 12 t/ha FYM every 2 or 3 years), taking into account individual site conditions such as conservation priorities, soil nutrient levels and past management history.

Figure 5. Changes in measures of species richness (mean numbers observed within quadrats) for main treatments between 2005 and 2013 (Means of all sites).





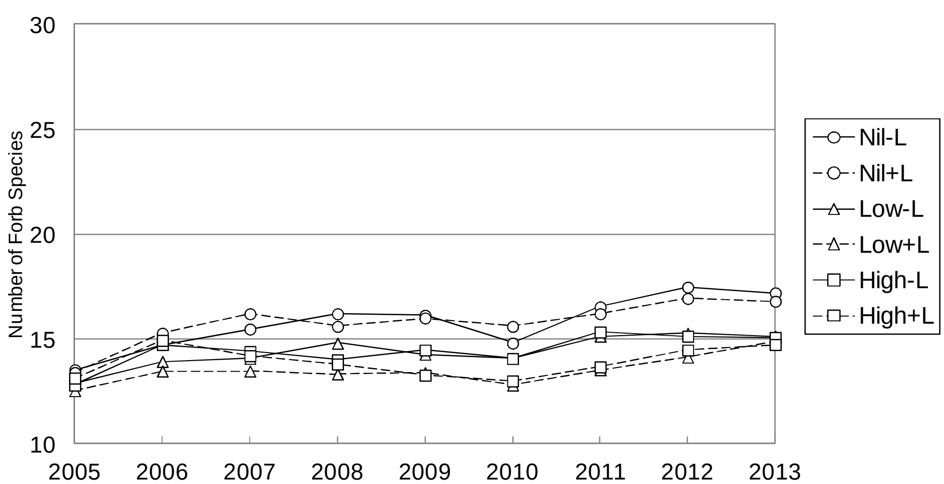
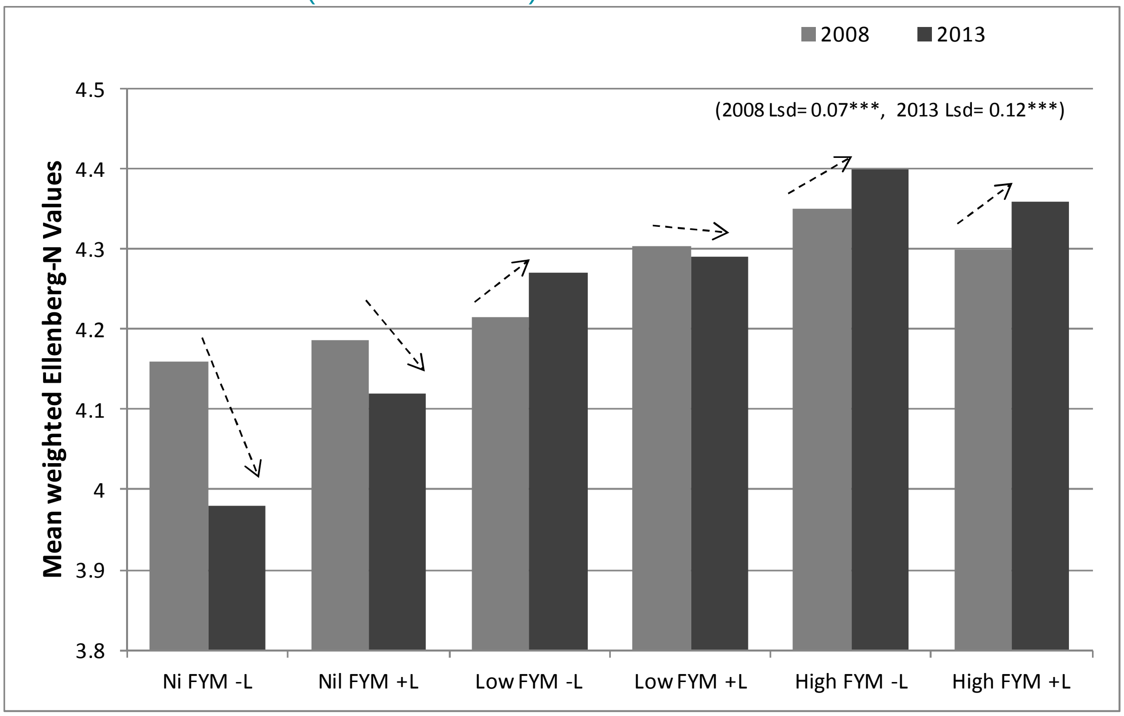


Figure 6. A comparison of mean weighted Ellenberg N-scores for the main treatments between 2008 and 2013 (Means of all sites).



Note: Dotted arrows represent trends for indicating either ‘increasing’ or ‘decreasing’ fertility between sampling years.

Figure 7. Effects of main FYM treatments on the cover (%) of main meadow components (Means of all sites and years).

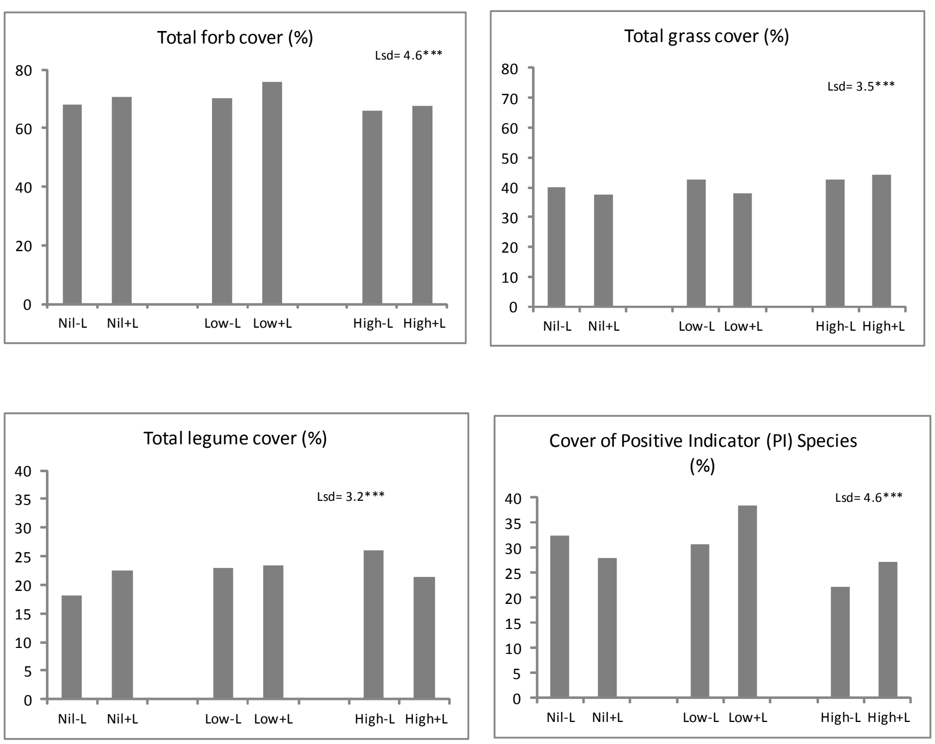
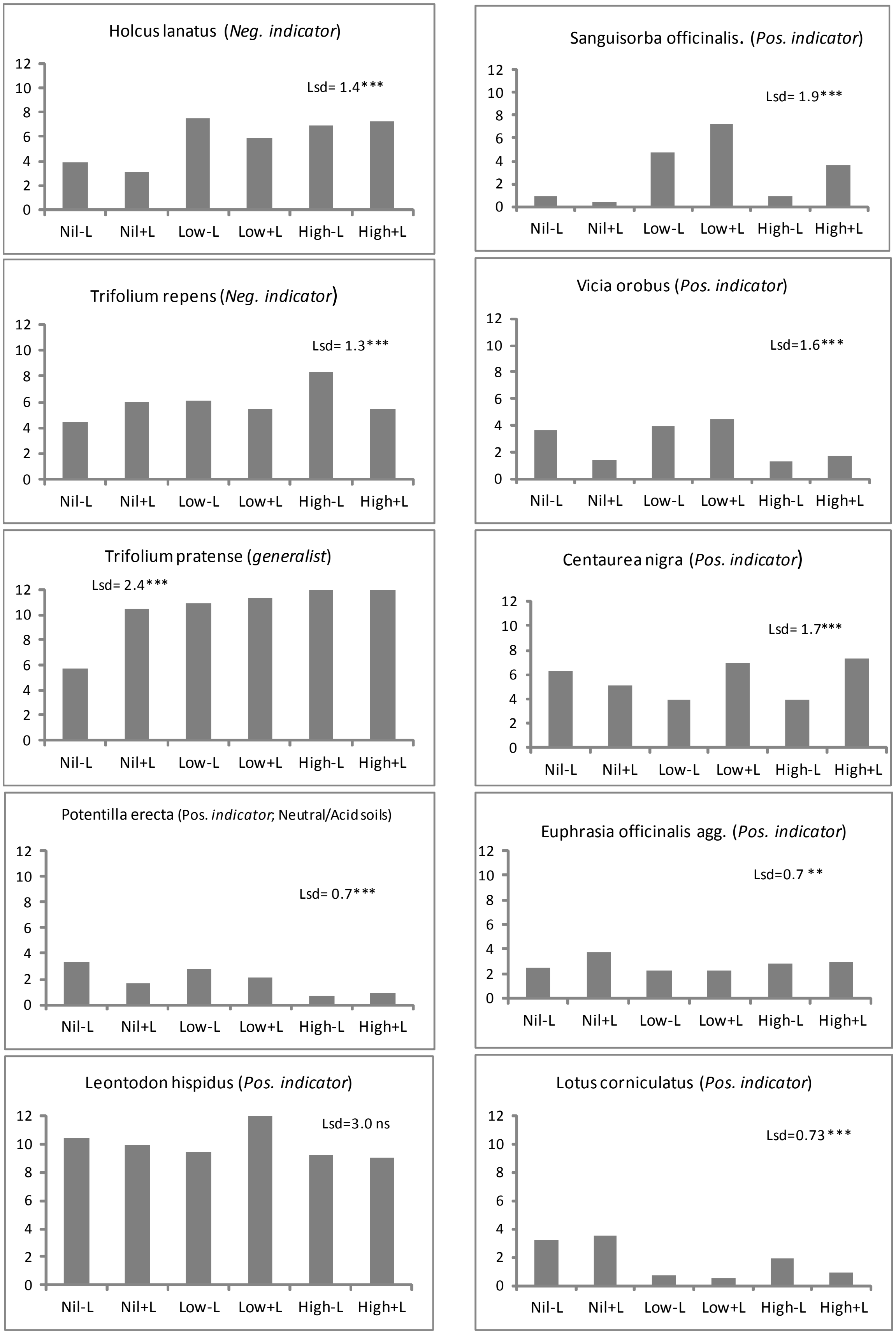


Figure 8. Effects of main treatments on the cover (%) of selected key species (Means of all sites and years).



- Site specific effects of nutrient treatments

As well as the above results providing useful information to help inform broad conservation management decisions for meadows within the Elan Valley, further detailed consideration of the botanical results from each of the study sites also allows for the development of more precise, site-specific management recommendations for the individual meadows in question:

- Penglaneinon sites (PEN A and PEN C)

Of all sites, these two meadows are clearly the most species-rich in terms of both species number and floristic complexity and for the presence of species emblematic of the Elan Valley grasslands, notably *V. orobus*. In consequence they appeared the most adversely responsive (sensitive) to the different rates of nutrients applied.

At these two sites evidence for temporal trends in changing fertility derived from the mean Ellenberg N-scores indicated that generally both the Nil+lime treatment and both of Low FYM rates (i.e. with or without lime) were generally maintaining fertility at current levels whereas all other treatments were causing development of either 'excessive' or 'sub-optimal' levels of fertility in terms of maintenance of the current species-rich plant communities.

At both these sites, despite lack of any significant declines in species richness, by 2013 the High FYM rate had particularly encouraged the growth of *T. pratense* (i.e. attaining cover values of 13% at PEN A and 22% at PEN C **(Tables 6a** and **6b).** The High FYM rate also resulted in relatively high cover values of a number of negative indicator species e.g. *T. repens* increasing to 5% at PEN A and 7% at PEN C; *H. lanatus* reaching 5% cover at PEN A and 9 % at PEN C. The High FYM rate also had the highest cover values for *Poa trivialis* (2%) at the PEN A site and *Rumex acetosa* (3%) at PEN C, both of which are negative indicator species and undesirable at levels any higher than these.

Albeit to a lesser degree, cover levels of these species were also increasing under the Low FYM application and probably reaching an extent that in the longer term could adversely affect some of the more highly sensitive, low growing species present such as *Lotus corniculatus, Linum cartharticum, Campanula rotundifolia, Viola lutea*, *Ophioglossum* and *Orchidaceae* species. Although at the PEN A site this Low FYM rate appeared the most favourable treatment for the cover of two highly desirable and emblematic species *Vicia orobus* and *Sanguisorba officinalis*.

At the other extreme, although the NIL FYM treatments at these sites did show a small (albeit statistically insignificant) increase in total species number compared with manured plots, the species involved tended to signify a shift towards more acidic grassland communities e.g. highest incidence of *Potentilla erecta* (at 5% cover) on the Nil FYM-lime treatment at PEN C. Indeed parts of PEN C field do already support areas of more calcifugous grassland subcommunities (e.g. the highly restricted *Lathyrus montanus-Stachys betonica* grassland (U4c) and scattered patches of *Danthonia decumbens* sub-community (MG5c**),** where intimate and rich mixtures of calcicolous and calcifugous species occur together and which generally require slightly more acidic soil conditions. As such it is important to recognise the presence of these areas and take into account their specific requirements when considering any potential future lime/nutrient applications.

From the above, due to the acute sensitivity of the species assemblages present at these two sites it would be expedient to recommend an even lower rate of FYM than the Low rate applied in this trial.

Although the effect of using sheep-derived manure as an alternative to cattle FYM applied at the two Penglaneinon sites showed no obvious pattern of response for broad measures of species richness, there was some evidence that the Low rate of Sheep FYM occasionally had the same potentially harmful effect as the High rate of Cattle FYM, by for example, reducing the total cover of forb species and cover of PI species. Specifically, at the PEN A site the Low rate of Sheep FYM appeared to reduce the cover of *V. orobus* and increase the cover of *Trifolium dubium* (4%) on the unlimed plot. However without any adequate replication of treatments at this single site this finding cannot be properly substantiated.

- Rhos y Hafod site (RYH)

Although this site maintains good general levels of floristic quality with a high overall cover of *T. pratense* together with the presence of notable species such as *Vicia orobus* and *Sanguisorba officianalis,* results indicated clear evidence of increasing acidity (i.e. the lowest soil pH of all sites at 4.7 in 2013) and with Ellenberg N-scores indicating a general trend for declining fertility over time. As also observed at other sites, this has not, as yet, led to any significant losses of species richness, although the site as a whole is now developing unacceptable levels of negative indicator species for maintaining levels of species diversity (*H. lanatus* 12% cover and *T. repens* 6 % cover) **(Table 6c)**. For this site, application of the low rate of FYM together with lime appears to be the most appropriate treatment and the best compromise for reinstating appropriate fertility levels while not significantly affecting species richness. However as for the Penglaneinon sites above, due to the generally high species diversity of this site it would again be expedient to recommend a slightly lower rate of FYM to be applied in practice. The High FYM rate in contrast appeared to encourage too much cover of *T. pratense* (*18%), T. repens* (10%) and *H. lanatus* (18%), with the latter species again seeming to particularly thrive on developing conditions of moderate soil fertility and increasing acidification. There were indications that *Potentilla erecta* cover was also starting to increase in the unlimed Low FYM plot.

- Hirnant sites (HIR A and HIR C)

The Hirnant sites are two further valuable examples of this distinct group of upland-fringe meadows although they are generally less well floristically developed than the other three sites as they have both undergone some degree of semi-improvement in the recent past. The more species-rich HIR A is notable for its high overall cover of *Leontodon hispidus* which gives the meadow its striking visual appearance during the summer months. In contrast it has a low general cover of *Centaurea nigra,* which is usually a more conspicuous component of such mesotrophic meadow communities. HIR C is an undesignated meadow that has been undergoing meadow restoration management for the last ten years (see later Expansion/Restoration Section). Over recent years this site has also developed a high cover of *Leontodon hispidus* with levels nearly approaching those found in HIR A. However it is still less species-rich than HIR A and maintains a relatively high cover of *Potentilla erecta*, again probably reflecting the slightly more acidic nature of the underlying soil at this site. Over the nine years of monitoring neither of these sites showed any decline in species number as a result of the nutrient applications and indeed species number actually increased, reflecting the ongoing process of species diversification and overall general decline in soil fertility. Again at both these sites the addition of lime and the Low rate of FYM seemed generally beneficial for maintaining the target soil pH while also encouraging the growth of desirable meadow species. However as seen in the other sites there were indications that by the end of the monitoring period the High FYM rate was overly increasing the cover of some species to levels that could lead to suppression of other more important meadow components in terms of conservation value. For example the High FYM rate resulted in high cover of *T. pratense* (up to 20*%* at HIR A)**,** together with the highest cover values of negative indicator species such as *H. lanatus, Poa trivialis* and *Rumex acetosa* at both sites (**Tables 6d and 6e)**.

Table 6a. The mean cover (%) of species within 3 permanent (1 m^2) quadrats at the Pen A trial plots in 2013.

Pen A 2013 Species list	Nil FYM -Lime	Nil FYM +Lime	Low FYM -Lime	Low FYM +Lime	High FYM -Lime	High FYM +Lime	SHEEP Low FYM -Lime	SHEEP Low FYM +Lime
Grasses:								
Agrostis capillaris	4.00	3.00	5.67	5.33	6.33	8.33	7.33	4.00
Anthoxanthum odoratum	6.33	5.00	10.00	9.00	7.67	8.67	10.00	7.00
Cynosurus cristatus	3.67	3.00	7.33	4.33	7.00	7.33	10.00	10.00
Danthonia decumbens	0.07	0.70						
Festuca rubra	10.00	9.00	8.33	10.67	8.67	4.00	4.33	8.00
Holcus lanatus	0.70	0.07	5.67	5.00	3.67	6.67	8.33	2.33
Poa trivialis			0.03	0.37		4.33	0.37	0.33
Sedges:								
Carex caryophyllea	2.67	2.00			0.10			0.10
Carex panicea		0.07						
Forbs:								
Achillea millefolium		0.03						
Campanula rotundifolia	0.10	0.10						
Centaurea nigra	20.00	14.00	18.33	21.67	13.00	26.67	14.00	18.33
Cerastium fontanum	0.10	0.07	0.10	0.10	0.10	0.10	0.10	0.10
Cerastium holostea				0.03		0.03		
Conopodium majus	0.03	0.03	0.07	0.07	0.03			
Crepis capillaris	1.33	3.67	0.40	0.10	0.10	0.40	0.73	0.70
Euphrasia officinalis agg.	2.33	2.67	3.33	0.70	5.00	1.00	1.67	3.00
Hypochaeris radicata	0.07	0.37						
Lathyrus linifolius								0.33
Leontodon autumnalis	2.33	8.33	1.00	0.40	1.33	0.10	0.73	1.03
Leontodon hispidus	13.33	11.67	3.67	2.00	8.67	2.00	6.67	10.00
Leucanthemum vulgare	0.10	0.10	0.03		0.10	0.03	0.40	0.07
Linum catharticum	0.10	2.00	0.03					0.10
Lotus corniculatus	8.33	6.00	1.73	0.03	3.67	1.40	0.70	1.33
Luzula campestris	0.70	1.00						
Plantago lanceolata	15.00	14.00	15.00	11.67	12.33	13.00	14.00	15.00
Platanthera chlorantha		0.33						
Polygala vulgaris	0.10	1.00						
Potentilla erecta	5.33	3.67	1.00	2.33	0.40	0.03	0.33	3.00
Potentilla sterilis		0.03						
Prunella vulgaris	2.00	3.67	1.00	0.07	1.00	0.40	0.03	2.00
Ranunculus acris	0.10	0.03	0.07	0.10		0.10	0.03	0.70
Ranunculus bulbosus	3.00	4.67	2.00	2.67	2.67	2.00	2.00	3.00
Ranunculus repens			0.10	0.10	0.10	0.10	0.10	0.10
Rhinanthus minor	1.03	1.67	2.33	1.00	2.33	1.33	4.33	3.00
Rumex acetosa	0.10		1.33	2.33	0.40	2.67	1.67	1.33
Rumex acetosella	0.03	0.03	0.10	0.07		0.10	0.07	0.03
Sanguisorba officinalis	2.33	2.00	11.67	25.00	3.33	10.33	8.67	0.67
Stellaria graminea		0.03		0.03		0.07	0.03	
Trifolium dubium							4.33	
Trifolium pratense	2.33	6.00	12.33	3.33	16.67	9.67	13.00	8.67
Trifolium repens	1.33	1.67	3.00	0.33	6.67	3.67	6.00	6.67
Vicia cracca			0.67	1.00		0.10		
Vicia orobus	16.67	5.00	12.67	12.33	10.33	2.00	1.00	4.33
Viola lutea		0.07						
No. of vascular spp.	33	38	30	30	26	30	29	30

Table 6b. The mean cover (%) of species within 3 permanent (1 m^2) quadrats at the Pen C trial plots, in 2013.

Pen C 2013 **Species list**	**Nil FYM -Lime**	**Nil FYM +Lime**	**Low FYM -Lime**	**Low FYM +Lime**	**High FYM -Lime**	**High FYM +Lime**	**SHEEP Low FYM -Lime**	**SHEEP Low FYM +Lime**
Grasses:								
Agrostis capillaris	9.00	5.00	8.67	3.67	9.00	9.00	9.00	4.67
Anthoxanthum odoratum	11.67	9.00	15.00	13.33	8.33	15.00	11.67	15.00
Cynosurus cristatus		0.70	0.40	1.67		2.03	0.33	1.03
Danthonia decumbens	0.70							
Festuca rubra	11.67	8.00	9.00	5.00	10.00	10.67	10.67	8.33
Holcus lanatus	2.33	3.67	9.00	5.67	8.33	9.00	7.33	6.67
Poa trivialis		0.10	0.33	0.10	2.33	2.67	1.33	1.33
Sedges:								
Carex caryophyllea	2.00					0.03	0.10	0.07
Carex panicea	0.03							
Forbs:								
Achillea millefolium			0.03					0.03
Campanula rotundifolia	0.07						0.07	
Centaurea nigra	6.00	13.33	6.00	16.67	5.00	13.00	9.33	10.67
Cerastium fontanum		0.07	0.10	0.10	0.10	0.10	0.10	0.10
Conopodium majus			0.10			0.03		
Crepis capillaris	1.33	4.33	0.40	0.40	1.03	0.07	1.33	0.10
Euphrasia officinalis agg.	2.33	1.67	2.67	2.00	2.67	2.33	2.00	2.33
Galium saxatile	0.10							
Hieracium sp.							0.03	
Hypochaeris radicata	8.33	2.67	0.67	0.33	0.70	0.07	0.70	0.07
Lathyrus linifolius	0.37							
Leontodon autumnalis	7.00	2.67	0.10	0.70	1.07	0.10	1.03	0.73
Leontodon hispidus		0.37		0.03	0.03		0.33	
Lotus corniculatus	4.33	0.07	0.03		1.67		0.03	0.33
Luzula campestris	2.33	0.10	0.07				0.07	0.10
Pedicularis sylvatica	0.03							
Plantago lanceolata	9.33	13.00	15.00	12.33	10.00	12.33	10.00	15.00
Potentilla erecta	4.67					0.37	0.70	
Prunella vulgaris				0.03		0.03	0.07	
Ranunculus acris	0.73	2.00	1.37	4.33	1.67	3.67	1.67	4.00
Ranunculus bulbosus	4.00	3.33	2.33	2.33	3.00	2.67	4.00	2.00
Ranunculus repens	6.33	7.33	6.67	4.00	7.00	6.00	5.67	4.33
Rhinanthus minor	1.00	2.00	4.00	4.67	3.33	2.00	2.33	6.67
Rumex acetosa	0.07	0.37	1.33	1.67	3.67	1.67	0.70	1.67
Rumex acetosella	0.10	0.10	0.10	0.10	1.00	0.10	0.10	0.10
Sanguisorba officinalis	0.03						3.67	
Stachys officinalis	0.33							
Succisa pratensis	5.33			1.33			0.03	1.67
Trifolium pratense	8.67	21.67	20.00	36.67	25.00	18.33	21.67	26.67
Trifolium repens	6.33	11.67	10.00	6.67	10.00	3.67	5.00	4.33
Viola lutea	0.07							
No. of vascular spp.	32	24	25	24	22	25	31	26

Table 6c. The mean cover (%) of species within 3 permanent (1 m^2) quadrats at the RYH trial plots, in 2013.

RYH 2013 Species list	Nil FYM -Lime	Nil FYM +Lime	Low FYM -Lime	Low FYM +Lime	High FYM -Lime	High FYM +Lime
Grasses:						
Agrostis capillaris	10.00	8.33	13.33	6.67	11.67	13.33
Anthoxanthum odoratum	18.33	9.33	15.00	10.00	20.00	10.00
Cynosurus cristatus	1.00	7.00	0.03	15.67	0.40	9.00
Festuca rubra	11.67	9.33	5.00	5.00	2.67	6.67
Holcus lanatus	11.67	3.67	16.67	10.00	18.33	18.33
Poa trivialis	1.00	1.33	5.00	8.33	7.00	7.67
Forbs:						
Achillea millefolium	0.33	0.10				
Campanula rotundifolia		0.07				
Centaurea nigra	5.67	6.00	3.33	7.00	3.33	5.33
Cerastium fontanum	0.10	0.10	0.10	0.10	0.10	0.10
Conopodium majus	1.00	0.10	1.00	0.07	0.40	0.40
Crepis capillaris	0.40	0.10	0.70	1.00	0.40	0.40
Euphrasia officinalis agg.	4.00	13.33	1.67	3.67	3.00	4.67
Hyacinthoides non-scripta	2.33	2.37	10.00	2.00	1.33	1.67
Hypochaeris radicata	3.67	2.00	1.33	0.03		0.37
Leontodon autumnalis	3.00	0.40	0.37	0.10		0.07
Linum catharticum	0.03					
Lotus corniculatus	2.00	2.00	2.00		0.33	0.37
Luzula campestris		0.07				
Plantago lanceolata	12.33	15.00	11.67	14.33	7.33	12.00
Potentilla erecta	0.37	0.03	4.03	0.67		
Pteridium aquilinum				0.33	5.00	
Ranunculus acris		0.10	0.10	0.07	0.03	0.37
Ranunculus bulbosus	4.33	4.67	4.67	2.33	2.67	3.33
Ranunculus repens	0.03			0.10	0.10	
Rhinanthus minor	0.70	0.40	1.33	0.70	1.37	0.33
Rumex acetosa	2.00	1.33	3.33	3.67	3.33	3.67
Sanguisorba officinalis	0.70	0.10	0.70	0.33	0.03	0.07
Stachys officinalis			0.70			
Stellaria graminea	0.10	0.07	0.03	0.37	0.03	0.37
Trifolium pratense	12.00	15.00	8.00	13.33	20.00	15.00
Trifolium repens	6.33	10.00	4.67	10.00	14.33	6.67
Vicia orobus	0.37	1.33	5.00	1.00	0.03	0.33
No. of vascular spp.	28	29	27	27	25	25

Table 6d. The mean cover (%) of species within 3 permanent (1 m^2) quadrats at the HIR A trial plots, in 2013.

HIR A 2013 Species list	**Nil FYM -Lime**	**Nil FYM +Lime**	**Low FYM -Lime**	**Low FYM +Lime**	**High FYM -Lime**	**High FYM +Lime**
Grasses:						
Agrostis vinealis			0.03			
Agrostris capillaris	9.00	8.33	7.00	8.67	5.00	8.33
Alopecurus pratensis				0.03		
Anthoxanthum odoratum	11.67	10.67	13.00	8.00	8.67	5.00
Bromus hordeaceus ssp. hord.		0.07	0.10			
Cynosurus cristatus	5.33	5.00	6.00	8.00	7.67	10.00
Dactylis glomerata				0.33		
Festuca rubra	7.33	5.00	8.33	4.67	5.00	5.00
Helictotrichon pratense	0.10	0.10	1.00	0.10	0.10	0.40
Holcus lanatus	1.00	1.00	1.33	1.00	4.33	4.33
Lolium temulentum var. arvense		0.40	0.33			
Poa trivialis	0.40	0.37	1.03	0.70	3.00	5.00
Forbs:						
Centaurea nigra					1.33	
Cerastium fontanum	0.10	0.10	0.10	0.70	1.00	0.40
Conopodium majus				0.03		
Crepis capillaris		0.40		0.03		0.03
Euphrasia officinalis agg.	3.67	18.33	7.33	10.00	6.33	18.33
Hypochaeris radicata	0.03					
Leontodon hispidus	28.33	15.00	13.00	26.67	21.33	13.33
Lotus corniculatus	6.00	1.40		1.00	1.67	0.37
Luzula campestris	1.00	0.10	0.03	0.07		0.03
Plantago lanceolata	10.00	10.00	9.67	10.00	8.33	10.67
Prunella vulgaris	0.07					
Ranunculus acris	0.40	2.00	1.33	2.00	0.70	2.33
Ranunculus repens	4.33	8.00	7.00	7.00	4.33	10.00
Rhinanthus major	3.33	4.00	9.33	7.33	5.00	10.00
Rumex acetosa	0.70	1.03	0.70	0.40	2.00	1.33
Stellaria graminea					0.03	0.03
Taraxacum officinalis agg.	1.67	0.70		2.00	1.33	1.67
Trifolium dubium	6.00	8.67	6.33	7.00	3.33	9.33
Trifolium pratense	6.33	6.33	9.67	6.67	20.00	3.67
Trifolium repens	2.33	2.67	8.00	2.00	3.00	3.33
No. of vascular spp.	23	24	22	25	22	23

Table 6e. The mean cover (%) of species within 3 permanent (1 m^2) quadrats at the HIR C trial plots, in 2013

HIR C 2013 Species list	Nil FYM -Lime	Nil FYM +Lime	Low FYM -Lime	Low FYM +Lime	High FYM -Lime	High FYM +Lime
Grasses:						
Agrostis capillaris	15.00	13.33	11.67	9.33	5.00	15.00
Anthoxanthum odoratum	15.00	16.67	13.33	11.67	10.00	15.00
Arrhenatherum elatius	0.33			0.33	0.33	
Cynosurus cristatus	1.33	1.00	0.70	5.67	6.00	6.67
Dactylis glomerata	1.67			0.33	1.00	0.07
Festuca rubra	18.33	18.33	13.33	12.33	10.67	15.00
Holcus lanatus	2.33	1.00	2.00	3.67	4.33	5.00
Poa trivialis	0.33			0.37	2.67	2.00
Sedge:						
Carex pilulifera		0.03	0.07		0.03	0.37
Forbs:						
Centaurea nigra					0.33	
Cerastium fontanum	0.03		0.03	0.07	0.10	0.10
Euphrasia officinalis agg.		1.70			1.03	
Leontodon hispidus	11.00	16.67	15.00	16.67	18.33	11.67
Lotus corniculatus	1.00	0.67		4.33	0.03	
Luzula campestris	0.67	0.67	1.33	0.70	0.37	1.33
Plantago lanceolata	18.33	18.33	16.67	14.00	19.00	20.00
Potentilla erecta	5.33	6.67	15.00	6.00	1.70	3.67
Prunella vulgaris	0.03					
Ranunculus acris		0.03	0.10	0.07	0.70	
Ranunculus bulbosus				0.03		
Ranunculus repens				0.37	2.00	0.03
Rhinanthus minor	7.33	3.33	17.67	3.33	2.00	2.00
Rumex acteosa	0.40	0.03	0.03	1.03	2.33	0.40
Taraxacum officinale agg.		0.07			0.03	
Trifolium pratense		1.00	4.67	12.67	10.00	3.00
Trifolium repens	0.33	1.00	10.00	3.67	13.33	2.33
No. of vascular spp.	18	18	16	21	24	18

4.4. Conclusions

The five separate meadows studied are clearly quite different in their vegetation characteristics as influenced by individual site conditions (location, soils and aspect), and past management etc. Now however, following the long-term monitoring on experimental plots subjected to a range of potential nutrient regimes, we have assembled a considerable database upon which more well-informed management recommendations can be based.

Results obtained from the soil monitoring provide clear evidence that all the meadow soils are slowly but steadily acidifying. It is possible that after many years of relative stability following the cessation of historic lime applications the fields may now be reaching a 'tipping-point' where soil acidity is beginning to have significant influence on herbage yields and progressively on species composition. Paradoxically such a reduction in soil pH, coupled with very limited nutrient inputs over recent years has, up until now, slightly increased the actual number of the species present by allowing species tolerant of very low nutrient conditions levels to thrive or colonise. In specific areas this of course can be beneficial as it helps to maintain or create valuable and increasingly scarce acid-neutral grassland communities. Such communities, most notably the U4c-type, already exist in some of these fields studied and they will need to be carefully managed. However in the mid to longer term, acidification of the more extensive areas of the meadows raises concerns that increasingly acidic low-nutrient conditions may result in losses in diversity within these predominantly neutral communities. Soil pH in itself is of secondary importance to the processes and conditions that it influences in relation to plants and hence species diversity. For example as calcium requirement for optimum growth appears to be generally lower for monocotyledons than dicotyledons, decreasing pH will tend to favour grass species over forbs. Once such an undesirable situation arises it may take many years to rectify and recovery may not be possible when local extinction occurs and this may be particularly so in highly localised and fragmented sites such as occur in the Elan Valley. The Lowland Grassland Management Handbook (Crofts & Jefferson 1994) states that where the soil pH of mesotrophic grassland falls below 5.0 and the nature conservation objective is to maintain a neutral community, a lime application could be considered, providing that strict control of nutrient inputs is maintained. For the above reasons it is recommended that judicious liming be reintroduced to all the meadow sites studied and potentially to other similar sites in the region where deemed appropriate. Naturally any lime applications need to be planned with care to ensure that other lime-sensitive biota are not inadvertently harmed (e.g. fungi, lichens, invertebrates etc.).

During an earlier stage of the project there was an attempt to monitor such changes in soil fertility and pH over a wider range of sites, but this did not detect any significant change over time. The different findings reported here are either a result of the more detailed sampling strategy used, with long term monitoring within precise locations, or because the meadow soils have only recently reached this 'tipping point' beyond which the rate of pH decline can readily accelerate. If the latter is true then it raises concerns that a similar situation could occur at other sites where soil conditions are a major factor for conserving specific plant communities.

Results reported here also suggest that periodic applications of organic manures (FYM) to the meadow sites should help maintain ecologically sustainable levels of fertility and prevent any further declines in soil nutrient status. It is generally accepted that maximum species diversity in grassland occurs at a low to intermediate level between nutrient-rich and nutrient-impoverished status and in the case of these meadows there clearly needs to be a compromise between maintaining the desired level of botanical interest while also providing a usable crop of harvested hay. Thus by enabling reinstatement of such traditional hay-cutting management it should be possible to conserve the present species balance (whether plant, animal, fungal or microbial) by adopting the conditions to which these species are ecologically adapted (together with periodic grazing and other factors). For two of the less species-rich sites studied here (HIR A and HIR C) applications of FYM at the Low rate of 12t/ha every two years generally appeared to meet the above conditions by maintaining or even increasing plant species richness and by increasing hay yields by over 40%. For these sites there was no major additional advantage of applying the higher (i.e. more frequently applied) FYM rate and moreover such rates were proven to be detrimental to the species balance. The three more developed species-rich meadows (PEN A, PEN C and RYH i.e. those without any recent history of nutrient inputs) appeared to be more sensitive to the above Low FYM rate and as such (bearing in mind their importance and national scarcity) it would be wise to exercise more caution. So for these sites it would be advisable to reduce the frequency rate of FYM application to 12t/ha every 3 years (or alternatively 8 t/ha every other year if preferred). Very similar findings have recently been reported for other sites that also have no recent history of nutrient inputs (Kirkham *et al*. 2014).

The nutrient content of the manures applied were shown to be highly variable. This is a normal feature of the use of organic manures on traditional meadows and is probably generally beneficial in terms of encouraging the maintenance of high levels of species-diversity through encouragement of spatial and temporal variations in nutrient release. However this does emphasise the desirability for continued regular testing of the nutrient content of applied manures so that cumulative nutrient budgets for the individual meadows can be readily determined and to avoid the possibility of inadvertently applying damaging levels of nutrients. In terms of increasing hay yield, there were no clear differences in the effects of using either cattle or sheep-derived manure at the levels applied, although due to some possible harmful effects on the cover of some sensitive species, it is probably unwise to advocate any large scale use of sheep-derived manures on the Elan Valley meadows without first carrying out more detailed investigations.

Although hay yields obtained from the meadows are relatively low even under the advocated rate of FYM application, the quality of the cut herbage was generally high for all the meadows sampled and thus provides high quality forage for livestock. As well as often providing adequate supplies of nutrients, hay from such species-rich unimproved meadows is also likely to contain many other nutritive/health benefits in terms of the relative contents of individual micro-nutrients, vitamins etc (e.g. Elgersma *et al*. 2012).

4.4.1. Suggested Recommendations for Nutrient Inputs to Individual Study Fields

(subject to gaining suitable derogation agreements):

For all fields reinstatement of periodic liming is required to prevent further soil acidification. In general low and infrequent rates of FYM should be applied to maintain the existing generally low/moderate levels of soil fertility and to encourage the continuation of more regular hay-cutting regimes. FYM application frequencies need to be varied for the different fields due to particular site-specific conditions, conservation priorities and past management:

- Penglaneinon (PEN A)

  Lime (ground limestone) to be applied to the whole field at a rate of **2.5 t/ha**. Liming to be repeated every 5 to 8 years to aim for a soil pH of circa. 5.5.

  FYM to be applied to the whole field at a rate of ≤**12 t/ha every <u>three years</u>.**

- Penglaneinon (PEN C)

  (In general same situation as for PEN A above, however in this field it is important to maintain the within-field soil heterogeneity to conserve the slightly more acid plant communities that occur on the lower slopes of the field)

  Lime to be applied to most of this field at a rate of **2.5 t/ha.**
  Liming to be repeated every 5 to 8 years to aim for a soil pH of circa. 5.5.
  <u>Withhold lime</u> application from an approx. 15 metre wide strip of this field extending along its eastern field boundary (i.e. lower slopes).

  FYM to be applied to the whole field at a rate of ≤**12 t/ha every <u>three years</u>.**

- Rhos yr Hafod (RYH)

  The whole field to be **limed** at a rate of **2.5 t/ha.**
  Liming to be repeated every 5 to 8 years to aim for a soil pH of circa. 5.5.

  FYM to be applied to the whole field at a rate of ≤**12 t/ha every <u>three years</u>**.

- Hirnant (HIR A)

  The whole field to be **limed** at a rate of **2.5 t/ha.**
  Liming to be repeated every 5 to 8 years to aim for a soil pH of circa. 5.5.

  FYM to be applied to the whole field at a rate of ≤**12 t/ha every <u>two years</u>.**
  (n.b. apparently such management has already been implemented on this field)

- Hirnant (HIR C)

  (Although this field is still undergoing restoration (see later) applications of lime and FYM should only be beneficial in achieving target plant communities and hopefully enabling reinstatement of traditional hay meadow management, at least on the deeper soils and less steep lower parts of this field)

  The whole field to be **limed** at a rate of **2.5 t/ha**.
  Liming to be repeated every 5 to 8 years to aim for a soil pH of circa. 5.5.

  FYM to be applied to the whole field at a rate of ≤**12 t/ha every <u>two years</u>**.

5. Expansion of Species-rich Grasslands by Restoration and Rehabilitation of Sites

5.1. Introduction

At a broader landscape scale, there are considerable opportunities within the Elan Valley for patch expansion of existing species-rich grasslands and linkage by diversification of adjoining semi-improved swards. In some cases, diversification is occurring naturally, and all that is required is a return to traditional low-input management together with an effective programme of monitoring to help guide the reversion process. In other cases more proactive management intervention is required such as bracken control, use of lime and introduction of propagules from adjacent fields using techniques such as green hay strewing.

Following acquisition of funding from the National Lottery's New Opportunities Fund (Creative Conservation Projects), a programme of site restoration was initiated in 2004. Appropriate sites for restoration and rehabilitation of species-rich grassland within the Elan Valley Estate were identified in consultation with the Head Ranger, the Estate Manager and CCW staff together with findings from the original project scoping study (Hayes & Sackville Hamilton 2001). The sites were chosen for their high restoration potential in terms of historic management use, soil conditions and proximity to existing species-rich sites. Most had remnant populations of mesotrophic grassland species but usually only at very limited frequencies due to their recent management, primarily continuous sheep grazing. Other research carried out in mid-Wales (Hayes & Tallowin 2007) has shown that such upland-fringe grasslands can undergo relatively rapid reversion to more species-rich communities if traditional hay-cutting and winter grazing managements are reinstated. The prevailing conditions of the area of relatively low residual soil fertility, rapid nutrient leaching through high rainfall **(Appendix 3)** and the close proximity of rich wildflower refugia, all favour the chances for successful reversion.

Bracken (*Pteridium aquilinum*) is thought to have increased greatly in extent in Wales over the last 100 years, mainly attributed to the changes from predominantly cattle to sheep grazing in the uplands, but also due in part to rural depopulation and farm land neglect in some areas (Hester 1996). Bracken encroachment has increasingly become a major threat to some of the Elan Valley hay meadows, (e.g. Rhos yr Hafod) and so an ongoing programme of bracken control has been implemented on selected sites.

The five sites selected for study included two fields at Tynllidiart and one at Hirnant, where traditional hay management has been reinstated; one field at Penglaneinon to investigate creation of species-rich grassland by liming and seed introductions; and one field at Rhos yr Hafod where rehabilitation of an existing species-rich site by bracken control had already been initiated.

5.2. Methodologies

The locations of the sites chosen for the various methods of restorative management are shown in **Figure 9.**

5.2.1. Reinstatement of Traditional Hay Meadow Management

This involved three separate semi-improved (MG6) sites, two adjacent pastures at Tynllidiart and another at Hirnant which is adjacent to the existing grassland SSSI. All these fields are known to have been historically managed as traditional hay-meadows:

Tynllidiart Field 1; (c. 0.6 ha) grid ref: SN909661 (monitoring transect along the centre of the field)

Tynllidiart Field 2; (c. 0.32 ha) grid ref: SN908660 (monitoring transect along the centre of the field)

Hirnant Field C; (c.1.8 ha) grid ref: SN888703 (monitoring transect across slope, 2/3rds up)

The prescribed traditional management at these sites involves spring grazing until May 15th. The grazing is then removed and the meadows are closed up until at least July 15th. They are then cut and weather permitting hay is made (silage may be necessary in exceptionally wet years). The aftermath is then grazed by sheep during the autumn. No fertiliser or lime is applied.

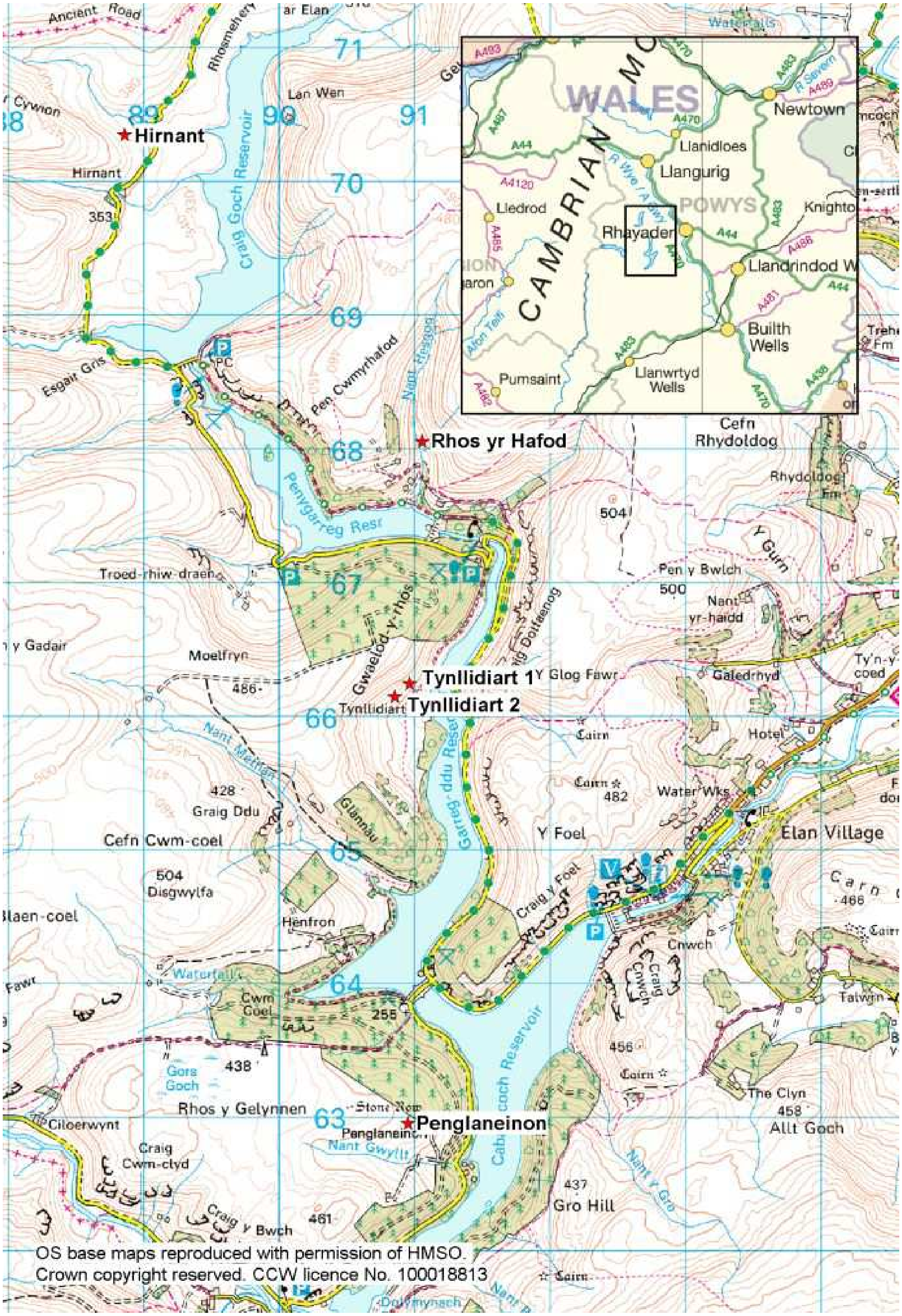
5.2.2. Creation of Species-rich grassland by Traditional Hay Meadow Management with addition of lime and seed introductions

Conducted at a single non-SSSI field selected due to its close proximity to SSSI meadows situated to the east and hence close to a rich seed-source:

Penglaneinon; (1.6ha) grid ref: SN909629 (Transect parallel to bottom fence line, c. 30m upslope)

This site involves a more ambitious and experimental attempt to improve the species diversity of a parcel of species-poor predominately acidic pasture (U4b grassland), adjacent to existing neutral meadows, by liming, ameliorating sward structure through harrowing and seed addition via green hay strewing. With this large field being so close to highly species-rich meadows it was considered an excellent opportunity to explore the potential for buffering and expanding the nature conservation interest of this site. With the combined help of Elan Estate workers, the Elan Valley Countryside Ranger Service and volunteers, hay was cut both in early August 2005 and late July 2006 from Penglaneinon SSSI meadow (PEN A). The freshly cut hay was raked off the donor site, loaded onto a flat trailer, taken to the restoration field and spread immediately by hand over part of the field. The receptor site was not scarified prior to the introduction of hay. After the hay was spread it was turned using a tractor.

Figure 9. Location of the five restoration sites.



5.2.3. Rehabilitation of a Species-rich Meadow by Bracken control

This involves annual control of bracken by cutting and hand pulling within a high quality SSSI-status meadow where bracken encroachment has been an ongoing problem:

Rhos yr Hafod Field F; grid ref: SN910680 (monitoring transect down the centre of the field)

Other Elan Valley meadow sites with dense areas of bracken are mechanically flail-mown using a tractor with less dense areas of bracken such as at Penglaneinon and this site being hand cut or pulled with the leaf litter raked off.

5.2.4. Monitoring

Vegetation was monitored annually at all sites between 2004 and 2013, except for the Rhos yr Hafod site where monitoring started a year later in 2005 and at Penglaneinon, where it was not undertaken in 2008 due to an earlier cutting date. Relocatable 1m x 1m quadrats spaced at 20m intervals along each transect were recorded at all the above sites, except at Rhos yr Hafod where the quadrats were spaced at 5m intervals. Quadrats were relocated by measuring from permanently sited posts located at the edges of the fields. Quadrats were surveyed each year between 1st and 15th July in all but a few cases (when survey took place in late June or August). Percentage cover for each species was recorded along with average vegetation height and any occurrence of bare ground or thatch build up. At Rhos yr Hafod, in quadrats monitoring the effect of bracken management, the number of bracken fronds and their height separate from the height of the rest of the sward were also recorded.

5.3. Results and recommended actions

Summary tables of the data obtained from quadrats are presented in **Tables 7-11.**

5.3.1. Tynllidiart Field 1

This site has freely draining soils with a generally low P status (P Index 0 as of 2000) and a soil pH of 5.1 (as of April 2011). When monitoring started in 2004 it was predominately grass dominated (78%) with *Agrostis capillaris*, *Holcus lanatus* and *Anthoxanthum odoratum* all at relatively high cover **(Table 7).** At this time there were 17 forb species recorded in the monitoring quadrats which on average amounted to 19% of the total cover, although 10% of this was represented by *Trifolium repens*. During the initial 5 years of hay-cutting management the cover of grasses steadily reduced with concomitant increases in total forb cover, until 2009 when these two components had broadly equal levels of cover (**Figure 10a)**. Over this period the most dramatic reduction in grass species was seen in *Holcus lanatus* which, for one four-year period, fell from 41% cover (in 2005) to just 9% cover (in 2009). By 2013 although the total number of species observed showed a relatively small increase (mean of 24 in 2004 compared with 27 in 2013) most of this increase was in forb species and most notably by *Euphrasia officinalis* (which reached 15% cover in 2013) and *Rhinanthus minor* (2% cover by 2013). The other main contributors to this increase in forb cover were *Trifolium pratense* (10%) and *Plantago lanceolata* (9%). Over time a number of other key indicative meadow species were showing small but positive increases from initially extremely limited cover levels. e.g. *Centaurea nigra*, *Conopodium majus* and *Leontodon autumnalis*. *Hyacynthoides non-scripta* was also present in quadrats for most years although always at low overall cover. There are promising indications that other desirable species will be able to further colonise this field as they have been seen to occur at low levels, but not recorded within the monitoring transect (e.g. *Sanguisorba officinalis, Succisa pratensis,* and *Campanula rotundifolia).*

A few species indicating the original 'semi-improved' conditions were still present by 2013, although there were generally in decline (e.g. *Trifolium repens* at 5% cover). Also *Holcus lanatus* was still at 14% cover in 2013. There was also a short-term increase in the cover of *Pteridium aquilinum* (6%) in one quadrat, where the field borders the open hill, although this level did not persist.

Recommended further actions (subject to local approval):

This field is showing high promise for restoration to a good quality species-rich neutral meadow (MG5a). Current hay-cutting and winter grazing management should be continued to allow further development of a locally distinct flora (i.e. no need for any seed additions).

As the soil pH of this field is approaching 5.0, lime should be applied in 2 years time to achieve a target pH of about 5.5 (lime rate to be determined by soil testing).

FYM applied at a rate of up to 12t/ha every 2 years would help produce a viable hay crop.

5.3.2. Tynllidiart Field 2

Due to impeded drainage the lower elevations of this field are less well draining than its neighbour (Tynllidiart 1 above), although it has a similar soil pH (5.09 in April 2011) and only slightly higher P status (although still at P Index 0) .

Although the vegetation of this site reflects its wetter nature in terms of the plant assemblages present, it showed the same overall pattern of response to the reinstatement of the hay cutting management. i.e. a dramatic change in the respective balance of total grass and forb cover over the initial 5 years of monitoring (**Figure 10b)**. Here, grass species *Agrostis capillaris* and *Holcus lanatus* again showed sharp declines in mean cover over time, although *Holcus* actually increased for a period between 2005 and 2008. In contrast to Tynllidiart 1, increases in species richness were more pronounced with the number of species increasing from 23 in 2004 to 33 by 2013, again mostly accounted for by re-colonising forb species (**Table 8)**. Again as in Tynllidiart 1 there are highly promising indications for further restoration success with the more recent spread of species such as *Rhinanthus minor* (10% cover by 2013 having not been recorded in the first 5 years), *Euphrasia officinalis* (up to 7% in one year) and *Trifolium pratense* (5%). Other positive indicator species present, which are likely to increase in the future, include *Centaurea nigra, Lotus corniculatus* and *Dactylorhiza maculata.* The typical meadow grass species *Cynosurus cristatus* was also showing greater prominence during some years.

Despite the above successes, by 2013 there still remained moderate levels of representative species from the original semi-improved sward, particularly *Holcus lanatus (13%*). Also the areas of impeded drainage were favouring *Juncus effusus* (4%) and *Ranunculus repens* (15%). As observed in TYN 1 there was a short lived and minor increase in *Pteridium aquilinum* cover and density at the top perimeter of the field.

Recommended further actions (subject to local approval):

As for Tynllidiart Field 1 above, this field is also showing high potential for restoration to good quality species-rich neutral meadow (MG5a). However due to the impeded drainage, large parts of this field appear to be reverting to the wetter, relatively species-poor rush pasture (i.e. MG10 Holcus lanatus-Juncus effusus community). Options include allowing this gradation to proceed to create a mosaic of wet and drier vegetation, or if resources allow, the preferred course would be to improve drainage to maximise the extent of developing species-rich dry grassland.

Current hay-cutting and winter grazing management should be continued to allow further development of a locally distinct flora. (i.e. no need for any seed additions).

As the soil pH of this field is approaching 5.0, lime should be applied in 2 years time to achieve a target pH of about 5.5 (lime rate to be determined by soil testing).

FYM applied at a rate of up to 12t/ha every 2 years would help produce a viable hay crop.

Any widespread bracken encroachment should be prevented.

5.3.3. Hirnant

This relatively large field was originally selected for hay meadow restoration management due to its particular proximity to the neighbouring SSSI field and for its highly suitable soil conditions: low soil P and pH status (pH 4.9 at the last sampling in April 2011).

At the outset of monitoring in 2004 this site was dominated by grass (total cover of 76%) **(Table 9)** and as at Tynllidiart showed the same dramatic turnaround in terms of the total cover of grass and forb components over time; indeed on this occasion the change was even more rapid (within just 4 years) (**Figure 10c).** At this site however it was the grass species *Agrostis capillaris* and *Festuca rubra* that showed marked declines in mean cover with levels of the forb species *Leontodon hispidus* (25%), *Potentilla erecta* (18%) and *Plantago lanceolata* (12%), showing the greatest increases by 2013. As in Tynllidiart Field 1, the total number of species did not show a particularly large increase over the course of monitoring (up from 21 to 24), as many of key positive indicator species were already present at the outset albeit at very low cover levels e.g. *Euphrasia officinalis, Rhinanthus minor, Lotus corniculatus, Linum catharticum etc.* Presumably at least some of these species are colonising the site from the adjacent SSSI field by wind blown seed or possibly via stock movements between sites. In contrast to the Tynllidiart sites above, *Holcus lanatus* had generally low cover levels here and no *Centaurea nigra* was recorded within quadrats.

At this site it was notable that the height of the sward was remarkably similar each year despite large variations in rainfall and temperature which may be a reflection of the site's north-facing aspect preventing any drought stress during warmer summers. In general this site has shown very successful reversion and appears to be rapidly approaching the quality of the neighbouring SSSI-designated meadows.

Recommended further actions (subject to local approval):

Areas of this field are already approaching the target community (i.e. becoming similar to the adjacent Hirnant SSSI meadows). Current hay-cutting and winter grazing management should be continued to allow further development of a locally distinct flora (i.e. no need for any seed additions). The higher slopes of this field are unlikely to produce croppable herbage but could allow development of high levels of species richness.

FYM applied at a rate of up to 12t/ha every 2 years would help produce a viable hay crop on most of the field, if the field is to be managed as a hay meadow.

As the pH is already <5, liming would be advisable at a rate of 2.5 t/ha with the aim of maintaining a target soil pH of about 5.5.

5.3.4. Penglaneinon

Due to this enclosures location, closer to the *Molinia*-dominated open-hill, it differs from the other sites mainly due to its more humic podzolic soils and vegetation characteristics (**Table 10)** i.e. soil pH of 4.6 and sward composition dominated by *Agrostis capillaris* (32%), *Festuca rubra* (15%), *Anthoxanthum odoratum* (13%) and bryophytes (mainly *Rhytidiadelphus squarrosus* (20%)). The presence *of Galium saxatile* and essentially upland grass species (e.g. *Nardus stricta*) are also clear indicators of continuously grazed acid grassland (NVC U4 type communities). Implementation of annual hay cutting management, lime and regular harrowing has all helped to break down the initial grass thatch layer (down from 19 to 1%) and reduce the bryophyte cover (20% down to 2%). The application of lime in 2010 led to a progressive increase in soil pH attaining a pH in the upper soil horizon of 5.3 by 2013. (n.b. a 10m wide strip along one side of this field has been left unlimed for potential future comparative purposes).

Although the total cover of grass species remains high to date, together with very limited increases in the cover of forb species **(Figure 10d)**, a relatively large number of forb species have begun to colonise the site, primarily in areas that received green-hay strewing from the nearby meadows (21 forb species in 2004 compared with 29 forbs in 2013). Promising examples of colonising species observed to date include: *Rhinanthus minor, Lotus corniculatus, Euphrasia officinalis, Centaurea nigra, Trifolium pratense, Stachys officinalis* and *Viola lutea.*

Recommended further actions (subject to local approval):

As this is more of an experimental attempt to assess the potential of creating forms of more mesotrophic species-rich grassland (e.g. MG5a or U4c) from very species-poor acid grassland (U4b), it was anticipated that the progress would be slow. In theory circum-neutral grassland should be able to develop as soil conditions are ameliorated by the effects of liming (through promoting biological activity and increasing rates of organic matter decomposition (mineralisation)). This process will be aided further by the harrowing and grazing action opening up the sward structure to create more suitable conditions for colonising species.

In terms of practical management the current regime of winter grazing, summer cutting and harrowing should be continued. When conditions are judged to be appropriate the site would then probably benefit from further seed additions via green-hay strewing from the adjacent species-rich meadows. Being a rare example of habitat creation in such circumstances results should be of great interest.

5.3.5. Rhos yr Hafod

Despite being a component part of a wider SSSI-designated site, bracken (*Pteridium aquilinum)* encroachment in this particular field had attained nearly 50% cover in 2004. This, together with a mean bracken frond height of over 50 cm, was clearly creating a significant canopy over the highly species-rich ground cover vegetation (**Table 11**).

The presence of this high bracken stand had also created significant levels of thatch build-up which is likely to physically smother/shade the particularly vulnerable forb species present. This is clearly a concern when the vegetation includes such a wide range of species of high conservation value e.g. *Vicia orobus, Sanguisorba officinalis* and *Viola lutea.* The presence of spring-flowering bluebells (*Hyacinthoides non-scripta),* that are dormant by the time the bracken completely unfurls its canopy, also adds to the particular character of this rich example of upland-fringe grassland.

The effect of bracken control measures over the eight years has been generally successful at reducing both the cover of bracken (50% decrease) **(Figure 10e),** while also reducing its mean height and number of fronds (**Table 11**). In addition, the raking and removal of litter significantly reduced the cover of thatch which was virtually eliminated in some years. The main result of this bracken and thatch reduction has been to increase the overall grass cover up to circa. 70% cover from 2008 onwards. This general opening up of the sward can only have positive effects on the large assemblage of valuable species present (between 30 and 40 species observed each year). Some transitional areas between dense bracken stands and meadow grassland are important and valuable vegetation zones particularly for various uncommon species of flora and fauna and where the greatest numbers of species are frequently recorded.

Recommended further actions (subject to local approval):

The priority at this site is clearly to conserve the existing extremely rich assemblage of grassland species already designated as part of the SSSI. To this end bracken control will need to be continued. In the absence of any likelihood of using cattle to help trample bracken stands, or any prospect of herbicide application being permitted, bracken control will need to involve continued regular cutting, pulling or bruising for the foreseeable future. At least such actions if done regularly should lead to progressively reduced vigour of stands and thereafter require less manpower to keep levels under control. In the absence of soil testing it is difficult to advise on FYM and/or lime rates at this stage.

Table 7. Transect data (mean % cover) from 5 monitoring quadrats at TYNLLIDIART – Restoration Field 1.

Species list	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Agrostis capillaris	35.00	23.00	30.00	34.00	35.00	29.00	24.00	19.00	20.00	14.00
Anthoxanthum odoratum	16.02	21.00	21.00	18.00	23.00	19.00	24.00	22.00	21.00	20.00
Arrhenatherum elatius	0.40	0.40	0.60	0.02	0.02	0.20				
Cynosurus cristatus	0.60	1.00	1.00	1.60	1.60	2.20	2.80	3.40	5.60	2.80
Dactylis glomerata	0.60			0.20						
Festuca rubra	0.60	0.62	2.40	0.40	1.40	0.80	0.62	0.80	3.60	2.80
Holcus lanatus	25.00	41.00	29.00	27.00	13.00	8.60	7.60	4.20	8.00	13.60
Lolium perenne			0.02	0.02	0.02	0.02	0.02			
Poa trivialis		0.24	0.22	0.40	0.22	1.64	0.82	1.00	1.40	2.00
Cardamine pratensis	0.02								0.22	0.04
Centaurea nigra								0.02		0.40
Cerastium fontanum	0.06	0.02	0.08	0.04	0.10	0.08	0.10	0.10	0.10	0.10
Cirsium arvense	0.82	1.20	0.06			0.02				
Cirsium palustre										0.20
Conopodium majus	0.04	0.04	0.06		0.24	0.06	0.04	0.02	0.42	0.82
Crepis capillaris	1.22	0.02	3.04	4.20	6.60	4.20	3.42	2.22	2.80	0.84
Euphrasia officinalis agg.						0.22	9.40	21.00	14.60	14.60
Heracleum sphondylium		2.00	0.02	0.20						
Hyacinthoides non-scripta	0.02		0.20	0.20	0.20	0.20	0.40	0.40	0.20	
Leontodon autumnalis	0.06	0.04	0.06	0.44	0.44	0.62	0.26	0.28	1.62	1.04
Lotus corniculatus	1.02	0.40	1.02	0.40	1.20	4.62	6.60	2.40	2.00	1.80
Lotus uliginosus		1.00	1.40	2.82	4.22	2.80	1.40			
Myosotis sylvatica						0.04		0.02		
Plantago lanceolata	0.62	1.20	0.62	0.80	1.20	1.40	2.20	3.20	5.60	8.60
Pteridium aquilinum	0.40	2.20	2.20	5.00	6.00	6.00	3.00	2.00	0.20	2.00
Ranunculus acris	0.04	0.04	0.24	0.24	0.62	0.26	1.00	0.64	0.64	0.46
Ranunculus bulbosus						0.46			1.80	4.20
Ranunculus repens	2.40	1.42	2.40	1.60	5.00	3.60	3.60	3.20	2.80	1.04
Rhinanthus minor							0.02	0.22	0.82	1.80
Rumex acetosa	1.00	0.86	0.84	1.20	2.20	1.40	2.20	2.80	4.00	3.60
Rumex acetosella	0.02		0.02		0.02	0.60	0.06	0.42	0.80	0.64
Rumex obtusifolius		0.00	0.02							
Stellaria graminea	1.24	0.26	0.82	0.02	0.04	0.06	0.04	0.04	0.04	0.06
Trifolium dubium										0.20
Trifolium pratense	0.02	0.22	0.42	0.22	0.62	8.40	3.20	10.60	9.40	9.80
Trifolium repens	10.00	5.00	11.60	5.00	8.02	23.20	12.00	13.80	7.60	5.20
Leaf height (cm)		35.0	35.0	38.0	26.0	23.0	14.0	13.2	20.8	26.0
Flower height (cm)		65.0	62.0	60.0	55.0	44.0	37.0	34.0	40.0	48.0
No. of vascular spp.	24	23	27	24	24	28	25	25	25	27
No. of Forb species	17	16	19	15	16	20	18	19	19	21
No. of Grass species	7	7	8	9	8	8	7	6	6	6
Cover of Grasses	78.2	87.3	84.2	81.6	74.3	61.5	59.9	50.4	59.6	55.2
Cover of Forbs	19.0	15.9	25.1	22.4	36.7	58.2	48.9	63.4	55.7	57.4

Table 8. Transect data (mean % cover) from 5 monitoring quadrats at TYNLLIDIART – Restoration Field 2.

Species list	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Agrostis capillaris	29.00	16.00	23.00	12.00	10.00	14.00	15.40	19.00	18.00	15.00
Alopecurus geniculatus					0.40	0.02			0.02	0.02
Anthoxanthum odoratum	11.00	21.00	22.00	15.00	12.00	19.60	19.80	16.00	17.00	14.00
Arrhenatherum elatius	0.02								0.02	
Bromus hordeaceus ssp. hordeaceus								0.02		
Cynosurus cristatus	1.20	0.42	0.60	2.40	1.84	4.82	1.82	5.20	6.40	2.60
Festuca rubra			2.24	0.60	5.00	0.80	0.08	0.08	0.08	0.24
Holcus lanatus	18.00	34.00	32.00	51.00	40.00	19.00	9.40	11.00	14.60	12.60
Lolium perenne	1.20	0.04	0.42	1.40	1.40	1.02	0.44	0.02	0.02	0.02
Lolium temulentum				0.22	0.06	0.06	0.08	0.08	0.06	0.02
Poa trivialis	0.04	2.02	1.42	0.28	0.06	1.62	1.02	0.26	0.80	1.40
Carex ovalis				0.40	1.00	0.02	0.20	0.02	0.02	0.40
Juncus bufonius			5.00		1.00	1.00		0.40		
Juncus effusus					0.20	1.80	0.40	0.80	1.40	4.00
Cardamine pratensis				0.20	0.04	0.02	0.02	0.08	0.06	0.06
Centaurea nigra							0.40	0.02	0.02	
Cerastium fontanum	0.64	0.04	0.10	0.04	0.28	0.46	0.10	0.10	0.10	0.10
Cirsium palustre	0.20	0.20		0.20	0.40	0.60	0.20	0.20	0.20	0.20
Cirsium vulgare	0.24				0.20	0.40				0.60
Cirsium arvense	0.42	0.40	0.40	0.20	0.20	0.80	0.60		0.40	
Crepis capillaris	4.22	0.06	1.80	1.02	2.80	2.60	4.40	5.00	3.40	1.84
Euphrasia officinalis agg.						0.02	7.00	2.20	1.40	2.62
Hypochaeris radicata	0.22		0.02	0.22	0.20	0.20	0.02	0.04	0.22	0.04
Leontodon autumnalis	4.20	0.24	0.04	2.40	2.00	1.42	1.06	1.62	1.60	1.60
Lotus corniculatus	0.60	0.40	0.02					8.00	3.20	3.20
Lotus uliginosus				0.60	0.62	4.02	10.20			0.60
Montia fontana				0.02	0.02	0.02	0.02	0.02	0.02	0.02
Myosotis sylvatica	0.02		0.02	0.02		0.02		0.22		
Plantago lanceolata	0.02	0.04	0.02				0.20	0.22	1.04	2.40
Pteridium aquilinum			1.00	1.00	1.00	4.00	1.00		1.00	2.00
Ranunculus acris	2.40	0.84	0.66	1.80	2.60	3.40	3.40	2.00	2.00	2.60
Ranunculus bulbosus						0.02				
Ranunculus repens	5.40	2.80	6.60	2.00	3.60	11.20	14.60	17.00	19.40	15.00
Rhinanthus minor						0.02	2.00	2.06	1.42	10.22
Rumex acetosa	2.02	1.24	0.84	2.60	2.40	2.60	3.22	5.20	5.40	5.00
Rumex obtusifolius	0.80	1.00	0.60	0.20	0.40	0.40		0.20	0.40	0.20
Stellaria graminea	0.20	0.04	0.02	0.02	0.02	0.20	0.02	0.02	0.04	0.02
Taraxacum agg.						0.02				
Trifolium pratense							0.60	2.20	4.40	4.60
Trifolium repens	19.00	12.00	9.40	10.60	14.20	11.20	13.20	11.60	10.00	5.20
Veronica montana										0.20
Rhytidiadelphus squarrosus							0.20	0.62	3.02	3.20
Eurhyncium praelongum							1.00	0.44	0.44	
Bare ground (mole hill)		10.0	0.2			0.2	1.2	0.6	0.0	0.8
Leaf height (cm)	19.0	33.0	19.0	39.0	37.0	26.0	23.4	19.4	26.4	22.0
Flower height (cm)	47.0	63.0	41.0	67.0	65.0	53.0	47.0	43.0	44.0	45.0
No. of vascular spp.	23	19	23	26	29	34	30	32	33	33
No. of Forb species	16	13	15	17	18	23	21	21	22	23
No. of Grass species	7	6	7	8	9	9	8	9	10	9
Cover of Grasses	60.5	73.5	81.7	82.9	70.8	60.9	48.0	51.7	57.0	45.9
Cover of Forbs	40.6	19.3	21.5	23.1	31.2	45.4	62.7	58.8	57.1	62.3

Table 9. Transect data (mean % cover) from 7 monitoring quadrats at the HIRNANT Restoration Field C.

Species list	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Agrostis capillaris	35.00	25.00	17.86	10.00	9.29	8.14	11.57	9.29	10.00	10.00
Anthoxanthum odoratum	10.71	12.57	13.57	11.43	13.57	10.71	13.14	12.14	13.57	13.57
Arrhenatherum elatius		0.14	0.03	0.03		0.29	0.17	0.01	0.29	0.01
Cynosurus cristatus	1.59	1.71	0.74	0.60	0.46	0.74	0.74	0.49	0.63	0.50
Dactylis glomerata	0.47	0.44	0.03		0.14	0.43	1.14	0.47	0.43	0.43
Festuca rubra	26.43	11.43	7.86	10.71	10.71	12.00	13.14	13.57	13.57	15.71
Holcus lanatus	1.71	3.71	3.29	2.17	1.44	2.16	1.71	1.71	1.63	1.06
Carex caryophyllea		0.01						0.03	0.03	0.03
Carex pilulifera	0.17									
Cerastium fontanum	0.01	0.03	0.20	0.07	0.03			0.01	0.01	0.04
Conopodium majus			0.01		0.01					
Euphrasia officinalis agg.			0.01	0.03	0.04	0.01		0.01		0.01
Hypochaeris radicata	0.14				0.14					
Leontodon autumnalis			0.01	0.01				0.01	0.03	0.03
Leontodon hispidus	15.29	30.00	29.29	34.29	26.43	44.29	34.29	32.14	25.71	25.00
Linum catharticum	0.03	0.04	0.01	0.44	0.19	0.01		0.01	0.01	
Lotus corniculatus	0.03	0.01	0.14	0.86	0.73	1.03	4.14	2.59	4.59	4.01
Luzula campestris	0.23	0.76	0.90	0.50	1.57	0.36	0.29	0.49	0.87	1.57
Plantago lanceolata	6.14	8.00	8.14	12.14	12.14	11.71	13.86	12.14	12.14	12.14
Potentilla erecta	5.57	5.57	10.86	6.14	11.43	8.71	10.86	15.71	17.86	18.57
Prunella vulgaris		0.01	0.17	0.03					0.01	
Ranunculus acris			0.47	1.17	1.17	0.03		0.03	0.16	0.17
Ranunculus bulbosus	0.04	0.34			0.03	0.07		0.04	0.03	0.17
Ranunculus repens				0.74	1.01				0.14	0.01
Rhinanthus minor	0.14	0.01	1.01	4.86	4.43	3.43	2.43	2.86	0.60	2.44
Rumex acetosa	0.03	0.01	0.01	0.01	0.01	0.01		0.01	0.01	0.01
Rumex acetosella	0.04				0.01	0.01		0.03	0.03	0.04
Trifolium dubium			0.01							
Trifolium pratense	0.60	2.14	1.86	4.57	3.86	1.89	0.86	2.87	1.60	2.16
Trifolium repens	0.03	0.17	0.59	3.14	1.86	0.20		0.71	0.29	1.29
Pleurozium schreberi						0.20	0.20	1.19	0.89	0.90
Pseudoscleropodium purum			0.03	0.06	0.03	0.04	0.04	0.06	0.06	0.04
Rhytidiadelphus squarrosus	1.89	1.06	1.50	4.76	0.80	1.21	1.77	4.73	5.00	9.00
Thuidium tamariscinum	0.29	0.30	0.30	0.03	0.01	0.01	0.04	0.07	0.07	0.07
Bare ground	0.9	0.6	6.7	0.3	0.7	0.2	3.7	1.7	1.1	1.6
Leaf height (cm)		15.0	13.7	16.9	15.3	20.4	18.3	12.0	9.9	10.4
Flower height (cm)		45.0	36.4	38.6	37.9	39.1	40.0	34.3	23.6	30.0
Grass thatch			2.7	2.4	0.9	2.4	4.6	3.9	2.4	3.0
No. of vascular spp.	21	21	24	22	24	21	14	24	25	24
No. of Forb species	14	13	17	16	18	14	7	16	17	16
No. of Grass species	6	7	7	6	6	7	7	7	7	7
Cover of Grasses	75.9	55.0	43.4	34.9	35.6	34.5	41.6	37.7	40.1	41.3
Cover of Forbs	28.3	47.1	53.7	69.0	65.1	71.8	66.7	69.7	64.1	67.7
Cover of Bryophytes										

Table 10. Transect data (mean % cover) from 9 monitoring quadrats at the PENGLANEINON Restoration Field.

Species list	2004	2005	2006	2007	2009	2010	2011	2012	2013
Agrostis capillaris	31.67	36.67	30.56	26.11	29.44	30.00	36.11	27.22	26.11
Agrostis vinealis	0.01	0.33	0.12	0.33	0.33	0.33	0.12	0.12	0.01
Anthoxanthum odoratum	13.11	19.78	18.33	19.44	21.67	33.33	26.11	28.89	27.22
Cynosurus cristatus			0.11				0.01	0.01	0.11
Danthonia decumbens			0.11	0.22	0.01	0.01	0.01	0.01	0.01
Deschampsia cespitosa	0.11								
Festuca ovina	0.33	0.57	0.89	2.00	2.56	1.78	0.89	0.67	0.44
Festuca rubra	15.33	10.57	9.33	17.78	22.22	18.89	18.89	17.78	19.44
Holcus lanatus	17.44	20.00	26.78	23.89	9.11	3.89	5.56	15.56	15.00
Lolium perenne	0.11					0.01			
Molinia caerulea					0.33	0.33	0.11		
Nardus stricta		0.01			0.01				
Poa trivialis	1.00	0.59	2.11	1.89	0.38	0.01	0.02	1.12	2.33
Carex ovalis								0.01	
Juncus effusus	4.78	2.22					0.44	0.11	0.56
Juncus squarrosus				0.44	0.01				
Achillea millefolium			0.57						
Centaurea nigra				0.03				0.01	0.11
Cerastium holostea		0.06	0.04	0.12	0.01	0.02	0.02	0.46	0.17
Conopodium majus	0.01		0.01	0.01	0.12	0.13	0.04	0.07	0.04
Crepis capillaris			0.01	0.01			0.01	0.01	0.01
Euphrasia officinalis agg.			0.02	0.22	0.13	0.34	1.78	0.01	
Galium saxatile	2.26	3.46	4.92	1.67	0.46	1.33	2.22	0.68	0.04
Hypochaeris radicata		0.23	0.22	0.56	0.23	0.22	0.23	0.36	0.34
Leontodon autumnalis	0.44	0.36	0.11	0.12	0.02	0.01	0.13	0.13	0.03
Lotus corniculatus	0.56		0.01	3.33	1.89	0.12	0.33	0.46	0.02
Luzula campestris	0.44	0.80	1.01	0.38	0.83	0.81	1.23	2.46	2.12
Plantago lanceolata	0.22	0.56	0.22	0.22	0.56	0.56	0.56	0.56	0.67
Polygala serpyllifolia				0.01	0.01	0.02			
Potentilla erecta	0.33	0.03	0.27	0.58	0.89	0.58	0.39	1.14	0.50
Ranunculus acris		0.12	0.46	0.16	0.34	0.27	0.14	0.37	0.80
Ranunculus bulbosus					0.01	0.01	0.11	0.33	0.57
Ranunculus repens	0.79	0.90	0.79	0.36	0.90	0.58	0.68	0.78	0.57
Rhinanthus minor			0.01	0.03	6.90	5.68	1.14	1.90	2.36
Rumex acetosa		0.34	0.56	0.68	0.49	0.26	0.58	1.11	1.12
Rumex acetosella	0.44	0.44	1.22	0.22	0.56	0.36	0.13	0.37	0.17
Stachys officinalis				0.22					
Trifolium pratense	0.11	0.01	0.11	0.33	0.11	0.02	0.22	0.33	0.56
Trifolium repens	2.00	1.90	0.56	0.58	2.11	2.11	1.23	1.56	1.22
Viola lutea								0.01	
Pleurozium schreberi			0.78	0.01	0.12	0.12	0.12	0.23	0.12
Rhytidiadelphus squarrosus	19.56	19.11	8.49	7.13	5.22	8.44	10.00	1.90	2.36
Leaf litter/thatch	18.9	15.0	9.5	7.6	4.1	5.7	7.4	0.1	1.3
Bare soil			0.9		0.1	0.3			
Leaf height (cm)	34.4	22.2	18.0	20.0	13.7	12.4	14.2	18.3	16.1
Flower height (cm)		46.7	43.9	45.6	38.3	29.4	32.8	36.1	41.7
No. of vascular spp.	21	22	28	30	30	29	30	32	29
No. of Forb species	11	13	19	21	19	19	19	21	19
No. of Grass species	9	8	9	8	10	10	10	9	9
Cover of Grasses	79.1	88.5	88.3	91.7	86.1	88.6	87.8	91.4	90.7
Cover of Forbs	7.6	9.2	11.1	9.8	16.6	13.4	11.2	13.1	11.4
Cover of Bryophytes	19.6	19.1	9.3	7.1	5.3	8.6	10.1	2.1	2.5

Table 11. Transect data (mean % cover) from 9 monitoring quadrats at the RHOS YR HAFOD Grassland Rehabilitation/Bracken Control study – Field F.

Species list	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Pteridium (no. of fronds)	10.33	10.44	9.44	7.22	8.22	5.56	9.22	9.33	7.11
Pteridium height (cm)	52.22	48.89	42.78	28.89	46.11	42.22	43.33	39.44	40.00
Pteridium aquilinum cover, %	48.89	46.11	30.67	6.11	43.33	25.00	20.00	28.33	23.33
Agrostis capillaris	14.78	15.78	17.33	16.67	19.44	17.22	18.89	25.56	26.11
Anthoxanthum odoratum	15.78	15.89	19.67	23.33	24.44	23.89	26.11	22.22	19.44
Arrhenatherum elatius					0.01	0.02			
Danthonia decumbens	0.22	0.36	0.26	0.14	0.13	0.24	0.24	0.04	0.04
Festuca rubra	2.01	2.00	1.91	1.89	1.01	0.56	0.67	2.89	4.00
Holcus lanatus	9.44	8.33	21.22	32.78	30.44	23.89	22.78	18.89	20.33
Poa trivialis	0.34	0.24	0.46	0.67	1.37	2.01	2.11	4.12	3.34
Anemone nemorosa						0.02	0.01	0.01	
Campanula rotundifolia			0.03	0.03	0.03		0.02	0.03	0.02
Centaurea nigra	0.11	0.33	0.46	0.34					
Cerastium holostea	0.01	0.02	0.11	0.02		0.01	0.02	0.01	0.01
Conopodium majus			0.01	0.04	0.07	0.03	0.02	0.02	
Crepis capillaris								0.01	
Dactylorhiza maculata			0.02	0.01	0.11			0.03	0.02
Euphrasia officinalis agg.				0.02	0.26	0.02	0.16	0.28	
Fragaria vesca	0.01	0.02		0.01			0.01		
Galium saxatile	1.46	1.90	2.69	1.34	1.46	2.23	2.79	2.79	0.26
Hieracium sp.	0.01	0.01	0.02	0.12			0.44	0.02	0.12
Hyacinthoides non-scripta	8.89	10.44	15.56	7.11	8.44	19.44	13.56	10.89	17.00
Hypochaeris radicata	0.79	1.11	0.89	0.80	1.34	1.12	1.01	1.23	0.81
Lathyrus montanus	0.01	0.12	0.11	0.13	0.33	0.01	0.13	0.03	0.02
Leontodon autumnalis					0.02		0.02	0.24	0.14
Leontodon hispidus						0.12			
Linum catharticum	0.12	0.13	0.02	0.02	0.01				
Lotus uliginosus	0.01	0.11	0.11	0.01	0.01	0.57	0.44	0.13	0.24
Luzula campestris	1.23	1.13	0.26	0.28	0.48	0.37	0.71	1.01	0.70
Luzula multiflora	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.03	0.03
Pimpinella saxifraga		0.01	0.22	0.01	0.02	0.01	0.01		
Plantago lanceolata							0.01	0.01	0.23
Potentilla erecta	11.11	10.00	13.46	11.69	12.58	12.00	10.44	13.44	12.33
Ranunculus acris	0.11	0.12	0.23	0.26	0.16	0.36	0.68	0.36	0.03
Ranunculus bulbosus						0.02	0.04	0.03	0.13
Ranunculus repens	0.02	0.01	0.01	0.04	0.04			0.11	
Rhinanthus minor	0.01	0.02		0.02	0.02	0.02	0.03	0.01	
Rumex acetosella									0.12
Rumex acetosa	8.79	7.69	4.02	2.47	1.57	1.58	1.70	1.60	1.27
Sanguisorba officinalis	0.67	0.78	0.23	0.23	0.57	0.36	0.37	0.23	0.23
Stachys officinalis	0.89	1.12	1.23	0.90	0.59	1.22	1.23	4.23	2.23
Stachys sylvatica							0.01		
Stellaria graminea	0.01	0.13	0.02	0.03	0.02	0.01	0.01	0.01	
Succisa pratensis	2.01	2.00	2.68	2.57	2.57	2.33	2.34	2.11	2.44
Trifolium pratensis				0.01		0.01	0.01		
Vicia orobus	1.11	1.89	3.34	3.34	0.11	0.11	0.12	0.22	0.78
Viola lutea			0.01	0.24	0.02	0.01	0.03	0.04	0.01
Hypnum cupressiforme	0.01	0.02	0.38	0.17	0.07	0.39	0.17	0.07	0.07
Mnium hornum	0.02	0.23	0.13	0.02	0.24	0.02	0.23	0.37	0.37
Pseudoscleropodium purum	0.01	0.02	0.57	0.36	0.24	0.13	0.30	0.48	0.48
Rhytidiadelphus squarrosus	3.12	3.44	6.44	5.89	6.00	7.67	7.67	6.44	7.00
Thuidium sp.	0.24	0.36	0.23	0.03	0.38	0.28	0.92	0.91	1.24
Thatch/Bare ground	20.1	21.0	6.6	0.6	0.2	6.8	4.8	0.7	0.9
Leaf height (cm)	28.9	29.4	21.7	22.0	35.6	23.0	21.2	25.6	30.0
Flower height (cm)	57.1	53.6	47.2	38.3	66.7	43.3	43.9	54.4	58.9
No. of vascular spp.	29	30	32	36	33	33	37	36	30
No. of Forb spp.	22	23	25	29	25	25	30	29	23
No. of Grass spp	6	6	6	6	7	7	6	6	6
Pteridium aquilinum cover	48.9	46.1	30.7	6.1	43.3	25.0	20.0	28.3	23.3
Cover of Forbs	37.4	39.2	45.8	32.2	30.9	42.0	36.4	39.2	39.2
Cover of Grasses	42.6	42.6	60.8	75.5	76.9	67.8	70.8	73.7	73.3
Thatch/bare ground	20.1	21.0	6.6	0.6	0.2	6.8	4.8	0.7	0.9

Figure 10a. Changes in the mean cover and number of main components at TYNLLIDIART 1 Restoration field.

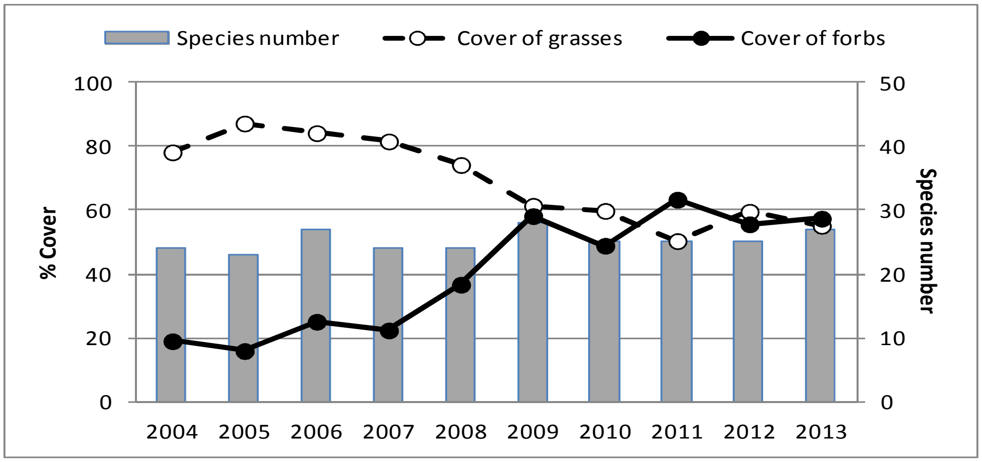


Figure 10b. Changes in the mean cover and number of main components at TYNLLIDIART 2 Restoration field.

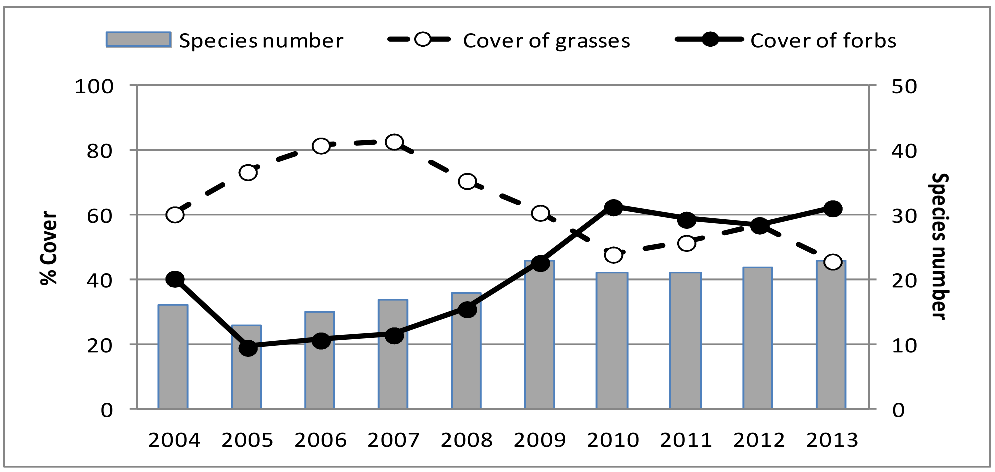


Figure 10c. Changes in the mean cover and number of main components at HIRNANT Restoration field.

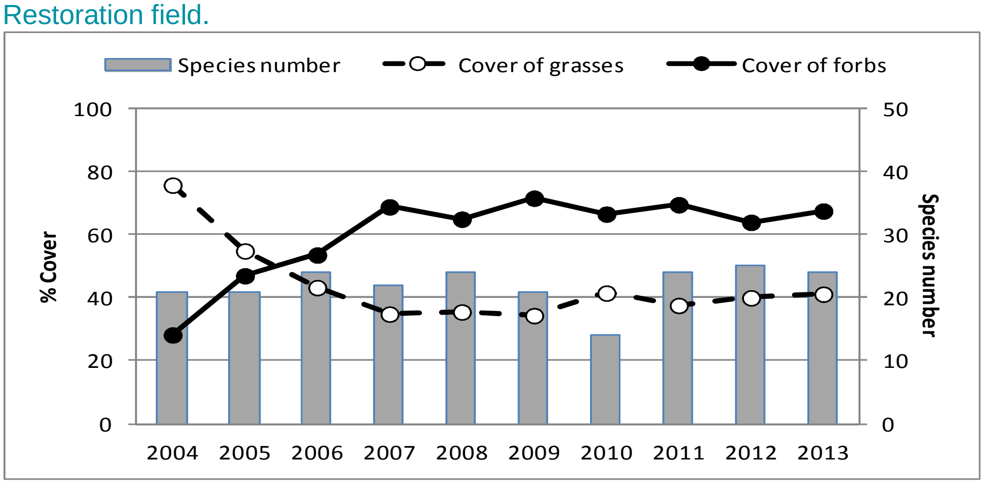


Figure 10d. Changes in the mean cover and number of main components at PENGLANEINON Restoration field

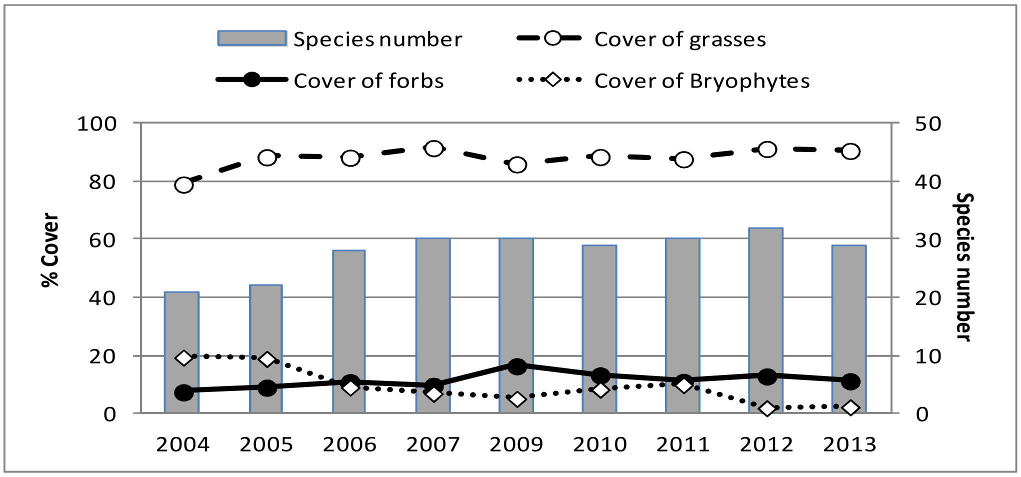
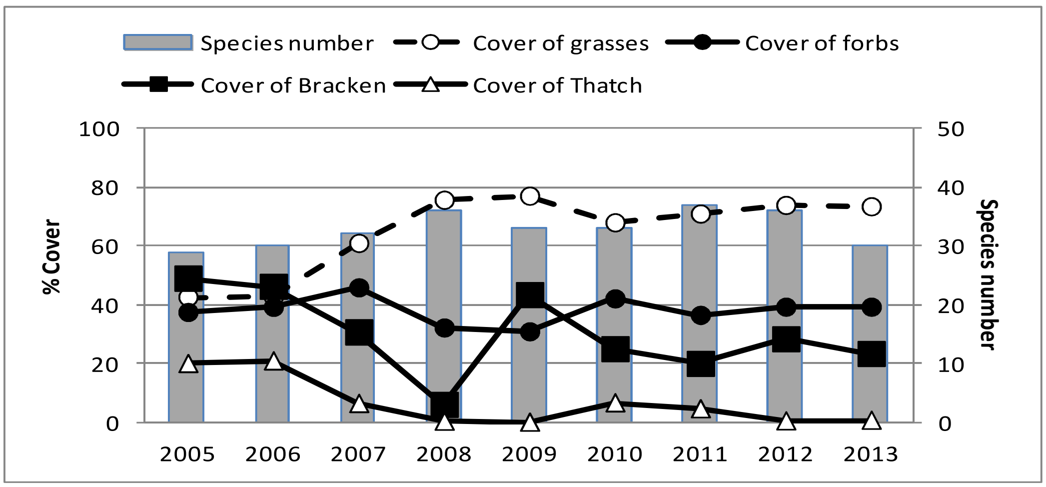


Figure 10e. Changes in the mean cover and number of main components at RHOS YR HAFOD Restoration field.



6. Additional Activities

During the course of the project a number of opportunities arose for holding field-based events in order to publicise the Elan Valley Meadows Project and in particular to demonstrate ongoing results of the FYM trial to professional managers of species-rich grassland, landowners and to the wider general public as part of the Elan Valley Trust's annual events programme. Further events included visits as part of Flora Locale's Wild Meadows Training Programme and the BSBI etc. Also a request from Kew Botanic Gardens resulted in seed of the Near Threatened wood bitter-vetch (*Vicia orobus*) from the Penglaneinon meadows being successfully added to the Millennium Seed Bank, reportedly a significant increase in the number of seeds conserved of this species.

7. Next Steps / Further Work

The logical next step for the project is to implement the individual site-specific recommendations relating to conservation and restoration management, together with further appropriate soil and botanical monitoring to gauge their success. This should include monitoring of any sites receiving increased application rates of FYM and lime. It could also include some limited further monitoring of the existing trial plots in selected meadows so that longer term changes can be assessed (the positioning and experimental layout of the trial plots could serve as suitable monitoring transects within fields, particularly as each run of treatments includes an untreated control plot together with a number of untreated discard areas). Further vegetation monitoring and soil testing (mainly soil pH) of the fields under restoration/ rehabilitation would also help inform future management decisions.

In light of the findings on increasing acidification of the SSSI meadows reported here, it would be expedient to do additional soil surveys on other circum-neutral species-rich sites in the locality that may also be under threat of undesirable changes in species diversity. This also applies to neutral meadows in similar upland fringe situations elsewhere in Wales.

Findings on the effects of nutrient inputs and restoration/rehabilitation management should also, ideally, be extended to other suitable sites in the locality, and wider, utilising the long-term comprehensive dataset already generated to help provide high quality advice. The wide range of grasslands studied here, in terms of age, vegetation community, soil conditions etc., should enable individually-tailored management recommendations to be proposed for similar ‘ecologically-matched’ sites within the catchment.

There are also further opportunities for interpreting the project findings to the public and for demonstrating the approaches used to the farming and nature conservation communities, for example, by wider publication of results and by hosting training events for conservation and agri-environmental staff such as Glastir officers. The high visitor numbers and central location of the Elan Valley Estate within the country also present good general opportunities for increasing public awareness of the importance of the Elan Valley grasslands.

If suitable funding was available then combining the above actions over a landscape/catchment scale could form the basis for a potential next phase of the Elan Valley Meadows Project.

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10. Appendices

Appendix 1. Rates of lime applied to experimental treatments in 2005 and 2009.

Fields	Limed Treatments	Initial pH Jan 2005	Rates of lime Spring 2005		pH April 2009	Rates of lime May 2009	
			kg/plot	equivalent rate t/ha		kg/plot	equivalent rate t/ha
PenA	Nil FYM +lime	5.51	7	2	5.58	3.5	1
	Low FYM +lime	5.65	7	2	5.64	3.5	1
	High FYM +lime	5.67	7	2	5.75	2.6	0.75
	Sheep FYM +lime	5.53	7	2	5.55	3.5	1
PenC	Nil FYM +lime	5.65	7	2	5.39	4.3	1.25
	Low FYM +lime	5.49	8.75	2.5	5.56	3.5	1
	High FYM +lime	5.44	8.75	2.5	5.62	3.5	1
	Sheep FYM +lime	5.45	8.75	2.5	5.55	3.5	1
RYH	Nil FYM +lime	5.41	8.75	2.5	5.58	3.5	1
	Low FYM +lime	5.37	8.75	2.5	5.61	3.5	1
	High FYM +lime	5.38	8.75	2.5	5.57	3.5	1
HirA	Nil FYM +lime	5.80	5.25	1.5	5.73	2.6	0.75
	Low FYM +lime	5.73	5.25	1.5	5.69	2.6	0.75
	High FYM +lime	5.78	5.25	1.5	5.66	2.6	0.75
HirC	Nil FYM +lime	5.80	5.25	1.5	5.39	4.3	1.25
	Low FYM +lime	5.71	5.25	1.5	5.70	2.6	0.75
	High FYM +lime	5.74	5.25	1.5	5.53	4.3	1.25

Appendix 2. Mean values of pH, nutrients, dry matter (DM) and organic matter (OM) content in the cattle and sheep derived FYM applied to experimental plots.

Year	pH	Content of nutrients, g/kg						DM, %		Ash, %	OM, %
		Ca	K	Mg	Na	P	N	fresh	dried		
Cattle FYM											
2005	8.53	44.5	30.8	10.2	8.9	0.6	6.1	30.2	-	31.8	68.2
2006	8.16	17.8	61.4	7.9	8.5	8.2	4.3	30.5	-	33.2	66.8
2007	6.62	24.0	1.8	3.9	0.3	4.2	8.6	26.3	96.4	36.8	63.2
2008	5.45	8.6	0.4	0.9	0.7	2.0	4.1	18.6	96.5	44.3	55.7
2009	7.50	31.9	2.4	3.0	0.5	3.9	4.9	21.3	93.2	30.9	69.1
2010	7.39	27.8	3.9	3.1	0.3	5.4	4.4	19.2	91.3	32.1	69.9
2011	7.36	29.5	8.9	4.2	1.7	5.4	4.2	19.1	93.4	27.8	72.2
2012	7.05	19.9	2.3	2.2	0.4	3.9	7.7	52.8	97.5	46.5	53.5
2013	7.68	18.4	1.4	1.8	0.3	3.5	3.2	34.9	97.6	57.0	43.0
Mean	**7.30**	**24.7**	**12.6**	**4.1**	**2.4**	**4.1**	**5.3**	**28.1**	**95.1**	**37.8**	**62.4**
*Typical			10.3			1.8	6.7	28			
Range			(3.3-34)			(0.6-4.7)	(2.3-17.2)	(16-60)			
**Typical			6.7			1.5	6.0	25			
Sheep FYM											
2005	7.93	119.9	25.6	37.7	9.2	4.2	10.7	33.4	-	24.8	75.2
2007	6.53	12.6	1.4	2.6	0.3	2.8	6.0	38.3	97.1	56.0	44.0
2009	7.58	25.1	2.8	4.2	0.8	3.7	4.4	23.0	94.1	49.9	50.1
2011	6.75	26.9	1.9	4.6	0.6	4.4	4.5	20.6	94.5	49.6	50.4
2013	7.86	34.0	1.3	4.5	0.4	3.5	4.7	23.8	97.9	51.1	48.9
Mean	**7.33**	**43.7**	**6.6**	**10.7**	**2.3**	**3.7**	**6.1**	**27.8**	**95.9**	**46.3**	**53.7**
**Typical			2.5			0.9	6.0	25			

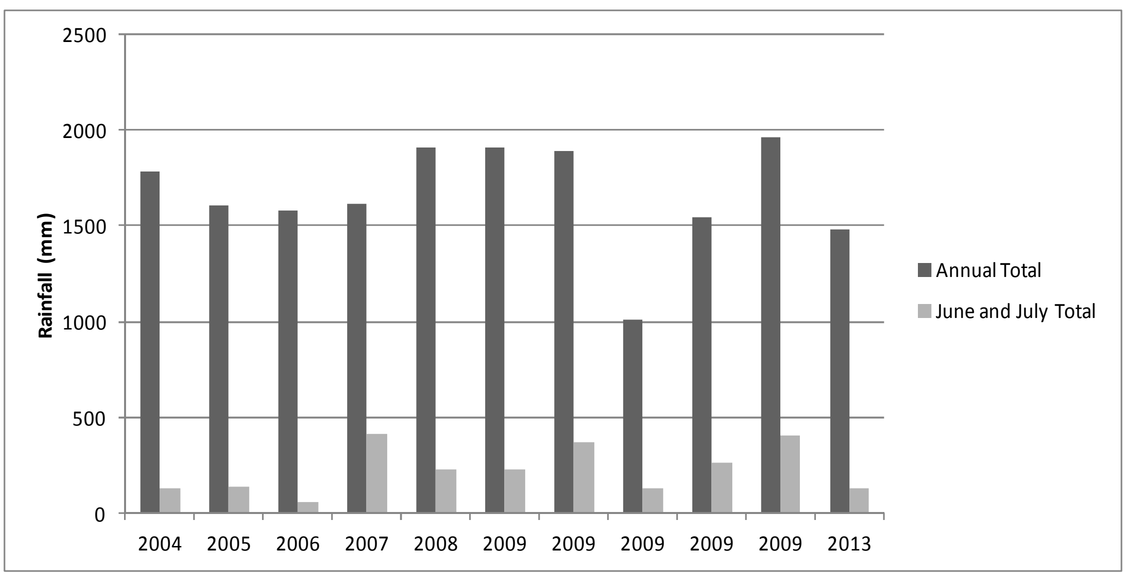
* Typical mean content and range of NPK and DM according to ADAS database (Simpson and Jefferson, 1996).

** Typical mean content of NPK and DM according to MAFF, 1994.

Note: Sheep FYM was not applied in 2006, 2008, 2010 and 2012.

Appendix 3. Annual Rainfall data for Nant Gwyllt monitoring station (Elan Valley): Data from Severn Trent Water Ltd.

	2004	2005	2006	2007	2008	2009	2009	2009	2009	2009	2013
Jan	174.8	161.2	78.4	301.8	361.5	361.5	198.8	126.9	194.1	243.9	158.4
Feb	191.1	129.3	170.9	163.8	79.6	79.6	40.7	33.8	185.5	80.3	136.9
Mar	107.2	111.3	170.6	155.3	233.6	233.6	67.5	100.7	25.8	28.3	56.2
Apr	101.6	142.2	55.2	4.0	123.5	123.5	93.1	38.9	8.2	192.0	74.4
May	89.1	60.8	167.4	118.3	68.8	68.8	112.2	46.6	125.4	65.0	138.3
Jun	80.1	42.2	20.3	198.9	92.7	92.7	95.0	50.8	119.2	284.0	65.6
Jul	50.0	93.7	36.3	217.8	137.3	137.3	274.6	77.2	142.8	123.0	66.0
Aug	152.5	62.5	110.8	44.4	172.4	172.4	87.2	53.5	55.0	158.3	98.1
Sep	203.0	116.0	55.9	63.1	196.2	196.2	64.7	156.4	128.1	117.6	71.0
Oct	321.9	272.8	141.8	35.7	204.2	204.2	143.7	112.0	138.9	146.5	259.1
Nov	102.6	255.0	257.9	93.9	155.1	155.1	495.2	147.6	124.2	186.7	144.9
Dec	206.0	162.3	314.8	215.2	85.3	85.3	215.6	64.6	293.1	333.6	212.1
Annual Total	**1780**	**1609**	**1580**	**1612**	**1910**	**1910**	**1888**	**1009**	**1540**	**1959**	**1481**
June and July Total	*130*	*136*	*57*	*417*	*230*	*230*	*370*	*128*	*262*	*407*	*132*



Data Archive Appendix

Data outputs associated with this project are archived at **HP TRIM Record Number: 09/90051** on server–based storage at Natural Resources Wales.

The data archive contains:

[A] The final report in Microsoft Word and Adobe PDF formats.

[B] Time-series floristic data from each of the sites (nutrient trial plots and restoration fields) in Microsoft Excel format.

Metadata for this project is publicly accessible through Natural Resources Wales' Library Catalogue http://194.83.155.90/olibcgi by searching 'Dataset Titles'. The metadata is held as record no. 115628.

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