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ADVANCES IN GRASSLAND TECHNOLOGY OVER THE PAST FIFTY YEARS

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SUMMARY

Advances have occurred at a remarkable rate and are interwoven below under the headings of Agronomy, Grazing and Forage Conservation. The introduction of royalties was a major stimulus to a flow of improved forage varieties by breeders. Varietal testing was formalized and resultant recommended lists are the norm in many countries. Seed is of assured genetic and analytical quality. An impressive array of herbicides and pesticides has been developed for control of weeds and pests in establishing and established swards. Nutritive value (NV) profiling identified of the most suitable species and varieties for grazing and conservation. Analytically the development of near infra-red spectroscopy has been a notable development. On account of their high NV and N-fixing ability, forage legumes are arousing increased reappraisal and interest in their use. Fertilizer technology has led to more concentrated forms, bulk handling and a better understanding of the interactions of N, P, K and S under different managements. Organic manures are now used more rationally and farm nutrient balances are making an increasing impact in efficiency of fertilizer use.

Early debate on grazing centred on methods but experimentation showed stocking rate was the key influence on animal output per unit area or per animal. Another key advance was the integration of grazing and conservation, manipulating their areas to achieve a succesion of leafy regrowths of high NV; buffer feeding was also introduced as an insurance. Physiologists elucidated the role of the carbon balance in swards and of tiller growth, leading to grazing management based on sward height. The use of indigestible markers to measure faecal output and hence estimate intake was a major step forward.

Silage making has become the most important method of conservation, aided by improved mechanization in all aspects of handling, an understanding of the microbiology and biochemistry involved and notable introductions such as precision chopping, plastic sheeting, wrapped big bales, choice of additives and improved methods of prediction of NV for ration formulation. Some of the advances are also applicable to hay making. It is forecast that the rate and degree of progress in technology, including biotechnology, will in al likelihood match or surpass the advances achieved in the past half century.

Key words: Grassland technology, advances, agronomy, grazing, forage conservation

INTRODUCTION

Grassland science is one of the youngest sciences and many notable advances, impressive in number and rate of appearance, have been made over the last half century. Some arose suddenly while others resulted from a slow accretion of knowledge or from refinements of previous technology. Some were rapidly adopted in practice, economic pressures being a powerful incentive, but others were more slowly incorporated or discarded on account of capital and labour requirements, risk or even complexity though the technology remains 'on the shelf' until some further breakthrough is achieved. Again, specific external events such as the energy crisis in 1973 or the imposition of agricultural production quotas, starting with milk in 1984, stimulated the uptake of certain technological advances. When highlighting developments it is also fitting to pay tribute to the pioneers Sir George Stapledon and William Davies who, together with their teams, laid the foundations during pre- and post- Second World War from which many advances were made, not least the multi-disciplinary approach to grassland research and development. There is also an art in grassland management, as farmers will testify. Sometimes the art preceded the science as exemplified by the technological innovations by leading grassland farmers such as Rex Paterson, Richard Waltham and Lloyd Forster. Intensification was the watchword for the first forty years or so but extensification, nature conservation, environmentally friendly systems and sustainability represent the new ethos which has emerged during the last decade.

AGRONOMY

Plant breeding and evaluation

The increases in grassland productivity and nutritive value over the last half century owe a great deal to successful plant breeding. The process of developing and testing takes some 15 years from initial selection until it reaches the farmer. This time scale explains why many new grass varieties became available, especially from continental Europe, 15-20 years after the Second World War. The introduction of the 1964 Plant Varieties and Seeds Act, enabling breeders to obtain protection for their varieties and royalties for their use, was a major fillip to the flow of varieties with improved production and persistence, particularly winter-hardy perennial ryegrasses from the Netherlands, though increasing numbers of 'home-bred' varieties are now emerging. The development of tetraploid ryegrasses and hybrids between perennial and Italian ryegrass, both diploid and tetraploid, were among marked individual achievements. A steady increae of 0.6% annually in the DM potential of perennial ryegrass varieties added to the National Institute of Agricultural Botany (NIAB) 'Recommended List' has been reported (Aldrich, 1987).

Improvement in white clover was achieved by the introduction in 1964 of Grasslands Huia, a New Zealand variety which has since dominated world white clover usage. However, since the 1970s, varieties have been released, notably from the Welsh Plant Breeding Station (WPBS) with improved productivity and cold tolerance, and suitable for different methods and intensities of utilization. Red clover varieties, including superior tetraploids, were developed with increased resistance to clover rot (*Sclerotinia trifoliorum*) and stem eelworm (*Ditylenchus dipsaci*), while lucerne varieties with resistance to stem eelworm and/or Verticillium wilt (*Verticillium albo-atrum*) were bred. In contrast to early plant breeding, modern programmes are supported by multi-disciplinary teams comprising plant physiologists, agronomists and plant and animal nutritionists, thus extending the range of selection criteria. From advances in genetic engineering and molecular biology, gene transfer systems are now being used to develop new traits such as disease and pest resistance, better nutritive value and more efficient physiological processes in grasses and forage legumes.

Varietal comparisons in the early post-war years were mainly made between single plants, or rows of plants, with the objective of type classification rather than assessment of productivity but eventually species and variety evaluations were carried out, at a range of UK centres, mainly in small plot cutting trials. Following the OEEC/EPA Project 210 'International Trials with Grass and Clover', which involved evaluating grass and clover varieties at 47 sites in 9 countries (Cowling and Kelly, 1960), varietal testing was expanded on a UK coordinated basis. NIAB published a 'Descriptive' List of grass varieties in 1960 and its first 'Recommended List' in 1968.

After UK accession to the EEC in 1973, statutory performance testing was followed by statutory distinctness, uniformity and stability (DUS) assessment and value for cultivation and use (VCU) trials, with frequent and infrequent cutting of plots to simulate grazing and conservation, respectively. The performance of grass and legume varieties, as judged by their yield, nutritive value and the factors affecting persistence, determined their suitability for the 'National List' and eventually regional 'Recommended Lists'. On-farm grazed trials of perennial ryegrasses and white clovers were also used by NIAB to provide additional information on the suitability of a variety for the 'Recommended List'. The synergistic relationship between evaluators and breeders has undoubtedly had positive effects on the development of new forage varieties.

Seed production

The present-day buyer of certified herbage seed is assured of a product guaranteed in its stated genetic and analytical quality as a result of the evolution of variety maintenance, multiplication and testing. The move towards named varieties has accelerated from 1967 when various seed certification schemes were consolidated into a comprehensive national scheme for pedigree seed certification, which became statutory in the 1970s. This scheme ensured that varieties produced in the UK were maintained true to genetic type and varietal purity by field inspection of seed crops and by maintenance of verification plots for seed stocks. Similar schemes evolved abroad under the auspices of the Organisation for Economic Co-operation and Development (OECD) so that seed companies could trade seed internationally with standard certification descriptions.

Formal testing of seed lots for viability, germination and purity started in 1921 with the establishment of the Official Seed Testing Station (OSTS) but over the years various improvements in methodology and standards were introduced. Statutory seed quality requirements were laid down in the official Seeds Regulations and included minimum standards for certified seed of the different herbage species though there were also Higher Voluntary Standards (HVS) to aim for (MAFF, 1983). There has been a decline in home-produced seed production compared with the early years, but the remaining specialist seed producers have refined their production procedures and, in conjunction with a high degree of mechanization, have improved seed harvesting, handling, drying, cleaning and storage (WPBS, 1978; NIAB, 1980, 1982).

Seed mixtures and establishment

Ley farming was a traditional method of regenerating soil fertility in alternate husbandry systems but was adapted to permanent grassland during and after the Second World War when over 2.5 million ha were ploughed up. Researchers and leading farmers began to appreciate grass as a crop and to use newly-bred superior grass varieties in seed mixtures. It was recognized that white and red clovers were vital for good ley productivity and that lime and phosphate were needed to maintain basic soil fertility. While there has always been a case for reseeding run-down and unproductive pastures *inter alia* to exploit the potential of new herbage varieties, the fact that well managed long term or permanent grass could be as productive as new reseeds, at least under low to moderate soil fertility, has been increasingly recognized (Mudd and Meadowcroft, 1964; Hopkins *et al.*, 1990).

Nevertheless, as Lazenby (1981) observed, the wartime plough-up campaign resulted in a revitalization of agriculture generally, engendering a spirit of adventure and flexibility of outlook lacking since the late Nineteenth Century.

In the early post-war years complex general purpose or 'shotgun' mixtures were the norm. These mixtures contained a good proportion of commercial grass species, often landraces or ecotypes. While these were not all 'stemmy and shortlived' as often alleged, most of them were gradually outclassed and replaced by more productive bred varieties. Initially the 'S' varieties from WPBS, in the 1960s, but later, and increasingly, continental European-bred grass varieties. Simpler special purpose mixtures were devised for use in swards for intensive grazing or silage under high fertilizer regimes. This was based on the rationale that modern varieties had been bred for specific requirements and therefore for sowing alone, or in mixture with one or two varieties with compatible characteristics, to realize their potential. In particular, perennial ryegrass was increasingly used in mixtures for medium- and long-term swards, and Italian ryegrass, or hybrid ryegrass, for short term swards because ryegrasses were the most competitive and most responsive to increasing fertilizer N application and had the highest yield and nutritive value. Perennial ryegrass has become by far the most widely sown grass species in UK grassland farming and has dominated grass seed sales for many years. White clover has always been a staple component of most seed mixtures and in the early years its role and potential were well recognized. However, rates of application of fertilizer N increased in the 1960s and 1970s, and management for clover persistence became neglected and its value ignored. This trend has been partially reversed in recent years with a greater appreciation of the value of clover and of its management needs.

Sward establishment

Possibly the most notable advance in sward establishment has been the development of sward renovation as an alternative to conventional reseeding, either where the productivity of a sward had deteriorated or for the improvement of hill and upland pastures. Since the 1950s, interest has waxed and waned in the various techniques, not all successful, devised to introduce seed mixtures to existing swards. Seed introduction by simple surface broadcasting (oversowing) proved successful for open swards (Gardner *et al.*, 1954). Dense swards required pre-conditioning by cutting, heavy grazing or suppressant chemicals to reduce competition to establishing seedlings, while some form of cultivation, such as light rotavation, discing or harrowing became an option to create soil tilth for the seed. Other supportive measures included rectifying soil fertility deficiencies, weed and pest control and choosing a time for sowing which ensured soil moisture was not limiting (see

Newbould, 1974, 1975 and Frame *et al.*, 1985, for reviews). Several seed drills of varying design have evolved over the years to overcome the various sward problems encountered, e.g. removal of strips of dense existing sward, creation of slits, strip cultivation by mini-rotavators, with or without fertilizer application attachments, or equipment for band spraying of herbicides to kill or suppress adjacent grass. The management guidelines for successful direct drilling are now more clearly understood (Naylor *et al.*, 1983; Tiley and Frame, 1991).

Grassland surveys and recording

A grassland map *'Vegetation: Grasslands of England and Wales'* was published by the Ordnance Survey in the mid 1940s, derived from earlier surveys by Sir George Stapledon and William Davies. Pastures were classified according to their botanical composition, which was related to agricultural value. Perennial ryegrass/white clover predominated in the best pastures and meadows while bent grass, bent/fescue or bent/rushes/sedges characterized the poorest. A survey in the 1970s covered all types of enclosed grassland but the format was amended to relate age structure and botanical quality to physical features of the environment and to derive indices of grassland-use capability (Green, 1982). The influences and limitations of soil and climate and the variability of environments in which grass was grown were highlighted and an insight into farmers' attitudes to grassland management was gained. In a comprehensive survey of permanent grassland (Forbes *et al.*, 1980), the factors limiting output, which was measured as utilized metabolizable energy (UME), and their relative importance were investigated on a whole-farm basis as well as field-to-field, and the priorities established for future research and development. The main factors affecting UME output were stocking rate, level of fertilizer N application, and land manageability, which was strongly influenced by field drainage status and topography. Rough grazings, though occupying just under half the total area of British grasslands, have been less closely surveyed than other grassland types but many of the ecological, soil and management inter-relationships have been the subject of study (HFRO, 1979).

The need for some form of recording to measure utilized output from grassland has long been recognized. Rex Paterson pioneered a method of using cow grazing days and milk yields in the late 1940s/early 1950s. The records demonstrated the effects of different pasture types and forage crops on stock carrying capacity and milk yields, and the influence of feeding and management. A report by a sub-committee of the BGS set out methods of farm and field recording based on utilized starch equivalent (USE) output (Barker *et al., 1955*). The energy value of all feeds other than grass and grass products was calculated and deducted from the total energy requirements of ruminant livestock and the residual energy ascribed to grassland. Later, an investigation into grassland recording on dairy farms was sponsored by the BGS to gauge the progress made with recording systems and to derive a simple system for general use which would measure effective grass output on any particular field or farm and the effect of different managements. An individual field system based on a cow day (CD) unit, equivalent to the amount of bulk feed the average lactating cow would eat in 24 hours, was recommended, with conversion factors allocated to other classes of stock and to winter-fed hay and silage (Baker *et al.*, 1964). In the 1970s UME replaced USE as the energy measure and the introduction of computers facilitated recording procedures which were increasingly linked to financial and to physical performance and were a stimulus to economic modelling of livestock enterprises.

Herbage nutritive value

The main cited parameter of herbage quality in the early years was crude protein (CP) concentration, generally determined as total N x 6.25, the N being estimated by the Kjeldahl method followed by distillation or, in later years, by colorometric estimation of ammonia. Other compositional parameters in use were water soluble carbohydrates (WSC), crude fibre (CF) and oil. The nutritive value of forages and feeding stuffs, including silage, hay and dried grass, was described by percentage protein and starch equivalents, these being derived from chemical composition values. A regression equation linking digestibility to CP content was also in use until the early 1950s, before its drawbacks were recognized. From the early 1960s, forage digestibility, particularly of organic constituents, was used as a guide to energy value because of its association with intake. Expressions used were: dry matter digestibility (DMD), organic matter digestibility (OMD) and the content of digestible organic matter in the dry matter (DOMD), popularly known as D-value (Raymond, 1969).

The use of digestibility was facilitated by the two-stage rumen-pepsin *in vitro* method of determination (Tilley and Terry, 1963) which required only small quantities of sample material. The *in vivo* determination of digestibility had been restricted by animal, labour and housing costs, though it is still used for validation of alternative methods including enzyme digestion of herbage and prediction from chemical analyses (Jones and Moseley, 1993). Detergent fibre analysis partitioned herbage DM into the mainly digestible cell contents and mainly indigestible cell wall constituents and was valuable in explaining the changes in DMD as forage plants matured. In reporting herbage quality, OMD is favoured by researchers but D-value is most familiar to farmers. However, when computing livestock requirements the unit of energy measurement to reconcile nutritive value and animal requirements is metabolizable energy (ME), i.e. the digestible energy minus the energy lost as methane gas and in urinary excretion (ARC, 1965). By determining digestibility *in vivo* on a wide range of forages, fresh and conserved, equations have been derived to estimate ME by laboratory estimates of *in vitro* digestibility or the content of modified acid detergent fibre (MADF).

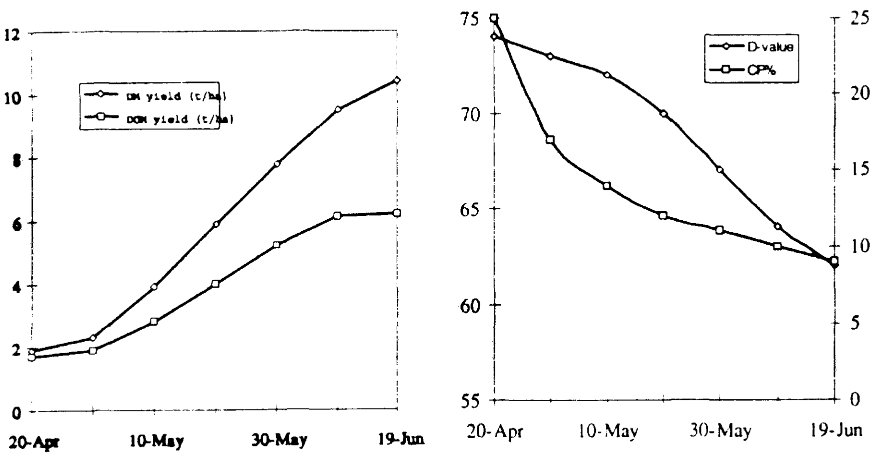

FIGURE 1

Profile of production and quality of late perennial ryegrass (Aberystwyth S23) (From Green *et al.*, 1971).

Perfil de la producción y calidad de una variedad de raigrás inglés tardío (Aberystwyth S23).

The concept of optimizing yields of digestible nutrients rather than DM from grassland has received greater credence from the 1960s and herbage digestibility work, in general, has contributed enormously to the improvement in quality of herbage cut for silage. Ear emergence (EE) was identified as the critical stage of growth, being the key reference point at which the rate of digestibility decline accelerates, although Italian ryegrass and timothy are exceptions in that decline starts before 50% EE. Heading date differed between species, as did D-values, and varieties at any given date and also at similar growth stages (Harkess and Alexander, 1969). Ryegrasses were found to be 'high-digestibility' species, cocksfoot and tall fescue 'low' and timothy and meadow fescue 'intermediate'. Among the legumes, white clover was 'high', red clover and lucerne 'intermediate'. Thus it became possible to construct profiles of DM production, D-value and DOM (Figure 1) for representative varieties of the major forage species (Green *et al.*, 1971; NIAB, 1986). An important outcome of the database collated was the D-value prediction schemes operated by official advisory bodies, which served as a guide to farmers of the potential qualities and yields of swards cut for silage or hay at specified dates and at particular altitudes/locations.

Most recently the development of near infra-red spectroscopy (NIRS) techniques for evaluating herbage quality has been a major advance and computer assisted NIRS can estimate several parameters such as N (and thus CP), fibre, or lignin which are then used to predict digestibility and voluntary intake. The NIRS techniques are particularly suited for large numbers of samples and are applicable to fresh herbage, dried or conserved products (Murray, 1993).

Forage legumes

With widespread use of fertilizer N the role and potential of white clover and its management needs were increasingly disregarded in both research and farming practice. Exceptions were found on lowland beef and sheep farms with low N input and extensive grazing systems, and hill sheep farms where reseeded grass/white clover pastures were incorporated in the 'two-pasture' system (see below).

Against a background of rising fertilizer N costs and a growing realization of the drain on fossil fuel energy which N manufacture entails and concern about the environmental consequences of high N usage, a reappraisal began late in the 1970s, of white clover and its N-fixing ability. Economic models of animal production from grass/clover *versus* N-fertilized grass swards concluded that the use of mixed swards was potentially profitable when annual fertilizer N usage was below 200 kg/ha, inferring a particular benefit for low-N-input beef and sheep farms. The nutritional superiority of clover in protein, minerals and sustained high digestibility and intake, relative to grass, were reconfirmed (Thomson, 1984) and its key management guidelines elucidated with special reference to choice of suitable clover variety and compatibility with grass, establishment needs, interactions with different fertilizer nutrients, ecophysiological requirements under grazing and cutting regimes and optimum methods of utilization (see review by Frame and Newbould, 1986). Recent research has also shown that grass/white clover swards receiving no fertilizer N can be cut for high quality silage in successive years without detriment to clover productivity and yielding 70-80% of the DM production from a grass sward receiving 300-350 kg N/ha annually. A rest interval within an intensive sheep grazing system and subsequent silage cut has proved beneficial to clover persistence and productivity. This tolerance to flexible grazing and cutting management has been highlighted in dairy systems comparisons with heavily N-fertilized grass (Bax and Thomas, 1992), and in beef and sheep systems compared with moderately N-fertilized grass swards (Stewart and Haycock 1984; Davies *et al.*, 1989). In the late 1970s and early 1980s there was evidence of the high yield potential and quality of red clover-dominant leys for silage cropping but their relatively short longevity militated against their adoption (Frame, 1990).

Forage crops

Although historically forage crops played a very important role in the provision of winter feed their use has declined throughout the last 50 years and the area grown fallen by 80%. This has been reflected in the level of research conducted and in breeding new varieties. The dominance of root crops was replaced by kale, rape and cabbage in the 1950s and 1960s and now, with the decline of root and leafy brassica crops, they each constitute about a third of the area grown, the other third being cereals, predominantly maize, for feeding as a conserved crop (Poole, 1990).

Potent reasons for a reduced usage of forage crops were high labour requirements, risks in establishment, pests and diseases, and the difficulties and high costs of harvesting. Research has addressed all of these problems and significant developments occurred. These include monogerm varieties of fodder beet and mangels, which removed the need for hand singling, the breeding of earlier maturing maize varieties, improved sowing and harvesting machinery, direct drilling techniques made possible by the discovery of paraquat in 1961 (ICI Plant Protection, 1976) to kill existing swards and stubble, and improved conservation and storage techniques. Work on the feeding value of maize, mainly for dairy cows (Phipps and Wilkinson, 1985) but also for beef cattle, has contributed to the marked increase in the area grown in recent years.

Soil compaction and drainage

As the intensity of grassland farming increased, swards, particularly those cut for conservation, had to bear more frequent and heavier wheel traffic, with its soil compacting and sward damaging effects. The soil/sward problems engendered, such as decreased water infiltration or disrupted soil structure, and resultant losses in herbage production, were first explored in the difficult soils and wet climes of north-west Europe during the rapid expansion in silage making. Reports later emerged from the UK confirming the losses in DM production, broadly in the range 10 to 20% relative to zero or minimal traffic, and noting the associated reductions in N and mineral concentrations, or offtakes, in the harvested herbage (see Douglas, 1994 for review). Major preventative measures were identified as minimizing wheel traffic, undertaking operations over short rather than long periods, keeping equipment size and weight to the minimum for economic effectiveness, and decreasing wheel induced stress on swards by the use of broad, low ground pressure tyres.

Plastic piping has become a cheaper alternative to traditional fired clay tile pipes and mechanized installation of drains has been introduced. Mole drains have proved effective and economic when used in conjunction with a widely spaced collection system of drains backfilled with permeable gravel, while on lighter soils gravel filling of the mole channels (gravel tunnel drains) has been beneficial. Subsoiling and spiking techniques have been developed to ameliorate compacted swards and aid root development and improved soil water/aeration conditions. It has been shown that grass yield, stock carrying capacity and animal performance benefited from good field drainage although the improvements in productivity were less than expected (Garwood, 1988).

Fertilizers

The increased use of NPK compound fertilizers, particularly 'high N' types, and straight N was mainly responsible for the increased productivity of grassland achieved in conjunction with advances in plant breeding, improved knowledge of rates and timing of fertilizer application and an understanding of other management factors. Nutrient concentration in fertilizers has increased; for example, N fertilizers now have 34.5% N (ammonium nitrate) or 46% N (urea) compared with 15.5% N ('Nitro-chalk') or 21% N (sulphate of ammonia) in the early years; a typical NPK compound now has a 40-50% nutrient sum compared with 21% in the 1940s. As well as there being lower bulk to be spread, machinery has been developed with improved precision of application and the once familiar one cwt and 50 kg bags have been increasingly replaced by one tonne containers for bulk handling. The development of compound fertilizer granules, uniform in size, density and composition was a notable technical advance, though in recent times blending of granules of individual nutrients has increased in popularity, because of lower costs and since it allows manipulation of nutrient ratios.

Nitrogen

Recognition that N was the most important nutrient governing grass production led to increasing rates of application from the 1950s onwards and consequent intensification of stocking. Average usage rose from *circa* 5 kg/ha annually in the 1940s to 120-130 kg/ha (range, 0-450 kg/ha) at present. Other sources of N - soil, excreta at grazing, manures from winter housing, rhizobially fixed N from legumes - became completely subsidiary to fertilizer N until a more recent revival.

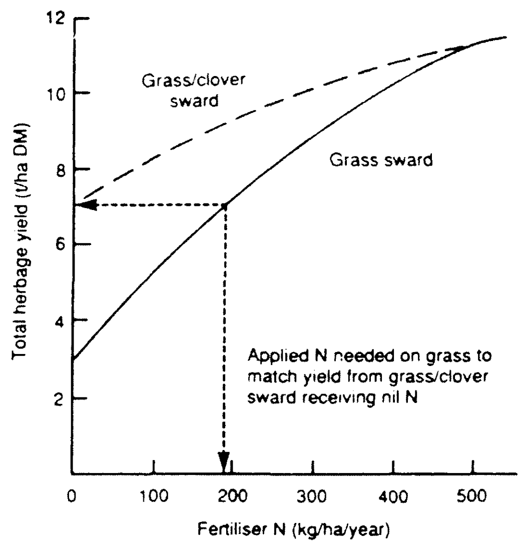

FIGURE 2

The effect of increasing fertilizer N application on grass and grass/clover swards.

Efecto de la aplicación creciente de fertilizante nitrogenado en pastos de gramíneas y de gramíneas/trébol.

A plethora of trials covering all the factors influencing sward response to N has been conducted over the past fifty years (see Whitehead, 1970; Wilman and Wright, 1983 for reviews). The effect of increasing fertilizer N application on grass and grass swards is shown diagrammatically in Figure 2. Sward yield response remains linear at higher rates of N application under frequent compared with infrequent cutting (Reid, 1978) implying that increased N can lead to higher quality silage subject to economic maxima. The seasonal distribution of grass has always engendered interest because of its variability in relation to the more constant needs of livestock. Manipulation of N application allows alteration of the seasonal yield pattern within a specific annual N rate without significantly affecting total yield (Reid, 1982). Under non-limiting fertilizer N, and in some cases irrigation, seasonal grass growth patterns were measured at 33 European sites, with different soil and climatic conditions, in order to provide yield potential data for a model to enable prediction of seasonal patterns wherever historic meteorological data are available and for validation of models developed from basic principles of plant physiology (Corrall, 1984).

The project made use of a special cutting regime involving a rotational but overlapping sequence of harvesting at short intervals, developed to supersede cutting at set intervals (Anslow and Green, 1967). Several practical attempts, e.g. the 'T-sum 200', have been devised to forecast the optimum timing for the first N application in spring but their use is much influenced by local soil conditions and current weather.

A series of fertilizer N trials on sites differing in soil and climatic conditions highlighted the importance of the level of N applied, and of rainfall, in determining annual herbage yield, and that, due to diminishing yield responses at high N rates, 80-90% of the maximum yield could be achieved from 50-60% of the amount of N needed for maximum yield (Morrison *et al.*, 1980). Fertilizer programmes and models of grassland production and utilization, and expected animal output together with financial implications, have been developed using the concept of site class, i.e.soil texture/depth, summer rainfall and water supplying capacity of the soil, and predicted herbage yield at specific N rates (Kilkenny *et al.*, 1978), later refined to take account of previous cropping history on soil N status and the effect of recycled excretal N during grazing (Baker *et al.*, 1991).

The use of N on grassland has recently been critically re-appraised in response to economic pressures and also as a reaction to concerns about the environment, especially nitrate levels in drinking water supplies and the impact of losses of ammonia and nitrous oxide to the atmosphere. Research has focused on the components of the N cycle and their interactions with special reference to reducing the losses or 'leakage' from animal production systems based on grassland (Ryden, 1984; Jarvis, 1993). Examples of practical measures developed are: more precision in rate, timing and spreading of N and allowing for N returned in excreta; environmentally safer levels of N loading on land; more use of long term swards; reduced autumn reseeding; greater use of grass/white clover swards.

Lime and other nutrients

Advances have been made in precision and timing of application of lime, its effects on trace element availability and in planned application programmes for the long term. There have also been significant improvements in soil sampling and analytical methodology for soil pH and nutrient status, classification and interpretation of the results (MAFF, 1973; Anon, 1985).

Phosphorus fixation/release processes in the soil have been clarified; P is progressively fixed by soil mineral compounds after application so subsequently the sward relies on the release of P from the compounds in the soil solution or humus. Clay soils have high rates of fixation on account of their high humus content and large surface area of soil particles so that heavy textured soils have high P reserves yet availability to plants may be limited. Conversely, P availability can be high from limited supplies of P in light textured soils. Basic slag was widely used as a P source on grassland after the war but was replaced by water insoluble ground mineral phosphate (GMP), the best form being the finely ground, soft mineral apatites from north Africa. The application of water soluble phosphate, preferably in a compound with N, on soils low or very low in P status can lead to increases in spring herbage of up to 52% together with improved P concentration (Swift *et al.*, 1988).

In contrast to P, K is highly mobile in soil solution and accordingly, heavy textured soils, in which K is held on clay minerals, normally have greater reserves and availability than light textured soils; the latter are therefore more prone to K deficiency and leaching. It has also been ascertained that while peaty soils may be high in K status, availability to plants is low. In fertilizer recommendations account is now taken of the high amounts of K needed to replace the large offtakes associated with highly N-fertilized silage crops and conversely, the small amounts needed annually in grazed swards because of recycling of K from excreta.

Grass requires S in similar amounts to P but this requirement was not appreciated in the past since 'free' S was present in the fertilizers used such as sulphate of ammonia and superphosphate. These were replaced by forms such as ammonium nitrate or triple superphosphate with more concentrated N and P, respectively, but with little or no S. In addition the amounts of free wet and dry S deposition onto land have declined due to various government anti-industrial pollution measures. The net result was the appearance and identification of S deficiency in the late 1970s/early 1980s. Maps have been constructed showing average deposition rates for various parts of the country and the soils and areas most likely to be S-deficient have been identified. Non-industrial areas, low rainfall regions and light textured soils have the lowest S reserves.

Soil surveys and herbage analysis have helped to identify and predict mineral deficiencies. Cobalt (Co) and copper (Cu) are the trace elements most commonly required. However, because of the more obvious adverse effects of such deficiencies on stock health, the main advances have been in blood analysis and direct or indirect animal treatment, e.g. slow release pellets in the rumen, or treatment of drinking water.

Organic manures

Historically, high value and reliance were placed upon animal manures, particularly farmyard manure (FYM), as a plant nutrient source. With increased stocking rates and changes in winter housing from the early 1960s to cubicles, self feeding of silage and slatted floors, the quantities of animal manures, especially as slurries, have increased enormously. Land suitable for spreading slurry was not always close to where it was produced so it came to be regarded by many farmers as a waste product, with a disposal problem, rather than a useful resource. However, increased emphasis on lowering farm input costs and minimizing pollution, such as run-off to watercourses, leaching of nutrients, ammonia volatilization and odour release, has resulted in a more positive and rational use of slurries and FYM (Van der Meer *et al.*, 1987).

It is now possible to calculate fertilizer equivalents and their monetary values, and to plan the use of organic manures to complement purchased fertilizers in planned soil fertility programmes. *Official Codes of Good Agricultural Practice for the Protection of Soil, Air and Water* are available as guides for the use of organic manures; for example, the volume of slurry storage facilities required on farms, the maximum volumes per ha which should be applied, the timing and frequency of applications, the maximum N loading in a year and the area of land needed to take this loading from various livestock enterprises. The net result is a better appreciation of the need to formulate whole farm balance sheets for nutrient flows combining soil/crop needs with the planned use of both inorganic and organic manures.

Innovations in slurry treatment and handling have been introduced in response to environmental and farm constraints. Slurry can be piped to the fields for slurry 'irrigation' or to waiting spreaders i.e. the 'umbilical cord' method. Injection of slurry rather than swash plate spreading reduces odour emission and ammonia volatilization, while acidification is another means of reducing ammonia loss. Acidification and injection cause loss of slurry N by denitrification in the soil but the addition of a nitrification inhibitor slows down nitrification thus restricting the nitrate available for subsequent breakdown (Pain, 1991). There are aerobic and anaerobic methods of treatment to decrease the solids, odours and importantly the biochemical oxygen demand (BOD), which is a measure of the risk of causing serious pollution in watercourses. Methods for the separation of the liquid and solid fractions of slurry, to aid handling and application, have also been developed. Similar work has begun on the use of sewage sludge on grassland.

Weeds, pests and diseases

Weeds have been tolerated more in grassland than in arable crops. Traditionally, less resort has been made to herbicides for control, but their effects on grassland and, hence, animal productivity and on economic impact can be appreciable (Doyle, 1982). A vast array of approved herbicides and formulated herbicide mixtures has been introduced over the past fifty years, ranging from selective to non-selective, soil- to foliage-applied and contact to translocation in action, while the time of application may be pre-sowing, pre-emergence, post-emergence or combinations of these. Some notable introductions for commercial use were MCPA and 2,4-D in 1945, MCPB, dalapon and mecoprop in the 1950s, paraquat, linuron and asulam in the 1960s, ioxynil, bromoxynil glyphosate, ethofumesate and clopyralid in the 1970s and triclopyr and fluroxypyr in the 1980s. These were accompanied by bi- and multi-component formulations particularly from the 1960s onwards, and in fact, most herbicides are now sold as mixed formulations to widen the weed spectrum controlled (Lockhart *et al.*, 1990).

Guidelines for herbicide use are now well documented as a result of evaluation prior to commercial release, subsequent experimentation and advisory literature. Strategies which integrate herbicide use with the older cultural and mechanical control methods have also been evolved (Williams, 1984). Following the Food and Environment Protection Act of 1985 herbicides must be used according to the manufacturers' label recommendations. There have also been concomitant improvements in application technology in relation to volume of spray, pressure of application and safety to operator and surrounding vegetation. Innovative equipment includes controlled droplet applicators, mistblowers, rope-wick applicators for weed plants standing above the level of the sward and spraying asulam by helicopter onto bracken-infested land.

Unless there are dramatic and noticeable attacks by pests and diseases on grassland, their insidious damage to shoots and roots may go unobserved or even ignored. As a result interest and work in the early years was more *ad hoc* and less intensive than in other grassland management factors. The greatest steps forward have been in assessing and recognizing the extent and effects of the major pests and diseases, their biology and population dynamics (Clements, 1995a). Control or alleviation involving cultural, mechanical and chemical methods, or integrated programmes involving these, are available in some instances, but, for many, plant breeding represents the best long term solution.

Surveys and experimental work have shown the substantial gains in production and its financial value, attainable from the suppression of pests and diseases (Henderson and Clements, 1977). Effective commercial fungicide treatment of some seeds has been devised to combat seed-borne fungi, especially *Fusarium culmorum* which attacks germinating seedlings (Lewis, 1988). Work in the 1970s identified frit fly (*Oscinella* spp.) as a major problem of establishing swards, and its biology and epidemiology were studied and control measures developed (Clements *et al.*, 1982). The adverse effects of viral attack on grassland are now fully appreciated but, as yet, no practical or economic methods of control are available. Effective chemical control has been developed to combat leatherjackets, the larvae of crane-flies (*Tipula* spp.) which damage swards, particularly at the seedling establishment stage, and also the netted slug (*Deroceras reticulum*) which is a problem pest in reseeds or swards renovated by direct drilling. The significant damage and decline or disappearance of forage legumes due to pests and diseases are also now more fully realized (Clements, 1995b).

GRAZING

In the first presidential address to the British Grassland Society, Stapledon (1946) stated that "grassland agronomists in this country must admit that they have rather neglected the grazing animal, to cater for whom, is the *raison d'etre* of all their endeavours". However, early attempts were made to rectify this situation (Linehan *et al.*, 1952) and grazing animals increasingly became a key feature in grassland experiments, though the extent of their use was limited by the high cost of animal trials. Thus, most advances in our understanding of the complex relationships existing between plant, animals and their managements have taken place in the last fifty years.

Grazing management and stocking rate

Grazing experiments in the 1940s and 1950s focused on the ways in which controlled grazing practices could be used to manipulate the botanical composition of pastures to favour the more productive and nutritious species. Concurrently ley farming exploited the newly-bred improved varieties of grasses and legumes which had become available. In evaluating these varieties, DM yields were higher as the rest interval between harvests increased and so claims arose, typified in the writings of Voisin (1959), for the superiority of rotational grazing. This was based on the assumption that the effects of frequency and severity of defoliation on cut swards would pertain equally to grazed swards and that the absence of rest periods and the uncontrolled frequency of grazing on pastures stocked continuously would depress herbage production. A number of comparisons were undertaken which confirmed this proposition but only because more stock were allocated to the rotational management in expectation of higher productivity. Although doubts were expressed over the superiority of rotational grazing in the early 1950s, real debate only began when McMeekan (1956) reported almost identical levels of milk yield from comparisons, over a range of stocking rates, between rotational grazing and set-stocking of dairy cows at Ruakura, New Zealand. He concluded that extreme differences in grazing method were associated with only small effects upon utilization efficiency and that the most powerful influence on output per unit area was stocking rate.

A major contribution to this debate was made by Mott (1960) who examined the interrelationship between output per animal and per unit area at different stocking rates. He explained earlier results favouring rotational grazing by showing how output per unit area continued to increase beyond the stocking rate or grazing intensity at which individual animal performance began to decrease. Thus, only comparisons made at the same stocking rates were valid. His work also emphasized the need for more than one stocking rate in treatment comparisons. Since then a number of reviews of experimentally rigorous comparisons have demonstrated that there is no consistent superiority of any single grazing system (Ernst *et al.*, 1980).

Grazing system

Rotational systems were adopted by many farmers in the 1950s and 1960s, particularly milk producers, thinking such systems would be more productive but also because of the apparent ease with which grass supply could be matched to animal needs. This was coupled with the relatively cheap creation of paddocks using barbed wire or electrified fences. The availability of electric fence units was of major importance in improving the utilization of pasture by permitting greater control and flexibility of grazing managements on farms. The very successful development of a system of 18-month-old beef production (Baker *et al.*, 1967) was also based upon paddock grazing and a well integrated programme of conservation and grazing to ensure grazing needs were always met. None of the improvements to planned beef production, which take account of the grazing and forage conservation requirements in relation to breed, slaughter weight and level of supplementary feed, would have been possible without the concurrent rapid advances in forage conservation dealt with below. For the first time the farmer had systems available which permitted surplus growth to be conserved quickly and at any time of the growing season, thus ensuring leafy regrowths for grazing when needed.

Subsequently simpler systems began to emerge, some of which were pioneered by ICI, and were preferred by producers; for example, a two field system reported by Hood and Bailie (1973) and later a modified version based on using three fields. The latter approach involved the continuous stocking of one paddock in early season with two paddocks being conserved. In mid season two paddocks were used for grazing and one for conservation while in late season all three paddocks were grazed. Continuous stocking systems with conservation integrated within them have now attained ascendancy, in the UK, over other systems.

In the hills and uplands a two-pasture system was developed (Eadie, 1978) in which there was complementary use of fenced improved areas and unimproved natural pastures. The higher production and better quality of the improved pasture were exploited by grazing it with the ewe flock before and during mating to enhance ewe condition, and during the first three months after lambing to improve ewe lactation and lamb performance. This strategy led to increased stocking rate, lambing percentage and weights of weaned lambs, while the higher stocking rate also allowed more efficient utilization of the hill grazings in summer.

The problems of obtaining high levels of animal output from grazed pasture stimulated interest during the 1950s and 1960s in feeding cut herbage indoors in what became known as zero grazing. In comparisons with conventional grazing improved outputs were demonstrated but did not prove cost effective in practice. The difficulties and commitment needed to provide a daily supply of high quality forage also proved a deterrent to its widespread adoption. The system is sometimes used for short periods in early or late season to avoid poaching of pastures by stock, or on farms with distant scattered fields. Storage feeding in which all the forage is fed in a conserved form, usually as silage, is in effect a variant of zero grazing and mainly suitable for highly mechanized large scale units. The provision of early spring grazing and extended autumn grazing was frequently undertaken in the early years but these practices were overtaken by the upsurge in silage making. Nevertheless, there has been renewed interest in recent years because of the lower cost of grazing relative to silage. Techniques to utilize pastures at these times of the year have been refined and now include the subdivision of paddocks by electric fence and limited but flexible periods of strip grazing with back fencing.

Questions were also asked about how grazing management could improve animal health. Thus systems were developed with the twin objectives of protecting young stock from worm parasites and improving their nutrition. Forward-creep and sideways-creep systems for breeding ewes were effective in sustaining good lamb performance, even at high stocking rates. Later, a 'clean' grazing system for ewes and lambs evolved in which equal areas of grassland were alternated annually between sheep, cattle and conservation or arable cropping, the critical feature being that ewes and lambs were not grazed in fields which had carried lambs or hoggs during the previous year. Leader and follower systems were developed for cows and young stock. Although the young stock benefited from these managements they were too complex and demanding to operate so their uptake in practice has not been widespread. In some areas mixed stocking of cattle and sheep has traditionally been practised. While trials have shown benefits from reducing parasitic burdens and from better utilization of pastures (Dickson *et al.*, 1981) the practice has not been significantly adopted in intensive systems of production. Nevertheless it highlighted how grazing management could keep parasitic burdens low and it stimulated a fresh approach to matching the nutritional requirements of different types of livestock to the seasonal pattern of grass growth.

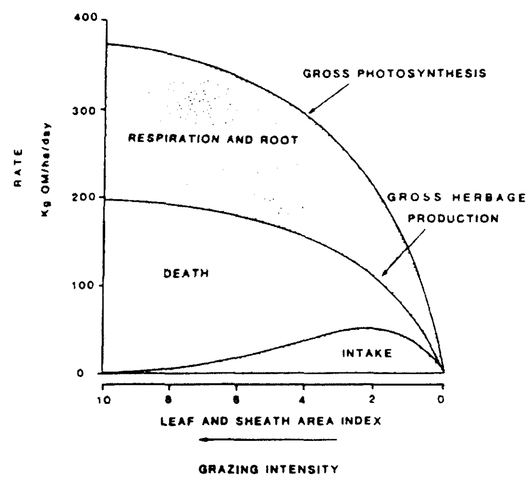

FIGURE 3

The effects of the intensity of continuous stocking on the balance between photosynthesis, gross tissue production, herbage intake and death (From Parsons *et al.*, 1983).

Efecto de la intensidad del pastoreo continuo sobre el balance entre fotosíntesis bruta, producción bruta, ingestion de hierba y muerte de tejidos.

Growth and utilization of grazed swards

The rapid turnover of tissue taking place as new leaves are continually produced and old ones die was well documented by the 1960s (Hunt, 1965) but the significance of these processes for grazing was not appreciated until much later. The stimulus to this was given by grazing ecologists who wanted to establish the extent to which grazing managements influenced the supply of herbage and the amount eaten. Once plant physiologists appreciated that a balance had to be struck under grazing between photosynthesis, gross tissue production, herbage intake and tissue death, rapid progress was made (see Figure 3). Studies of both the carbon balance of swards and the rate of growth of individual tillers provided the information from which a wider understanding could be developed using mathematical modelling techniques (Johnson and Parsons, 1985). It became clear that maximum yield per unit area was obtained when swards were kept at a leaf area index (LAI) below rather than above the maximum for light interception, as was originally suggested, and the best utilization from the compromise between gross tissue production, herbage intake and loss of herbage through death achieved at lower LAI than the maximum. These findings added substantially to the confidence in new recommended approaches to grazing management based on sward height.

Herbage intake and grazing behaviour

It was increasingly recognized that the scope for improvements in animal management and production could only be identified if factors influencing grazing behaviour and intake were elucidated. This posed problems not only in developing appropriate techniques (see Leaver, 1982 for a review) but also in presenting the results in terms of practical significance. Early attempts to measure intake from pre- and post-grazing sward measurements proved unsuccessful because of large inherent variability in such measurements. Eventually, intake was estimated from measurements of faecal indicators, initially based upon the faecal N technique (CAB, 1961) and then the use of indigestible markers, particularly chromic oxide (Le Du and Penning, 1982) and more recently n-alkanes (Mayes *et al.*, 1986), to estimate faecal output. As these estimates must be linked to the digestibility of forage consumed to calculate intake, the development in the 1960s of the *in vitro* digestibility technique, using only small quantities of herbage representing the grazed material, was significant.

As adequate equipment became available for recording and processing data, grazing behaviour was studied from recording jaw movements on tape recorders (Penning *et al.*, 1984) and more recently by telemetry coupled with the writing of computer programmes to summarize the electrical wave-forms associated with the different jaw movements in ruminating, prehension and mastication. This opened up the comprehensive study of the grazing process for the first time.

Grazing intensity

The influence of grazing pressure, defined as severity of defoliation or as stocking rate, proved of over-riding importance in determining animal performance. Therefore, considerable attention was devoted to defining grazing pressures that limit production on the farm.

In many experiments an asymptotic relationship was observed between herbage allowance and herbage intake or animal performance but the relationship was only defined in general terms. Allowance was measured as the quantity of herbage available per animal but because of the difficulties of establishing the quantity per unit area with reasonable accuracy at a point in time and knowing the significance of an allowance to an animal when measured at ground level or some predetermined height above the ground, the findings could only be applied on farms at a superficial level. The digestibility of the herbage grazed contributed little to explaining differences in intake but the weight of herbage present, whether absolute or green material or green leaf, had a major effect.

Sward height, measured by ruler or the HFRO sward stick, either as the stubble height after grazing in rotational systems or as the sward height on pastures stocked continuously, gave a good indication of the intensity of grazing and the likely effects on grassland utilization and animal production (Baker, 1985). The practical sward height guidelines which emerged for the management of pastures in relation to severity of defoliation were summarized by Hodgson *et al.*, (1986). Although they provide an objective method of assessing pasture conditions they are not often used in practice but the knowledge gained has created confidence in the adoption of efficient grazing managements.

The use of buffers

The use of integrated systems of grazing and conservation overcame many of the problems of sustaining high levels of animal performance and effective utilization throughout the growing season. Nevertheless, temporary shortages of grass inevitably occur and 'buffer' strategies have evolved to maintain intakes by offering hay, silage, or straw mixes or alternatively, there may be a buffer area of grassland which is utilized for grazing or conservation as required and often adjusted in size by moving an electric fence.

In the past, the offering of concentrate supplements to dairy cows at pasture has invariably produced uneconomic results. This outcome was finally explained by the way cows modify their grazing behaviour in response to supplementation (Sarker and Holmes, 1974). They immediately reduce the time devoted to grazing, especially at higher herbage allowances, and as a result a high substitution rate of the supplement for grass occurs. Using forage buffers also brings this effect and so it is now generally agreed that the most profitable use of supplements is when they act as a buffer to shortages of grazing, when very high grazing pressures are deliberately chosen, when adverse weather conditions reduce intake or when growing animals have not fully adapted to grazing conditions. The offering of restricted quantities of concentrate or forage is also recognized as an effective strategy to maintain optimum sward conditions. The same objective is also achieved by having a buffer area of land which is used in a flexible manner for grazing or conservation. The value of buffering practices is the creation of confidence to stock heavily in early season. This increases sward tiller populations and proportions of live, leafy material; the maintenance of leafy conditions at this time also has beneficial effects on sward density and production later in the season with benefits to animal productivity.

Manipulation of sward conditions

The fuller appreciation of the causative relationships between sward structural characteristics and herbage intake has led to an increased recognition of the mutual benefits of cattle and sheep grazing. Examples are the use of cattle to control the spread of bracken and thistles on pastures grazed by sheep and the use of sheep to remove rejected herbage in late season from swards previously grazed by cattle. The improved understanding of how severity of grazing alters tiller numbers, the proportion of flowering tillers and the patterns of defoliation of swards by cattle and sheep has emphasized the possibilities for manipulation. The adverse effects of lax grazing in spring on sward structure and on the quality of the diet later in the season are now well recognized. The more uniform patterns of grazing by sheep and large effect on increasing tiller numbers and sward density when grazed to low levels are being exploited to improve the structure of deteriorating swards.

The quest to improve pasture utilization by the adoption of rotational systems of management focused attention on many other associated topics because of the negative effects that could also arise (McMeekan, 1956). While many paddock grazed systems maintained vigorous swards, poaching damage was common on wet or poorly drained land, particularly when dairy cows were stocked at high grazing pressures (MAFF, 1970).

Further problems arose because of a failure to match herbage growth with an adequate grazing pressure. This led to under-utilization and herbage rejection at subsequent grazing cycles. In the worst cases of lax grazing, swards of poor density developed which were susceptible to weed ingress, aerial tillering and winter damage. These problems stimulated great interest in the load bearing and drainage properties of soils, the consequences of poaching soils and the effects of dung and urine on plant growth. A suitable grazing system is the answer to most of these problems but a number of strategies exist to prevent or reverse the damaging effects, e.g. effective drainage, use of long term rather than short term swards, renovation, manipulation of type of stock, use of 'sacrifice' areas or fields. Investigation of sward abnormalities in intensive systems showed how swards could be maintained in good condition by close topping or hard grazing provided the tiller buds at ground level were viable, and highlighted the need for at least one close defoliation of grazed swards during the grazing season (Jackson, 1975).

FORAGE CONSERVATION

Over the past 50 years conservation has become more specialized and highly mechanized, and there is a better understanding of the microbial and chemical processes involved. After the Second World War it was claimed that farmers who overcame the minor difficulties involved in making silage would testify to its high nutritive value (Watson, 1946). The high losses incurred in making hay were recognized and artificial drying was considered, in theory at least, to be the ideal method of grass conservation. Although silage making increased steadily during the 1950s and 1960s it was not until the late 1970s that silage overtook hay as the principal method of crop conservation in the UK (MAFF, 1993) (Figure 4).

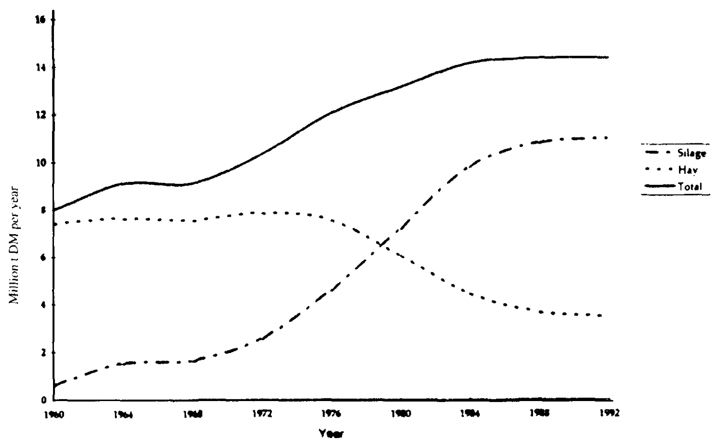

FIGURE 4

The quantity of hay and silage made in the UK (MAFF, 1993).

Cantidad de heno y silo producido en el Reino Unido.

Mechanization

Hay

In the 1940s hay was built in ricks or heaped onto tripods and after a month or so stored in a stack or a barn. Pick-up balers came into common use in the fifties. Around 1960 major research began into improved conservation methods (Raymond, 1981). Better mowing machines and conditioners which crushed and bruised grass stems, to speed up the rate of water loss, were designed and drying of hay in barns introduced. Since the hay had then to be transferred to a shed, the system was too labour intensive and so was replaced by storage hay drying, in which the bales are stacked around wind tunnels in a shed and dried by blowing through a uniform flow of air. Although effective, the extra capital and fuel costs incurred have restricted the adoption of this technique, even in wet areas where most needed and field baling became the norm with improved bale handling equipment and increasing bale size.

Mat-making is one of the newer ideas in forage conservation machinery (Bosma, 1991) and is designed to increase the rate of wilting in the field. The cut swath is lifted and fed through a maceration device to remove some of the water and the mashed forage is then squeezed into a thin mat and deposited on the stubble to dry naturally. However, the process has not yet been commercialized.

Silage

A notable innovation in the late 1940s was the Paterson Buckrake, a grass pick-up sweep operated by the hydraulic three point linkage on the tractor. With the introduction of forage harvesters in the 1960s and government support for silo construction, silage became increasingly popular (Wilkinson, 1987). Tower, stack, bunker, pit and clamp silos, silos with movable walls and later silos with flexible walls have all been effectively used. Early advice to farmers, that grass be allowed to heat up before consolidation, was proved to be wrong and improved mechanization ensured that silos were filled quickly and well consolidated. In the 1970s high-output, wide mowers produced dense swaths which were picked up by larger-capacity metered or double chop forage harvesters, some with metal detectors to prevent damage by foreign bodies. Research showed that the use of a shorter chop length than before gave better consolidation, a quicker release of sugars for fermentation and, therefore, a more rapid drop in pH. In addition, precision chopped silage was consumed more readily than long material by ruminants (Dulphy and Demarquilly, 1991). For the upland farmer, the forage wagon, originally designed for hay, was converted for silage making. Around 1970 the Dorset wedge system of filling a silo was developed and widely adopted; this permitted parts of the silo to be filled to its full depth and sealed quickly. As machines continued to increase in size and cost the trend was for farmers to employ contractors to ensile their crops. In the late 1970s tractor-mounted silage cutters revolutionized the cutting and transporting of silage from the silo. Cutting even blocks from the silo face causes less disturbance than other methods of removing silage since less air penetrates the mass and losses due to aerobic deterioration are reduced.

The 1980s saw the introduction of the big round bale (Forster, 1989) and big bale silage, now more commonly wrapped than bagged, accounts for almost one-fifth of silage in the UK. Variable chamber balers give a bale with a more uniform density than fixed chamber balers and now balers with a chopping mechanism have been introduced. Key guidelines for effective baling, storage and feeding have been elucidated. Big bale silage is especially useful when small quantities of silage are to be made, for example, in association with buffer grazing systems and in situations where permanent silos are unaffordable (Eyers, 1989). On a larger scale the Ag-Bag System has been developed in which grass is filled under pressure into a long sausage-shaped plastic bag holding 150-170 t of herbage. Excellent air exclusion is achieved with this system but, because of the good fermentation quality of the silage, it is liable to deteriorate rapidly on exposure to air (Kennedy, 1984).

Dried grass

Grass drying advanced rapidly in the late 1940s, but when cereal-based concentrate feeds were derationed in 1952, dried grass, produced by existing technology, could not compete. Conservation by high temperature drying requires about six times the energy used in making hay or silage. This can be reduced by field wilting, but following the energy crisis in 1973, it was obvious that dried forages would only be offered as a supplement to other forages (Raymond, 1974).

Microbiology and biochemistry

Hay

Research has shown that if hay is made quickly and baled at a low moisture content and stored or barn dried efficiently, to 20% or less moisture, there will be very little microbial or proteolytic activity on the crop. Conversely, if the moisture content is over 20%, moulds develop with the subsequent heating and growth of thermophilic actinomycetes, loss of nutritive value results and the hay will be a health hazard to man and farm animals (Elsässer, 1991).

Silage

Silage is the material produced by the controlled fermentation of a crop by lactic acid bacteria (LAB) (McDonald *et al.*, 1991). Interest in the 1950s focused on the sugar contents of crops and the availability of sugars to the LAB. The development of paper chromatography meant that individual sugars could be identified and fructans were found to be responsible for much of the variation in WSC among crops. In temperate grasses, fructans were the most abundant of the WSC but legumes were shown to accumulate starch instead of fructans as their main reserve polysaccharide. In general, ryegrasses contain most WSC and cocksfoot least (Waite and Boyd, 1953). Legumes with their low WSC content and high buffering capacity proved to be more difficult to ensile satisfactorily than grasses. The introduction of gas liquid chromatography in the 1960s and later high performance liquid chromatography allowed the biochemistry of the ensilage process to be studied in even greater detail.

In the 1950s numbers of LAB on the growing plant were thought to be low and to multiply rapidly when the crop was harvested and ensiled. Microbiologists now believe that techniques used to count the bacteria may have underestimated their numbers (Pahlow, 1991). Clostridia from soil contamination have long been associated with the production of butyric acid and ammonia in silages but since the 1950s other organisms responsible for secondary fermentation in silages have been identified. Certain strains of enterobacteria produce ammonia. Yeasts, even under acid conditions, ferment sugars, and in the absence of sugars, LAB convert lactic acid to acetic acid. Big bale silage proved particularly prone to the growth of listeria, the bacterial pathogen most frequently associated with silage but in anaerobic silage listeria die out rapidly if the seal is adequate and oxygen ingress is prevented (Fenlon, 1988). Yeasts, moulds, a proteolytic species of *Bacillus* and LAB have all been implicated in the deterioration of grass silages (Woolford, 1984) and acetic acid bacteria in the deterioration of maize silages (Spoelstra *et al.*, 1988).

Additives

Hay

Research showed that mould growth in stored hay can be modified or prevented by the addition of chemicals at the time of baling. Propionic acid, widely used to prevent moulding in grain, was effective in laboratory studies in the 1970s but was less effective under field conditions, due to evaporation of the acid and/or uneven distribution on the hay. Improved applicators and the use of an ammonium salt of propionic acid, ammonium bispropionate, now allow hay to be baled at higher moisture contents with less risk of moulding but the use of the additive is not widespread because of added cost.

Silage

The most important factors affecting fermentation were established as WSC content and buffering capacity. The original objective in applying an additive was to supply additional substrate, usually molasses, for the LAB. Molasses is still used but enzymes are also available to break down the polysaccharides to simple sugars. Added to low DM grass they do produce additional sugar but they also increase the flow of effluent. When an effective additive applicator was designed in the 1960s the range and numbers of additives increased. Formic acid, a by-product of the oil industry, competed for a place on the market with mineral acids and soon attained dominance. The ability of formalin to restrict the fermentation and to protect protein from degradation in the silo and the rumen was recognized. Applied with either formic or sulphuric acid it may improve liveweight gains of cattle and sheep on silage diets and increase milk yields from dairy cows. The Liscombe Star System was introduced to help farmers decide whether or not they should use an additive (ADAS, 1979). In recent years additives containing salts of acids, mainly ammonium salts of formic acid, have been introduced on to the market. These are safer to handle than the free acid and, if applied at a higher rate, will have a similar effect on the fermentation (McGinn *et al.*, 1990).

The application of efficient LAB to improve the fermentation pattern became a viable proposition in the 1980s with the introduction of freeze-drying and encapsulation techniques (Seale, 1986). Initially many products were ineffective since the LAB were not viable and/or application rates were too low. Products have improved gradually and many independent trials have proved their use can lead to to increased liveweight gain (Henderson, *et al.*, 1988) and milk production (Gordon, 1989). Unlike acids they are safe to handle, and bacterial inoculants now dominate the additive market (see review by Mayne and Steen, 1990). To aid farmers in their choice of silage additive a UK Forage Additive Approval Scheme has recently been introduced, with categories encompassing all types of silage additive and benefit. Approval depends on the manufacturer providing a dossier containing the results of well-designed and analyzed trials.

The increase in silage making, the move towards direct-cut silage in the 1980s and the use of acid and enzyme additives exacerbated the problem of the pollution of watercourses by silage effluent but it was established that materials such as bruised barley, straw (pelleted or alkali-treated) or sugar beet pulp ensiled with the crop reduced effluent flow and DM loss (Offer *et al.*, 1991). However, efficiency of absorption was influenced by the physical characteristics of the crop, method of absorbent application, silo design and drainage.

Nutritive value of conserved forage

Interest in improving the quality of conserved grass was stimulated from the 1960s onwards when the links between digestibility, maturity of herbage at cutting and voluntary intake were clarified. Earlier cutting than previously practised was advocated to obtain maximum yields of nutrients rather than DM, and this ethos eventually led to the dominance of silage over hay. Unless losses were high during ensilage the digestibility of a well preserved silage was shown to be similar to that of the ensiled crop. The toluene distillation technique for determining the true DM of silages (Dewar and McDonald, 1961) led to more accurate measurements of DM losses during ensilage and of the DM intakes of silages. Contamination from soil or slurry has a detrimental effect on fermentation and on losses, but is avoidable if the fields are rolled in spring and slurry is applied six weeks or more before harvesting. However, even well preserved silages proved likely to have lower intakes and efficiency of utilization of nutrients than those from the fresh ensiled crops. The relationship between digestibility and intake is frequently very poor as high acidity and high ammonium N are both associated with depression of intake.

In the 1970s the introduction of silage additives encouraged the ensilage of young grass, with its low DM content. Trials throughout Europe showed that, although intakes of wilted silage might be higher than those of direct cut silage treated with formic acid, low DM silage was used more efficiently for liveweight gain and milk production (Zimmer and Wilkins, 1984). Direct-cut silage produces more effluent and this, if stored, is consumed readily by cattle or pigs (Patterson and Steen, 1982). Nevertheless, the polluting effect of effluent has been increasingly appreciated in recent years so more emphasis is now placed on rapid field wilting whenever possible and on good silo management to curtail DM losses. Effective guidelines developed include reduced swath density to hasten wilting, short chopping to aid crop consolidation, overnight sheeting, airtight sealing and weighting down of the final plastic sheeting.

Studies have shown that the release of amino acids and ammonia in the rumen from many silage diets is not matched by a corresponding supply of available energy and, therefore, protein synthesis by the rumen bacteria is poor (Thomas and Thomas, 1985). The traditional supplementation of silage for dairy cows with low protein, cereal-based diets was challenged in the late 1970s. Protein concentrates, especially those with a source of low degradable protein such as fishmeal, protected amino acids, methionine and lysine, and improved milk yield from dairy cows.

Although grass is the principal crop for silage, the ensiling of maize and whole crop cereals has increased in recent years. The digestibility pattern of cereals proved quite different from that of grasses since the declining quality of the leaf and stem was balanced by an increasing proportion of highly digestible grain. Maize ensiles well but maize silage is prone to aerobic deterioration, as is silage made from whole crop cereals. Investigations of the value of applying alkali to cereal crops have provided methods for improving the feed value of straw and of conferring aerobic stability to very high dry-matter silage by treatment with urea (Wilkinson and Stark, 1990). Legumes, unless wilted or treated with an effective additive, suffer extensive proteolysis during ensilage.

Prediction of nutritive value

The true nutritive value of a conserved forage can only be determined using the type of animals for which it was intended and using techniques which have become more sophisticated over the years and which range from simple intake and digestibility studies to comparative slaughter, animal calorimetry and measurements of energy retention from carbon and nitrogen balance techniques. However, animal trials are expensive and laborious and methods of predicting the nutritive value of forages have been developed. Until recently only DM, pH and ammonia were used to predict silage intake. Now an automated titration of silage juice provides a more detailed analysis of a silage and a better prediction of intake (Offer *et al.*, 1993), both of which are required for accurate ration formulation.

Metabolizable energy prediction from the digestible energy of forage was introduced in the 1960s as there is a good statistical relationship between fibre content and digestibility, the modified acid detergent (MAD) fibre content being used to predict ME. This technique proved suitable for hays but not for silages, especially those which had high fermentation and effluent losses. Recent research has shown that NIRS is more accurate in predicting ME, especially now when calibrated directly with measurements made with animals. Interest is now focused on the fermentable ME (FME), that part of the ME which is utilized by the rumen bacteria, and on laboratory techniques for determining this, synchronization of FME with protein degraded in the rumen being of prime importance in maximizing animal production from silage diets (Oldham, 1993).

Traditionally the N content of forage was expressed as CP and converted to digestible crude protein for ration formulation. Now it is more meaningfully expressed as dietary protein degraded or undegraded in the rumen. The artificial fibre bag technique developed in the 1970s (Ørskov and McDonald, 1979), in which forage is incubated in bags in the rumens of sheep or cattle, gives a measure of degradability with time. Research continues into finding a laboratory technique which will predict protein degradability accurately.

SCIENCE INTO PRACTICE

Grasslands, ranging from short term leys to permanent rough grazing, currently comprise about 70% of the UK agricultural land area and provide from two-thirds of the diet of dairy cows to nine-tenths that of sheep. Livestock numbers now total about 12 million cattle and 44 million sheep in contrast to *circa* 9.5 million and 16.5 million, respectively, in the mid forties. It has been estimated by Wilkins (1992) that UME output from UK grassland increased from 26 GJ/ha in 1950 to 42 GJ/ha in 1990 as a result of increases of 1.8% annually from 1950 to 1970, 1.4% over the next 15 years but no increases since 1985.

Technology transfer is the bridge across which the results of investigations were translated into uptake by farming practice, and state and commercial advisory services can be proud of their achievements. The synthesis of individual research findings into practical production systems at experimental husbandry and development farms, and evaluation of the systems for input-output interactions and economic viability were invaluable parts of the process. Nationally, the activities of the British Grassland Society in association with its affiliated local Societies played a leading role in publishing and promoting advances in grassland technology over the years (see Powell *et al.*, 1995, for a review of these activities). Internationally, the European Grassland Federation Meetings and International Grassland Congresses must be acknowledged for the interchange of research results which occurs and for the new ideas which are presented.

Clearly, those farmers who apply 'science into practice' are taking advantage of a major resource and are honing their competitive edge, an edge increasingly required in the current climate of changing political and economic pressures and of intensifying competition for agricultural markets. The large variation in UME output between fields, farms or specific stock enterprises demonstrated in various surveys, and the UME levels achieved by leading grassland farmers, indicate the scope for greater uptake of existing technology which in turn would lead to more efficient grassland production and utilization. Furthermore, the rate and degree of technological progress in the next fifty years will, in all likelihood, match or surpass the advances made in the past half century.

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AVANCES DE LA TECNOLOGÍA DE PASTOS EN LOS ÚLTIMOS CINCUENTA AÑOS

RESUMEN

Los avances, que han tenido lugar a una notable velocidad, se agrupan en los apartados de Agronomía, Pastoreo y Conservación de Forrajes. El establecimiento de regalías fue un gran estímulo para que los obtentores incrementasen la creación de variedades pra-

tenses mejoradas. Se formalizó la evaluación de variedades y, como consecuencia, muchos paises disponen de listas de variedades recomendadas. La semilla tiene garantía de calidad genética y analítica. Ha aparecido un número elevado de insecticidas y herbicidas para el control de plagas y malas hierbas en pastos establecidos o en fase de establecimiento. Los estudios de valor nutritivo (VN) permitieron identificar las especies y variedades más adecuadas para pastoreo y conservación. Desde el punto de vista analítico, el desarrollo de la espectroscopía de reflectancia en el infrarrojo próximo ha supuesto un avance muy importante. Existe un renovado interés por el uso de las leguminosas pratenses debido a su alto VN y a su capacidad para fijar N atmosférico. La tecnología de fertilizantes se orientó hacia la obtención de productos más concentrados, al uso a granel y a un mejor conocimiento de las interacciones de N, P, K, y S bajo distintos tipos de manejo. Los abonos orgánicos se usan ahora de una forma más racional y el estudio del balance de nutrientes de la explotación está teniendo un creciente impacto sobre la eficiencia del uso de fertilizantes.

Los primeros debates se centraron sobre los tipos de pastoreo pero la experimentación demostró que la carga ganadera tiene una influencia capital sobre la producción, tanto por unidad de superficie como por animal. Otro avance clave fue la integración del pastoreo y de la conservación, manejándolos de manera que se alcance una secuencia de rebrotes frondosos de alto VN; también se introdujo el pastoreo "amortiguado" como un seguro. Los fisiólogos dilucidaron el papel del ciclo del carbono y el de la dinámica del crecimiento de los vástagos (hijuelos) en los pastos, lo que ha llevado a la utilización de la altura del pasto como herramienta para el manejo del pastoreo. El uso de marcadores indigestibles para medir la producción de heces y estimar la ingestión supuso también un gran paso adelante.

El ensilado se convirtió en el método más importante para la conservación del forraje, a lo que ha contribuído una mejora de la mecanización en todos los pasos del proceso, un mejor conocimiento de la microbiología y bioquímica del proceso, e importantes mejoras como picado de precisión, cierres con lámina de plástico, grandes pacas envueltas en plástico, aditivos y mejores métodos de predicción del VN para la formulación de raciones. Algunos de los avances son aplicables también al proceso de henificación. Se predice que el progreso actual de la tecnología, incluída la biotecnología, igualará o sobrepasará, con toda probablidad, los avances conseguidos en el último medio siglo.

Palabras clave: Tecnología de pastos, avances, agronomía, pastoreo, conservación de forrajes