4. Literature search

4.1 Outline of Methodology

4.1.1 The first author commissioned a literature search using on-line library databases available to ADAS. Keywords included manure(s), muck, organic manures, time/timing of application, rates/quantities, methods of application/spreading, grass(es), grassland(s), hay, meadows, flora, species, botanical composition, etc. Books and articles in English Language Journals dating back to 1970 were identified, traced and obtained for study. The references contained in these articles were used to find further references as far back as 1850, concentrating on UK conditions. The information obtained is summarised in this report under appropriate topic headings (sections 5-8).

4.1.2 ADAS personnel have written review articles and undertaken extensive research into these topics recently so by asking colleagues for help the first author obtained useful additional references which were not found by the on-line databases.

4.1.3 Relevant unpublished data known to the authors is cited. ADAS are able to look at utilisation of grassland and management systems and economics, which a study based purely on grassland productivity may miss. Given the desire to identify best practice such an omission would make it more difficult to ascertain best practice, when conflicts arise or compensation is necessary. ADAS have a knowledge and experience of livestock which will complement the botanical study and provide credibility in suggesting appropriate action.

4.1.4 As a result of the literature search a bibliography is given for those who wish to examine the subject in more detail and to assist in future research.

5. The use of farmyard manure on grassland

including history, timing, application rates, methods of application, and impact on floristic composition of Hay Meadows, both unimproved and improved.

5.1 Summary of findings from the literature review

Generally the proportion of grasses and the extent of floristic change increases with increasing FYM rate and frequency of application. However, directional change, cyclical change and stability are also influenced by other factors to the extent where the results are not entirely predictable even after this review. This review suggests that one may use good information to set **appropriate** limits on the use FYM, linked to expected hay yields and the sensitivity of the desirable species present, to try to maintain the traditional appearance of a site as well as achieving the farmer's aim of economic hay yields.

5.2 History of the use of FYM

5.2.1 "The addition of animal and vegetable waste products and other organic materials to the soil to improve its fertility is an age-old practice... FYM is probably the oldest soil amendment known and practical ways of making and storing it have been known from very early times. Field experimentation and scientific studies on the use of this manure from about 1850 onwards have explained much of its value..." (Anon 1976b). Up until 1939 animal manures provided the main source of nitrogen, phosphate and potash applied for crop production in the UK (Archer 1985).

5.2.2 Pastures and meadows had a place on arable farms both as forage for the main sources of motive power the ox and then the horse and the less obvious but still important function to feed animals which then fertilised arable land. Soil loses fertility by crop removal and by leaching of nutrients. Before fertilisers were imported, these crop nutrients were replaced from the dung of animals fed on grassland (Rackham 1986). Rackham goes on to say "Sheep, especially, could be fed on pasture during the day and folded on arable at night, which saved the trouble of handling the dung." Folding sheep on the lord's land was a requirement in some tenancy agreements from the Middle Ages onwards. "Sheep dung was the most highly prized, followed by that of fowl, horses and cattle" (Whyte 1979 quoted by Shaw in Foster & Smout 1994). Why sheep dung was considered the best is not revealed; but we know today that it is a more concentrated source of nutrients than the other commodities mentioned with the exception of poultry muck, which may have proved too concentrated, causing scorching of crops, for our ancestors.

5.2.3 From the time that Man, or maybe more properly, woman, started to keep livestock in yards or indoors manure handling and spreading has been a necessity of life. Initially this may have been by women carrying wicker baskets, or creels containing manure on their backs to where it was desired as a means of improving soil (Shaw in Foster & Smout 1994). Some had other ideas, "hill farmers in the Cheviots often had at their doors 'immense dunghills, the accumulation of unnumbered years, probably centuries': however, some -wiser than their surrounded neighbours - ingeniously contrived to build their houses near a 'Burn side' for the convenience of having it [the dunghill] taken away by every flood" (Bailey & Culley 1797 quoted by Woodward in Foster & Smout 1994). In the lowland river valleys, water meadows were sometimes deliberately constructed. Water fertilised grass for hay with the calcium out of chalk springs; it brought nitrate and phosphate out of the leachings of arable, the dung of roads and farmyards, and even the sewage of Winchester (Rackham 1986).

5.2.4 Wrightson (unknown date, c1875) wrote " As a 'general manure' it (FYM) has already been seen to contain all the requisite constituents for the growth of plants. The exhaustion of a field is due to the removal of the very constituents which yard manure is ready to give back..." He quotes Liebig "Upon a field deficient in potash, the farmyard manure acts by the potash contained in it; upon a soil poor in magnesia or lime, by its magnesia or lime..." and so on. Wrightson by an extensive discourse shows the extent of current knowledge at the time of writing.

5.2.5 Duffey *et al* (1974) state "The application of farmyard manure was the principal means of improving grassland before the manufacture of artificial fertilisers."

5.2.6 So we are trying to perpetuate a tradition, which has produced what we see today in some areas; and not necessarily introduce change. Today we hope to understand the consequences of our actions, with a view to a positive contribution to the future.

5.3 Timing of FYM application

5.3.1 Wrightson (unknown date circa 1875) writes "Dung is applied... to meadows in March.." Yet Arnold *et al* (1976) in describing the Cockle Park Experiment started in 1897 state "The FYM is traditionally applied in November..". Peel (1938) states "Farmyard manure should be applied to grassland before the end of February. If applied later than this month there is the risk of loss of a certain amount of nitrogen during a dry March and April through volatilisation of ammonia, but a more important reason for an early application is that it gets into the soil before the field is cut for hay." However, Peel is obviously aware that not everyone practises the husbandry he advocates because he adds:- "Further, when applied to grassland *in early autumn* it provides plant food *to the grasses* (this author's italics) whilst they are still growing and before winter stops growth... Dung should be spread as soon as it is carted out, except perhaps in very dry weather, when there will be less loss if it is left in heaps than if spread..." Lampkin (1990), made the general comments that "On spreading, nitrogen will be lost through leaching and volatilisation. Spring applications are more efficiently used, because nitrogen leaching losses are greater with autumn and winter applications." Smith (1980) stated "Responses tend to be most erratic from summer applications of manures when crop up-take of manure nitrogen can vary from practically nil, to almost all of the available nitrogen, depending on the weather. Smith and Unwin (1983) wrote "the reduced efficiency of autumn/winter applied FYM is often ascribed to nitrate leaching over winter. There is little evidence to support this effect when the manure is applied to a growing crop".

5.3.2 To illustrate that this subject area has been constantly reviewed in recent years - Smith (1991) interpreting Thompson *et al* (1987) wrote "Nitrate leaching losses from grassland following slurry/manure applications are generally thought to be negligible. Gaseous losses (volatilisation, denitrification), combined with possible negative effects (scorch, smothering), are thought to be the factors mainly limiting the efficiency of nitrogen utilisation by grass." However, this work was done in relatively dry years with slurry which largely lost nitrogen by gaseous losses, on soils where little drainage occurred, and therefore these comments should be amended in the light of current knowledge, that leaching does occur on grass but the extent is variable, and generally is less than in arable cropping, when equivalent amounts of organic manures are applied.

5.3.3 A more accurate picture is given by Chambers (1994) from ADAS Experiments studying nitrate leaching losses on freely draining grassland soils which showed that manure type, application timing and over-winter rainfall patterns all have a significant effect on leaching losses. Straw based FYM's present a considerably lower nitrate leaching risk when applied during this period (September-December) reflecting the lower ammonium (available) N content of these manures. Such leaching losses are liable to be greater under grazing compared to cutting regimes and where drainage is good compared to poor (Garwood & Morrison 1988).

5.3.4 Smith (1991) goes on to say "The basis of the technique is for... manure to be applied to the soil rather than to the crop; uptake of nitrogen will occur through crop roots following mineralisation of organic nitrogen and nitrification of ammonia nitrogen. Therefore, allowing for slightly delayed nitrogen uptake and subject to satisfactory soil conditions, earlier rather than later timings will generally be appropriate. Wet soils, however, can be expected to cause problems with machinery access and increased nitrogen losses.. Late winter/early spring applications offer the best opportunity for efficient utilisation (and refers to a table showing equal efficiency compared to fertiliser nitrogen autumn/winter and early spring FYM applications of 25% compared to 10% after first cut silage). This conflicts with more recent research and advice (Chambers and Smith 1992). This later advice was published in MAFF (1994), therefore these more recent percentages of nitrogen availability suggested in section 5.3.5 should be followed. Applications at this time (January-March), have been shown to check the early growth of grass, due to smothering/scorch, but this effect is of no significance when application rates are based on crop nutrient requirement." (Smith 1991).

5.3.5 More recently MAFF (1994) has not distinguished between arable and grassland surface applications of animal manures giving a range of total nitrogen's available to the next crop varying between 5-20% depending on soil type and month of application; with the note that values should be reduced by up to half for FYM materials that have been stored in the open for long periods, or composted. Table 9 is constructed assuming that residual nitrate is leached from the soil by an excess winter rainfall of 250 mm (equivalent to an annual rainfall of 750 mm). Unwin and Vellinga (1994) state "The autumn (August-October) availabilities relate to this moisture regime. In drier areas or in an unusually dry winter the

November-January values which allow for an excess of 150 mm should be adopted for August-October. When average or actual excess winter rainfall is over 350 mm (= 1150 mm annual rainfall) value on silty or clayey soils should be reduced by half for autumn and winter applications as an alloowance for increased denitrificjation.

5.3.6 There appears to be a need for verification of the percentages of total nitrogen to be used for different application timings **to grassland** and if any adjustment is required due to soil type. However, it is suggested that the MAFF figures for grass given in 5.3.5 above are used in the absence of any better information.

5.4 Application rates

5.4.1 In fertiliser experiments using FYM - as at Rothamsted and Cockle Park on permanent grassland - FYM rates have been relatively high. At Rothamsted from 1856 to 1863 bullock FYM was applied annually in November/December at 14 tons/acre, to the extent where applications were ceased due to smothering of herbage in the relatively dry Rothamsted climate - enabling long-term monitoring of residual effects which persisted for 100 years. A more moderate one in four year cycle at 14 tons/acre (35 t ha^{-1}) has been practised on Plot 19 at Rothamsted since 1905 (see also section 8.1.2). At Cockle Park, annual and alternate year dressings of 20 tons/acre (50 t ha^{-1}) have been applied since 1897, these indicate extremes beyond the tolerances of most sensitive dicotyledonous plants and are therefore useful for study but not practically relevant to meadows of high nature conservation value. Recent MAFF funded experiments at Harper Adams Agricultural College found that applications of FYM to grassland at 30-40 t ha^{-1} or more annually caused smothering and bare patches. Application rates were therefore reduced accordingly to 20-30 t ha^{-1} (K Smith pers. comm.). Peel (1938) from an agriculturalist's viewpoint states "The best plan is to give a dressing of farmyard manure, 10 to 15 tons acre (25-35 t ha^{-1}), every third or fourth year.." but goes on to suggest supplementation in the intervening years with inorganic fertilisers, presumably to maximise hay yield and probably based on work at Rothamsted on the Park Grass Plots. Such advice is therefore not to be taken as appropriate to grassland of a nature conservation interest, even if it has been "traditional".

5.4.2 In the introduction in section 3.7 we saw the discrepancy in advice on appropriate rates of FYM application to semi-natural grassland and the time intervals of application. Current advice (Jefferson, in Crofts & Jefferson 1994) suggests one dressing of up to 20 tonnes ha^{-1} every three to five years on grasslands of high nature conservation value; whilst the rules for farms managed under ESA Agreements state a maximum of 12.5 t ha^{-1} **per year** (ie two to three times Jefferson's advice). However, the conflict is diminished if one imagines that grasslands of high nature conservation value (ie SSSIs) follow Jefferson's advice; whilst the typical and individual hay meadows in an ESA can possibly be considered adapted to their differing management regime and possibly therefore differing constraints/resources may be appropriate. Constant review in individual circumstances is probably better than blanket limits, and this report will suggest a basis for individual assessment, recording and consequent adjustment of management.

5.5 Periodicity of application of FYM

5.5.1 A lack of consistency is noted in the way in which FYM has been used in the past, both in the literature which covers experiments and in the information relating to nature reserves. This is hardly surprising, given that FYM has been regarded as a scarce resource by some, and a waste product by others, which result in some trying to apply it as often as possible, in as large a quantity as possible and others eking out their meagre supplies in terms of their own agricultural priorities.

5.5.2 Besides differences in availability, other important causes of variation are differences in farmers' attitudes and management, distance from the holding, accessibility and soil type, with the latter affecting both the need and the perceived response. Smith and Jones (1991), who studied meadows in the Pennine Dales, state "Outlying meadows on more infertile soils have a different range of species from those on more fertile soils closer to the steading. These site differences will be exacerbated by management which puts more manure and fertiliser on the intrinsically more fertile meadows, freeing them from livestock earlier in the year in order to cut them first. A range of vegetation type is produced that has considerable wildlife interest when fertility is enhanced solely with moderate amounts of organic manures."

5.5.3 Even Lawes and Gilbert tried in the early years of the Park Grass Experiment at Rothamsted to apply to some plots 14 tons per acre (35 t ha^{-1}) of bullock manure per year, but found that the unrotted material accumulated on the surface, until after eight years, further applications to these plots were ceased entirely (Warren & Johnston, 1964). This has enabled us to see the considerable residual effects which persist to this day both in terms of the vegetation of these plots compared to the nil fertiliser plots and the effects on hay yields. Since 1905 some plots at Rothamsted have received similar dressings of bullock manure every four years (see also section 8.1.2).

5.5.4 Since 1897, in the higher rainfall area of Northumberland on the Cockle Park Palace Leas Plots dressings of FYM have been applied to some plots at rates of 20 t ha^{-1} on annual and biannual cycles and 40 t ha^{-1} $year^{-1}$. These must have been regarded as worth testing or else would not have been included in these experiments; but they do represent extremely high frequencies of considerable quantities of nutrients. Whether farmers would ever apply or did apply such high dressings to permanent grassland on a regular basis is not known. However, it may be representative of certain fields on upland farms where the area available for mowing is limited to the more level and accessible fields and there is a need for large quantities of fodder to be conserved for the relatively long winter period.

5.5.5 In the past, the term 'muckit land' was used in some areas to distinguish infield from outfield, suggesting the importance of manuring (Shaw in Foster & Smout 1994) and FYM being applied frequently?

5.5.6 Peel (1938) states "Mowing the same field year after year for hay tends to increase the tall grasses, poor species such as soft brome as well as good species (preferred species by agriculturalists are: *Lolium* spp, *Dactylis* *glomerata, Phleum pratense, Festuca pratensis, F. arundinacea, Trifolium repens, T.pratense, Medicago sativa* (Forbes et al, 1980) at the expense of the bottom grasses. Wild white clover is depressed or entirely eliminated, the sward becomes open and weeds increase....it has been shown that better use can be made of the grassland of a farm by alternating mowing with grazing. In many districts the principle is steadily gaining ground, but the practice of using certain fields for hay will undoubtedly continue. The effects of mowing the same field for hay each year are often accentuated by the excessive use of farmyard manure." This implies that before inorganic manures were more commonly used farmyard manure was applied to hay fields either annually or bi-annually. However Peel (1938) advocates "The best plan is to give a dressing of farmyard manure, 10 to 15 tons/ acre, every third or fourth year and to apply fertilisers in the intervening years." This is presumably following the example set on some Park Grass Plots at Rothamsted post-1905, as described above.

5.5.7 In arable rotations the advice was to dung either once or twice during a four course rotation, either to roots alone and, if included in the rotation, to any intervening young seeds - which may include grass for hay (Wrightson, unknown date). So it is possible to see how the frequency of manure application has been regulated in the past in an attempt to best apply what was regarded as a valuable material.

5.5.8 More recently Jefferson (1994 *in* Crofts and Jefferson 1994) has recommended that application rates should not exceed 20 t ha^{-1} every three to five years and should only be applied as a single dressing on grasslands of high nature conservation value, which include agriculturally unimproved , semi-natural meadows. Lower rates of FYM could be desirable from a nature conservation perspective on particular sites, especially if one wishes to try to enhance species diversity. However, the rules for farms managed under ESA Agreements state a maximum of 12.5 t ha^{-1} per year (ie two to three times Jefferson's maxima).

5.5.9 There will be a difference between annual dressings of manure compared to application once in three to five years in the amounts and pattern of nutrients available to a hay meadow related to the amount of FYM applied. Periodicity (and rate) of FYM will influence the yields and botanical composition of such a meadow, if only on a cyclical basis. The different effects will be buffered to differing degrees according to soil type and soil pH. More frequent dressings of FYM may be desirable to improve hay yields on lighter soils which lose nutrients more readily by leaching, but more frequent dressings may have greater consequential loss of botanic diversity. Such conflict of interest between farmers and conservationists is not new; but careful evaluation of this particular subject may be a novel suggestion. In contrast to light soils, heavier soils are inherently more fertile, (having higher organic matter contents and with greater available water capacity, and maybe even releasing potash by natural weathering), so have a greater buffering capacity, ie would suffer less from cessation or delay in manure applications or suffer less from more frequent dressings compared to light soils. So heavier soils require a higher input of nutrients to cause a measurable change in the nutrient status. Heavier soils with their different flora and microbes are likely to show different effects to lighter soils in their reaction to differing periods between manure applications.

5.5.10 The authors believe that to predict effects on individual communities one should compare experimental treatments on differing soils in areas with differing rainfall over a period of (say) 10 years, to encompass two or more cycles of manure application, to allow sufficient time for changes to be observed, note their consistency, and even out annual rainfall effects. It would be sensible to compare representative sites with varying hay yield potentials rather than monitor all sites.

5.5.11 Duffey *et al* (1974) quote Davies (1969) and Johnson & Meadowcroft (1968) who found that over seven years, annual dressings of FYM on meadow grasslands in the Pennines, had little effect on floristic composition, in so far as the proportion of grasses to broad-leaved species remained about the same. However, this is an over-simplification, the frequencies of actual species found did change (Johnson & Meadowcroft 1968) but no details are given.

5.6 Methods of application of FYM

5.6.1 The usual method of handling manure is to use a manure fork attachment on a tractor front-end loader (ADAS 1983b), although increased use is being made of specialised loading vehicles, owned by contractors, for this type of work. The size of the fork should be matched to the tear out and lift capacity of the loader to which it is attached. Forks on front end loaders hold 250-700 kg of manure depending on the tractor power. (Compared to rear end loaders capacity of around 250 kg, rough terrain fork-lift trucks and industrial loaders 1 tonne per 'bite', and tractor grab loaders, 100-200 kg depending on the model.). The actual choice will depend on ability to travel over difficult terrain, manoeuvrability, ease of control, lift capacity, lift height and reach, range of implements and tasks required and the budget available.

Table 1. A guide to loading performance (tonnes hour^{-1}) - Anon 1983b.

Equipment	Working Conditions	
	Ideal	Poor
Tractor front loader	45	20
Tractor powered grab	50	25
Rough terrain fork-lift truck and industrial loader	100	50

5.6.2 Manure properties affect the performance of manure spreaders. Different spreader types are influenced in different ways when the manure properties change. Dry matter content alone is not enough to completely describe the relevant physical properties of a manure (Malgeryd 1994).

Spreaders should be reliable, easy to maintain, constructed from corrosion resistant materials and **capable of spreading the manure evenly with a choice of application rates.** Wheels which minimise compaction should be preferred, and where required, consider the need to handle a range of manure types from heavy solids to thick slurry, although the use of the latter will seldom be appropriate on sites with high nature conservation value.

5.6.3 There are basically two types of spreading equipment in use: side discharge and rear discharge.

5.6.4 **Side discharge spreaders (also called 'rotary spreaders')**

The spreading mechanism relies on rotating flails attached to the end of chains, spaced at intervals on a shaft mounted horizontally along the axis of the barrel. It is powered by the tractor power take-off. The flails shed and distribute the manure, working from both ends of the barrel, towards the centre, discharging the material sideways about 3 m. Capacities range from 2.5-5 m^3 (manure density typically ranges from 0.6-0.9 tm^{-3} (ADAS 1983b) but National Institute of Agricultural Engineering, Silsoe reported densities varying from 0.39-1.065t m^{-3} (Grundey 1980), possibly with an average of 0.75-0.8 tm^{-3}). Malgeryd (1994) reported bulk densities of 400-1050 kg m^{-3} (0.4-1.05 tm^{-3}) and said that bulk density and consistency affect manure flow and spreading width. The principal control over application rate is by changing travel speeds. Where an even distribution is considered critical, skilful operation is required to match up successive bouts. The rate at which the machine empties varies as the load is progressively discharged, unless changes in the tractor gear ratio are made to compensate. When unloading begins, the discharge is less than when all the flails are in action. Intelligent operation and experience is required to achieve an even distribution, depending on the type of manure and the stage of discharge; particular attention should also be paid to optimising spread width/overlap.

5.6.5 Other variants of the side discharge type offer a more controlled and more even discharge (ie much better) pattern. These include a front side rotor fitted with radial vanes fed by a chain and slat conveyor to spread the material. These have a spread width of about 6 m. ECON produce such a machine capable of achieving a fine, even distribution, however normal machinery is better able to cope with a wider range of moisture contents (Lampkin 1990). Another side discharge machine uses a rear mounted side discharging impeller to which the manure is pushed by a steel plate.

5.6.6 **Rear discharge spreaders**

These consist of a low-slung trailer body with a moving floor which delivers manure to a spreading mechanism at the rear. The moving floors are driven by a variable speed drive. Various spreading mechanisms exist, possibly the most suitable for grassland is a rotor fitted with a number of flails or blades on rotating discs is claimed to produce a fine spread of manure. Rear discharge spreaders mainly handle solid manures but the versatility of some models is increased by fitting a slurry door at the rear of the machine to contain more liquid for transport. FYM, whilst mainly solid, often has associated liquid due to insufficient use of straw, or the addition of rain or run-off.

5.6.7 The discharge rate is controlled by a combination of changes at which the manure is conveyed backwards and travel speeds. Application rates can range from 15-120 tonnes ha^{-1}. These spreaders usually travel at between 3.5-7 mph when unloading, discharging manure at 1-2 tonnes $minute^{-1}$. The capacities of rear discharge spreaders are typically 2 -10 tonnes and require tractors of 30-65 kW (40 - 90 Horsepower).

5.7 Organisation

(For advice on avoiding pollution see Section 10.1)

5.7.1 Factors which influence the choice of machinery for handling FYM include the quantity and types of manure to be handled regularly and the man hours available for this task. A one man system can load and spread about 8 t $hour^{-1}$. Use of a contractor is often made.

5.7.2 The most important organisational aspect for a site manager is the calculation of application rates of FYM, yet to date appears to be carried out imperfectly. Given the variation of straw use, storage losses and gains aside from the variable production from animals this is not surprising. Therefore the following (after Grundey 1980) may be useful:

1. Decide the required application rate based on the initial quantity of FYM in store and area to be covered, within the constraints of any management agreement. (Later in this report typical FYM nutrient contents and hay removal estimates are given to ensure an appropriate balance of inputs to off-take are applied, or replaced with the precision of soil, hay and manure analyses where possible.)

2. Determine or estimate the average load weight in the spreader, eg 3t.

3. Divide the application rate (say 20t ha^{-1}) by the weight per load (3t) to give the number of loads ha^{-1} = 6.67 loads ha^{-1}.

4. Divide 10,000 by the answer to 3 to give the number of m^2 to be covered by one load, eg 10,000 ÷ 6.67 = 1500 m^2 per load.

5. Divide the answer to 4 by the average spread width to find the distance to run with each load, eg with a 3 m width of spread 1500 ÷ 3 = 500 metres.

By pacing out the distance covered by the first load, after measuring 10 typical stride lengths, the gears and revolutions required to achieve the required application rate can derived by trial and error.

5.7.3 Obviously much depends on the average load weight, determined by material density, remaining constant. Denser material should be spread at higher speed or wider bout widths, whilst strawy material can be applied using a lower gear, or narrower bout width, the latter being preferable. As is readily seen, muck spreading is not very scientific; but the aim is a reasonable working arrangement.

5.7.4 For improved evenness of spread one could also suggest that half the target application rate could be applied and two coats applied to the field working at right angles to the first pass with the second. However, given the relatively low nutrient concentration of FYM this is not very practical or useful on grasslands of high nature conservation value including SSSIs, with relatively low application rates. Variation in eveness of spread may actually be desirable to provide a wider range of localised nutrient concentrations to maximise the niches for the widest range of species, and to allow re-colonisation at a later date, where a niche is temporarily unfavourable.

5.7.5 **The above does not include any reference to methods of storage or composting; which can have an over-riding effect on the composition of the manure and its spreading characteristics. See Section 6.2 on Changes in storage.**

5.8 Impact of FYM on floristic composition

5.8.1 Grass meadows are not monocultures, and even if sown with a single species then management, principally defoliation system and fertiliser input, combine with 'weed' ingress, to produce great changes in sward composition (Jones 1933). Hence the reason for this study, looking at how we understand and **manage** nature conservation and agriculture, with a view to minimising conflict to achieve our desired aims.

5.8.2 FYM typically increases the amount and proportion of grasses in a sward at the expense of dicotyledonous plants, and lower plants, and alters the proportions of the actual grass species found (Lawes & Gilbert 1859, Part III p268; Lawes & Gilbert 1880, Part I, p291). Even in the second year the differences in the flora..were so marked that a first attempt at botanical analysis ..was then made (Lawes & Gilbert 1880, Part I, p291); however, the 1858 data is less reliable than later data. The results of some of these botanical analyses are shown in Tables 2-7.

Table 2. Number of species in the botanical analysis of unmanured and unlimed Park Grass Plot 3 (Brenchley 1958 and Williams 1978)

	1862	1867	1872	1877	1903	1914	1919	1929	1939	1948	1975
Grasses	18	15	17	17	13	13	12	12	11	11	11
Leguminosae	4	4	4	4	4	4	3	4	4	4	4
Other Orders	28	24	28	31	26	23	14	20	17	21	14
Total	50	43	49	52	43	40	29	36	32	36	29

Table 3. Percentage of species by weight in hay in the botanical analysis of unmanured and unlimed Park Grass Plot 3 (Brenchley 1958 and Williams 1978)

	1862	1867	1872	1877	1903	1914	1919	1929*	1939	1948	1975
Grasses	70.6	65.5	68.7	71.2	52.2	56.8	47.8	47.6	37.9	53.0	64
Leguminosae	8.1	5.4	9.0	8.5	7.8	6.1	4.5	9.3	6.7	7.2	7
Other Orders	21.3	29.1	22.3	20.3	40.0	37.1	47.6	46.1	55.4	39.8	29
Total	100	100	100	100	100	100	100	100	100	100	100

* Figures quoted by Brenchley here, but Williams indicates these apply to 1930 and gives slightly different score for other orders.

NB There is insufficient space here to indicate trends in species but these references give this information, for all the various plots of the Park Grass Experiment.

Table 4. Number of species in the botanical analysis of unlimed Park Grass Plot 2 which received annual dressings of FYM in 1856-1863 with none applied since (Brenchley, 1958)

	1862	1867	1872	1877	1903	1914	1929	1939	1949
Grasses	14	17	18	18	-	-	13	13	12
Leguminosae	3	4	4	4	-	-	4	3	4
Other Orders	13	20	25	28	-	-	18	16	16
Total	30	41	47	50	-	-	35	32	32

Table 5. Percentage of species by weight in hay in the botanical analysis of unlimed Park Grass Plot 2 which received annual dressings of FYM in 1856-1863 with none applied since (Brenchley 1958)

	1862	1867	1872	1877	1903	1914	1919	1929*	1947	1949
Grasses	75.1	84.5	80.0	75.4	-	-	60.5	57.9	58.0	53.6
Leguminosae	1.9	1.6	4.9	6.5	-	-	5.7	4.4	10.7	15.4
Other Orders	23	13.9	15.1	18.0	-	-	33.9	37.7	31.3	31.0
Total	100	100	100	100	-	-	100	100	100	100

Table 6. Number of species in the botanical analysis of unlimed Park Grass Plot 19 which has received FYM since 1905 every four years after nitrate and minerals 1872-1904 (Brenchley, 1958)

	1862	1877	1908	1914	1919	1930	1940	1948
Grasses	16	16	?	13	13	10	12	12
Leguminosae	4	5	?	4	2	4	2	4
Other Orders	21	18	?	14	15	12	13	13
Total	41	39	39	31	30	26	27	29

Table 7. Percentage of species by weight in hay in the botanical analysis of unlimed Park Grass Plot 19 which has received FYM since 1905 every four years after nitrate and minerals 1872-1904 (Brenchley, 1958)

	1862	1877	1905	1914	1917	1919	1936	1948
Grasses	89.4	81.0	64.0	78.8	68.7	75.2	84.1	50.3
Leguminosae	2.5	8.7	17.8	10.0	21.4	6.1	5.2	17.4
Other Orders	8.1	10.3	18.2	11.2	9.9	18.6	10.7	32.3
Total	100	100	100	100	100	100	100	100

For more information on the Park Grass Experiment see Brenchley 1924; Dodd *et al* 1994; Hall 1905; Lawes & Gilbert 1859 a, b & c, 1880, 1882, 1900; Jenkinson *et al* 1994; Silvertown *et al* 1994a; Smith 1924; Thurston, Williams & Johnston 1976; Warren & Johnston 1964; in addition to Brenchley 1958 and Williams 1978 mentioned above.

Dodd *et al* classified the untreated plot 3 (Tables 2 and 3) as the agriculturally unimproved species-rich MG5 *Cynosurus cristatus-Centaurea nigra* meadow community. The NVC classification of Plot 19 is discussed in section 8.1.2. There was insufficient data to match Plot 2 to the NVC.

5.8.3 Stapledon & Hanley 1927, citing the results of the effects of different treatments on the University of Leeds Garforth meadow hay plots, showed that FYM applied at 6 tons/acre (15t/ha) every two years compared to untreated controls, increased the proportion of agriculturally desirable grasses, decreased the so-called 'bad' grasses (eg *Anthoxanthum odoratum, Agrostis* spp., *Holcus lanatus*) but interestingly scarcely reduced the proportion of 'weeds'. These 'weeds' appear to be species which would be considered valuable now by ecologists. Stapledon and Hanley (1927) cite or infer that the following species are classed as weeds: *Ranunculus* spp., *Rhinanthus minor, Centaurea nigra, Plantago lanceolata, Linum catharticum* and *Rumex acetosa.*

5.8.4 Manure thus often increases Graminaceous species and alters individual species frequencies as do grazing and hay cutting. However, individual species composition in a community also varies from year to year, due to other influences as set out overleaf; with the rates and periodicity of FYM application being an important influence in this respect. Floristic change due to nutrient additions, including FYM, is thought to be caused by the following sequence:- some species (usually grasses) generally grow faster and bigger than other (mostly dicotyledonous) species when well-fertilised; but even species, varieties/ecotypes and even individual plants differ in their competitive ability (van den Bergh 1991). However, it is often observed (van den Bergh 1968) that a high yielding species is less competitive in a mixture with a low yielding species under sub-optimal conditions. Grime (1977) suggested 'competitors' exploit conditions of low stress and low disturbance, stress-tolerators have evolved to exploit high stress and low disturbance and ruderals are characteristic of low stress and high disturbance. So with the help of FYM the competitors shade out these other 'stress-tolerator' species. So the latter then grow less, reproduce less and there are less niches for such (often broad-leaved) species, producing change. Growing conditions fluctuate so change is capable of being either unexpected, or reversible providing tolerance limits are not exceeded (Rorison 1991). The actual species that occur or thrive on a particular area of ground within a site can thus change according to many influences of which FYM is only one factor.

5.8.5 The biomass/yield, and composition of herbage and hay, and the rate of change and succession, both botanically and chemically, is also dependent on:

- ❑ the species and ecotypes present. In addition to the external influences cited below genetical differences between species and ecotypes of the same species cause interactions, (eg competition), differences in seed production, dispersal, germination, growth and development rates and resource requirements (Antonovics, Lovett & Bradshaw 1967; Brenchley 1918; Carson & Peterson 1990; Goodman 1968: Grime, Hodgson & Hunt 1988; Grime 1991; Huston and DeAngelis 1994; Huston 1994; Lawlor 1991). Given that a grassland site consists of 'communities' (Marshall & Porter 1991; Grime 1991) predation, symbiotic and other interactions occur to influence the overall botanical composition and survival (Hulme 1990; Gill & Vear 1958; Reader 1993; Sarapatka, Holub & Lhotska 1993). An attempt has recently been made to draw together some of these influences with other species or ecological characteristics in the Ecological Flora Database (Fitter & Peat 1994).

- the date of 'shutting-up' and timing of hay cutting (Moore 1968; Peel 1938; Smith & Jones 1991);

- climate, not just in the season of cutting, as in spring rainfall (Cashen 1947, Jenkinson *et al* 1994; Silvertown *et al* 1994), April-June sun/light, air temperatures, and soil moisture deficit (Coleman, Sheil & Evans 1987; Lawlor 1991) but also the soil moisture deficit in the previous season (Garwood & Tyson 1978), and other historical weather influences (Coleman, Sheil & Evans 1987);

- soil, texture, drainage, nutrient status and pH (Green 1974; Hopkins & Green 1978; Morrison & Idle 1972); and

- other site factors, eg topography and situation (Smith & Jones 1991), previous cutting regime - ie height, timing, frequency, (Peel 1938), stocking rate and sward gap sizes (Peel 1978; Carson & Pickett 1990), livestock type, period of livestock grazing (Smith & Rushton 1994; Milton 1934), historical and recent farmyard manure, fertiliser and lime inputs (Arnold *et al* 1976; Brenchley 1924 & 1958; Hall 1905; Lawes & Gilbert 1859a, b & c, 1880, 1882, 1900; Smith 1924; Smith 1993; Thomas, Holmes & Clapperton 1955a & b; Thurston 1969; Thurston, Williams & Johnston 1976; Warren & Johnston 1964; Williams 1978), fluctuating conditions (Rorison 1991) and even the hay yield from the previous season (Coleman, Sheil & Evans 1987).

5.8.6 The list above is not complete; but a set of examples of the more important known influences, with example references. By consulting the cited references the reader will be led to other influences for which there is not the space available here, and the list is still growing as a result of further research. Given the list it is hardly surprising that species co-exist and yet succession and 'extinction' occurs given the range of ecological niches created, to form a dynamic, constantly changing 'equilibrium' community. Lawes & Gilbert (1882) wrote concerning 'natural rotation' (ie succession) "the conditions of success are so variable, even for the same plant at different stages of growth, and in different seasons, that we can scarcely predict with any certainty whether any individual species will gain or lose in the conflict; although we may perhaps form a fair conclusion as to the prevalence of certain groups of species: as, for instance, the poorer grasses - one or other of them according to the wetness or dryness of the season or series of seasons, and also according to the decline of the freer-growing competitors... The factors are so numerous, so complex, and so interdependent, that the "survival of the fittest" depends not only on any one quality, but on a capacity for adaptation to a combination of conditions some favourable, others detrimental."

5.8.7 Morrison (1978) writing concerning agricultural grassland wrote: "There is great variability in the botanical composition of sown and unsown grassland in lowland Britain, a consequence of the numerous species available for colonisation and the contrasts in environment and management practices. There are relatively few direct observations on the sequence of change in swards with time at specified sites." However he went on to describe survey evidence and "experimental evidence that sward botanical composition can be drastically altered by management, that changes can usually be reversed, and that, while relatively stable equilibria may be attained, there is no guarantee that a sward will remain the same indefinitely...Virtually none of this grassland is natural, it having been brought about by the activity of man...has at some time been cultivated for crops. However most of the species present have arisen naturally, and have not been sown." This is equally true for grasslands of high nature conservation value.

5.8.8 There are many factors which we can control in a meadow, eg stocking rate, FYM application, timing of hay cutting, and even drainage where necessary. There are other factors which are largely uncontrollable such as weather and climate and the population dynamics of individual species. Despite the latter, it is usually possible to maintain a 'stable' meadow plant community where species abundances fluctuate within certain tolerances but species do not decline to extinction. The exception to this would be where there is a prolonged change in a factor such as climate. We might adjust the management to compensate for uncontrollable factors such as local weather fluctuations but it is important to recognise that management can influence both the direction of change and rate of change.

5.8.9 The literature shows that there are no defined 'safe' limits for any operation under a site manager's control but it does appear from the literature that there are appropriate limits (eg in FYM, stocking rate, cutting dates, etc). What is appropriate in one situation may not be appropriate in another. The authors suggest that research will answer the questions **who** is to say **what** is appropriate and ask researchers **how** to judge appropriate limits. However, in the meantime, history does provide a guide; hence the value of this literature search.

5.8.10 Ideally, to this end care should be taken not to import weeds into a site by use of weedy straw or manure (see section 7.3). Similarly **care should be taken not to use litters that have been contaminated with toxic substances (eg certain pesticides, such as clopyralid in cereal, linseed or oilseed rape straw, by asking for records of pesticide use, or copper or boron wood preservatives in sawdust or wood shavings.)** So it is vitally important that the source of all FYM and litter contained in FYM used on a particular site can be traced back to source. If the source of FYM or litter (eg straw) is unknown, it may be appropriate to prevent application.