# THE HURLEY AND NORTH WYKE STORY: 60 YEARS OF GRASSLAND RESEARCH 1949 – 2009

**Editors: Roger Wilkins, Steve Jarvis and Martin Blackwell**

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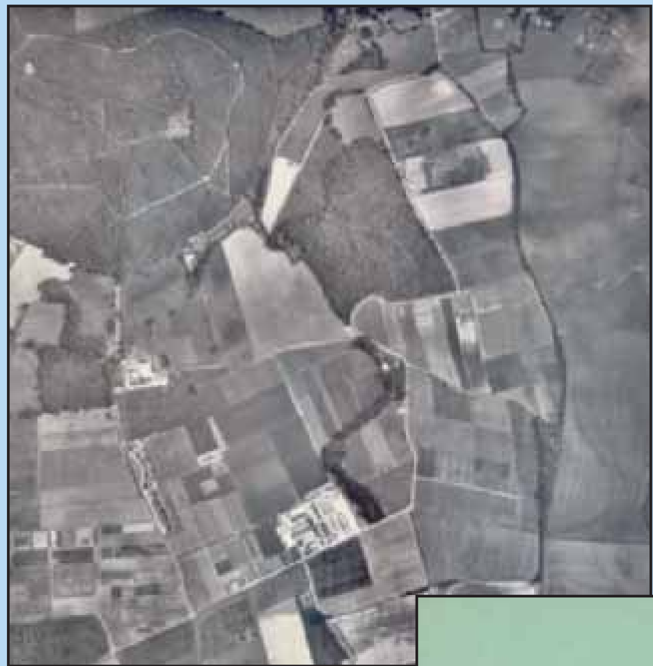

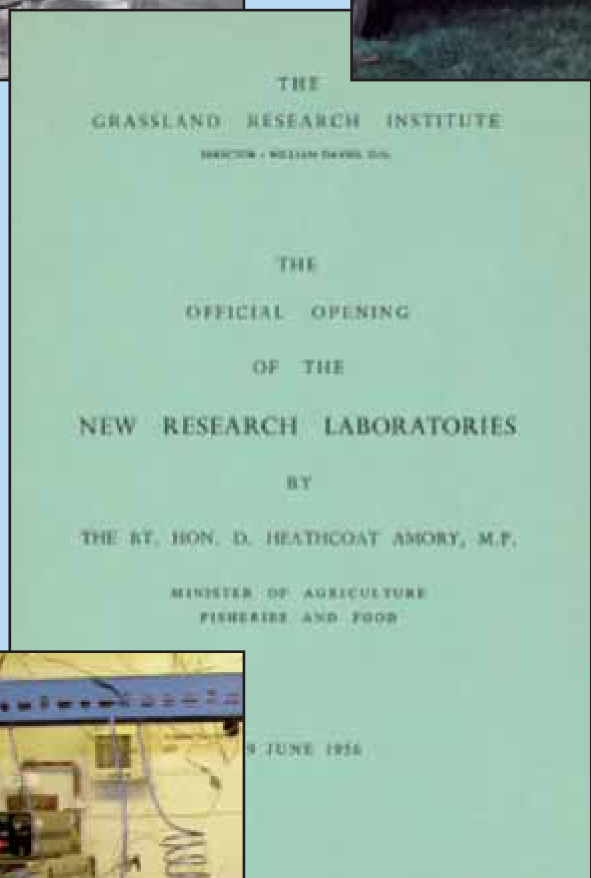

THE

GRASSLAND RESEARCH INSTITUTE

THE

OFFICIAL OPENING

OF THE

NEW RESEARCH LABORATORIES

BY

THE RT. HON. D. HEATHCOAT AMORY, M.P.

MINISTER OF AGRICULTURE

FISHERIES AND FOOD

JUNE 1956

*Back cover illustrations:*

*Invitation to the opening of the new laboratories at Hurley (1955) with (clockwise from top right):*

- *Field measurement of grass yield in the 1960's*
- *Aerial plan of the North Wyke estate*
- *Contemporary controlled environment equipment for measuring nitrous oxide emissions*
- *Aerial view of the Hurley estate*

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## 1949 – 2009

**Editors: Roger Wilkins, Steve Jarvis and Martin Blackwell**

Published by North Wyke Research

North Wyke Research Station
North Wyke, Okehampton, Devon, EX20 2SB

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ISBN 9780956450104

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The book was printed by Hedgerow Print, Crediton. Copies are available from North Wyke Research, Okehampton, EX20 2SB, England or can be downloaded from www.northwyke.bbsrc.ac.uk

## ACKNOWLEDGEMENTS

This book was prepared with the guidance of a Steering Group comprising Martin Blackwell, Andrew Bristow, David Hatch, Steve Jarvis, Phil Murray and Roger Wilkins. We wish to thank the many present and former members of staff, research students and visiting scientists to Hurley and North Wyke who have written articles and provided photographs. Additionally, we wish to acknowledge all members of staff who contributed to the success of the research stations. We are also indebted to those who have read and improved the various chapters in the book and particularly acknowledge the advice from Frank Raymond and David Beever on the chapters on 'The Development of Hurley and North Wyke' and 'Herbage Quality and Utilisation', from Bob Clements on 'Grassland Production' and Brian Pain and David Scholefield on 'Soil and Environmental Science'. We thank Gilles Lemaire for contributing a short 'outside' appreciation of the research at Hurley and North Wyke and Les Firbank for his future perspective.

Finally, it is a great pleasure to acknowledge the organisations that have made this publication possible through their financial support. The Stapledon Memorial Trust covered about half of the total cost and valuable contributions were made by The British Grassland Society, Dave Simmons Plant Hire, Ecosyl Products Limited, Mole Valley Farmers, The NPK Club, North Wyke Research, North Wyke Social Club, North Wyke Tennis Club and Ruminations Limited (David Beever).

*The Steering Group*

DAVE SIMMONS
PLANT HIRE

## FOREWORD

This timely publication records the major events in the history of grassland research both at Hurley, arguably the finest such Institute in the world in its heyday, and in the continuing important investigations at North Wyke. The international reputation of the two stations has been built largely on the research findings of the staff, many being world leaders in their field. Their work, covering soils, plants and animals, of necessity ranges from the analytical, to increase understanding, to that to improve practice. Some of the techniques that have been developed (e.g. for studying herbage quality), or pioneered (e.g. modelling), are now used worldwide. It is hardly surprising that both stations have attracted a continuing stream of visiting research workers and post-graduate students.

Any research institution's long-term international reputation depends on the continuing quality and relevance of its output. This book indicates how the work programmes have successfully anticipated, or been adapted to, constantly changing research needs. For instance, investigations on factors limiting the potential production from grassland, issues of sustainability, effects of management on the environment and the role of grassland in wider land use, can all be identified as research priorities that have changed over time. The major responsibility for determining the strategic research direction of an institute falls to its Director, together with the Governors who, with their standing and influence, provide invaluable support.

Research can only be undertaken if financed. The sole source of funds until the mid 1970s was the Agricultural Research Council (ARC), which evolved subsequently to form the Biotechnology and Biological Sciences Research Council (BBSRC). Although I recall moments of 'creative tension' – early discussions on the possibility of establishing a research centre at North Wyke and the appointment of an agricultural economist spring to mind – we enjoyed good relations throughout my time at Hurley, with ARC supportive of the work and encouraging some flexibility in the programme. The fact that staff have been so successful in obtaining continuing support during the subsequent period when available traditional funds have decreased progressively says much for both the quality of the work and the ingenuity of the research scientists.

No research centre could have wished for more loyal and dedicated staff than the colleagues that I had whilst at the Grassland Research Institute (GRI). It was a stimulating and pleasurable experience to have been a member of a team including scientists, technical and administrative staff, working together in a happy and productive environment. As reported in this publication, longstanding friendships have developed amongst staff, some resulting in marriages, and many social activities initiated, a number becoming a tradition. I can only reiterate some of the words of appreciation expressed by former visiting research workers and students in their vignettes, and also say that it has been a rare privilege to have played some small part in the history of Hurley and North Wyke.

*Alec Lazenby, Director, Grassland Research Institute 1977–82*

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# INTRODUCTION

The Grassland Research Institute was founded on 1st October 1949. This Institute was initially based at Drayton, near Stratford-upon-Avon, whilst new facilities were being established at Hurley, near Maidenhead. The Institute acquired a second research station at North Wyke, Devon, in September 1981. There was a period of progressive restructuring of Institutes that led to the formation in 1990 of the Institute of Grassland and Environmental Research (IGER), with headquarters in Aberystwyth, and the closure of the Hurley Research Station in 1992. In a further major change, IGER ceased to exist at the end of March 2008 with the Welsh sites becoming part of the newly-founded Institute of Biological, Environmental and Rural Sciences (IBERS) of Aberystwyth University. North Wyke remained with the BBSRC, as North Wyke Research, and then became part of Rothamsted Research.

This book is being produced to mark 60 years of research by the constituent parts of the Institute at Hurley and North Wyke. It also spans the era in which there was an institute in Britain with ‘Grassland’ within its title. The importance of grassland to many aspects of UK agriculture and landscape function is as great now as it was 60 years ago, but the focus has changed from the use of grassland to produce milk, meat and fibre to multi-functional grassland providing a range of products and services. Research on grassland will continue, particularly at North Wyke Research and in IBERS, with much of this carried out in a broad context relating to land-use patterns and rural economies.

Inevitably in this short book we have not been able to give comprehensive coverage of all the achievements and happenings at Hurley and North Wyke or to name all those involved in particular developments. A characteristic of the Research Stations has been the strength of the total staff, with all contributing to the ability to deliver high-quality research. Many of the front-line scientists have been named, but they represent only the tip of an iceberg. They have been dependent on expert assistance within their groups and on technical and administrative services provided at Hurley, North Wyke, Aberystwyth and BBSRC headquarters. The integrated efforts of the whole have been crucial during good and bad times over the 60-year period.

We are proud of the achievements and the quality of the science from Hurley and North Wyke and seek in this book not only to produce a historical record of these and to highlight key developments in the research, but also to give some impressions and insights of life in the research stations over the years. The first part takes a chronological approach tracing changes in organisation, research foci and facilities. This is followed by chapters that outline major research accomplishments in key areas of research. Prominence is given to short features or vignettes on social and cultural aspects and on specific research achievements written by former or present members of staff and visiting scientists. A final section gives a perspective on the future for research at North Wyke.

# THE DEVELOPMENT OF HURLEY AND NORTH WYKE

## Background and Establishment of Hurley

Much of the inspiration for the foundation of GRI came from Sir George Stapledon when he was Director of the Welsh Plant Breeding Station (WPBS), Aberystwyth. Grassland surveys carried out in the 1930s by William Davies, a senior scientist at WPBS, had highlighted the prevalence of neglected and unproductive grassland in England and Wales. With the onset of war and the crucial need to increase agricultural production, a Grassland Improvement Station was set up at Drayton, near Stratford-upon-Avon, in 1940 under the direction of Stapledon. The object of work at Drayton and at the sub-stations at Mixon Hey in Staffordshire and Colesbourne in Warwickshire was to demonstrate the practicability of making run-down grassland more productive. Sir George Stapledon retired in 1945 and was succeeded as Director by William Davies

Much was achieved, but the need for more research on grassland was highlighted. The requirements were considered by a Grassland Research Group set up in 1945 by the Agricultural Improvement Council of England and Wales. This Group recommended the establishment of a permanent institution for grassland research and that it should be located in an area with annual rainfall of 600–750 mm and be close to a University or a Provincial Centre of the Advisory Service. The Group's recommendations were accepted and Hall Place Farm, Hurley, near Maidenhead, was bought by the Ministry of Agriculture and Fisheries and split between use for grassland research at Hurley and the Berkshire Farm Institute (later the Berkshire College of Agriculture) at Burchetts Green. This land, extending over 200 ha, fully satisfied the specification and close proximity to the University of Reading was an important asset. The land was occupied in September 1948.

The GRI was formally established on 1st October 1949 as a company limited by guarantee. The Institute had a Governing Body appointed by the Ministry of Agriculture and Fisheries and by the Secretary of State for Scotland with scientific supervision from the ARC. The Governing Body has played a key role over the years in steering the development of the Institute and bringing the wide expertise of its members to support the Director and to act as ambassadors for the Institute. A block grant was received from the Ministry of Agriculture and Fisheries, although responsibility for the block grant and for the Institute was subsequently taken over by ARC.

Research was carried out at both Drayton and Hurley until Drayton was relinquished in 1955 to become an Experimental Husbandry Farm. The headquarters was at Drayton until transfer to Hurley in 1952. The activities at Drayton and Hurley during this period were described in the annual publication *Experiments in Progress*. Whilst much of this early work was concerned with agronomy, with focus on seeds mixtures, manuring and seed production, even from the foundation of GRI considerable emphasis was given to grassland utilisation and animal production. Likewise, the effects of grassland and grassland management on soil characteristics received strong emphasis in the research. The belief that grassland research needed to span soil, plants and animals was strongly held by senior staff and by the Governing Body and led to substantial debate with Ministry of Agriculture and Fisheries and ARC, at a time when most research and most Institutes had a focus on either plants or animals and little encouragement was given to multidisciplinary research. The views from the Institute prevailed and the programmes of research were reflected in the titles of the five Departments established in the Institute: Ley Agronomy, Animal Agronomy, Herbage Agronomy, Chemistry and Nutrition and Plant Physiology.

The six-year period from the acquisition of land at Hurley to the final relinquishment of Drayton in 1955 seems a long time compared with the speed of major subsequent changes, but much needed to be done. The only building at Hurley was a single-storey building that had been used as a radar station during the war and this remained in continuous use for various purposes until the closure of Hurley in 1992. There were no field supplies of water or electricity. An important appointment was that of Ralph Dean as Farm Manager. He came to Hurley in June 1949 and remained as Farm Manager until 1981, playing a key role in supporting research and accommodating the fastidious requirements of the many research scientists. Staffing at Hurley was strengthened early in 1950, when Idwal Owen, Assistant Secretary (later to be Institute Secretary) and Frank Alder (later to be Head of Animal Agronomy) moved from Drayton to Hurley. There was an early programme of establishing farm buildings and houses for the Farm Manager and farm staff. Fields were laid out in lots of about 6 ha, suitable for field research, and footpaths were diverted.

Despite the shortage of facilities, the first experiments at Hurley were sown in April 1949 with observation plots of different varieties of grasses and legumes and studies on root development, soil structure and grazing being established in that year. Approved experiments were allocated an 'H' number, a convention that continued until towards the closure of the Station. The number of livestock at Hurley was built up with 159 cattle, 221 sheep and 51 pigs being present in 1953.


*Cattle grazing at Hurley, 1950*

The main programme of farm building was completed by 1953 and half of the Institute staff was at Hurley by that time. *Experiments in Progress 1953* reports that "the Radar Hut is now congested"! The number of graduate staff in the Institute increased gradually from 16 in 1949 to 42 in 1955.

Construction of the Research Building (later named the Sanders Building, after Professor Harold Sanders, Chairman of Governors at the time) commenced in October 1952 and was officially opened by Sir Derrick Heathcoat Amory, the Minister of Agriculture, Fisheries and Food (MAFF) on 29th June 1956, although one wing of the building had been in use for over a year. This provided offices and a comprehensive laboratory facility. An animal house and facilities for drying and processing herbage samples were also set up. An important feature was a large cold store in which frozen herbage could be stored prior to use in animal feeding experiments.

In 1953, the Commonwealth Bureau of Pastures and Field Crops was transferred from Aberystwyth to Hurley and accommodated initially in temporary buildings. The main function of the Bureau, now part of CAB International, was to serve as a source of information for Commonwealth scientists on investigations relating to grassland, fodders and annual field crops published throughout the world. This started a mutually beneficial relationship that continued until 1987, when the Bureau moved to a new headquarters for CAB International in Wallingford. The Director of GRI was a Consultant Director of the Bureau and the Institute benefitted from enhanced library facilities and the presence of professionally qualified staff, many of whom had extraordinary knowledge of many languages, required for preparing abstracts from non-English literature. Bureau staff also played a full part in social life at Hurley. An important publication from the Bureau was the 1961 monograph *Research Techniques in Use at the Grassland Research Institute, Hurley.*

In 1944, Sir George Stapledon convened a meeting at Stratford upon Avon which led to the formation of the British Grassland Society (BGS). The Society met for the first time at Stratford in June 1945 and included a visit to the Grassland Improvement Station. A close relationship with the Society was continued with the Society's office being at Hurley from 1957 until 1991. During much of this time the Society Secretary was a member of GRI staff and eight current or past members of staff became Presidents of BGS, including the only three people to have served two terms as President (Sir George Stapledon, William Davies and Roger Wilkins). This close link with BGS, and subsequently with local grassland societies, helped reinforce contacts with the farming community and made a big contribution to knowledge transfer, both from research to practice and in the reverse direction.

### 1955–1964: continuing the Davies era

This was a period of steady expansion of GRI with an increase over the nine years of some 57% in the number of graduate and technical staff. A complete list of staff was not given in the Annual Reports until 1968! There were developments in the organisational structure with Frank Raymond joining 'TE' Williams as a Deputy Director in 1963. Plant and Soil Sciences, headed by 'TE' Williams, comprised the Departments of Herbage Agronomy (Joe Green), Plant Physiology (Owen Jewiss), Ley Agronomy ('TE' Williams), Extra Mural (Ken Baker) and the Microbiology Section (Erna Grossbard, located at Liverpool University), whilst Animal Sciences, headed by Frank Raymond, comprised Biochemistry and Animal Nutrition (Frank Raymond), Grass/Animal Ecology (Colin Spedding), Animal Agronomy (Frank Alder) and Biometrics (Leslie Chapas).

*An 'informal garden party' at Hurley in 1964*

**Social Life at Hurley in the 1950s**

The Institute recruited a lot of assistants during the late 1950s. Most of us were in our late teens or early 20s; we were away from home living in digs or bedsits and the Social Club at Hurley was an important part of our social life.

I remember going to the cinema in Maidenhead. The last bus went very early so we would watch the end of the film first, then watch the beginning and then run for the bus.

If there was a dance nearly everyone went. There was the Tennis Club, the Photographic Society and the Jazz Club which put on dances and trips to concerts. These activities threw us young people together and resulted in many successful Hurley marriages. I think they lasted because we were all very similar people in terms of education and tastes and we were friends. A few of us lived in Marlow and would go to the cinema or the pub as a group before going out as a couple.

For several years there was a Summer Fete so that wives and children could come along and the director William Davies and his wife invited many of the staff to their home to get to know them socially.

*Valerie Lockyer, Hurley 1957–69*

This period established GRI as the premier grassland research centre in the world. A key to this success was the close integration of soil, plant and animal studies in the same Institute and the assessment of the impact of management variables in terms of animal production rather than herbage production. The impact of the research was increased by a philosophy that encouraged very close links with the advisory service and with farmers (Open Days often attracted 1500–2000 visitors). As well as experiments at Hurley, research was carried out off-station, particularly by the Extra Mural Unit, established in 1956 and to become a full department in 1958.

A steady stream of senior grassland scientists came from overseas to work as visiting scientists at Hurley and the Hurley model was increasingly adopted in other countries. The external reputation and impact was further enhanced by the leadership provided internationally by senior staff. The International Grassland Congress was held in Reading in 1960. Frank Raymond was the General Secretary and many of the lead papers were given by GRI staff. This is still widely recognised as one of the most influential meetings in the development of grassland science. The European Grassland Federation resulted largely from the initiative of William Davies, with the Federation being formed at a symposium held at Hurley in 1963. William Davies became the first Honorary Life President of European Grassland Federation at that meeting (an honour also bestowed on Roger Wilkins in 2002).

This heavy involvement with international grassland science was continued through the life of GRI and its successors. There were often as many as 15 senior visiting scientists spending extended periods at Hurley at the same time. This added much to the Institute and to spreading its influence more widely. Major contributions were also made by research students working for their PhD degrees. Many of these students were also from overseas and rose to leading positions in their own countries.

This period saw long-term experiments on the place of grassland in arable rotations come to fruition. Ley farming, with the alternation of grassland with arable cash crops, had been a key feature of the philosophy developed by Stapledon and Davies, and Hurley was an ideal location for work on that topic. There was a major thrust to extend the grazing season for the full 12-month period. This included research on the deferred grazing during the winter of grass grown in the autumn (foggage) and the use of forage brassicas for winter grazing. There was much interest in winter-active grasses and much attention was given to tall fescues derived from North Africa. Unfortunately, the collected material suffered badly in the very severe winter of 1963, leading to the abandonment of this line of research. Perversely, one of the varieties bred at Cambridge as part of this project was subsequently 're-exported' to Morocco and was a successful variety!

There was an intensification of work on grass quality and utilisation. Research at both Drayton and Hurley did much to identify the importance of digestibility in determining animal performance potential from grassland and the general patterns of change in digestibility with maturity, season and conservation method. This was done through feeding studies with sheep that required large quantities of feed. The real breakthrough was the development by Mike Tilley and Ron Terry of an *in vitro* technique that provided an excellent prediction of digestibility in the animal. This was arguably the GRI's biggest single contribution to grassland science and application. Research on parasite control with grazing sheep was progressed during this period, despite severe concerns from some members of the veterinary profession that this area of work was not appropriate for a grassland institute! A key tool in this research was the establishment by Colin Spedding of a substantial area of grassland that was maintained free of gastrointestinal parasites by isolation procedures. This facilitated studies on grazing management unconfounded with parasite burden and the research identified appropriate management procedures for parasite control.

**Impressions of Hurley**

A few days after arriving in England to study for my PhD at the Grassland Research Institute (as it was then) at Hurley, I was placing an order at the delicatessen in Waitrose in Marlow. "Ha", exclaimed the man behind me in the queue, "with an accent like that you'd better keep a low profile!" England had just won the Ashes series, and I was being mistaken for an Australian! Shortly after, I bumped into the same gentleman in the corridor at Hurley: it was David Beever, cricket tragic, and one of the many internationally renowned scientists that built upon the already world class reputation of Hurley. (Ironically, I now live in Australia and hold dual Australian and New Zealand citizenship).

It was this reputation that drew me to Hurley when I was lucky enough to be able to study for my PhD overseas. When it came to choosing where to study, it was Hurley first among all options, by quite a margin. Roger Wilkins and Tony Parsons smoothed the path, for which I am eternally grateful.

Professionally, my time at Hurley altered my view of grassland science profoundly. I learnt an awful lot at Hurley, but perhaps the most important thing I gained was a better ability to think critically about the issue at hand, and how best to tackle it experimentally. Mike Robson, my supervisor, can take the credit for this: his wonderfully precise and elegant way of looking at plant function was a revelation. Hurley was teeming with such people, many of whom helped me to become a better scientist, probably without ever knowing it.

Personally, living in the Thames Valley was magical. I had to pinch myself while cycling from Marlow to Hurley along the Thames tow path. Tennis on the courts at Hurley, twilight cricket on village greens followed by Brakspears at the Dew Drop or Black Boy, and the staff Christmas lunches are enduring memories. Many friendships made at Hurley also endure, despite the expanse of time and geography.

The decision to close Hurley was announced about the time I finished my PhD. I was shocked that an institution so rich in talent, facilities and history could be so easily abandoned. But also thankful to have been a tiny part of it.

*David Chapman, post-graduate student, Hurley 1986–89, now Professor, University of Melbourne*

**Hurley: The Grassland Club**

Complex organisations such as the Institute employed a wide range of staff from many walks of life and it was the role of the Grassland Club to arrange events allowing the opportunity to meet and socialise. In this, the Club was remarkably successful and well supported by all staff.

Tennis, road running, bridge and putting were regular lunchtime activities but the major events were organised by the Grassland Club and among these the Christmas Dance was pre-eminent. Always well attended and with a band and disco to cater for all tastes this highlight of our social calendar was usually enhanced by some home grown entertainment, though one year a less-than-appropriate bought-in 'comedian' came very close to being thrown out.

Other mid-year events included debates, river trips, dances and discos at least one of which was held al fresco in High Wood, which overlooked the Hurley complex. The Summer Festival provided an opportunity for staff and their families to participate in a number of frivolous activities suitable for all ages.

Following completion of the new Trehane Building a former lecture room was released as a staff room. The Club raised funds for furnishing this room with various events and an auction following generous donations from staff, one of which was a Daimler shooting brake. In due course some comfortable and rather brightly coloured seating was purchased which was much in tune with the optimism of the time.

*Nigel Young, Hurley 1966–81, North Wyke 1981–97*

The establishment at Hurley by Frank Alder of a series of self-contained farmlets provided an important tool for assessing the effects of management variables such as grass species on animal performance. This work and the extra-mural studies of Ken Baker and Dick Baker did much to encourage the systems approach developed further in subsequent years and to define more efficient grass-based systems of production.

Research on the role of grassland in both poultry and pig production had been carried out at both Drayton and Hurley, but work on pigs ceased in 1957 and on poultry in 1960.

## 1964–77: the Woodford years

Ken Woodford succeeded William Davies as Director of GRI on 1st October 1964. At that time ARC still administered their Institutes as either 'plant' or 'animal' and GRI clearly did not fit that pattern. Thus Ken Woodford was appointed with a brief from ARC to shift the Institute's work to a more basic and less applied level and to reduce or eliminate animal research. He made progress with the former, but after a short period at Hurley recognised the great importance of grass quality and utilisation by animals and of integrated studies. He thus proceeded to increase the attention given to animal research, despite his brief from ARC, a policy vigorously supported by the Governing Body.

*Retirement party for William Davies, 1964*

*The Research Building at Hurley in 1964*

There were massive changes during this period in terms of staffing, facilities, finance and research direction. Total staff numbers increased from about 180 in 1964 to 309 in 1972, when a plateau was reached.

A Divisional structure was set up and in 1967 there were Divisions of Soils and Plant Nutrition (Lloyd Jones), Botany (Ted Leafe), Agronomy ('TE' Williams), Animal Science (Frank Raymond) and Ecology (Colin Spedding). A Permanent Pasture Group was set up in 1971 and headed by Tom Forbes. With Frank Raymond taking up the post as Deputy Chief Scientist at MAFF, Colin Spedding moving to the Chair of Agricultural Systems at the University of Reading and the retirement of 'TE' Williams, there was progressive change in organisational structure to give in 1976 some seven Departments and three Groups. The Departments were Soils and Plant Nutrition (Lloyd Jones), Agronomy (Roger Wilkins), Botany (Ted Leafe), Feed Evaluation and Ruminant Nutrition (Dennis Osbourn), Animal Husbandry and Production (Dick Baker), Systems Synthesis (Dick Brockington) and Biometrics (Leslie Chapas). The Groups were the Permanent Pasture Group (Tom Forbes), the Grassland Entomological Group (Bob Clements) and the Grassland Veterinary Group (Tony Austin).

**Radar Hut Days**

When the Hurley site was taken over in 1948, the only building on site was a T-shaped single-storey building erected during the 1939–45 war as a radar station. Initially, this building was mainly occupied by Ley Agronomy staff and Institute administrators.

Staff moved to a new building in 1955. However, in the mid 1960s, with staff numbers increasing, the Radar Hut was occupied by the Ecology Division under Colin Spedding. The Radar Hut was about half a mile from the main building, situated at the top of an escarpment overlooking the Thames valley. On entering the Radar Hut, there was a large room with a big table where staff took their coffee breaks. Off this room was a smaller common room where a keen group of card players could be found at lunch times. Some South American PhD students were particularly good card sharps. Sunbathing was a popular pastime in summer and one particular individual would sleep all afternoon if not woken.

Although part of the Institute, 'Ecology' was almost an autonomous outpost. A regular transport service existed between the Radar Hut and main building transporting staff, goods and mail between the two sites. A statistician visited on Friday afternoons (mainly for tea and cake). A courier service to use the Atomic Energy's Harwell computer was established. A wooden hut extension was added and I recollect these offices being unbearably hot in summer and freezing in winter.

These days of 'splendid isolation' ended with the completion of the Trehane extension to the main building and staff going 'down hill again' in the mid 1970s. The Radar Hut was then converted to become the Works Service Centre.

*Peter Penning, Hurley 1963–90, North Wyke 1990–97*

The first part of this period saw budgets for ARC increasing by around 10% per year in real terms and GRI shared in this increased support. There was, however, developing increased concerns about research strategy at a national level and in particular the relationship between the requirements perceived by MAFF and the emphasis on more basic research being encouraged by ARC. The Rothschild Report *A Framework for Government Research and Development* published in 1971 enunciated the customer-contractor principle, specifying that the organisation (e.g. Government Department) requiring research should contract with a provider (e.g. Institute or University) to carry out the necessary research. This principle was accepted by Government and over half of the budget of ARC was transferred to MAFF, with this process completed by 1975. MAFF to a large extent acted as a proxy for the agricultural industry and the

Joint Consultative Organisation was set up to advise MAFF (and others) on research priorities.

Initially the nature of the work in the Institute changed little, with MAFF 'buying up' large chunks of ongoing programmes and funding around 70% of GRI research. Scientists were generally happy that their work was deemed to be required by the customer (MAFF) and had been commissioned. However, MAFF funding became progressively more aligned to Ministry policy, rather than the requirements of the agricultural industry. The flexibility possible within MAFF-funded research was reduced and competition for MAFF funds progressively increased.

There were major expansions in GRI facilities during this period. There was new housing for cattle and sheep, including a dedicated lamb rearing shed and facilities for suckler cows. The Visiting Group, reviewing the Institute for the Research Council in 1968, approved plans to start research using dairy cows and a new facility was commissioned in 1970. A high-temperature grass drier was installed in 1966 and a second drier and grass processing equipment in 1968. Facilities for experimental silos were set up. A new wing was built on the research building in 1968 and new glasshouse and controlled environment facilities established in the same year with an additional glasshouse and header house in 1970 for plant nutritional studies. An operating theatre, animal surgery and veterinary laboratory were built in 1974. The land facilities were increased by the lease of 50 ha at Warren Farm, near Wantage, to extend research with suckler cows.

*For many years a 'perk' of working at Hurley was potatoes for staff at a low price. These were grown on-site for experimental purposes. This was eagerly awaited and occurred two or three times during the winter with a strict ration of one bag per person*

*Champion ploughmen from Hurley*

The Silver Jubilee in 1974 of the foundation of GRI also saw a major extension in facilities at Hurley with the completion of the Trehane Building and the William Davies Hall. The Hall much enhanced conference facilities, whilst the Trehane Building provided much needed office accommodation and facilitated re-location of the Ecology Division from the Radar Hut (their base from 1968) to the main complex. The jubilee was celebrated by the production of a Silver Jubilee Report that reviewed achievements over the 25-year period, the opening of the new buildings by Sir Richard Trehane, Chairman of GRI Governors, a symposium on 'British Grassland – the next 15 years' and Open Days.

The main features of research during this period were the shift in much of the soil, plant and animal work to a more basic approach to increase our understanding of the processes determining nutrient uptake and growth by grasses and legumes and the determinants of forage quality, intake and nutrient utilisation by ruminants. Major emphasis was put on improving the efficiency of forage conservation with large programmes on grass dehydration and processing and on silage, with emphasis on effects on nutritive value. A vigorous programme on grazing was carried out, but with the emphasis on improving the efficiency of grazing during the main growing season, rather than extending the grazing season. Research on grass quality expanded to include basic studies on the structure of plant cell walls in relation to their digestion by ruminants.

Despite the shift to more basic research, there was much emphasis on the need for a holistic approach and to the evolution of new grassland systems. It was realised that progress in computers and the development of computer simulation languages presented new opportunities for producing mathematical representations of important biological processes and, at a coarser level, of systems of production. Under Colin Spedding's guidance the Institute rapidly became a leader in this area. A strength of the GRI approach was to explore potential systems theoretically and then to test some of the predictions in production systems carried out at a reasonable scale of operation. The ability to tackle systems was enhanced by the recruitment of Bill Roberts, the first economist to join the staff of an agricultural research institute in the country.

Ken Woodford continued the pattern set by William Davies in encouraging close contact with the National Agricultural Advisory Service (NAAS, later succeeded by the Agricultural Development and Advisory Service (ADAS)) and with the farming industry. Interaction with NAAS was increased by the location in 1967 of a member of NAAS staff at Hurley as a Grassland Liaison Officer (this appointment was continued until 1986).

Another important initiative was the founding of the Permanent Pasture Group. Ken Woodford realised that despite most of the country's grassland being permanent, and rarely if ever being resown, practically all research, at least in the lowlands, was conducted with sown grassland. He sought and obtained collaboration from ADAS and established the Joint Permanent Pasture Group. The main work of the Group was to be the conduct of a National Farm Study to quantify levels of utilised production on farms with a high proportion of permanent grassland and to identify reasons for variation in production between farms. This study would help orientate any subsequent research on permanent grassland.

### 1977–82: the Lazenby years

Following the retirement of Ken Woodford in March 1977 and an inter-regnum during which Ted Leafe was Acting Director, Alec Lazenby took up his appointment as Director in August 1977. This period was characterised by increased emphasis on permanent grassland, which resulted in the acquisition of North Wyke for the Institute in 1981, increased collaboration with the University of Reading, including the launch in 1980 of an MSc course in Grassland Science run jointly by the Institute and the University, and increased research on legumes. Research on denitrification and other nitrogen losses from grassland was started in 1979 by John Ryden. This was the beginning of what became a major thrust of research in the Institute on the environmental implications of grassland farming. Links with ADAS and the farming industry continued to receive emphasis and the GRI Associate Members scheme, targeted towards leading farmers, was launched in 1980.

Overall staff numbers were remarkably constant over this five-year period, being 307 in 1977 and 306 in 1982, although numbers at Hurley fell, with 38 staff being based at North Wyke in 1982. There was some consolidation in the organisational structure in the Institute with establishment of the Animal Nutrition and Production Division led by Dennis Osbourn, the Permanent Grassland Division (Roger Wilkins) and the Biomathematics Division (John Thornley). The Botany Department was renamed as Plant and Crop Physiology (Ted Leafe) and the Soils and Plant Nutrition Department remained under the leadership of Lloyd Jones. The Agronomy Group was led by Joe Green.

*Staff at Hurley, 1981*

Funding from ARC was relatively stable during the early part of this period, although it was reduced in 1982. The Institute was, however, well supported by MAFF. There was still flexibility within the MAFF commissions and world-class research programmes could be developed on MAFF funding. The Institute was also successful in attracting funds from the European Union for multi-national programmes.

The National Farm Study highlighted large variation between farms in utilised output from grassland and substantial difficulties in achieving efficient animal output from grassland in wet conditions. The predominance of permanent grassland in the country and the reduction in area of grassland in the relatively dry conditions typical of Hurley were realised to limit the relevance and applicability of some of the applied research carried out at Hurley. A major feature of the Institute submission to the Visiting Group in 1979 was the case for a sub-station in an area of higher rainfall with predominance of permanent grassland. This case was accepted by the Visiting Group and supported by MAFF. After a search for a suitable location in either NW or SW England, a total of 250 ha at North Wyke and Rowden Moor, part of the adjacent Rowden Manor Farm Estate, was purchased by the Crown Estate Commissioners and leased to GRI for a 25-year period from September 1981. This arrangement was facilitated by Oscar Colburn who was both Chairman of GRI Governors and a Crown Estate Commissioner. The new Station was officially opened in October 1981 and a commemorative plaque was unveiled by Lord Selborne, the then Vice Chairman of ARC.


*Staff at North Wyke, 1982*

The land was ideally suited to the requirements of the Institute. An added bonus was the fact that North Wyke had been an experimental farm of Fisons Fertilisers from 1955 to 1981. Much excellent grassland research had been carried out by Patrick Shaw, John Brockman, Meg Wolton, Ian Richards and their colleagues. This was a farm with good records and a 'lock stock and barrell' takeover by GRI purchased all the animals, the library and some laboratory equipment. In contrast to the North Wyke land, the grassland on Rowden Moor had a background of very extensive management and, in agricultural terms, poor botanical composition. Some of the farm staff previously employed by Fisons joined GRI and this gave good continuity. The initial staff build up at North Wyke was complete by 1983, with 21 staff transferred from Hurley, 11 new appointments of scientists using vacant positions redeployed from Hurley, five staff transferred from Fisons and a further eight new administrative and farm staff appointments. North Wyke was dependent on Hurley for almost all laboratory support and there was close collaboration between the two sites particularly in research on soils and grassland pests and diseases. Much of the early research from North Wyke was carried out in collaboration with ADAS.

There was much work to be done in improving the infrastructure, particularly of Rowden Moor, and an urgent need to improve the facilities


*The Manor House North Wyke*

**North Wyke: Early Days**

From a state of the art research facility at Hurley with some 40 years of investment and development behind it to a 400-year-old, partly residential manor house with little more than a cowshed was a culture shock to say the least. Staff were remarkably pragmatic about the lack of facilities and rapidly adapted and improvised to get research under way with the first experiments starting within a week of taking over the property. Having moved in October 1981, one of the first items to be replaced was the antiquated and unreliable coal-fired heating system. Radiators actually froze in that first winter!

What the site lacked in amenities, however, it made up for in character and everyone was charmed by the ambience of the Manor House and tolerant of the never-seen, but often heard, resident ghost. Life was about constant change as offices were occupied, vacated for refurbishment and modified to suit other uses.

On the farm, most equipment had to be replaced, buildings brought up-to-date and a new entrance drive concreted for the first time. In many instances the farm staff made these major changes. This was while undertaking 30 miles of fencing in the first year, creating roads and installing field drainage, while accommodating the everyday requirements of running the farm. Life wasn't without its challenges but it was satisfying to get the benefits of the changes that were made.

*Nigel Young, Hurley 1966–81, North Wyke 1981–97*

for dairy cow research, but a new dairy building was not constructed until 1983. A key early development was the establishment in 1982 of the Rowden Drainage Facility by Ted Garwood in conjunction with ADAS. This unique facility provided 12 hydrologically isolated plots of 1 ha each, with six being drained and six undrained. Two further plots were later incorporated into the facility. Whilst the early emphasis was on the effect of drainage on grass and animal output and water balance, this facility rapidly became used principally for studies on nutrient movements and water quality that did much to establish the uniqueness and international reputation of North Wyke.

The major facility developments at Hurley related to more basic studies on animal nutrition, with cattle calorimeters being commissioned in 1981 followed later by new dairy cow and beef cattle digestion and metabolism facilities. With the increase in land availability through acquisition of North Wyke, the lease on Warren Farm was terminated in 1982.

## 1984–88: GRI to IGAP, the Prescott Years

*Tour of experiments, North Wyke, 1983*

Following the return to Australia of Alec Lazenby in 1982, Dennis Osbourn was Acting Director of GRI until John Prescott took up the post of Director in January 1984. This was a particularly difficult and turbulent period for the Institute and for the whole of the Agricultural Research Service, with rationalisation and restructuring to adjust the Service to new requirements and generally reduced levels of funding. The first change was the amalgamation of GRI with the Animal Division of the National Institute for Research in Dairying (NIRD), Shinfield, to form the Animal and Grassland Research Institute (AGRI) in April 1985. Although some facilities were retained at Shinfield, there was relocation to Hurley of staff concerned with ruminant nutrition and lactation (in 1983) and with endocrinology and animal physiology (in 1987). AGRI was succeeded in June 1986 by the Institute for Grassland and Animal Production (IGAP). IGAP became one of eight generally commodity-based

Institutes in the Agricultural and Food Research Service. A total of 22 separate Institutes in 1983 had been consolidated into eight large Institutes by 1986. The rationale for consolidating related work within one Institute was sound, but the geographical dispersion of IGAP presented substantial management problems, which were accentuated by declines in funding and requirements to reduce staffing levels. IGAP was based at Hurley, but incorporated the WPBS at Aberystwyth, the research on poultry nutrition and environment at Roslin, near Edinburgh, previously part of the Poultry Research Centre, as well as the former AGRI facilities at North Wyke and Shinfield. The total number of staff at the formation of IGAP was 700.

The Annual Reports for 1983/4 and 1984/5 refer to the freezing of a large number of vacant posts (45 in 1984/5) and staff departures through voluntary redundancy. There were substantial cuts in the block grant from the Agriculture and Food Research Council (AFRC) and in funding from MAFF. There was much effort and considerable success in generating funding from contract research for industry. In 1987 for IGAP as a whole, 56% of funding came from MAFF, 28% from AFRC and 16% from contracts (including Open Contracts from MAFF). The proportion of income from contracts for research at Hurley and North Wyke was though considerably lower than for the animal nutrition and production work based at Shinfield and Roslin. There was during this period not only losses through staff taking voluntary redundancy, but also from 1985 through compulsory redundancy. Staff numbers at Hurley fell from 258 in 1983 to 221 in 1988, despite the relocation to the site of approaching 80 staff previously based at Shinfield. At North Wyke, numbers fell from 48 in 1983 to 42 in 1988. Dennis Osbourn retired in 1984 and Ted Leafe in 1985, both had been Acting Directors of GRI. A Divisional structure was re-introduced with the Grassland and Ruminant Division based

**The Ron Terry Tournament, 1983–2008**

Hurley was always blessed with good facilities for tennis, with two hard courts and two grass courts. For many years the most frequent player (and one of the best) was Ron Terry. To mark his forthcoming retirement in 1984 staff presented a cup for 'The Ron Terry One Day Open Mixed Doubles Championship'.

The tournament was traditionally played on the last Saturday in July and remarkably, completed on the day, every year, usually in fine weather. After a few years a competition format evolved which became the spirit of the 'Ron Terry'. The 16 pairs played a 'round robin' for seeding and then all pairs played a quarter, semi and final match with prizes for the 'Cup Final' and the other seven finals.

A consequence of keeping all players involved all day meant that more family and friends started to come for the day and bring a picnic and enjoy the sunshine. The tournament was well established when the Hurley site closed, so many of the players who relocated to North Wyke and Aberystwyth continued to travel back for the tournament which was now being played on the superb grass courts at Reading University. The 25th and final tournament took place on the last Saturday in July 2008 at Wellington College where Ron, in addition to playing, presented the cup and prizes as he had done most years.

More than 150 players from GRI, students, visiting research workers, family, friends, and from Thames Valley clubs took part in the tournaments, with players with GRI connections winning the trophy on 15 occasions.

*John Paradine, Hurley 1973–91*

*Ron Terry presenting prizes at the 2002 tennis tournament, Reading University* at Hurley (Roger Wilkins), Pig and Poultry Division based at Roslin and Shinfield (Colin Fisher) and Plant Science Division based at Aberystwyth (John Stoddart). The Departments within Grassland and Ruminant Division were Plant Nutrition and Growth (George Ryle), Grassland Production and Utilisation (Roger Wilkins), Ruminant Nutrition and Metabolism (David Beever), Endocrinology and Animal Physiology (Isabel Forsyth) and Cattle and Sheep Production (Dick Baker). John Prescott did much to encourage close linkage between applied and more basic research and to maintain a multidisciplinary approach to grassland and animal research. He and his senior colleagues were very active in seeking synergies between the different Stations in the Institute. Probably one of the greatest achievements during this period was the development of an extremely strong programme in ruminant nutrition, bringing together strengths from the former GRI and NIRD in an integrated programme led by David Beever.

Another feature of this period was the increased emphasis on the environmental implications of grassland farming following the start made by John Ryden at Hurley. Research at Hurley and North Wyke highlighted the large leakage of nitrogenous compounds to water and to the atmosphere and the large effects of management and soil conditions on the magnitude of loss.

*Staff relaxing in the garden at North Wyke*

There was considerable change and refurbishment to laboratories at Hurley during this period, principally to accommodate research on nutrition, microbiology and animal physiology based previously at Shinfield. A small extension was built to the Sanders Building for offices for the Director and Secretary.

At North Wyke there was consolidation of the programmes started in 1981–83. The main emphasis continued to be on efficiency of grassland production and utilisation in conditions of high rainfall and heavy soils, but increased attention was paid to nutrient use efficiency and nitrate loss to water, with the Rowden facility being of crucial importance.There was progressive improvement in infrastructure, but no major facility developments.

John Prescott left IGAP in 1988 to become Principal of Wye College, University of London.

### 1988–93: IGAP to IGER, the Stoddart Years

John Stoddart directly succeeded John Prescott as Director of IGAP and led the further restructuring of the Institute. The progressive implementation of the Government policy to withdraw funding for near-market research announced in 1987 led to a prospective loss of 26% of MAFF income over a three-year period. This, coupled with reduction in AFRC funding for crop and animal research, led to severe financial pressures. AFRC requested a plan that would involve reduction in the number of sites in the Institute and a structure that would facilitate increased emphasis on the environmental implications of grassland farming.

This was a necessary but extremely painful process. The result was a decision, announced in December 1989, to form the Institute of Grassland and Environmental Research (IGER) from April 1990. Research at Roslin, formerly in IGAP, was to be continued within the Institute of Animal Physiology and Genetics Research and research on endocrinology and animal physiology was to be excluded from the remit of IGER. Some of the staff in this area were transferred to Babraham and other positions were lost. The earlier decision to close pig research in the Institute was confirmed and the Pig Department at Shinfield closed in 1991. IGER was to be based at Aberystwyth and maintain sites at Bronydd Mawr, near Brecon, and North Wyke. The Hurley and Shinfield sites were to close by April 1992. Additonal land and animal facilities would be provided by the acquisition of Trawsgoed, near Aberystwyth, formerly an ADAS Experimental Husbandry Farm. Considerable funding was provided for staff transfer and for new facilities at Aberystwyth and North Wyke for programmes re-located from Hurley and Shinfield.

These decisions clearly had severe implications for staff based at sites scheduled for closure. Staff in non-mobile grades (broadly speaking most of the technical, administrative and farm staff) had the right to a redundancy package or to be considered for transfer to posts at other sites in IGER (and AFRC more widely). Staff in mobile grades (mainly research initiators) were to be transferred to other sites in IGER, if the programmes they were involved in were to be sustained. If this did not apply, then the staff could apply for

**Closing Hurley**

The closure of the Hurley site was a protracted process as some research and some staff were to transfer to other sites and existing commissioned programmes had to be concluded. It began in 1989 and was not completed until August 1992.

For many staff, closure began when they were asked to provide a comprehensive list of all furniture, equipment and machinery under their care. The consolidated inventory then became the basis for allocating items for use elsewhere or for sale. At first changes were imperceptible but as the pace of redundancies quickened, empty offices appeared, services were cut back and farewells to friends and colleagues occurred with ever-increasing frequency. On the farm there was a run-down of research activity, the sale of the dairy herd and a change to commercial farming, accompanied by many staff redundancies.

For four months after the official closure of Hurley the task of clearance fell to six members of staff. Everything was removed to central storage areas, unwanted dry- and cold-stored samples disposed of and papers sorted through prior to saving or shredding. Removal lorries made some 30 journeys to either North Wyke or Aberystwyth, and other organisations collected many items. Finally, at the end of July everything remaining was sold at auction and closure completed.

After closure, the land was let until sold much later. The fields behind the Institute and to the left of Honey Lane went to Hurley Farms. Juddmonte Stud Farms acquired those to the Hodgedale side of the bridleway and Michael Shanly Homes bought the remainder. All buildings on the farm site were removed and a country estate was created. A new entrance to this estate was made off the Henley road, opposite Shepherds Lane. A grand, unoccupied, country house now stands on the farm buildings site and a large lake exists in the fields running to Ashley Hill. The main Institute buildings and grounds have been successively owned by a number of firms who all ultimately decided not to proceed with renovation or rebuilding. Property developers finally decided to knock down the old buildings and replace them with an attractive modern office block. Sixteen months on from completion, they are still looking for a tenant.

*Dick Baker, Hurley 1960–92*

**BBSRC Sports Days**

An annual sports day was a feature from the 1970s. Initially it was confined to Institutes in the Thames Valley, but later was widened to involve all Institutes and Stations in the Research Council.

The BBSRC sports day always played a large part in North Wyke life. Despite the size of North Wyke, we tended to have the highest proportion of staff attending. North Wyke always fielded teams in as many events as possible and developed a tradition of turning the event into a three-day camping festival. Sometimes this was not such a good idea as revelries on the night before the events had a detrimental impact on the results. Perhaps if the all-star football team had rested the night before, then the disappointment of being beaten in the final by a 'golden goal' would not have been so great! Home advantage has always played a part, so that when it was the turn of North Wyke to host the event in 1999, the instructions for the cycle race were to 'cycle along Station Road until you get to the Army Camp' forgetting to mention it was uphill all the way. Needless to say, 1999 was our finest hour with North Wyke winning the overall and the 'Small Institute' prizes with a proud Roger Wilkins, fresh from a second place in the tennis, being able to present the trophies to his own staff.

*Phil Murray, Hurley 1983–92, North Wyke 1992–*

consideration for redeployment to other posts in IGER and elsewhere in AFRC or be made redundant. It took some months before the complement of the restructured Institute and the siting of continued programmes was determined, prolonging the uncertainty for staff. In the event, some 16 staff transferred from Hurley to Aberystwyth, 18 to North Wyke, four to Babraham and two were relocated as IGER staff to Reading University. A total of 137 Hurley staff left the Institute through redundancy or retirement, 18 by resignation and eight at the termination of short-term contracts.

Research on ruminant nutrition and production, feed quality, microbiology, plant nutrition and statistics was re-located to Aberystwyth and with substantial reduction in the magnitude of work in the first two areas. Interestingly, the animal calorimeters were deemed not to be required and were transferred to Reading University and Hillsborough, Northern Ireland, where they continue to be fully used. Meanwhile, research on soils, farm wastes, grazing ecology, modelling and grassland pests and diseases was relocated to North Wyke and fully sustained. Most of the research leaders and a large proportion of support staff in programmes to be transferred to North Wyke stayed in the Institute and moved to Devon, whilst a considerable number of scientists in the animal areas resigned from the Institute or were made redundant.

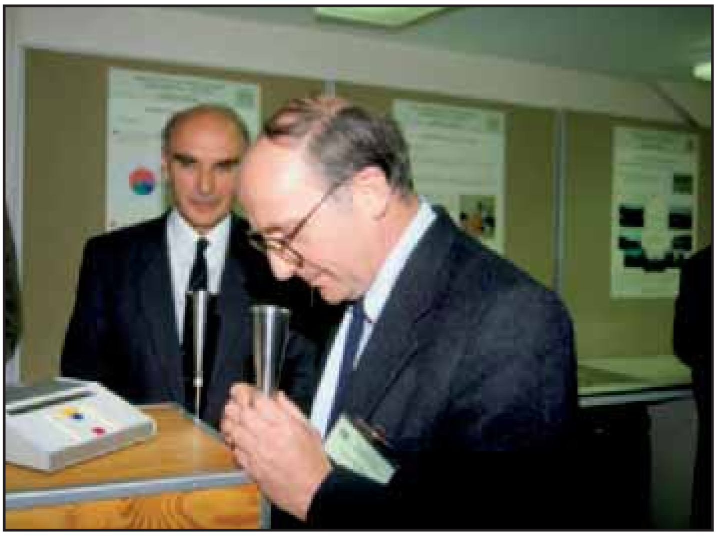
The organisational structure was changed to reflect these changes in the remit of the Institute with two Research Divisions: Plant Science (David Wilson) and Ecology and Land Use (Roger Wilkins). All staff based at North Wyke were in the Soils and Agroecology Department (Roger Wilkins) with the following Groups: Agronomy and Ecology (Roger Sheldrick), Invertebrate and Fungal Ecology (Bob Clements), Farm Wastes (Brian Pain), Ecophysiology and Grazing Behaviour (Tony Parsons and Peter Penning), Soil Science (Steve Jarvis) and Modelling and Statistics (Jim France).

*Lord Selborne planting a tree at the opening of the Selborne Building in 1992: Roger Wilkins appears to have got in on the act and is holding the ceremonial spade that had been used to cut the first turf on the site of the new research station at Hurley in 1952*

A booklet was produced in 1989, *'The Grassland Research Institute 40 Years On'*, to highlight achievements during this period and to outline current research.

A characteristic of John Stoddart's leadership was his emphasis on high quality innovative science. He strengthened the Institute in molecular biology, but also encouraged holistic approaches to agricultural and environmental issues and consideration of the wider countryside. In the Annual Reports for 1991 and 1992 he noted the increased importance of landscape and leisure and for grassland utilisation for purposes other than animal production. He envisaged a future mosaic of land uses and drew attention to the importance of management to maintain or enhance botanical diversity.

Many of these areas were to be developed in future years at North Wyke. This period at North Wyke had two distinct phases: one of contraction and one of expansion. Some 35% of the funds from MAFF programmes at North Wyke were lost from 1989 to 1991 through implementation of the near market policy. Research on animal production systems was particularly hard hit and resulted in staff redundancies. The number of staff at North Wyke fell from 50 in 1987 to 36 at the end of 1989. With plans being prepared for Institute restructuring, there was considerable uncertainty about the future. However, the decision to retain North Wyke heralded a period of major expansion with staff numbers increasing to 85 in 1993. In addition to staff relocated from Hurley, several new appointments were made, particularly at the post-doctoral level, with these new scientists having a large impact in research in the subsequent years.



*Lord Selborne and John Stoddart with olfactometer in Odours Laboratory at North Wyke*

There was intense activity in planning the new research building at North Wyke during 1990. This was to provide laboratory facilities for all staff at North Wyke and to give meeting room and canteen facilities. It was a substantial challenge for this to be achieved close to, but in good accord with, the Grade 1 Listed main building. The new building was fully occupied by January 1992, within 25 months of the decision on Institute restructuring. It was formally opened in May 1992 by Lord Selborne and named after him. Glasshouse facilities were also constructed at this time.

In 1993, office accommodation was increased by the partial conversion of part of an old cob barn to offices. Expertise on site was increased by the location at North Wyke of Tim Harrod, a senior soil scientist from the Soil Survey and Land Resource Centre and of David Hogan from the

> **A Norwegian in Devon: Perspectives from a Visiting Scientist**
>
> The challenges of grassland management are not quite the same in different European countries. I have always been of the opinion that there is a lot to learn by visiting other countries and by participating in international conferences. I have on two occasions stayed a year at research institutes in Europe. My first stay was in Switzerland, where I had the opportunity to work on a specific subject; biological nitrogen fixation in white clover. On my second stay, at North Wyke in 1997–98, I had a much broader approach. I wished to work with several of the research groups at the Station in order to learn about research methods and results. All members of the staff had a positive attitude to me as a visiting scientist, and they were helpful and did not seem to be tired of all my questions on research issues, or on social and political conditions in Great Britain. Much of the discussion occurred during breaks in the coffee room. My participation in the football team at the Station also resulted in valuable relations with members of the staff. I am proud to have been a part of the team that reached the first football final at Sports Day in the history of North Wyke. The experience of the whole family by staying a year in a small town in Devon was invaluable.
>
> *Lars Nesheim, Visiting Scientist, North Wyke 1997–98, now Senior Researcher, Norwegian Institute for Agricultural and Environmental Research*

Royal Holloway Institute of Environmental Research, arrangements that continued for more than ten years.

## 1993–2007: The Pollock Years

On the retirement of John Stoddart in October 1993, Chris Pollock took up his appointment as Director of IGER. There was consolidation of changes made during the formation of IGER and Chris worked tirelessly on developing collaboration and synergy between the different parts of IGER. He was fully committed to the importance of environmental aspects and the need to develop multi-functional patterns of land use. Another feature was increased emphasis on promoting the Public Understanding of Science, with outreach to schools and to the wider community. Schools Fairs and Science Weeks have been held annually at Aberystwyth and North Wyke. Members of staff became Science and Engineering Ambassadors for schools. Public debates on wide land-use issues were held at both Institute sites.

During Chris Pollock's tenure, IGER was successful in attracting increased funding from the BBSRC, the successor organisation to AFRC, via the Competitive Strategic Grant and through other competitive funds: the proportion of funds from BBSRC increased from 28% in 1997 to 38% in 2007. Funding from MAFF and then the Department for Environment, Food and Rural Affairs (Defra) was, however, under great pressure with reductions in overall spend on

> **North Wyke: A Dream**
>
> My family and I were fortunate to spend several years at North Wyke whilst working for my PhD. It was an unforgettable experience that has forever marked us all with a 'before and after'. These were times where research brought together key figures in an experimental station, and me as a student involved in a project, felt part of it. The everyday environment was great: good relationships mixed with the tranquillity and the hard work. Coffee time and delicious lunches, were good moments for conversation. I can't forget the people from whom I received great support, which from the beginning were very kind and honest, helping us feel confident in a world so far away from our customs. Together with work, there was a great social activity, darts and bowls groups, table tennis, parties and invitations to great homes and unforgettable musical moments. Later, in Chile, many of the contacts made allowed the organisation of technological trips to England and help in the development of research in Chile with several staff from North Wyke visiting Chile and Marta Alfaro and Francisco Salazar from my Institute in Chile coming to do post-graduate work at North Wyke. These contacts remain active despite time and new generations of researchers and new lines of investigation. North Wyke will remain a focus of attraction for us; and has been forever in my heart and in my family. One of my sons, Paulo, is now studying for his PhD at North Wyke.
>
> *Juan Carlos Dumont, PhD student, North Wyke 1988–92, now Research Leader, INIA, Chile*

research and increased emphasis on policy-driven research. The proportion of funding declined from 59% in 1997 (MAFF) to 47% in 2007 (Defra). Over the years, funds from industry and levy bodies varied between 5–12% (tending to decline), from other government departments between 3–8% (tending to increase) and from European Union between 2–5%.

**North Wyke Schools' Interactions**

North Wyke has a long history of working with schools. The first 'North Wyke Science Fair' was held during National Science Week in 1995. Over 300 primary school children from ten local schools attended the event. Since then the event has been held every year, with a break only because of the foot and mouth disease outbreak in 2001, and the numbers attending have risen to over 500 children from up to 17 schools. Primary school children are offered few opportunities to experience science at a level which they can understand and also be shown to be relevant in the 'real' world. We therefore believe there is particular educational value in targeting this age group and the event is also much appreciated by teachers. It is particularly useful to demonstrate how basic science experiments can be carried out in school too. The other major schools-related event is 'Science WithInTent (sic)' which is held in a marquee at the Devon County Show. Here North Wyke scientists work with other groups such as SetPoint, the BA, @Bristol, Institute of Physics, the Met. Office and Universities to promote science to a wider audience. This event has run for ten years and attracts over 2000 children each year.

*Phil Murray, Hurley 1983–92, North Wyke 1992–*

Roger Wilkins retired from his positions as Head of North Wyke and Deputy Director of IGER in 2000 and was succeeded as Head of North Wyke by Steve Jarvis until his retirement in 2006 and the subsequent appointment of Les Firbank.

A departmental structure was adopted with staff at North Wyke being within the Soils and Agroecology Department until 2002, when this was renamed Soil, Environmental and Ecological Sciences Department. This department had the following teams: Behavioural and Community Ecology (Andrew Rook), Soil Science and Environmental Quality (David Scholefield and Phil Haygarth) and Manures and Farm Resources (David Chadwick). In 2007 the research was organised in two programmes; Delivering Multifunctional Landscapes headed by Les Firbank and the Cross-Institute Programme on Sustainable Soil Function (SoilCIP) managed by Keith Goulding at Rothamsted and supported at North Wyke by Phil Murray.

*North Wyke Science Fair in action*

The increase in support from BBSRC was particularly marked for North Wyke, with the contribution from BBSRC to the budget increasing from about 10% to 35%, as Institute resources were progressively deployed towards science to underpin environmental research. A particularly important development was the formation in 2005 of the SoilCIP, the first of BBSRC's cross-institute programmes, which linked more closely soil-based research at North Wyke and Rothamsted. Despite the national decline in funding from MAFF/Defra, North Wyke was successful in maintaining income from this source during the first part

*Discrete analyser at North Wyke with capability of analysing 150 samples per hour for six different constituents*

of this period. Whilst support for research on grassland agronomy and on grazing ecology was reduced and eventually led to termination of research in those areas, the prevention of pollution, the implications of climate change and the enhancement of biodiversity were all priority areas. North Wyke was extremely successful in attracting competitive funding in these areas. A key feature of North Wyke research was the development of effective collaborations with other groups, with ADAS, Centre for Ecology and Hydrology (CEH) and Silsoe Research Institute being particularly important partners. North Wyke was also an Associated Institute of the University of Reading and a Partner Organisation of the University of Plymouth. Post-graduate students at North Wyke were also registered with these and other Universities, depending on the topic. The site also benefitted from strong international contacts through leadership and participation in European Union programmes, bilateral projects with Australia, New Zealand, Japan, USA and South America and through visiting scientists and students. The North Wyke site was purchased by BBSRC from the Crown Estate in 2002, with the site leased to IGER. This was a clear endorsement by BBSRC of the importance of North Wyke's research. The 25th anniversary of the establishment of North Wyke was celebrated in 2006 with a conference and Open Day. *IGER Innovations 2006* was entirely devoted to North Wyke, describing previous and ongoing research. This year also saw the commissioning of new buildings to upgrade the farm facilities, particularly for animals. It was, however, a rather poignant period with a number of staff redundancies and the termination of research on grazing behaviour, an area within which Hurley and North Wyke had been international leaders for many years.

Staff numbers at North Wyke between 1985 and 2000 fluctuated between 75 and 98, but then fell slowly to 57 in 2007. There was, however, considerable re-positioning of research focus during this period and new areas of research were opened up. In particular, research was extended beyond the farm gate with studies increasingly considering effects of land use and land use change at the catchment level. Research on grassland biodiversity was broadened to include effects not only on plant communities, but also on birds, invertebrates and microbes. Whole patterns of land use were considered in landscape studies and linkages with social scientists, particularly in the University of Exeter, facilitated wider appraisal of the impacts of changes in grassland management and land use. A start was made to develop physical resources at North Wyke into 'research platforms' to facilitate integration of science effort into the soil-plant-animal-environment continuum.

## 2007–09: Transition of North Wyke from IGER to Rothamsted Research

The governance of the Institutes parented by BBSRC was considered by a committee chaired by Sir Brian Follett. It was concluded that it was anomalous that whilst Institutes were constituted as companies limited by guarantee and had charitable status and their own Governing Bodies, staff were employed by the Research Council which had to fund pension and redundancy costs. BBSRC decided in 2006 that Institutes should be either directly controlled by BBSRC or become independent from BBSRC. A number of options for the future of IGER were considered, but the result was a decision that the Welsh sites in IGER would become part of a new Institute within the University of Aberystwyth, whilst North Wyke would remain within BBSRC and be aligned with Rothamsted Research.  Chris Pollock retired in March 2007 and Mervyn Humphreys, as Acting Director, led the Institute through a year of preparation for change. IGER closed at the end of March 2008. The Institute of Biological, Environmental and Rural Sciences (IBERS) was formed within Aberystwyth University and North Wyke Research was launched. After a short period of direct administration from BBSRC, the merger with Rothamsted was completed in August 2009 with North Wyke Research becoming an Operational Department of Rothamsted Research. Close links are maintained with the Universities of Exeter and Plymouth, and the Peninsula Partnership for the Rural Environment (PPRE), a consortium of academic organisations in SW England.

*Roger Wilkins*

# GRASSLAND PRODUCTION

This chapter outlines agronomic and physiological research on grasses and legumes. Work at Hurley won international acclaim for the provision of new understanding of the determinants of growth of grasses and their reaction to the environment. This information has provided a basis for efficient grassland management on the farm.

## The Growth of Grass

Although at the foundation of GRI it was well known that most grasses in British agriculture were long-lived perennials, dependent on the production of tillers from the compressed basal internodes of their forbears, their developmental morphology was not well understood. A better understanding was needed and in the 1950s Reinhart Langer and George Ryle described the life history of tillers, showing them sometimes to be annual and sometimes biennial, with those that become reproductive subsequently dying. This work showed that the sward is never static and indicated critical times when tiller populations may be small and may prejudice sward persistence and subsequent production. The work at Hurley was mainly with timothy, cocksfoot and tall fescue and complemented John Cooper's work at Aberystwyth with ryegrass. It was shown that flowering is controlled by photoperiod and vernalisation and influenced by mineral nutrition and irradiance, with species varying considerably in their requirements. Elegant and definitive research was carried out despite rather primitive facilities, with home-constructed light-regime trolleys and simple growth cabinets.

*Small-plot experiment at North Wyke with Dartmoor in background*

There was early focus on the development of the inflorescence and on seed yield, with Douglas Lambert undertaking valuable research in the field. The results were not only important for the seed industry, but also for management because of the major influence of reproductive development on pattern of growth and dry-matter (DM) production and on forage quality.

Research in which Mike Robson played a major role showed that during active growth, tillers produce a new leaf every seven to ten days. Tillers carry a constant number of green leaves, normally three, so that unless harvesting is very frequent and severe there is a continual loss of leaf tissue by death and detachment. This research highlighted the importance of tissue loss to the carbon economy of the sward.

With increased understanding of the developmental morphology of grasses attention to quantitative aspects of growth increased. From the mid 1950s George Ryle, Owen Jewiss and

Mike Robson made extensive use of growth analysis techniques to study the development of individual grass plants and responses to irradiance, temperature, mineral nutrition and defoliation. This research was much aided by the acquisition of more sophisticated growth cabinets in the 1960s and by the development of equipment for measuring carbon dioxide exchange and factors influencing individual leaf photosynthesis.

## Seasonal Patterns of Production

Variation in growth rate within and between years presents a major challenge for grassland management and much early work at Drayton and Hurley described production patterns of different grass species and varieties. Drawing on earlier work by Reg Anslow, Jim Corrall and John Fenlon developed a methodology for describing seasonal patterns of production and for statistically analysing the data. This involved the use of four series of plots each cut at four-weekly intervals through the growing season, with the cuts overlapping so that in each week one of the series was cut. This facilitated calculation of a daily growth rate that represented the average of the four series of plots. This methodology has been widely adopted throughout the world. Using this approach a characteristic seasonal pattern of production was confirmed with a peak of growth in April/May. Growth at Hurley later in the year was shown to be strongly influenced by rainfall. In years when mid-summer production was severely limited by water shortage, there was often a secondary peak in production in the early autumn when soil moisture conditions were more favourable. Although there were some differences between varieties and species in the timing of the spring peak, when plots were irrigated and supplied with high rates of fertiliser, almost all of the grasses examined followed this basic pattern. Some exotic materials, such as tall fescues from North Africa, demonstrated considerable winter growth, but more pronounced depression in mid-season production, whilst the production pattern of annual grasses, maize and sorghum was shown to be radically different from that of the perennial species.

The technique was also used to study variation between seasons and between sites. Reference plots of perennial ryegrass re-established each year provided comparable data at Hurley for 19 years and at North Wyke for 11 years, with plots grown with and without irrigation. Jim Corrall led a FAO-supported experiment in which this technique was used to study production from perennial ryegrass and timothy at 32 sites in 16 European countries for one to five years. This data set has been used extensively to validate models of grass production in relation to climatic variables. The large variations in production within and between years at a single site and between sites underlined the need for physiological research to understand reasons for these production patterns.

## Understanding Grass Production Patterns

A major programme was mounted at Hurley to understand the physiological reasons for the seasonal pattern of grass production. The demonstration by Reg Anslow that there was no simple correlation between growth measured by DM increase and leaf area index (LAI), indicated the requirement for study at greater depth and the need to link research in the growth room with work in the field.

*Assimilation chamber for measuring single leaf photosynthesis, 1974*

Leaf photosynthesis underlies production and was investigated intensively at Hurley and Aberystwyth. Jane Woledge showed how halving the irradiance in which leaves develop halves their photosynthetic efficiency when fully expanded and how efficiency declines with age. These factors were shown to have a major effect on the seasonal pattern of production.

Investigation of assimilate utilisation using $^{14}CO_2$ provided further clues to the reasons for the production patterns. It was shown that in seedlings and juvenile plants priority is given to root growth, but then as tillers develop their share increases at the expense of roots. Reproductive development further increases allocation to stem growth rather than to roots. In low light, more is allocated to leaf growth and after cutting distribution is reorganised to favour re-establishment of leaf area.

Attention was also given to respiration losses. Research by George Ryle using $^{14}CO_2$ gave strong support for the concept being developed by McCree and Troughton in the USA for two components of respiration to be recognised, with one linked to photosynthesis and growth and the other to maintenance of biomass. The possibility of reducing respiration losses was explored at Aberystwyth by David Wilson in collaboration with Mike Robson. Lines of S23 perennial ryegrass having fast or slow rates of maintenance respiration were selected. In simulated swards the slow line gave greater yield, mainly because of the cumulative effect of greater investment in leaf growth.

Research in the field on seasonal production patterns concentrated on perennial ryegrass cut at 50% ear emergence and on four further occasions. The enclosure apparatus was used extensively and linked with studies in the growth room using simulated swards. By the early 1970s the reasons for the seasonal pattern of production were elucidated by the team led by Ted Leafe with Walter Stiles. In the reproductive sward, large rates of canopy photosynthesis coupled with a large allocation of assimilate to stem growth leads to a high rate of production and high ceiling yield. After the first cut there is often a negative carbon balance and a lag in production. Reduced rates of production in subsequent vegetative regrowths result from restricted canopy photosynthesis because of the poor efficiency of leaves developed in the prostrate canopy. John Sheehy extended this work and made detailed studies on the canopy structure, light distribution and photosynthesis in swards of several forage grasses. The data facilitated the construction of a model of canopy photosynthesis and growth of perennial ryegrass and response to environmental factors.

Research by John Peacock clarified the time of the start of growth in spring. He showed that the temperature in the region of the shoot apex, which in spring is near or just below the soil surface, determines the rate of leaf extension and that the response significantly increases before the transition to reproductive growth.

The development of the enclosure apparatus gave the opportunity to measure the effect of water stress, another factor influencing seasonal production pattern, on canopy photosynthesis in the field using rain covers. Mike Jones found that canopy photosynthesis declined progressively in the stressed swards. Leaf water potential fluctuated diurnally, but until there was severe stress there was overnight recovery and leaf water potential declined only slowly. There were no marked differences in stomatal resistance until severe stress occurred; until this point, reductions in canopy photosynthesis arose primarily through effects on leaf growth and tillering which reduced leaf area and light interception. This contrasted with the results obtained in container-grown swards in which stress developed rapidly when water was withheld and canopy photosynthesis was reduced principally through increased stomatal resistance.

**Enclosure Apparatus: The 'Moon Machine'**

In the field it is difficult to discern meaningful relationships between environmental factors and grass yield. In the 1960s there was a move towards the measurement in the field of the processes underlying yield and particularly canopy photosynthesis. There were two approaches, both taking advantage of the development of sensitive Infra-Red Gas Analysers (IRGAs). In the aerodynamic method, the flux of $CO_2$ is calculated from concentration profiles above the crop, whilst in enclosure methods a small area of the crop is enclosed in a transparent cover. The latter method was chosen for the work at Hurley because of its greater simplicity and suitability for small plot work.

Walter Stiles and Ted Leafe devised, and Walter, with notable ingenuity and skill, built the enclosure apparatus, known as the 'Moon Machine' because of its futuristic appearance. It proved practical, reliable and sensitive; an aircraft vapour trail passing over the face of the sun was readily detectable in the photosynthesis trace! The use of the apparatus provided new understanding of the growth processes in cut and grazed swards. After a period at North Wyke, the 'Moon Machine' was transferred to Trinity College Dublin for research by Mike Jones, who had been one of the early users at Hurley.

*Ted Leafe, Hurley 1968–85*

## Modification of Grass Production

***Cutting pattern and frequency*** Early research demonstrated that as cutting frequency was reduced, seasonal yield of dry matter increased. This was associated principally with late cutting in spring leading to full exploitation of the high growth potential of the reproductive sward. However, whilst taking a late cut gives a large first cut, regrowth is delayed, and Keith Dawson and Owen Jewiss showed that this effect arose largely

*The 'Moon Machine' for measuring canopy photosynthesis and gas exchange in the field at Hurley*

**The Hurley Pasture Model**

This is a comprehensive grassland ecosystem model, which comprises plant, animal, soil and water submodels. Work got underway on this project in 1980 when I joined the staff at Hurley. I was part of the re-organisation of the Biomathematics Department being carried out by the recently arrived Director, Alec Lazenby. Alec understood both rationally and intuitively the necessity of having such a quantitative and integrating approach in order to help give grassland research programmes focus, motivation and momentum, and to pull together the strands of what is a very complex system. Nowadays most credible agricultural research programmes have a modelling dimension. Alec, recognising these benefits early on, gave steady, unspectacular support to our modelling group of some half-a-dozen scientists. As a niche group, without a stand-alone raison d'être, we were largely protected from the burgeoning bureaucratisation which was causing much frustration elsewhere. We began quickly to work with scientists from other departments, and our efforts were helped by some excellent visiting scientists. After some ten years, various aspects of the modelling programme were pulled together in the Hurley Pasture Model, which has seen continued development and use. The model has been adapted, translated and used by scientists elsewhere in the world. In 1998, CAB International in Wallingford published a detailed account of the model. Interestingly, the model still has relevance because changes in research management emphasise the short-term, and taking an intellectual position, however carefully argued, does not find sympathy. This gives an environment in which long-term projects, such as an ecosystem model, cannot easily be done.

*John Thornley, Hurley 1980–89*



from small tiller population and survival after cutting. This is a particular disadvantage if continuity of production is required and early first cuts gave improved mid-season production and better continuity. Research by Bob Large subsequently demonstrated a similar effect with swards grazed by cattle. Mid-season production was greater in swards that had been grazed severely in spring than in swards that were more laxly grazed.

The *in vitro* digestibility technique enabled herbage quality to be assessed on material from agronomic experiments. Information on production and digestibility was produced by Jim Corrall and Joe Green for a range of grass species, varieties and cutting regimes. This facilitated calculation of optimal management strategies in relation to the requirements of the particular animal production system and the information was widely used in models of grass and animal production systems.

***Grazing*** It was increasingly realised in the late 1970s that results from cut plots could not be directly applied to grazed swards. Research on the growth and physiology of grazed swards was started by Mike Jones and Ted Leafe in 1977 and extended by Tony Parsons and Peter Penning to assess the dynamics of carbon uptake, utilisation and loss in continuously grazed swards. It was shown that in contrast to cutting management, with continuous grazing leaves may be frequently removed and these are often the youngest and most photosynthetically efficient. This was, however, partially compensated for by the leaves in severely grazed swards developing in a favourable light environment and having high photosynthetic potential. It was shown that as the LAI at which the swards were maintained was reduced, there was reduction in losses by respiration and death, but with further reduction in LAI there was reduction in light interception and gross photosynthesis. Consequently the

*The introduction of the Haldrup in the mid 1970s much reduced the labour required for harvesting small plots; a modern version is shown!*

quantity of herbage consumed by the grazing animals (equivalent to net herbage accumulation) was found to be greatest in swards maintained at an intermediate LAI. Tony Parsons and Ian Johnson extended this research by modelling the predicted net herbage accumulation for continuously stocked and intermittently stocked swards managed to different criteria. The results indicated that when swards had similar mean LAI, net herbage accumulation was 10–20% greater with intermittent than continuous stocking.

Research by Tony Parsons, Robert Orr and Peter Penning also demonstrated that with irrigated swards continuously stocked by sheep to maintain a low sward height or LAI, the seasonal pattern of production fitted the pattern of incoming radiation with the peak occurring in mid-summer. This was associated with the hard grazing in spring which suppressed the expression of flowering in these swards and then the leaves developed in good light conditions throughout the growing season.

***Response to nitrogen fertiliser*** Early research with cut swards established positive responses in grass production with increase in seasonal rate of nitrogen application up to 400–600 kg nitrogen/ha. For many years increases in nitrogen application together with increases in stocking rate powered increase in output from grassland on farms, with utilised output calculated to increase by around 1.8% per year from 1950–70. Considerable effort was devoted to quantifying response to nitrogen in different situations and to refine fertiliser advice to farmers. 'TE' Williams and John Morrison led a series of experiments conducted jointly with ADAS and other organisations at 26 sites throughout Great Britain, the Grassland Manuring (GM) experiments. These were carried out with different cutting regimes and, on a more limited number of sites, with grazing. The optimal rate of application was shown to increase with increased soil moisture supply, as determined by water-holding capacity of the soil and summer rainfall. This provided the basis for site classification and was incorporated into the *RB 209 Fertiliser Recommendations* published by MAFF and ADAS and in *Milk from Grass* published with ICI. There were greater problems in establishing responses to nitrogen fertiliser with grazing than with cutting, but Dick Baker evolved an appropriate protocol and coordinated the GM 24 experiments carried out at five sites. Responses to added fertiliser were generally smaller with grazing than cutting, this being attributed to much of the nitrogen being returned to the grazed sward in faeces and urine.

The GM experiments explored the possibility of producing a more even production pattern by adjusting the seasonal pattern of nitrogen fertiliser. Considerable flexibility was demonstrated with a pattern involving more application in mid-season than early season resulting in much more even production, with no sacrifice in annual yield. Research at North Wyke confirmed that this

*John Morrison describing his experiments to Michael Griffith, Council Member of AFRC, with Joe Green and Roger Wilkins in attendance: the infamous Radar Hut is just visible in the background* approach could be effective with grazing as well as with cutting.

***Water supply*** Irrigation was extensively studied at Hurley by Ted Garwood and Walter Stiles. At Hurley, irrigation increased average seasonal herbage production by 25% and resulted in much more predictable production in mid-season. Reduced yields in dry conditions arose from a combination of the direct effect of water stress and reduced availability of nitrogen to the plant when the soil surface layers were dry. A system of partial irrigation was devised in which water was supplied by irrigation at only half the rate required to completely alleviate water deficiency. This resulted in substantial increases in production compared with non-irrigated conditions but with less water use and lower cost than with full irrigation. However, irrigation was still a costly operation and economic analysis carried out by Chris Doyle indicated that there were only few situations in which grassland irrigation would be economic. Attention shifted to the search for grasses that would make more efficient use of soil moisture. Ted Garwood demonstrated the superiority of tall fescue over a number of other species including perennial ryegrass in this respect, with the advantage arising from the greater root depth with tall fescue exploiting a greater reservoir of soil water. This advantage is now widely recognised and efforts to incorporate genes from tall fescue to give better performance of ryegrass in dry conditions have become an important focus of breeding research in Aberystwyth.

The effects of excess water on grassland production and utilisation were a major aspect of early research at North Wyke carried out by Ted Garwood and Adrian Armstrong (ADAS). It was, however, found that with a management protocol that avoided grazing in conditions of excessive soil moisture (and a big poaching risk) in spring and autumn, drainage resulted in only a 3% increase in herbage production and an 11% increase in animal production. There were, however, large effects on soil moisture content, soil nutrients and the environment as discussed later.

***Pests and diseases*** Research at Hurley in this area was led by Jack Heard and Bob Clements and the initial work was carried out in close collaboration with Rothamsted. The importance of ryegrass mosaic virus particularly in Italian ryegrass was confirmed. The method of transmission was established and Italian ryegrass plants with resistance to ryegrass mosaic virus were identified and used subsequently in breeding programmes at Aberystwyth.


*Larva of frit fly on Italian ryegrass*

Bob Clements studied the impact of pests and diseases on production by comparing production following application of broad-spectrum chemicals to eliminate pests and pathogens with that from control plots. Positive responses were found in both sown and permanent swards, with yield increases often approaching 20%. Responses were particularly marked with Italian ryegrass and were attributed to the control of frit fly infestation. With pesticide treatment yields of Italian ryegrass were sustained for up to four years, whereas without treatment yields were extremely small by the third year.

Subsequently, Bob Clements and Graham Lewis turned their attention to pests and diseases of seedling grasses. Frit fly larvae were found to be responsible for the loss of a large proportion of ryegrass seedlings, especially in swards sown in the early autumn. Simple and straightforward control measures using an insecticide were developed with Industry and effective pest avoidance strategies were also found that did not require the use of chemicals. Soil-borne diseases, principally *Fusarium,* were also shown to kill many seedlings. Practical avoidance strategies and advice were researched and developed. An endophytic fungal infection of ryegrass was also researched. In New Zealand the same fungus was used to control certain sward pests and also increased grass drought resistance, but no large benefits were found here.

***Sward age*** The main focus of research at Hurley was on the management and utilisation of sown grassland. Ken Tyson, however, studied the production of a mixed grass-legume sward for a 30-year period following sowing into an old arable field with little soil organic matter. Production declined for the first 4–6 years associated with movement of nitrogen into soil organic matter. There was then a recovery in yield with production from the tenth to thirtieth year varying with summer rainfall but showing no long-term trend. Experiments carried out by Alan Smith with large fertiliser inputs with cutting and grazing showed little effect of sward age on grass output up to seven years, the oldest age examined.

Alan Hopkins led a joint study with ADAS on production from permanent swards compared with re-seeds of perennial ryegrass at 16 sites through England and Wales at a range of nitrogen fertiliser application rates. Whilst production in the first year after sowing was considerably greater for the sown swards, in subsequent years there were only small differences in production between the sward types with an advantage, on average, of 7% for the permanent sward with 150kg nitrogen/ha and an advantage of similar magnitude to the sown sward at 450kg nitrogen/ha. Research at North Wyke using grazing cattle confirmed the large production potential of permanent grassland with animal output per hectare with a 400kg fertiliser nitrogen application being only 5% greater on reseeded swards than on permanent swards over a five-year period. This programme did much to increase confidence in the production potential of permanent swards, provided that plant nutrient deficiencies are eliminated and a sound grazing or cutting management is practiced.

### White Clover and Other Legumes

Forage legumes have been studied throughout the 60-year period, but the focus on legumes has varied over this period. Much of the early work at Drayton and Hurley used mixed swards of grass and white clover, and lucerne was prominent in the early cropping at Hurley. However, during the 1960s and early 1970s the accent was very much on production from pure grass swards receiving large fertiliser-nitrogen application rates. Research interest in legumes was sustained largely because of the excellent rates of animal performance achieved with legumes demonstrated at Hurley, rather than because of the contribution of the legume to the nitrogen economy of the sward. However, increasing concern on the high energy inputs in systems based on nitrogen fertiliser led to resurgence in agronomic and physiological research on legumes from the late 1970s, a move that was reinforced on the appointment of Alec Lazenby as Director. The main legume studied has been the stoloniferous white clover for use in grazing-based systems, but substantial research has also been carried out with the erect legumes red clover, lucerne and sainfoin that are better suited to cutting systems.



***Yield potential and seasonal distribution*** Research at Hurley was extended by John Morrison in multi-site experiments carried out in collaboration with ADAS on the yield and seasonal distribution of yield of white clover based swards. On average, grass-white clover swards without nitrogen fertiliser gave yields similar to those of pure grass swards with 200kg nitrogen/ha. Although yields were more variable with the mixed swards than with pure grass, there were no systematic differences between parts of the country. There was a close relationship between the yield of the mixed sward and its content of clover. Application of nitrogen fertiliser to the mixed swards produced small increases in yield, with depression in the contribution from clover. The commencement of growth in spring was well recognised to be later with clover than with grasses, but provided there was good supply of moisture it was shown that grass-clover swards gave more even production over the main growing season than swards of grass with nitrogen fertiliser. However, white clover is sensitive to dry conditions and very responsive to irrigation, so that the good seasonal distribution of yield applied particularly to the wetter parts of the country. The possibility of extending the growing season by application of nitrogen fertiliser in spring was examined, but generally any nitrogen application, although stimulating grass production, was shown to be prejudicial to future clover production. Much effort has, however, been devoted at Aberystwyth to breeding white clover varieties that are more competitive with grass in the presence of nitrogen fertiliser and some of the currently available varieties may well give different results.

*Sorting grass from clover occupied many happy hours of many people over many years!*

The production from swards of red clover and lucerne was shown by Jim Corrall and Roger Sheldrick to match that from grass receiving large rates of applied nitrogen when only three cuts were taken annually: more frequent cutting of these legumes resulted in large reductions in yield and persistence. As with the major grass species, valuable information was obtained on changes in yield and digestibility of forage legumes during the year and as the species matured. Roger Wilkins led a European Union funded project on the production of legumes and their utilisation as silage. Multi-site experiments through northern Europe confirmed the wide adaptability and large yields of red clover and excellent performance of lucerne on some sites, including a freely-drained soil at North Wyke. It was calculated that the cost of production of metabolisable energy in silage was markedly smaller for red clover, lucerne and mixed grass-clover swards than for grass with nitrogen fertiliser. An added advantage of lucerne is a deep-rooting system, meaning that this species rarely suffers from drought in Britain. Red clover was also less affected by drought than the grasses. Red clover and lucerne are not well adapted to grazing, but research by Alan Hopkins and Andrew Rook at North Wyke indicated potential for use of bird's foot trefoil as an alternative to white clover as a grazing legume, particularly in conditions of poor fertility and extensive grazing.

*The adult and the larva of the weevil* Sitona lepidus *both cause widespread damage to white clover*



***Legume physiology*** A major effort on legume physiology commenced in the mid 1970s and centred on white clover and its competition with grass. White clover was widely considered to be unreliable at the farm scale and was thought to suffer from shading by grasses. Research by Jane Woledge in the 1970s, however, demonstrated that with the commonly-used variety Blanca, clover leaves were generally present towards the top of the canopy of a mixed sward and with their horizontal disposition were better able to capture incoming radiation than were the more vertically oriented grass leaves. The effect of light on competition in mixed swards was clarified by research at Aberystwyth which demonstrated that the development and branching of white clover stolons was reduced with reduction in the quantity of light penetrating to the base of the sward.

Considerable attention was given to the nitrogen fixation process. George Ryle focussed on the energetics of the process and his results highlighted the energy costs of fixation that amounted to some 10–30% of the total net photosynthate produced by the plant. Respiration rates were shown to be exceptionally large in the nodules of a wide range of legumes and it became clear that this was one of the reasons for the lower production of white clover than of grass.

John Sheehy and Frank Minchin studied the relationship in the field between photosynthesis, respiration and nitrogen fixation and developed models of these processes. They highlighted the importance of diffusion resistance of the nodules to oxygen and did much to establish the nature of the barrier in the nodule to oxygen diffusion. They concluded that fixation was governed by photosynthate supply and the rate of oxygen supply to the fixing bacteroids. This research ceased at Hurley in 1987 with the transfer of Frank Minchin and Tony Gordon to Aberystwyth, following a decision by the Research Council to consolidate work in this area at that site. Susanne Schwinning and Tony Parsons at North Wyke made a major breakthrough by producing a model that predicted changes in the composition of a mixed grass clover sward both spatially and temporally. This was driven by nitrogen dynamics and highlighted patch effects and the cyclical nature of sward composition. Essentially in an area with low soil nitrogen supply, clover is at a competitive advantage over grass and will proliferate in that area. However, rates of fixation will then be large and this area will be transformed to one of increased soil nitrogen, shifting the competitive advantage to the grass and with this a reduction in nitrogen supply to favour re-development of clover. The deposition of urine, producing patches with large nitrogen contents, was shown to have a major effect on nitrogen cycling and dynamics and sward composition in grazed swards.

Less work was carried out on the physiology of the erect legumes, but John Sheehy and Ian Woodward studied the growth of lucerne in the field with assessments of photosynthesis, respiration and microclimate in the growth canopy. This was extended in work with Sue Popple to compare sainfoin with lucerne. Despite leaf photosynthetic rates being similar for the two species, sainfoin was consistently lower yielding. This arose from a combination of larger respiratory losses associated with nitrogen fixation and less favourable pattern of assimilate utilisation leading to leaves of greater thickness, but of a smaller area giving less light interception and reduced canopy photosynthesis

### Key Outputs

Key outputs have included:

- Provision of understanding of the physiological basis of seasonal differences in grass production, including the importance of tiller dynamics, leaf photosynthetic efficiency and effects of temperature, radiation and soil moisture.
- Detailing changes in yield and quality of grasses and legumes during and between growth cycles.
- Quantification of responses to nitrogen fertiliser with different sward types and in contrasting situations and improving recommendations for fertiliser use.
- Establishing effects of both shortage and excess of water on grassland production and utilisation.
- Establishing effects of pests and diseases on production of grasses and legumes and developing methods for control.
- Quantification of the dynamics of carbon uptake, utilisation and loss in grazed swards and predicting effects of differences in grazing control on net herbage accumulation.
- Confirmation of the large production potential of permanent grassland with both cutting and grazing management.
- Provision of understanding of the growth, production and persistence of forage legumes grown alone and in mixture with grass and elaboration of management guidelines for effective production and utilisation of clover-grass swards.

*Roger Wilkins and Ted Leafe*

# HERBAGE QUALITY AND UTILISATION

## Introduction

The philosophy developed at Hurley, and indeed before that at Drayton, was that grass production is not an end in itself, but was only a step towards the output of animal products. The Annual Report *(Experiments in Progress)* for the year 1949 describes ten experiments in which assessments were made of animal production (by cattle, sheep and poultry), together with investigations on methods of measuring herbage intake, grazing behaviour and the effects of cold storage of grass on digestibility.

The strong focus on grass quality and animal production was maintained throughout the life of Hurley and much of the early research at North Wyke was concerned with animal production from long-term grassland. Following the closure of Hurley, research in IGER on feed microbiology, ruminant nutrition and animal production was transferred to Aberystwyth and to newly-established facilities at Trawsgoed. Research on grazing ecology was transferred to North Wyke, but ceased in 2007. Several of the staff from Hurley took up appointments at CEDAR, University of Reading, to continue research on ruminant nutrition and dairy production.

Frank Raymond identified at an early stage the main components determining the nutritive value of grassland feeds as being digestibility, intake and the efficiency of utilisation of digested nutrients, particularly nitrogenous constituents and energy. This framework is used here and major findings relating to these components of nutritive value are outlined followed by consideration of production efficiency from conserved and grazed forages.

## Digestibility

Research at Drayton and Hurley led by Frank Raymond did much to establish appropriate methodology for determination of digestibility *in vivo*. This group pioneered the freezing of herbage in quantities appropriate for the daily feed allocation of individual sheep through the course of an experiment. Freezing was shown not to affect the digestibility of herbage and this facilitated studies on the quality of herbage cut on a particular date and growth stage, unconfounded with change in the developmental stage of the grass or changes resulting from ensiling or haymaking. Design criteria were worked out for large cold stores, a key facility established during the early building programme at Hurley.

*In vivo* studies using sheep established characteristic differences between grass and legume species in digestibility (white clover > ryegrass > cocksfoot) and changes that occurred with maturity and season. The rapid drop in digestibility (up to 0.5% digestibility units/day) as grasses matured during first growth was highlighted, with this drop being particularly rapid after ear emergence in some varieties. The fall with time was shown to be much slower in re-growths when

**_In Vitro_ Digestibility of Forage**

Nutritionists have long sought to estimate the digestibility of forage by incubating a sample of the forage with a culture of micro-organisms taken from a ruminant animal, generally a sheep. However, when, in 1960, Mike Tilley, Roger Deriaz and Ron Terry tested a number of published procedures, they found that they gave consistently lower estimates of digestibility than when the same forages were fed *in vivo* to sheep, with the divergence being most marked with forage of high digestibility and protein content. They argued that this was because the *in vitro* digestion simulated only part of the ruminant digestive process, and omitted the subsequent enzymic digestion, particularly of microbial protein, in the ruminant hindgut. Thus they introduced a second stage, following the 48-hour digestion with rumen micro-organisms with a further 48-hour digestion with acid pepsin. They found a remarkably close agreement between this two-stage procedure and the digestibility of the same forages fed *in vivo*, of particular importance with forages of high digestibility and protein content.

This technique was rapidly adopted worldwide and opened up new possibilities for precise estimation of digestibility for advisory purposes, for plant breeding and for agronomic studies. The technique is still used nearly 50 years later and the Tilley and Terry paper published in 1963 remains a frequently quoted reference in scientific journals.

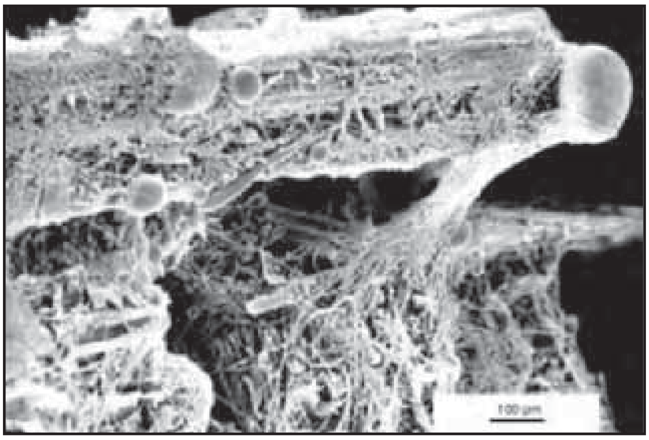
*Frank Raymond, Drayton 1945–52, Hurley 1952–72*

little stem development occurred. Likewise, with white clover the fall in digestibility with delay in harvest was much slower than that with grasses.

Research by Colin Harris showed that ensiling had little effect on digestibility, whilst work carried out jointly with the National Institute of Agricultural Engineering (later Silsoe Research Institute) demonstrated that a substantial drop in digestibility may result from haymaking, particularly if poor weather conditions had resulted in substantial losses in the field. High-temperature drying, with the dried product fed without further processing, had only a negligible effect on digestibility, but Dennis Osbourn found that grinding and pelleting before feeding led to a marked reduction in digestibility, particularly of the fibrous components. This reduction was much larger with grasses, with their higher content of digestible fibre, than with legumes and was greater at higher levels of intake.

Whilst much was established using *in vivo* techniques, the development of the *in vitro* technique by Mike Tilley and Ron Terry opened up many new possibilities. With accurate assessment of digestibility being possible from only small samples of dried material, the technique was used to assess effects of many agronomic treatments on digestibility, to describe the patterns of change with development of herbage species and varieties and to assess the digestibility of different morphological parts of the grass plant. Research in collaboration with WPBS demonstrated significant heritability of digestibility and highlighted its use in grass breeding. The technique was adopted throughout the world and is still routinely in use.

The *in vitro* technique, whilst providing a good estimate of *in vivo* digestibility, did not directly give information on the dynamics of digestion and required the use of surgically-prepared animals to provide a source of rumen inoculum. Both of these limitations were addressed in a technique for measuring the amount and speed of gas production during the incubation of forage samples. This technique, initially developed in Germany, was simplified at Hurley




*Electron microscope image showing colonisation of particles of barley straw by rumen fungus* Neocallimastix hurleyensis by Mike Theodorou in the early 1990s so that it could be used as a screening tool. Collaborative research with Reading University showed that similar results, though with a longer lag-phase before digestion started, could be obtained using inoculation with faecal rather than rumen micro-organisms, thus obviating the need for surgically-prepared animals. Gas production techniques are now probably used more widely worldwide than the Tilley and Terry technique.

Mike Theodorou and his team provided a new insight to rumen digestion through their studies of anaerobic fungi. Another approach was the research led by Roy Hartley which provided a new understanding of cell wall chemistry and the factors that determined the susceptibility of cell walls to digestion by the ruminant. Phenolic acids in the cell walls of cereal straws and grasses were shown to be linked via their carboxyl groups to arabinose moieties in hemicellulose. Esterification of cell walls with increasing amounts of coumaric and ferulic acids was highly correlated with decreased cell wall degradability.

Phillip Harris used histochemical techniques to study the location of phenolic compounds in different grass tissues and confirmed reductions in degradability in tissues containing phenolics. This information provided new possibilities both for breeding grasses with enhanced degradability, but also for the chemical treatment of straws and forages to enhance feeding value. The increase in digestibility resulting from alkali treatment was shown to be associated with the release of phenolic compounds. Roy Hartley, Mike Wilkinson and Vic Mason carried out research on the use of alkalis and other physico-chemical treatments to enhance feeding value, concentrating on grasses and whole crop cereals. Although sodium hydroxide and ammonia gave large increases in digestibility and intake with low-quality forages, there were difficulties in the development of safe, practical and economic systems for use on farms.

**Do Anaerobic Fungi Live in the Digestive Tract of Ruminants?**

A persistent belief in mycology is that fungi require oxygen to grow. In the mid-late 1970s, two research groups, in England and Australia, began to produce evidence questioning this dogma. By the early 1980s and, as a recently graduated scientist at Hurley with experience in mycology, I began working with colleagues at Manchester University on the intriguing possibility that the ruminant digestive tract might harbour highly specialised populations of fibre-degrading, obligately anaerobic fungi that are killed in the presence of oxygen. This research continued until Hurley closed and early pickings were noteworthy. Today, we have a wealth of evidence to show that all large domesticated and wild mammalian herbivores harbour populations of anaerobic fungi in their digestive tracts. These micro-organisms have three stages to their life cycle and are highly cellulolytic; perhaps more so than any other micro-organism known to man.

Hurley research contributed to the mapping of the entire life cycle (using our own species, *Neocallimastix hurleyensis*) and described the relationship between fibre degradation and fibrolytic enzyme production. We achieved many firsts during the early years, but perhaps our most important discovery was the ability to isolate anaerobic fungi from the fresh and air-dried faeces of mammalian herbivores that harbour fungal populations in their gut. This led to an appreciation that fistulated ruminants were not required to obtain anaerobic fungi and encouraged others, without access to animal house facilities, to develop research programmes. With molecular methodologies and gene sequencing procedures, the future of gut fungal research is set to continue. I would predict for the future that these organisms, with their ability to degrade fibre and form stable co-cultures with the methane-producing Archaea, are set for industrial exploitation in the production of energy from waste/energy crops to mitigate climate change.

*Michael Theodorou, Hurley 1981–91, Aberystwyth 1991–*

### Intake

Research carried out in USA in the 1950s had indicated that physical distension of the rumen was one of the main factors limiting the intake of forages and had established a general positive relationship between digestibility and voluntary feed intake. Research at Hurley on dried forages led by Dennis Osbourn, on silages led by Roger Wilkins and at grazing by John Hodgson, Dick Baker and Peter Penning explored these relationships further.

Voluntary intake was shown by Jim Tayler and Chris Lonsdale to be similar for zero-grazed fresh grass to that from the same material after dehydration at high temperature and chopping. Dennis Osbourn confirmed with dehydrated materials that within a plant species the positive relationship between intake and digestibility applied up to the highest level of digestibility explored. There were, however, large differences between species in intake at a particular digestibility, with intake being particularly low with timothy, but higher for any of the legumes studied than for any of the grasses. These differences were associated with differences in the ratio of cell contents to cell wall constituents in the herbage fed, with intakes being greater when cell contents were high. This confirmed work carried out by Peter van Soest in the USA and was in line with the bulk hypothesis for intake control, with the feeds with the greater content of the rapidly digested cell content fraction contributing less rumen bulk per kg DM consumed and so being eaten in larger quantity.

It was, however, established that the intake of silages was generally less than that of fresh forages. Roger Wilkins and his colleagues explored the relationship between silage composition and intake by sheep using data from 70 silages fed at Hurley between 1961 and 1967. In contrast to the situation with dried forages, there was no correlation between intake and digestibility. There was though a close association between intake and silage composition, with intake being severely reduced in silages that had undergone a clostridial fermentation. These were characterised by ammonia-nitrogen being a large proportion of the total nitrogen and lactic acid being a small proportion of total acids present. An additional factor was the total quantity of fermentation acids, with intake also being reduced in silages that had undergone extensive fermentation. This effect was confirmed by Dinsdale McLeod who showed that the neutralisation of low pH silage prior to feeding resulted in increases in intake. The silages studied from 1961–1967 had been made without additive and many were very poorly preserved. An analysis of 142 silages made from 1968 to 1977 produced different results. Many of these were made with additives or after wilting and were well-preserved. Whilst there was still a negative relationship between ammonia-nitrogen and intake, there was a positive relationship between intake and digestibility for both grasses and legumes, with levels of intake tending to be greater for the legumes. This series of experiments provided strong support for efforts to reduce protein breakdown and excessive acid production in the silo.

It is clearly more difficult to assess intake with grazing than with housed animals and this has been a challenge for research in the Institute. In the earliest techniques exclosure cages were placed randomly on the pasture before grazing, with intake measured as the difference between the amount of herbage on these plots and that remaining on the grazed area after the grazing period. Estimates of the intake of individual animals were derived from their total faecal output and *in vitro* estimates of the digestibility of the herbage grazed. Faecal output was measured directly by fitting the grazing animals with harness and collection bags or, more commonly, by dosing the animal with an indigestible marker such as chromic oxide or alkane. All of these techniques have substantial weaknesses and an alternative approach was developed by Peter Penning on the basis of assessments of animal behaviour. Here, intake was calculated as the product of grazing time recorded automatically and eating rate (g forage/minute grazing). Eating rate was assessed by directly weighing animals before and after short periods of grazing, allowing for insensible weight loss and the exact time spent grazing. The grazing recorders developed from research at Hurley and North Wyke have been used throughout the world on a range of domesticated and wild animals.

**Grazing Behaviour**

It has long been realised that measuring ingestive behaviour would help us to understand the relationship between herbage intake and sward state in grazing animals.

During the 1970s, with the availability of miniaturised electronics, work began on the development of techniques to record and process grazing behaviour automatically. Initially, radio telemetry was used to transmit electromyograph signals obtained from fine wire electrodes planted subcutaneously over the masseter muscles to record eating activity. However, this technique proved to be unreliable. A flexible nose-band sensor was developed to measure the jaw movements of animals and the analogue electrical signals produced were recorded on miniature tape recorders carried by the animals. These recorded signals were subsequently replayed at 60 times recording speed, digitised and analysed by computer to give temporal patterns of time spent ruminating, eating and idling and the jaw movements associated with each of these activities were counted. Together with sward measurements this led to the development of sward management guidelines. Subsequently, solid state devices carried by the animals, replaced the tape recorders. These devices digitised and stored the signals for subsequent computer analysis. These solid state recorders, developed by Peter Penning, Mark Rutter and Rob Champion have been patented, manufactured commercially and used by researchers in many countries.

*Peter Penning, Hurley 1963–90, North Wyke 1990–97*

*A beef animal fitted with equipment for measuring ingestive behaviour and a global positioning system to track movement*

John Hodgson and Jorge Rodrigues demonstrated that in circumstances in which there was ample herbage available there was a close relationship between intake and digestibility of the herbage consumed by grazing cattle. It was, however, clear that sward architecture and the quantity of herbage on offer may limit intake. A general positive relationship between sward height and intake was demonstrated for continuously stocked sheep, beef cattle and dairy cows grazing perennial ryegrass, grass-clover mixtures and permanent swards. Intake per animal was least with the most severe grazing, but there was often little difference in intake between moderate and lax grazing. The critical limits were shown to vary between different classes of stock. Peter Penning showed that as grazing severity increases there is a reduction in intake per bite, which is not completely compensated for by increase in grazing time and

**Indirect Respiration Calorimetry at Hurley**

The first respiration calorimeters 'arrived' at Hurley in 1984. Occupying some of Dennis Osbourn's valuable real estate in Shed V, two 'home-built' wooden structures were linked to some sophisticated analytical equipment to measure energy utilisation, including methane production, in sheep. Early results were encouraging but controlling temperature and humidity became an issue in the DIY chambers and alternatives were required.

Through Institute and commercial funding from British Sugar (with some deft negotiation by David Thomson), the next two years saw the Hurley facility grow to six purpose-built calorimeters for dairy cows (four) and beef cattle (two). In animal science terms, GRI had entered the Premier League.

A sustained period of research for both Government and commercial sponsors followed and, fittingly, these data contributed to a large dataset of measurements on individual cows subsequently used to revise UK energy feeding standards. More recently, data on methane production has been used to develop more rigorous inventories of methanogenesis as a basis for mitigation strategies.

With the demise of Hurley, new homes for the chambers were needed. The dairy chambers were shared between CEDAR (Reading University) and Hillsborough (Northern Ireland) and continued long and profitable lives; the beef chambers went to Newcastle University but were never re-installed.

Accompanying the chambers to CEDAR was Steve Cammell, who deserves special mention for the dedication and devotion he put into building eight chambers from scratch. He was then tasked with dismantling six of them and subsequently rebuilding two. Without this effort, as well as that of the maintenance/fabrication teams at Hurley, none of this research on energy utilisation of forage-fed ruminants would ever have been possible

*David Beever, Hurley 1969–92*



the number of bites per minute. Intake per animal was greater for sheep grazing white clover, than grass-clover mixtures, which were in turn greater than for pure grass. This was shown to arise from higher intake per bite with white clover. With mixed swards, however, Peter Penning and Mark Rutter showed that the pattern of selection between clover and grass followed a diurnal pattern with more clover being consumed in the morning and more grass in the evening. Greater levels of intake were found when sheep had simultaneous access to pure swards of grass and clover than with mixed swards or pure white clover swards.

## Efficiency of Energy and Protein Utilisation

***Energy*** A range of techniques were developed at Hurley to study the efficiency of nutrient utilisation. In the late 1960s David Thomson developed a comparative slaughter technique to measure energy and nitrogen retention in the whole body over a lengthy feeding period. A group of animals was slaughtered at the beginning of the experimental period with the remaining treatment animals slaughtered at the end of the experiment and energy and nitrogen retention calculated by difference. This approach was later complemented by direct measurements of heat and methane production over a short time interval using calorimeters for sheep, beef cattle and dairy cows

*Indirect respiration calorimeter at Hurley*

Although the research confirmed a general positive relationship between the efficiency of energy utilisation and digestibility, important exceptions were identified. Efficiency of energy utilisation was generally less in autumn-grown herbage than in spring-grown herbage, confirming earlier work at the

Rowett Institute. This was associated with the autumn-grown grass having low content of water-soluble carbohydrate and high content of crude protein, a large proportion of which was as non-protein nitrogen. Whilst grinding and pelleting reduces digestibility, this process resulted in a marked increase in the efficiency of utilisation of digested energy, attributed to a change in the ratio of the components digested and a reduction in the importance of the rumen as a site for digestion. A greater understanding of the reasons for poorer energy utilisation in forage than concentrate diets was obtained. This was shown to arise from greater heat production and more excretion of nitrogen with forages. The large load of nitrogen absorbed from many forages was shown in research with the Universities of Nottingham, Reading and Newcastle to lead to large heat losses and inefficient amino acid utilisation at the tissue level.

***Protein*** At the time of the foundation of Hurley, crude protein (or nitrogen) content was the main quality criterion for grassland feeds. However, it became abundantly clear that protein in forages was often used very inefficiently, leading to poor animal responses. Latterly, this concern was extended to the large potential loading to the environment of nitrogen in excreta.

Increasingly sophisticated techniques were used to study nitrogen utilisation. Nitrogen retention was measured in many short-term experiments as the difference between nitrogen consumption and the losses in faeces and urine. This technique was, however, liable to considerable error and gave no insight to the dynamics of nitrogen use by the animal. In collaboration with David Armstrong from Newcastle University, re-entrant cannulation techniques, involving cannulae in the proximal duodenum and the terminal ileum, were developed by David Beever and David Thomson. The results, in conjunction with measurement of rumen microbial protein synthesis, provided insights into the location of nitrogen digestion and the supply of amino acids to the animal. In the 1980s the range of techniques used was further broadened to investigate metabolism in individual tissues, concentrating on the gut, liver and muscle.

David Beever, David Thomson, Rod Siddons, Alex McAllan and their colleagues showed key factors affecting amino acid supply to the animal to be the rate at which forage nitrogen compounds were broken down in the rumen and the supply of energy in the rumen, required for the synthesis of microbial protein. The results stressed the need to synchronise the relative availabilities of energy and nitrogen in the rumen.

Generally, the breakdown of nitrogen compounds in fresh grasses and legumes was found to be particularly rapid. Several approaches were identified to reduce breakdown rates in the rumen. High-temperature drying was shown to have a marked effect on the pattern of nitrogen digestion: although drying resulted in a small reduction in whole-tract nitrogen digestibility, this was more than compensated for by slowing protein breakdown in the rumen, reducing ammonia losses and increasing the quantity of amino acids absorbed from the small intestine. Some forage species contain tannins that bind to proteins and reduce breakdown in the rumen. Sainfoin is one such species and research at Hurley showed much greater efficiency of nitrogen utilisation

> **The History of Ruminant Modelling at Hurley**
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> By the early 1970s, GRI had become a world leader in forage evaluation, in particular with the development of the Tilley and Terry *in vitro* digestion system. At the same time the importance of rumen function was being recognised, and led to the introduction of surgically-modified sheep at Hurley to measure rumen and post-rumen function.
>
> Many defining studies on the digestion kinetics of artificially dried forages (popular at that time), silages (including some of the earliest work on maize) and even fresh pasture followed. Initially with sheep, these graduated over time to beef cattle and to dairy cows. It was a period of new and exciting knowledge in the area of forage evaluation and utilisation.
>
> Working independently, Lee Baldwin (UC Davis, California) produced the first simulation model of rumen function and a chance meeting with Dick Brockington gave me my first exposure to Baldwin's research. Driven to learn more and apply the science, a Stapledon Travelling Fellowship allowed me to follow Baldwin to Australia and New Zealand, where he was on study leave. Further models of rumen function were published, and by the early 1980s, Hurley had its own dedicated team of animal modellers, with Jim France, Maggie Gill and John Thornley.
>
> It was this commitment and resource that finally enticed Baldwin to spend a year at Hurley, a truly electrifying experience in terms of personal scientific endeavour. Two dairy cow models, aptly named Daisy and Molly (after Lee Baldwin's father's favourite cow back in the US) emerged, to become bywords in animal science and rightfully placed into the history of ruminant nutrition.
>
> *David Beever, Hurley 1969–92*

with sainfoin than with the tannin-free lucerne. It is now clear from research in New Zealand that there is an optimal range of tannin content and that very large contents may adversely affect protein utilisation. Irene Mueller-Harvey developed techniques for separation of tannins from other polyphenols to facilitate research on the exact mode of action and to progress research with both temperate and tropical forage and browse species.

Ensiling was shown to exacerbate the problems of nitrogen utilisation with grasses and legumes. Not only is much of the protein in the forage broken down in the silo to amino acids and simpler compounds leading to large levels of ammonia in the rumen, but also most of the readily-available carbohydrates in the fresh forage will have been fermented in the silo to organic acids, thus reducing the supply of energy in the rumen for microbial protein synthesis. Whilst the standard value used for microbial protein synthesis is 32g microbial nitrogen/kg of feed DM apparently digested in the rumen, values collated by David Beever from a series of experiments with silages ranged from 13 to 28g/kg. Inefficiency in use of nitrogen with silages was shown by Chris Lonsdale and Jim Tayler to lead to increased proportions of fat and reduced proportions of protein in the carcase gain of beef cattle. Much research was carried out on the possible use of formaldehyde as a silage additive. As with tannins, formaldehyde resulted in reduction in whole tract nitrogen digestibility. In some cases there was an overall increase in amino acid supply and nitrogen retention, but this did not always occur and the optimal range of formaldehyde application appeared to be too narrow for practical application.

With most grasses and legumes, the best approach to improve nitrogen utilisation appeared to be to use complementary forages or concentrate supplements to improve the balance of supply of nitrogen and energy in the rumen. Considerable progress was made by Maggie Gill and John Sutton in identifying optimal supplements for grassland feeds, with supply of readily-available carbohydrate and protein with low rumen degradability being particularly important with silages.

Information generated at Hurley made a crucial contribution to models of rumen function and animal metabolism. These models facilitate the calculation of nutrient supply to animals that is at the heart of modern feeding systems for ruminant animals. A key to progress was the close collaboration between the mathematicians (John Thornley and Jim France) and ruminant nutritionists (Maggie Gill and David Beever) at Hurley and inputs from visiting scientists, particularly Lee Baldwin from USA, John Black from Australia and Marc Ullyatt from New Zealand.

## Production Efficiency

***Animal population*** Colin Spedding and his team highlighted the importance of the structure of the animal population in determining the efficiency of animal production systems. Efficiency could usefully be expressed as the energy in the animal products as a proportion of the energy consumed, calculated over a complete production cycle. High reproductive efficiency and the need to minimise the proportion of nutrients providing only for maintenance were highlighted as key factors. Of the animals studied, the highest values were obtained by Jean Walsingham in studies with rabbits, which combine high reproductive efficiency with rapid growth. Research by Dick Baker, with beef suckler systems, however, showed that the growth rate of the calf was often of greater consequence than the size of the dam in determining overall efficiency of feed use, despite the higher maintenance requirements of the larger dam. With both sheep and cattle, increase in the number of offspring had large effects on efficiency.

Whilst Colin Spedding in the 1970s considered principally energy and protein efficiency, the same principles determine efficiency in terms of methane (a greenhouse gas) production per unit of animal output, a current central issue.

***Silage*** The production of grass silage in the UK increased six-fold from 1970 to 1990, by which time some 80% of the total quantity of conserved forage was silage. Several factors were responsible for this increase, but research at Hurley made a major contribution. The research, together with that led by Peter McDonald in Edinburgh, had established the major fermentation pathways and the impact of crop composition on the ensiling process. This research was facilitated by the development at Hurley by Bob Wilson and Roger Wilkins of simple laboratory silo techniques. Also, Mike Woolford developed a simulated silage system involving semi-purified chemicals to provide a medium with controlled composition which was then inoculated with specific microbial populations. The imperative in producing silages of high feeding value to avoid clostridial fermentation had been established and by the early 1970s there was ample demonstration that combinations of the use of formic acid additives and wilting could give predictable and effective silage making. This was aided by the development of a new technique for silo filling.

*Harvesting for silage in 1970 with additive application*

**Dorset Wedge Silage**

The process of ensilage was introduced from France in the 1870s but, despite numerous 'silage campaigns', by the 1960s it had still made remarkably little progress in the UK, with only some 10% of winter forage stored as silage. We were thus greatly interested to learn of the reported success of a silage method that was being used by Dorset farmer Richard Waltham. We visited his Manor Farm in 1965 together with Gordon Shepperson from the National Institute of Agricultural Engineering and identified two key features: the filling of the silo progressively as a wedge instead of the usual layers and the covering of the surface of the cut forage with plastic sheets whenever loading was not in progress. Most importantly, we concluded that the role of the sheet was not to prevent air getting into the silo, but to prevent warm air escaping from the fermenting crop and drawing in fresh air. We quickly tested and demonstrated the system at Hurley and parties of farmers were soon visiting Manor Farm to see the practical operation of what was termed 'Dorset Wedge' silage. These included a party of Aberdeenshire farmers led by grassland advisor Graeme Copeman. With the later growing season in the north of Scotland, they were able to put the system into practice the same year.

Since then there have been further advances in silage systems, in particular the use of chemical additives and inoculants, high-capacity machinery operated by contractors and, more recently, big-bale silage. However, we have little doubt of the key role that the Dorset Wedge played in the spectacular increase in silage making from the mid-1960s, so that by 1980 some 80% of conserved forage was stored as silage.

*Frank Raymond, Drayton 1945–52, Hurley 1952–72*

Mike Woolford developed a screening method for establishing the anti-microbial spectrum of potential chemical additives. Several of the promising chemicals identified, including acrylates and higher acids, were subsequently used commercially. However, more progress was made in the development of microbial additives. Roger Merry, Mike Theodorou and David Beever, in conjunction with the Milk Marketing Board and a Somerset farmer, Steve Edmunds, developed the 'Live System' approach for providing a low-cost effective additive. The farmer is provided with a freeze-dried inoculum of lactic acid bacteria and a growth medium. These are activated a day before addition at ensiling and generate a large population of active bacteria at application, resulting in a more rapid drop in pH in the silo than with the direct use of a freeze-dried inoculum. Effectiveness was shown to be enhanced by the use of strains of lactic acid bacteria that rapidly degrade fructan, thus increasing the quantity of substrate available for acid production and preservation.

***Hay*** Research at Hurley on haymaking was mainly at a strategic level, looking at ways in which weather risk could be reduced by increasing the rate at which water was lost from cut grass. Bob Thaine, Colin Harris and Yoel Leshem carried out experiments with single leaves and tillers in controlled environments. They highlighted the importance of cuticular resistance to water loss, greater rapidity of water loss from leaves than stems and differences between species in drying rate, with tall fescue being particularly rapid drying. Chemical treatments that damaged or removed the cuticle accelerated drying. This research was extended by Lewis Jones and Martin Tetlow. They found that drying in the field was often limited by swath resistance rather than resistance at the tissue level and stressed the need to spread the swath over the complete field area and to turn it frequently in order to minimise swath resistance and maximise drying rate. The advantage of tall fescue over ryegrass was confirmed in the field. Martin Tetlow used this information to develop a system for rapid making of hay of high quality involving the cutting of leafy crops of tall fescue at six-weekly intervals, intense treatment to minimise swath resistance and the use of preservatives to enable storage of

*A group of farmers show intense interest in kale silage made at North Wyke* moist hay. However, such systems still had greater weather sensitivity than silage making and have not been widely adopted in the UK. The approaches identified to increase water loss are, however, highly relevant to the production of high DM silage.

***Grazing*** Grazed swards are particularly dynamic. The characteristics of the sward and the numbers and type of animals used will determine the quantity of feed consumed per animal and in total. However, the nature and quantity of herbage removed will affect the photosynthetic efficiency of the sward and the subsequent balance between new growth and losses through senescence and decomposition. This in turn affects the material subsequently available for grazing. The nature of these interactions presented major difficulties in design of experiments to give real understanding of the grazing process and how it could be manipulated. The development of the concept of steady-state management of continuously-stocked swards by Tony Parsons and Peter Penning and associated work in Scotland led by John Hodgson, was a real breakthrough. This approach, with swards managed to maintain a target LAI or sward height, enabled the examination of contrasting severities of grazing, contrasting sward types and other agronomic treatments in a biologically sound and reproducible way. With steady-state management, utilised herbage production or net herbage accumulation could be equated with total animal intake, thus obviating the need to make sward-based measurements of herbage growth.

**Grazing Management to Control Parasites**

Internal nematode parasites are a major cause of poor production in sheep and we found that this was even true of sub-clinical infestations. This meant that it applied to the vast majority of sheep.

In order to establish and study such low infestations, with known species, we had to start with 'worm-free' lambs (which therefore had to be reared artificially) and graze them on 'worm-free' pasture – not easily created! This required the development of methods of artificial rearing (also useful for rearing orphaned lambs) and 'worm-free' pasture within a designated area with controlled access by people and machinery.

We further found that twin lambs carried far more parasites than singles, partly because the latter received more milk and thus consumed less grass, on which the infective larvae were ingested, and partly because they grew faster and thus took far less time to finish. In any case, it was the lambs, lacking resistance, that were most vulnerable, so we designed a system of rotational grazing management (called 'sideways-creep-grazing') that gave the lambs access to 'clean' grass alongside the paddocks that were grazed by the ewes.

Although such systems proved to be too laborious for general adoption, the work drew attention to the need for grazing management to focus on parasite control, without the routine use of anthelmintic drugs and avoiding the resistance that steadily developed to them.

*Colin Spedding, Drayton 1949–52, Hurley 1952–75*

In all circumstances examined there was a conflict between the need to minimise losses through senescence (achieved with severe grazing) and the need to achieve large intakes and performance by individual animals (achieved with lax grazing). Often the best results were achieved at an intermediate level of grazing severity.

It was realised that not only was management to maintain a fixed sward height a useful experimental tool, but it was also a technique that could be used for grazing control on the farm. Results from Hurley and elsewhere were brought together and advice provided in articles for farmers and in a 'Grazing Calendar' produced by ADAS.

**Sward Height and Grassland Management**

Sometimes a simple solution is the best! During the 1980s we were looking for practical ways to apply, on farms, the many new insights that were coming from our combined plant and animal studies. We knew we could characterise the 'carbon economy' of grazed pastures (their photosynthesis, respiration, growth, partitioning and the turnover of shoots and roots) in terms of the vegetation state (leaf area index) sustained. Detailed work on the grazing behaviour and intake of sheep and cattle was showing this could be characterised, too, in terms of a 'vegetation state' (as opposed to trying to estimate a feed 'allowance'). Some practical trials showed that we could even predict the morphology (tillering and flowering) based on simple measurements of the state of the sward at different times of year. Talks with the Meat and Livestock Commission and MAFF led them to help us promote seasonal 'sward surface height' guidelines for management, using calendars that hung on many a farm-office wall. These worked particularly well where a large proportion of the farm was grazed more or less continuously, and where monitoring made it possible to optimise production on the grazed area, by altering the area grazed, and so giving every indication of how to integrate the management of grazing and conservation. This had always been a very difficult task on farms. It was perhaps that farmers were encouraged to monitor the state of their pastures more closely, rather than to understand the 'heavy science' behind it, that reaped the benefits of this simple approach. Some of those calendars still hang on office walls as far afield as NZ: and a new tranche of grassland students seem bent on rediscovering the principles today!

*Tony Parsons, Hurley 1969–90, North Wyke 1990–97*

Several attempts have been made to avoid the conflict between the use of the animal as an efficient harvesting machine and the need to achieve high levels of intake per animal. The leader-follower approach was pioneered by Roy Blaser in USA in the early 1950s and involves rotational grazing with the preferred stock, with high nutrient demand, grazing the paddock ahead of animals with lower nutrient demand, for which high individual animal intake is not required and for which grazing can be severe. Forward-creep grazing with lambs in front of ewes, used by Bob Large and Jim Tayler in the mid 1950s, is a variant of leader-follower grazing, with additional potential advantages in parasite control. Sinclair Mayne at North Wyke, demonstrated large advantages in milk production for a group of leader spring-calving cows, but his work also illustrated the potential problem of too much sacrifice in the yield of followers.

***Legumes*** Considerable attention has been paid to forage legumes at both Hurley and North Wyke. Interest has been sustained both by the contribution of legumes to nitrogen economy of the sward and by the high nutritive value of legumes. In 1984 David Thomson collated experiments involving comparisons in performance between animals fed white clover or pure grass. He found that liveweight gain of sheep was, on average, 65% greater with white clover than with grass, whilst the empty body weight gain of cattle fed white clover was 30% greater than that with grass. White clover was shown to have a greater nutritive value than grass for all classes of ruminant livestock, whether grazed, zero-grazed, dehydrated or ensiled. High levels of intake apply also with red clover, lucerne and sainfoin, but with these crops digestibility at harvest is often lower than with grasses and there may be problems with weed ingress and persistence. Calculations by Chris Doyle indicated economic advantages for systems based on white clover and on lucerne, but

*Grazing experiment at North Wyke*

there was little adoption of legume-based systems in the period up to about 1990. It is perhaps regrettable that the Institute had not set up and examined whole systems of production. This deficiency was partially rectified at North Wyke by Jon Newton and John Morrison. Jon Newton set up clover-based sheep production systems in the early 1980s and John Morrison participated with the Meat and Livestock Commission in on-farm projects with white clover use in beef production. These were developed further by Robert Orr with a demonstration at North Wyke of a low-input clover-based system as part of the ‘Pasture into Profit’ project funded by MAFF. The development of organic production from the 1990s has provided considerable stimulus for, and practical experience in, the development of clover-based systems with work on organic milk production in IGER at Trawsgoed providing a good example.

***Maize*** Research on maize commenced at Hurley in 1966 with agronomic studies on the development of the crop by Jack Heard, Jim Corrall and Roger Sheldrick, alongside parallel work with sorghum and other whole-crop cereals. Of these annual crops, maize was outstanding in terms of both yield and digestibility, attributes that contributed to the major subsequent adoption of maize as a crop for silage though much of England, which is still expanding with further development of improved varieties.

Work on maize silage started in 1969 with studies by Jim Tayler and Chris Lonsdale on the use of maize in beef production. This was developed subsequently by Mike Wilkinson together with Cled Thomas, Ines Penning and Dennis Osbourn to produce an intensive beef system based on housed animals fed maize silage from the age of three months with low levels of concentrate feeding. Much of the research was concerned with satisfying the requirements of the young animals for protein. Without supplementation, the intake of maize silage by young cattle was found to be low. Increases in intake and performance resulted from the addition of non-protein nitrogen either at ensiling or feeding, but there was still a requirement in 3–6 month old cattle for some supplementation with vegetable or fish protein. Bruce Cottrell and David Beever quantified the supply of amino acids to the cattle from undegraded feed protein and from microbial protein and confirmed the responses to supplements with low degradability in the rumen. Parallel to this work on beef production at Hurley, Richard Phipps and his colleagues at Shinfield did much to establish the position of maize in milk production systems.

Institute staff participated in the late 1960s and 1970s in the activities of the Maize Development Association and produced booklets for farmers. Likewise in the 1980s and 1990s, staff from Hurley and Shinfield strongly supported the successor organisation, the Maize Growers Association. These linkages contributed to rapid and effective technology interaction with the maize crop.

### Key Outputs

Key outputs include:

- Development of methodology for determining *in vivo* digestibility and establishing differences with plant growth stage and species and method of conservation.
- Development of *in vitro* and gas production techniques for assessing digestibility and rate of digestion on small samples of forage.
- Increased understanding of cell wall chemistry in relation to forage digestion and upgrading.
- Identification of factors limiting the intake of fresh, dried, ensiled and grazed forages and developing methods to increase intake.
- Demonstrating the prevalence and importance of rumen fungi and ascertaining life cycle and survival stages.
- Development of techniques for assessing energy and protein utilisation and tissue metabolism.
- Establishing reasons for low efficiency of protein and energy use with forages and identifying means of improving utilisation by varying the forage, method of conservation and type of supplement used.
- Production of models to predict nutrient supply to the animal.
- Development and patenting of equipment for monitoring the behaviour of grazing animals.
- Development of improved methods of grazing including management to sward height guidelines.
- Highlighting the importance of the structure of the animal population in determining efficiency of feed utilisation and identifying the importance of maintenance requirement, reproductive rate and level of output.
- Identifying reasons for the high nutritive value of legumes and developing systems based on white clover.

*Roger Wilkins*

# SOIL AND ENVIRONMENTAL SCIENCE

## The Early Days: Foundations of Grassland Crop Nutrient Responses

Soil science has always featured as an essential part of the Institute's programme and as a component of the integrated approach to the delivery of its research. In the initial phase of development, soils-related work was particularly focussed on the agronomic aspects of optimising supplies of the major nutrients to maximise forage crop growth to increase food, feed and fibre production. The work was very much based, therefore, on the concept of the response curve to define conditions that would enable farmers to produce the maximum amount of dry matter for their particular circumstances. Trials at Hurley and throughout the country (the GM series) established the basis of fertiliser recommendation schemes for grasslands that would hold for decades. At the same time, Con Clement, Derek Cowling and David Whitehead were establishing the background to understanding the controls over major and minor nutrient supplies in grassland soils with important work, for example, linking soil potassium status with crop content and requirements. David Whitehead produced a series of authorative books that defined the normal ranges for the nutrient status of temperate grassland species which again became important reference sources for the UK and beyond.

It was also at this time that Ted Garwood and colleagues established a series of large intact isolated monolith lysimeters which, unforeseen at this time, would provide the basis of some of the early work which looked at the fate of nitrogen in grassland soils. Ted Garwood also made important observations on the distribution of roots in soils and the interaction between roots, water supply and the performance of the crop. Long-term, field-scale trials established on the freely-draining soils at Hurley to look at crop responses, would again form an important base on which later observations on nitrate leakage were founded. Measurement of changes in soil organic matter with changes in cropping management provided an early forerunner of the current interest in carbon storage in soils. The long-term trials that were abandoned when the Hurley site closed would have been a fantastic resource for the current issues concerned with carbon storage in soils and effects of climate change. There were also studies on optimising the role of clover, and other legumes, in swards and nitrogen supplies.

*Installation of intact soil lysimeters at Hurley in 1978. In 1991 the sixteen lysimeters were re-installed at North Wyke where they are still in use.*

## Changing Focus at Hurley

The changing nature of the Institute's brief and the arrival of Lloyd Jones resulted in a substantial change in the nature of the research. More basic studies on the nutrition of plants (by Con Clement,

### Flowing-Solution Culture

Excessive or 'luxury' uptake of potassium by grass can cause problems of hypomagnesemia in lactating dairy cows. This prompted the question of what was the lowest concentration below which plant roots would be unable to extract potassium from the soil solution? To explore this, grass was grown in static-water culture (hydroponics), but maintenance of a low, specified concentration proved impossible and, encouraged by Lloyd Jones, a project to construct a flowing-solution-culture system was devised in the early 1970s. A team led by Con Clement with Mike Hopper and other colleagues achieved a world-beating system based on ion-selective electrodes. This enabled plant roots to be continuously bathed in a nutrient solution which was replenished via peristaltic pumps in response to removal of nutrients by the plants. By this means, uptake could be followed over intervals of just a few minutes and the effects of light, temperature, cutting, nutrient supply etc, could be evaluated. Control of the concentration of major nutrients was achieved, including potassium, nitrate, ammonium, phosphorus and pH and other nutrients were supplied *pro rata*. In a very productive decade, over 50 papers were published from experiments using the system, and by linking up with the 'Moon Machine', the aerial canopy above the sward was enclosed to measure simultaneously photosynthesis and nutrient uptake. Another first!

The system now resides at IBERS, Aberystwyth. It is managed by James Macduff and is a key tool in breeding grasses and legumes for improved nutrient use efficiency.

*David Hatch, Hurley 1965–91, North Wyke 1991–*

Mike Hopper and David Hatch), trace elements including toxic metals (Lloyd Jones, Steve Jarvis and David Whitehead) and the supplies of sulphur (Derek Cowling and David Lockyer) brought a greater international flavour to the programme and capitalised on techniques and approaches established elsewhere but set their own standards for others to follow. In particular, the flowing-solution culture system for sustaining low, realistic nutrient concentrations at plant root surfaces was a world leader in increasing understanding of the controls over elemental behaviour and impact in plant parts, whole plants and crop canopies under controlled conditions. This system, with contributions from a series of research fellows from Reading University and many international visiting research workers, produced an important series of papers helping to define the regulatory controls over nitrogen, phosphorus and potassium uptake and utilisation by grassland plants. This work demonstrated, for example, differences between plants in their nitrate and ammonium nutritions, the effects of cutting and other simulated managerial/environmental controls on nutrient demand, uptake and utilisation, effects of nitrogen supply on fixation by grassland legumes amongst other effects. Other work defined interactions between supplies, uptake and distributions of copper, cadmium, manganese and silicon in grasses and other plants. The system of flowing-solution-culture, first fully operational in the early 1970s, was transported lock, stock and barrel to Aberystwyth when Hurley closed, where it continues to function effectively in research led by James Macduff.

*Flowing-solution culture system at Hurley in 1980s*

Derek Cowling, with David Lockyer, established systems that demonstrated the role that atmospheric deposition of sulphur had in sustaining supplies of this element to intensive grassland systems and the effects of sulphur dioxide had on crop responses. Exposure chambers were built to maintain constant concentrations of sulphur dioxide at leaf surfaces to determine effects on grassland

*Mass spectrometer for isotope analysis, North Wyke, 2009*

plants. This research clearly demonstrated the possibility of sulphur deficiencies developing on many UK soils in the absence of an atmospheric input of sulphur dioxide. Research led by Steve Jarvis on heavy metal distribution in soils and effects of plants and supplies of essential trace metals such as copper from soils to plants and then to animals was also an important component of the work at this time.

**Isotope Ratio Mass Spectrometry**

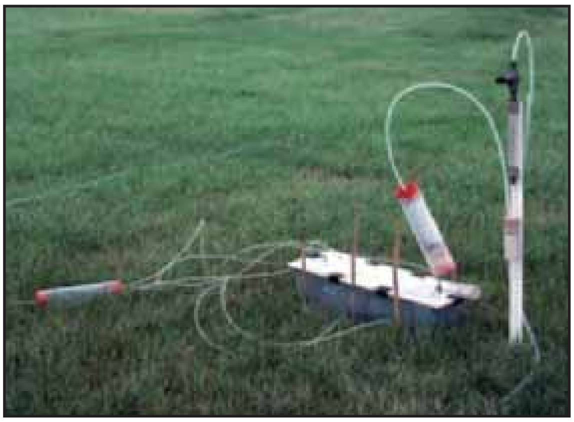
Up until the 1970s the preparation of material for isotope ratio mass spectrometry was a laborious business, involving all sorts of digestion and distillation procedures. Nitrogen had to be converted first to ammonium-N and then to nitrogen gas by alkaline lithium hypobromite in the complete absence of air. Incomplete conversion and cross contamination were ever-present sources of error.

In 1980 I began exploring the possibility of linking an automated combustion analyser to an isotope ratio mass spectrometer, thereby eliminating all these preparatory steps. Jerry Whiteway became interested in the software control aspects of the project and together we overcame many seemingly impossible problems to develop a successful system.

Other research groups were also working on the problem and we were just beaten in the publication race by Preston and Owens from Plymouth Marine Laboratory. Now you can buy such systems off the shelf, if you have enough money.

*Rick Marshall, Hurley 1974–92*

Nitrogen had been a focus of the work of the Institute from the outset but the arrival of John Ryden in 1979 brought a range of new techniques to examine all aspects of the nitrogen cycle in grasslands. This enabled the work to take several large and important steps forward. This was coincident with a rising interest in the environmental aspects of grassland management by funders and policy makers. Further, the acquisition of the North Wyke station with its very contrasting soil (poorly-drained, silty-clay loam) to that at Hurley (freely-draining loam over chalk) provided the opportunity to extend studies to include an important, representative soil type for lowland grassland in the UK. The installation of the Rowden field-scale hydrologically-isolated lysimeters provided an important platform, not only for its original purpose, the impact of drainage conditions on dry matter and beef production, but also for studies of the comparative behaviour of nitrogen in these grassland types. John Ryden and Ted Garwood demonstrated at an early stage the role of the animal in recycling nitrogen and creating local surpluses in the soil which lead to much larger leaching losses than had been recorded under grassland that had been harvested for winter feed. Additionally, the arrival of Brain Pain at Hurley, following the closure of NIRD at Shinfield, brought another dimension to the studies, that of the impact of nitrogen applied in manures (slurries and solid manures, such as farmyard manure) from housed livestock.



*Early equipment (1980) for measurement of nitrous oxide loss in the field*

Throughout the 1980s and 1990s this area of work, in reaction to the shifting governmental policy changes from food production to environmental aims and targets, produced pioneering information on aspects of the nitrogen

**Leaching from Grazed Grassland**

Until the early 1980s, losses of nitrogen in drainage from agriculture were thought mainly to be associated with arable cultivation and the limited information for grassland was based on measurements made under cut swards, or using soil monolith lysimeters. Data on leaching losses from grazed grassland began to emerge from research at Hurley and from the Rowden Drainage Experiment established at North Wyke in 1982. Work by Ted Garwood's team laid the foundations for understanding the interactions between fertiliser, animal excreta and soil mineralisation when soils in traditional grassland growing areas with high rainfall were drained.

A seminal paper by John Ryden, Roger Ball and Ted Garwood in Nature in 1984 demonstrated a more than five-fold increase in leaching potential found under grazed swards compared with similarly fertilised cut swards. These losses also exceeded losses normally associated with arable land.

From the field-scale lysimeter studies at North Wyke, leaching data were obtained over seven years by David Scholefield and his colleagues which averaged 39 and 134 kg nitrogen/ha per year from grazed swards receiving 200 and 400 kg nitrogen/ha, respectively. They went on to produce a model of the nitrogen flows in grassland (NCYCLE) and the losses that occur when there is an imbalance between uptake of nitrogen by the sward and the supply of nitrogen from the soil. This early model was later extended and improved (NGAUGE) to provide recommendations for the timing and applications of fertiliser to more closely match the demands of the crop and avoid surpluses that could be vulnerable to loss.

*David Hatch, Hurley 1965–91, North Wyke 1991–*

*Hydrologically-isolated, one hectare plots at Rowden, with seven of the plots being drained and seven undrained*

cycle that had not been tackled to any great extent before in all components of a grassland production cycle. Thus information on ammonia volatilisation, nitrous oxide production, nitrate leaching, the role of animals and the impact of excreta and manures was produced which was essential to the development of policies by government on nitrate leaching, atmospheric quality and, latterly, climate change.



## Continuation at North Wyke

***Nutrient cycling*** The transfer of the work to North Wyke in the 1990s meant that the nitrogen studies became more and more centred on the Rowden experiment. By this time Steve Jarvis had, after the early death of John Ryden, taken over this area of research at Hurley and then continued its development at North Wyke. David Scholefield and Ted Garwood had already produced information from the Rowden experiment that demonstrated the interaction between soil conditions, water supply and crop growth and, importantly and critically, again emphasised the role of the grazing animal in controlling nitrogen losses. At this time the funding for this work became much more competitive and often much more short term. Nevertheless, the researchers involved at North Wyke were tremendously successful in obtaining funding for research and the work continued to produce both important applied outputs which were of immediate relevance and use to policy makers and land managers. It also encompassed some fundamental studies on the controls over nitrogen dynamics from all aspects in soils and its subsequent fate. Thus, basic understanding of nitrogen mineralisation, nitrification and denitrification made substantial progress.

There was by this time sufficient information available to indicate that another approach to the basis of formulating nitrogen recommendations for grassland should be developed and David Scholefield took the initiative to devise a new system. This depended upon a knowledge of available nitrogen supplies present in the soil (by means of a field test kit) coupled with prediction of immediate crop demands at specific times in order to regulate the supplies of any additional fertiliser nitrogen at times and amounts required to meet that demand. Although very successful in optimising efficiency of nitrogen fertiliser use, there was reluctance on the part of funders to provide the means to develop the scheme further. However, the concepts involved and the research findings were extremely important in stimulating the development by David Scholefield and his colleagues of an important series of models to predict the behaviour of, and the requirements for, nitrogen in grassland managements. In this and in other components of the research, an understanding of the role of the grazing animal continued to be especially important. The field-scale plots, firstly at Hurley and then at Rowden of a sufficient scale to accommodate grazing livestock and their effects, were instrumental in helping to trigger a change in thinking throughout the world on nutrient cycling, especially of nitrogen. Similarly, the level of understanding that evolved from the full life cycle consideration of manures and slurries enabled a better understanding of nutrient supplies and losses.

By the mid 1990s funding patterns had continued to evolve and whilst nitrogen was still important, funding from MAFF (later Defra) was much more targeted at specific, often relatively short-term interests. There was, however, an increased interest in phosphorus movement away from soils and into waters and the arrival

**The Sulphur Story**

During the 1970s the UK was emitting five million tonnes of sulphur dioxide annually and it was suspected that, at the concentrations found in rural England, dry deposition of sulphur dioxide was contributing to the sulphur nutrition of agricultural grassland. Would a clean air policy lead to sulphur deficiency?

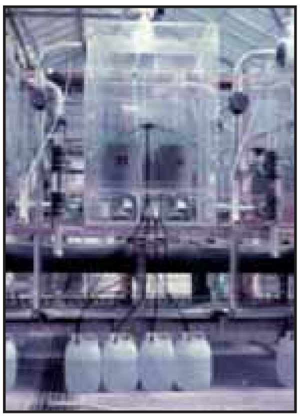
When ryegrass was grown on a wide variety of soils in a controlled environment where sulphur dioxide was filtered out of the air and where all other nutrients were adequate, the soil reserves of sulphur were often found to be insufficient.

During 1972 a series of exposure chambers was designed and constructed by David Lockyer and Gill Eary to enable plants to be exposed to controlled concentrations of sulphur dioxide, in order to evaluate the contribution made by atmospheric sulphur dioxide to the sulphur status. Joint work with the University of Oxford used $^{14}CO_2$ to study the effect on photorespiration and the effect on amino acid metabolism was also examined.

Meanwhile, Ken Tyson had been estimating atmospheric inputs of sulphur using data from lysimeters and this led to the setting up in 1976 of a four-year lysimeter study involving different agricultural soils. These lysimeters were subsequently transferred to North Wyke where they continue to be used.

By the time Hurley closed, the grassland sulphur story was largely understood but a field trial run by Elaine Jewkes at North Wyke in the late 1990s showed that sulphur deficiency was still an important issue in the field. Moreover, the application of gypsum (calcium sulphate) reduced nitrate leaching presumably by enabling the crop to utilise more inorganic nitrogen.

*Andrew Bristow, Hurley 1966–91, North Wyke 1991–*



*Chambers to expose plants to controlled concentrations of sulphur dioxide*

*Weirs for measuring water flow and nitrate from drains and by surface flow at Rowden*

of Phil Haygarth in 1993 meant that North Wyke had an important role to play in supplying information that was of relevance to national and international polices in this area. The work was also significant in reinforcing the importance of understanding effects at all scales and extended the process by initiating studies that took the research from soil crumb to soil profile and from field scales up to catchment scales. Again the work at North Wyke was instrumental in the development and delivery of new approaches and information which obtained strong international recognition.

Other work provided information which underlined the importance of previous studies at Hurley that demonstrated the likelihood of sulphur deficiencies with the cleaner fuels now being used to provide power and a reduction in sulphur deposition. It was shown by David Scholefield, Lorna Brown and Elaine Jewkes that soils, now lacking sulphur were, because of this deficiency, not utilising the available nitrogen and thus could create a greater potential for losses of nitrogen to air or water. Other studies provided a complete potassium balance for grazing systems and demonstrated the extent of leaching losses of this nutrient into waters.

***Manure/slurry management*** The work on farm manures by Brain Pain, David Chadwick, Phil Hobbs, Tom Misselbrook, John Laws and others had much influence in determining the mechanisms for improving the management of livestock manures and reducing losses to the wider environment. Working in a series of long-term partnerships with others, especially with ADAS and Silsoe Research, the team developed/adapted methods to look at the complete life cycle of manure management from many perspectives, but with emphasis on nitrogen cycling. This has been extremely important because, and as with all components of grassland management, manipulation of one phase of manure management has consequential effects at others. Thus the research examined the impact of, for example, methods to reduce ammonia emission, by band spreading or shallow injection of slurry (initially with what was then IMAG-DLO in the Netherlands), on the 'knock-on' effects on emission of nitrous oxide. At the same time, the effects of different managements and definitions of the overall flows of nutrients and supplies to crops from these and other materials added to land were important. Thus, as well as reducing nitrogen losses, the work was always concerned with the more effective use of the nutrients contained within manures to reduce the demands for additional supplies from fertilisers, and to change the consideration of manures by farmers from being a disposal problem to one of being a valuable resource. The integration of the organic matter contained in manures and slurries into the fabric of the soil was also of importance and of much current relevance. There were also important practical outcomes in studies of the effects of different methods of application of slurries to swards to ensure palatability for subsequent grazing animals and of utilising slurry on grass/white clover swards through a series of self-contained 'farmlets'. Other studies focussed on the transport both through and

*'Micro-met.' mast for measuring ammonia loss from shallow-injected slurry.*

across soils of nutrients and fine organic matter (responsible for high Biochemical Oxygen Demands) in dirty water from dairy farms with the aim of devising safe disposal strategies. Much of the research undertaken in all these areas still forms the basis of knowledge transfer exercises to inform grassland famers on approaches to improve their manure management and to meet environmental targets.

Another unique aspect of the work was the question of odours. This, often an issue of immediate concern to the public at large, was examined by Tom Misselbrook and Phil Hobbs with the development of a specialised odours laboratory first at Hurley and then transferred to North Wyke. With the aid of some computer-controlled dilution equipment and a panel of human 'sniffers', the odour concentration in air was measured and, coupled with mass spectrometry and other techniques, the composition of odiferous compounds and the conditions which promoted their proliferation could be determined. Latterly, the work was developed by Phil Hobbs to identify specific compounds responsible for the odour and also those contributing to other aspects of environmental quality including the emission of non-methane volatile organic carbon compounds. The wide base of the expertise on manures and other materials thus developed has meant that the team has been able to capitalise on new issues as they have arisen. This includes research by Dave Chadwick on the potential for transfer of pathogenic organisms from managed land into waters and work by Phil Hobbs on the use of manures and other organic waste materials as resources for anaerobic digestion and the supply of energy (again representing a return to a research area undertaken over 30 years ago at NIRD and at other sites).

***Gaseous emissions*** Gaseous emissions have been an important component of the work firstly at Hurley and then at North Wyke. Studies on the controls and emissions of ammonia from all components of animal production, i.e. grazing (by David Hatch and Steve Jarvis), housing, spread and stored manures and slurries (by Brian Pain and colleagues) and from fertilisers, formed a key part of the research required by MAFF/Defra's policy development to limit fluxes of ammonia to the atmosphere and to establish advice for farmers to change their managements to achieve this. As with many aspects of the soil/environmental work, much of this was in collaboration with others, in this case with ADAS, Imperial College, Silsoe Research, CEH and others. The work on manures was important not only from an ammonia perspective, but also to drive the philosophy of considering manures as a resource of nutrients and enabling savings to be made on mineral fertiliser use.

## Ammonia Emissions

Agriculture is the major source of ammonia emissions to the atmosphere and subsequent deposition can damage sensitive habitats through acidification and eutrophication. Quantification and mitigation of ammonia emissions from agriculture have therefore been key research aims in a significant programme of research from the late 1980s led initially by Brian Pain and subsequently by David Chadwick and Tom Misselbrook with manures and slurries, and John Ryden and then David Hatch and Steve Jarvis with grazed swards.

One of the largest emission sources is manure applications to land, where ammonia emission also represents a loss of potential nutrient nitrogen for plant uptake (up to 50% of applied manure nitrogen may be lost), and this was a major focus of much of the initial work. The system of small wind tunnels developed by David Lockyer in the mid 1980s was used in small plot studies to improve our understanding and to develop mitigation techniques. The wind tunnel system has subsequently been copied and used in many other countries. Larger-scale measurements were made using micrometeorological techniques and the combination of these studies at different scales enabled the development of emission models which highlighted the key factors influencing emission, such as slurry DM content and wind speed. Techniques which gave low emissions were developed and demonstrated, including shallow injection and band spreading and rapid soil incorporation of manures applied to arable land.

The development of an inventory model of ammonia emissions from UK agriculture became increasingly important in order to comply with internationally agreed ceiling emission targets. Our research has contributed to improved quantification of emissions from all significant sources (livestock grazing, livestock housing and outdoor yards, manure storage, manure spreading and fertiliser application). Mitigation potential has been assessed through a combination of controlled studies using a purpose-built cattle housing and manure storage facility at North Wyke and measurements on commercial farms.

*Tom Misselbrook, Hurley 1987–91, North Wyke 1991–*



Development of an agricultural emissions inventory of ammonia for the UK, as required to meet European Union policies and targets, was very dependent on the work of the Institute to provide information relevant to grassland/ruminant production. Tom Misselbrook is still responsible for the co-ordination of new material to update the national emissions inventory required by government. North Wyke also holds the co-ordination role for greenhouse gas emissions data for agriculture, now undertaken by Laura Cardenas. This includes nitrous oxide and methane. Nitrous oxide was first of research interest to the Institute as a loss component of the nitrogen cycle. This has become increasingly important with the greater appreciation of the role of this gas as a key component of climate change effects and recognition that agriculture was a major source.

The development of techniques introduced by John Ryden to inhibit the transformation of nitrous oxide to nitrogen gas in the denitrification process enabled methods to be used which overcame some of the problems of spatial (exacerbated by the hot spots caused by the excreta of grazing animals) and temporal variability that is associated with the processes involved. More and more sophisticated mobile field chambers with in-field measurements, developed by Sirwan Yamulki and Dave Chadwick, provided additional reliability and certainty to measurements. The systems developed also had the capacity to measure other important gases such as NOx, methane and carbon dioxide. An alternative approach developed by David Scholefield, Jane Hawkins and Laura Cardenas was to move to an entirely laboratory-based system that used intact soil cores under controlled conditions and supplied information on all the products of denitrification. This has been used, along with $^{15}N$ stable isotope studies, to enhance understanding of the controls over the processes involved in nitrous oxide production and the impacts of fertilisers, excreta, soil properties and environmental conditions have been defined. The results obtained for nitrous oxide in particular (but also to some extent for ammonia) has enabled the development by Lorna Brown and others of predictive models for gaseous emissions. Another important greenhouse gas from agriculture, methane, has also been a subject of investigation. An initial grant from a Japanese foundation (RITE) in 1990 was the kick-start to this area of work which was developed by Steve Jarvis to look at the impact of dung pats, and then by Dave Chadwick to look at manures and slurries, and exchanges with soils on methane emissions. The North Wyke site was amongst the first to monitor the net effect of grazing on the emissions of methane. David Lockyer and Phil Murray developed and deployed a chamber system, large enough to enclose grazing animals, to demonstrate strong diurnal patterns in the net emission of this gas to the atmosphere, as well as providing emission factors for grazing systems.

## The Development of Research on Soil, Manures and the Environment

From an early stage, integration of knowledge of soils with all aspects of the complexity of grassland systems has been a key feature of the research. For example, the early studies on production at North Wyke were coupled not only with nutrient cycling but also with aspects of soil structure, in particular the impact of the grazing ruminant on soil physical conditions, especially important on the 'difficult' North Wyke soil. Effects of 'poaching' were determined. This involved the creation by David Scholefield of an artificial cow, or at least part of a cow, the hoof (affectionately known as Mabel), to determine more precisely the pressures and stress placed on soil by grazing animals under different conditions.

Despite the now contracting research funding base from the Defra, soils work continued to make progress, although with a rather different emphasis than previously. On the one hand there was an increasing reluctance to provide the means of supporting long-term applied research. On the other, there was a growing base of basic

**Cows in Tents!**

One of the major agricultural contributors to climate change is the emission of methane from ruminants, produced as a by-product during the rumen digestive processes. Estimates of methane from ruminants, including that from grazing animals, are based largely on measurements made from sheep and cattle housed in metabolic chambers. For grazing ruminants, there was a developing method based on controlled release from the rumen of a tracer gas (sulphur hexafluoride) from a capsule placed in the rumen and then captured in a vacuum device on the animal's head. This, for a variety of reasons, was not an easily applied method and North Wyke won a contract for an alternative approach. David Lockyer took on the responsibility of doing this and developed what was essentially a large enclosure system. This comprised a poly-tunnel, large enough to house a number of sheep, with a controlled air-flow rate and a field-based measurement system to measure inlet and outlet methane concentrations. From this, a release rate of methane per animal under realistic grazing conditions could be determined. This system caught the attention of local and national media including the national 'red-tops' who managed to 'spin' the work so that it was described as "cows" – *they were sheep* - in "tents" – *it was a poly-tunnel* – on "Dartmoor" – *it was on the farm at North Wyke* – emitting methane by "flatulence" – *they used a different word, and most is emitted in the breath anyway!* So, nearly correct! Despite this, the system was a success and provided emission factors under more realistic grazing conditions, demonstrating for example some important diurnal variations not previously described.

*Steve Jarvis, Hurley 1970–91, North Wyke 1991–2006*

*Grazing sheep in polythene tunnel with controlled air-flow rate for measuring methane emission*

*'Mabel' the one-hoofed cow: designed to simulate and measure the pressures and stress placed on soil by grazing cattle.*

studies supported by an increased provision of core funds from the Institute and a very healthy acquisition of funding from BBSRC, the Natural Environment Research Council (NERC) and others. This enabled mechanistic work on nitrous oxide by David Scholefield and others, phosphorus by Phil Haygarth, solute movement by David Scholefield, pathogen movement by Dave Chadwick, soil-plant-root-herbivore intereactions by Phil Murray, nitrogen and organic matter dynamics by Roland Bol amongst other topics to be established and advanced. Soil biology had been a missing component of the work for some time and recommendations from three successive Visiting Groups eventually meant that a soil microbiology interest could be followed. There was also a development of the interest in soil macro-biology. Stable isotopes had long played a role in determining process rates and transfer routes and their controls (nitrate transfer, nitrous oxide production and evolution for example). An increase in the recognition that there was variation in natural isotopic abundance, especially of nitrogen, in soils encouraged investigation by Roland Bol of the role of components of soil organic matter. The availability and sensitivity of mass spectrometry equipment at North Wyke was an essential feature in allowing this to happen. An interest in organic matter and its role through mineralisation in different managements and linkage with other processes were common objectives in both soils and farm manures research.

There was also an interest in organically managed soils that developed at this time, initially stemming from a joint research project based on the Duchy Farm at Tetbury with Rothamsted Research which, along with other participants, was part of an early programme sponsored jointly by BBSRC, NERC and the Economic and Social Research Council (ESRC). Partnerships have been very important in developing the research over many years. This has particularly involved ADAS, the Silsoe Research Institute, Rothamsted Research, NERC sponsored institutes (especially at Wallingford and Edinburgh) and numerous Universities (but especially Reading and Plymouth) both as academic partners in PhD projects but also as full partners in major research programmes. The research programme and its outputs also stimulated a number of strong overseas collaborations and projects particularly with New Zealand, the Netherlands, Chile, Portugal, France and Ireland amongst others. A number of European Union sponsored research projects widened the network of European collaborators. During Chris Pollock's directorship there was encouragement to develop

*Wind tunnels and enclosure apparatus being used for measuring ammonia and greenhouse gas emissions on cultivated grassland* even stronger interactions between different disparate components of the Institute at different sites. Thus there was a strong drive to ensure that there was good linkage between the strengths at North Wyke on environmental issues with, for example, the genetic control over grassland crop potential to enhance nutrient use efficiency. The research in this area, particularly that on nitrogen and including the modelling and consideration of on-farm nitrogen flows, contributed much to the big drive for a change to consider top-down drivers and helped to initiate the strong links that North Wyke had with Aberystwyth scientists and to support the Director's firm stance with BBSRC of the value to them of an institute which could deliver solutions for multifunctional land-use problems. A further, and major, initiative was the development of the SoilCIP for soils research. Encouraged by the then Chief Executive of BBSRC (Julia Goodfellow) and the directors of IGER (Chris Pollock) and Rothamsted Research (Ian Crute), the SoilCIP was developed by Keith Goulding and Steve Jarvis. This was to ensure in the first instance that the soils research programme of both organisations was fully integrated and that there was an optimised utilisation of, and output from, the joint resources (human, technical and physical) of the two groups. This was launched in 2005 and now not only involves the two initiating groups but also includes interactions with other similar-minded groups at other Institutes and Universities.

## Concluding Comments

As well as providing novel information on the specific areas under investigation, soil and environmental scientists at Hurley and North Wyke have played key roles in enabling other research institutes and their scientists, nationally and internationally, to undertake research relevant to their own particular conditions and circumstances. The continuum of research from basic process understanding through to practical on-farm advice has also been enabling for farmers and other land mangers as well as policy makers to optimise their circumstances to ensure optimum production with minimal environmental impact. The ability to respond to an ever-changing suite of policy changes has been a key attribute that will continue to be important in the future. Many of the findings have been deployed to develop models for the prediction of effects at a range of scales.

Key outputs have included:

- Improved understanding of the nutrition of grassland plants and the distribution and impact of elemental (including trace elements) distribution within plants and soils.
- Provision of the bases for fertiliser recommendation schemes for grassland managements and the optimisation of supplies of nutrients from soil, manure and mineral fertiliser sources.
- Development of systems-scale investigations for nutrient cycling and the demonstration of the role of the ruminant in having impact on the extent of recycling and potential for leakage from grassland production systems to the wider environment and the opportunities for controls.
- Development of methodology for an improved understanding of the controls and extent of

emissions of nitrate, phosphorus, nitrous oxide and ammonia.

- An improved understanding of the basic processes controlling the forms and distributions of nitrogen and phosphorus in soils and manures, including the functions of organic matter.
- Provision of information to allow the quantification of emission factors and the calculation of national emissions of important atmospheric pollutants (ammonia, nitrous oxide, methane).
- Improved understanding of the composition, impact and improved methods for manure storage, spreading and utilisation.
- Improved understanding of the grassland nitrogen and phosphorus cycles at a range of different spatial and temporal scales.
- Delivery of models and predictive capability.
- Integration of this information into full production systems in order to aid on-farm management and decision making and to identify options for the future.

*Steve Jarvis*

## BIODIVERSITY AND SYSTEMS RESEARCH

### Biodiversity

During the early days of the Institute, scientists responded to the demand for more information to drive feed production and the delivery of livestock-derived food. The driver for this was the by-and-large mono-culture grass crop supplied with large quantities of nutrients, especially nitrogen. This left little capacity to consider other components of the production which occurred on other wide-ranging and diverse sward types which were prevalent in grassland-based agriculture. GRI and its forebears had a long-term interest in the botanical composition of grasslands. Attention was, therefore, focussed on the proportion of the agriculturally-preferred grasses, such as ryegrass, and the prevalence of weed species. Less attention was given to the diversity of the species present although potentially valuable data were collected. Information from grassland surveys carried out throughout England and Wales in the 1970s and led by Joe Green and Tom Forbes provided key inputs to a review of the state of grassland in the country published by Robin Fuller of the Institute of Terrestrial Ecology in 1987. This report noted that the majority of neutral grasslands lacked significant wildlife interest and only 3% had not been 'damaged' by intensification. A detailed survey for the SW was also conducted in 1983 by Alan Hopkins which provided a base of information for the later development of the research at the North Wyke site and was also important to a more recent study by Alan Hopkins and others on the impact of climate change on local grassland farming systems.

The completion of the surveys was more or less co-incident with two other events: i) the acquisition of North Wyke by GRI to provide a site that was more representative of typical lowland grassland conditions and ii) the widespread growth in the belief that biodiversity was of major importance in its own right for the future of many aspects of the sustainability of UK landscapes and their multi-functionality. At North Wyke this was initially encapsulated into some major projects undertaken by Jerry Tallowin and his colleagues on botanical diversity.

*Making botanical assessment of diverse grassland*

The long-term study on grazed swards at Tadham Moor by Jerry Tallowin and Francis Kirkham examined the effects of management of herb-rich pastures in Environmentally Sensitive Areas. This clearly demonstrated the effects of only small quantities of fertiliser in reducing biodiversity and highlighted the major challenge of combining a high level of biodiversity with efficient agricultural production. Attempts in other experiments to enhance biodiversity of swards that had been managed intensively were often disappointing, particularly where there were large reservoirs of nutrients, especially phosphorus, which increased the

**Grassland Surveys**

Between the late 1940s and mid 1980s the Institute conducted a series of surveys of the grassland on farms in England and Wales. Information was gathered on the botanical composition, agricultural quality and management of the nation's grassland which was invaluable in improving our understanding of grassland farming and in helping with prioritisation of grassland research.

The first national grassland survey (completed in 1939–40) was carried out by Stapledon's team at Aberystwyth. The survey method combined general reconnaissance of pasture types with a detailed record of 250 transects of about 400 hectares each and the results were invaluable for planning wartime agriculture. In 1945 a national grassland map was published by Ordnance Survey, based on the 1939 survey. In 1947, and then again in 1959, the detailed transects were re-examined by GRI staff, and, as in 1939, attention focussed on the older swards. Interest in the potential for agricultural improvement showed a need to also survey physical features of the land and to consult with occupiers. Following preliminary work by John Morrison, in the early 1970s the newly formed Grassland Intelligence and Survey Team (including Mike Nicholson, Angus Idle, Roger Davies and Eric Evans) working under the supervision of Joe Green, was charged with a sample survey of 1327 whole farms in 28 districts of England and Wales. Surveyors typically worked in pairs, interviewing the farmer and covering one farm per day on average, with botanical composition recorded for individual fields as assessed by visual estimation of plant species proportions; minor species and weeds were also recorded. Ten of these districts were re-surveyed in 1983 and 1986 by staff from North Wyke, with survey objectives which included identifying the farm management that had been compatible with landscape and conservation objectives.

During 1974–77 GRI, in partnership with ADAS, carried out a National Farm Study involving the participation of 500 predominantly permanent grassland farms. This was a really mammoth project: detailed farm recording was made over two years on each farm, including all inputs, outputs and management, including individual daily field records of grazing. The Hurley survey team again carried out the field recording of the grassland and its composition, following a similar method to the 1970–72 survey, but this time relating the grassland to its farm output in terms of utilised metabolisable energy and to its grazing management at the field scale. The survey team was again led by Joe Green, with Steve Peel, Alan Hopkins, Andrew Ginger and Cynthia Link as its core members. Other GRI staff occasionally joined in as assistants, gaining valuable experience through farm visits.

A feature of the surveys between the 1930s and 1986 was the overlapping of personnel. This was a reflection of the long years of continued service and contributed much to achieving consistency in approach and recording. 'TE' Williams had worked with Stapledon on the first survey and then organised those in 1947 and 1959. Joe Green had contributed to these and organised the 1970–72 national sample survey and the 1974–77 National Farm Study; Alan Hopkins and Steve Peel had carried out most of the fieldwork of the National Farm Study and then went on to organise the resurveys of selected districts of the sample survey from North Wyke in the 1980s. Sadly, no national grassland surveys have been conducted since the late 1970s, and outside of certain localities, such as designated Environmentally Sensitive Areas, we can only speculate on today's grassland composition, output and management.

*Alan Hopkins, Hurley 1973–82, North Wyke 1982–2006*

competitiveness of aggressive species and reduced the biodiversity potential. These studies were important in stimulating research to develop other options and latterly to involve the grazing ruminant as a key factor.

As a consequence of these initial projects, a number of large-scale and often long-term projects sponsored by MAFF/Defra and led by or involving North Wyke scientists and colleagues in CEH, ADAS and universities have been conducted until the present day. These provided valuable information on which practical solutions to enhance biodiversity could be based and guidelines provided which could be incorporated into agri-environmental schemes and policies, including Environmental Stewardship, for example. Key findings have been that i) there is a need to reduce competition by reducing soil fertility, ii) sward disturbance was good for biodiversity, iii) there must be an appropriate management including taking a late cut after sward establishment, iv) usually it is feasible to restrict biodiversity promotion to patches and/or strips only and v)



**The Tadham Project**

Conflict between farmers and nature conservationists spurred on by the designation of Sites of Special Scientific Interest on the Somerset Levels in the early 1980s opened a new chapter of research for North Wyke. Farmers on the Levels wanted to be able to use inorganic fertilisers to boost yields; the nature conservationists, on the other hand, were convinced that this would lead to severe loss of biodiversity. The hay meadows of the Levels were exceptionally rich wildlife habitats. The conflict highlighted fundamental gaps in knowledge about the likely impacts of fertilisers on species-rich grassland. Specifically, empirical evidence was needed to support the contention that even small increases in grassland management intensity would cause ecological damage. There was also little information on how readily such meadows could be restored after the cessation of fertiliser use and the reinstatement of traditional management.

Addressing these uncertainties was the remit of the Tadham project, which was co-ordinated by North Wyke, with the Institute of Terrestrial Ecology as research partner. The project was commissioned by MAFF, English Nature and the Department of the Environment. The project (1986–1993), led initially by Francis Kirkham and then by Jerry Tallowin, with the Institute of Terrestrial Ecology component led by Owen Mountford, was daunting both in size and logistics. Remote, situated in the heart of the Somerset Levels, the 20-ha site was criss-crossed with deep drainage channels (rhynes), which posed a whole new set of challenges. Not least being the pulling of unwary cattle out of rhynes by lassoing them and dragging them out of the water by tractor!

The research demonstrated that fertiliser nitrogen inputs as little as 25 kg/ha per year were unsustainable for the plant species diversity of the Tadham meadows and that the application of inorganic phosphorus and potassium also caused rapid major losses to the meadow flora under cutting management. We showed that the productivity of the species-rich meadows under a range of fertiliser nitrogen inputs could be predicted from general response models for grassland in the UK and that there was no residual benefit to productivity in the year after large fertiliser application because of leaching losses of nitrogen in the peat soil. The team found that after stopping phosphorus inputs, the recovery of plant diversity was slow and uncertain: this was in accordance with findings of other major studies on grasslands elsewhere in Europe. The project highlighted the importance of ameliorating elevated soil fertility conditions prior to biodiversity restoration. This foreshadowed an ecological restoration research theme at North Wyke that continues to the present. The project was amongst only a few studies that identified the important role of grazing the regrowth from the hay cut in ameliorating fertiliser effects and in maintaining species-richness in meadows. Prior to this project there had been few well-documented multidisciplinary studies on biodiverse grassland: the project put North Wyke on the ecological map by setting a benchmark for sustainable management of such meadows in the UK. The findings underpinned the formulation of agri-environmental policy on fertiliser use for species-rich hay meadows.

The project came to an end, like so many ecological experiments, when its value was still in its infancy. Tadham was a classic research ‘platform’, which in its seven year life produced twelve scientific papers, one PhD, and featured in more than five international and national conferences on grassland management and nature conservation.

To the many who assisted with the Tadham project, sweating and/or sneezing their way through hay sampling, seemingly endless weighing and grinding of samples, spending hours in apparent religious devotion to botanical surveys, cursing the perversity of cattle that repeatedly jumped into rhynes, it was, nevertheless, a memorable experiment!

*Jerry Tallowin, Hurley 1975–82, North Wyke 1982–*

**Soil Phosphorus and Grassland Plant Diversity**

A fine piece of roast beef and an excellent bottle of red wine had a defining role in the initiation of a new phase of agro-ecological research at North Wyke. The context being a dinner, in the summer of 1992, at which Alain Peeters, on sabbatical leave at North Wyke from the Universite Catholique de Louvain in Belgium, and I hatched the idea of a European project to look at the interaction between extensive management of grassland and biodiversity, agronomic output and socio-economic value. This became the EGRO project, which was co-ordinated by North Wyke. Alain and his research team, Jan Bakker and his team at the University of Groningen, Thies Oomes at Wageningen and Federico Fillat and his team at the Instituto Pirenaico de Ecología at Zaragoza were the principal collaborators. Amongst the scientific objectives of this project was one to identify values of soil macro-nutrient availability and primary production in extensively managed (semi-natural) grasslands that allow species-rich plant communities to develop and be maintained.

The EGRO project established a general relationship between grassland botanical diversity and soil phosphorus status. Subsequent Defra-funded research led by Richard Bardgett at Lancaster University in which we at North Wyke, Roger Smith at Newcastle University and Simon Mortimer at Reading University collaborated, further confirmed the relationship between poor soil phosphorus supply and grasslands of nature conservation value. These research findings now underpin agri-environmental policy on grassland floristic diversity restoration and maintenance in the UK.

The EGRO project generated a substantial ecological and agronomic database on the semi-natural grasslands of Western Europe. From a national perspective, the database was invaluable to a review of the agricultural productivity of lowland semi-natural grassland in the UK. A measure of the quality of science emanating from this project was receipt of the Southwood Prize of the British Ecological Society for the best paper published in the Journal of Applied Ecology in 1997 in which Roger Smith of North Wyke was a co-author.

*Jerry Tallowin, Hurley 1975–82, North Wyke 1982–*

some species are more easily introduced than others and yellow rattle (with a semi-parasitic interaction with strong competitors) can produce particular benefits. Another approach by Alan Hopkins was to introduce deep-rooted species with the specific objective of 'mining' nutrients (and reducing nitrogen leaching). This is of particular importance in organic systems. Whilst this nutrient mining effect was considered to be important, the introduction of such species into grazed swards was also thought to convey palatability benefits.

The role of the herbivore, including the grazing ruminant, in determining sward structure is all important in helping to develop biodiversity through effects on niche creation and dispersal of propagation material. Research teams led by Jerry Tallowin and Andrew Rook examined the role of cattle in manipulating the canopy structure/architecture, in determining sward composition and, as a consequence, influencing faunal assemblies (and therefore the supply of food for further up the food chain). This was further linked with other studies which examined the interactions between biodiversity, cattle breed and product (beef composition and taste) and grazing on improved, species-poor or more diverse semi-natural pastures. Research also demonstrated the important role that manipulating field margins by grazing, mowing or sowing plants has in providing feed or shelter for insect and bird life. A joint project with Lancaster University differentiated and evaluated the relative roles of above- and below-ground processes in impacting upon competitive ability and maintaining or restoring biodiversity. There was thus an evolution

*Experimental site on Tadham Moor*

in the research programme that concentrated initially almost entirely on floral diversity to one that considered biodiversity in much broader terms to include birds, insects, soil fauna and microbes. The challenge still remained, however, to provide mechanisms that were able to combine the requirements for both biodiversity and agricultural output that met the economic and other needs of the farmer. Whilst this proved difficult in many circumstances where the drivers were entirely dictated by economic needs, in other more specialised situations (low input, niche and local products for example), the research demonstrated clear opportunities for at least partial success in meeting both requirements. The work has laid the foundations for future requirements as the need for food security grows in order to be able to ensure that any increased drive for production jeopardises biodiversity only minimally. To do this will, however, require the maintenance of long-term and large-scale systems approaches for research to provide relevant and practical options.

### Systems Research and Modelling

The research brief of the Institute has always been broad and has, as noted elsewhere, been differentiated into many and diverse distinct and focussed components of the complexities of grassland systems: the structure of a grassland-based production system is much more complex with more interactions than, for example, a grain-producing enterprise. However, it has always been recognised that there is a need to consider the whole system, and all its integrated parts. A system can mean all things to all men, the soil, the plant, the ruminant etc. can be, and have been, considered to be systems, but, in the context of the Institute's activities, systems have also been studied at scales larger than these, for example, management systems, farm scale and, more latterly, catchments and landscapes. There has thus been a long and important history of using large-scale, and often long-term, experiments and farm-based studies and developing mathematical models to capture the interactions and effects, either empirically or mechanistically for practical or theoretical definition or prediction of the particular issue(s).

During the early stages, the work focussed particularly on key sectors of grassland management and on particular facets of these and their synthesis into effective new options for farmers. This activity was particularly targeted at using the information that was being accumulated by GRI to develop systems for the effective use of intensive grass production for beef and sheep and to incorporate a number of the components of a whole production system, herbage production, intake, feed conversion, meat production for example. The first large-scale 'farmlet' experiments were led by Frank Alder over a 12-year period from the mid 1950s. These were multi-faceted in objectives and layout and incorporated components of grazing/supplementary feeding/seed mixtures and other management factors. This was followed by research in the 1960s and 1970s conducted by Ken Baker, Dick Baker, Bob Large, Tim Treacher, Jon Newton and others, which included work under experimental conditions at Hurley and development projects on farms. The work provided much information, as did the other production studies already noted, to be used for the development of novel managements. Other system-scale studies at this time showed the effects of pasture quality on reproduction, lactation and growth, all of which played a large role in the leap in

### Eighteen-Month-Old Beef Production

The development of an intensive grassland system of beef production was undertaken to demonstrate that the accumulated knowledge from research on the growth of grass and its utilisation, conducted at Hurley and in extra mural trials on farms, could be effectively synthesised into a workable system. It was based upon autumn-born calves fed on high-quality grazing and silage plus controlled inputs of concentrates so as to achieve target rates of growth.

The work was significant as an early attempt to base advice on an understanding of the principles and interactions occurring within systems. Whilst lacking the sophistication of mathematical modelling, which later became possible with developments in computing, it did embrace the consequences of interactions between growth rate, slaughter weight, stocking rate and effects on the areas to be set aside for grazing and conservation. Crucial to understanding appropriate managements was research on how forage quality changed with time and on efficient silage making. However, it was the advent of the forage harvester that meant managements could be undertaken on a time basis rather than being weather-dependent.

The success of this system on farms owes much to organisations with similar objectives coming together to form a Joint Beef Production Committee and to publish a handbook through the Beef Recording Association. A second edition followed, from the Meat and Livestock Commission, which incorporated their findings from farms. The handbooks proved extremely popular with advisors, farmers, teachers and students and dealt with the physical and financial implications of variations that are possible and occurred in practice.

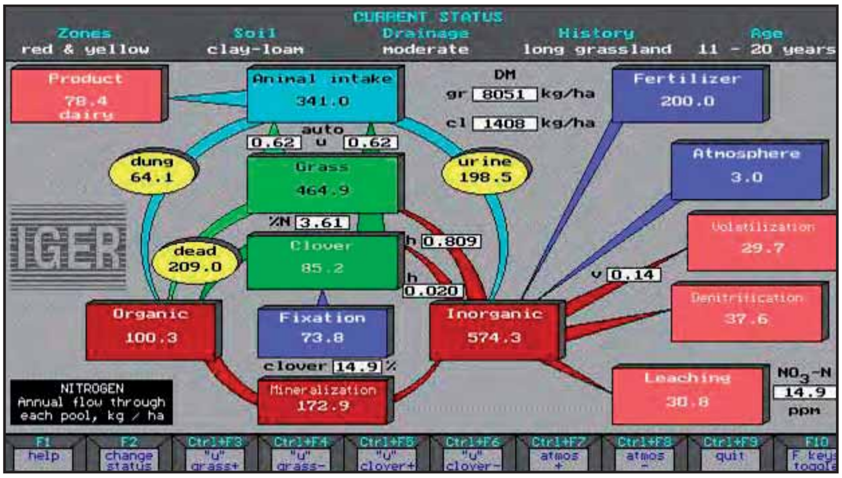
*Dick Baker, Hurley 1960–92*

animal production achieved on pastures through the 1960s and 1970s. This work demonstrated the capacity for the maximum/optimal use of herbage, either grazed or conserved in practical on-farm managements. Objective models were produced which defined input-output relationships (including those for the ‘cow-calf’ production unit), often in very simplistic terms at this stage. This information and modelled outputs were then used to inform studies at Experimental Husbandry Farms or for incorporation into practical management strategies. This was demonstrated well by the combination of systems–type experimentation on sheep management undertaken by Jon Newton with Peter Edelsten’s simulation modelling. This produced practical and effective new guidelines for sheep production.

An important development was the formation in 1965 of a System Synthesis unit led initially by John Jones and then by Dick Brockington. The brief was to objectively build and test models and identify gaps. Over time, model building evolved and changed and modellers became more and more integrated with scientists within particular areas. In contrast to the earlier ‘models’ there was now an emphasis on changing from the often simple ‘back of the envelope’ type of calculations that were the basis of many of the changes and recommendations to a more formal mathematical representation or simulation of the systems being studied. Many of the models produced have been noted elsewhere throughout this book, but those developed by Jim France on the kinetics and metabolic processes of rumen function and efficiency, Tony Parsons and others on grazing interactions, John Thornley on the ‘Hurley Pasture Model’, Bob Crabtree on the optimal management policies for dairy systems, Chris Doyle on economics of grassland systems, and David Scholefield and others on nutrient flows have been seminal and have had especial impact on the development of the science and practical aspects of grasslands throughout the world. Many of these are still very influential today.

More recently, soil nutrient management to minimise environmental impact provided a major focus to understand the wider-scale complexities at the systems scale of the interaction and controls over the losses of, initially, nitrogen and then phosphorus into waters and air. Although funding patterns latterly tended to favour single component issues, coordination of a broad spectrum of projects over the whole programme meant that it was often possible to deploy funding to achieve multiple objectives. However, that was not always the case and large and extended programmes on nitrogen were also funded by Defra to achieve multiple objectives. This was key to providing understanding of the interactions between soil-based processes in temperate soils such as mineralisation, immobilisation, nitrification and leaching and their interaction with management in determining losses to waters. An earlier study by 'TE' Williams and Con Clement had set a precedent at Hurley by looking at the long-term aspects of the effects of a systems approach to management (various grass swards and a barley crop rotation) which defined the effects of sward management including grazing on production, long-term soil fertility, carbon and soil organic matter accumulation in grass swards and cereal rotations. However, the subsequent work in a range of large-scale studies led by David Scholefield, Brian Pain and Steve Jarvis, made major strides in raising the level of understanding of total nutrient flows for grassland soils and their production systems to those already available for tilled, arable soils. At an early stage in the nitrogen research programme, North Wyke and other organisations were involved in the analysis of the pros and cons of a complete farm-scale study to follow not just nutrient behaviour but also all aspects of biodiversity and other features of land management. There was enthusiasm by all for this, except by funders who balked at the financial implications of such a project. However, the importance and relevance of doing this has remained and the current developments at North Wyke underline the significance of taking this whole farm approach.

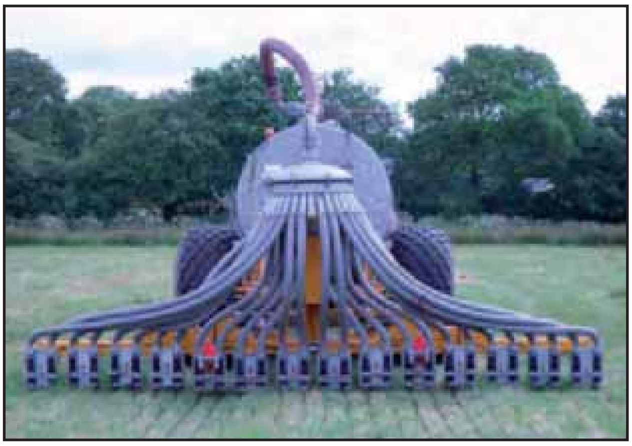
The Rowden drainage experiment has provided a key location for the nitrogen and other nutrient studies. Its initial use by Ted Garwood, Ken Tyson and others (and jointly with ADAS) considered the grassland system as far as soil conditions (drainage, water status) and nitrogen input influenced beef production over a number of years and provided a system study in its own right. The work clearly showed that although drainage had impact on the pattern of pasture growth, there was overall little benefit in terms of live-weight gain and the economics of beef cattle production.The interactions with nitrogen were also noted and the experimental system then became the focus for grassland nitrate leaching studies and, as noted elsewhere, allowed us to indicate the extent of losses when typical lowland grass was grazed in a realistic way by cattle. The effects of drainage now became very important as did the effects of nitrogen fertiliser inputs and the increased carrying capacity that this allowed. Then, fuller understanding of the integration of other nitrogen processes was built up over time so that a much more complete picture of the controls over nitrogen flows within and from grazing systems was achieved.




*Output from NCYCLE model of nitrogen flows in grassland systems*

Over the same period, the work led by Brian Pain on slurries and manures was moving along much the same lines in terms of trying to integrate, understand and quantify multiple effects of manure management. This was especially important because it was clearly demonstrated that changing any stage of the manure production process (from generation in animal houses, storage, through to application on land) to, for example, reduce the effect of one process, had repercussions for both that process at later stages and also for the effects of other processes. Thus steps taken to reduce ammonia losses from storage (from slurry in tanks for example) may increase the opportunity for increased loss at spreading or an increase in denitrification potential. In other words, a life-cycle understanding of the complete on-farm cycle of the manure management system was required. At North Wyke this culminated in the development of experimental animal housing and manure storage facilities which were then coupled to studies on the application techniques for manures and slurries to provide a full life-cycle. This approach was instrumental, amongst other things, in quantifying the trade-offs between ammonia emission and nitrous oxide production after actions were undertaken to reduce ammonia volatilisation (by band spreading or shallow injection, for example).

*Life-cycle studies on effects of manure management on emissions of greenhouse gases*

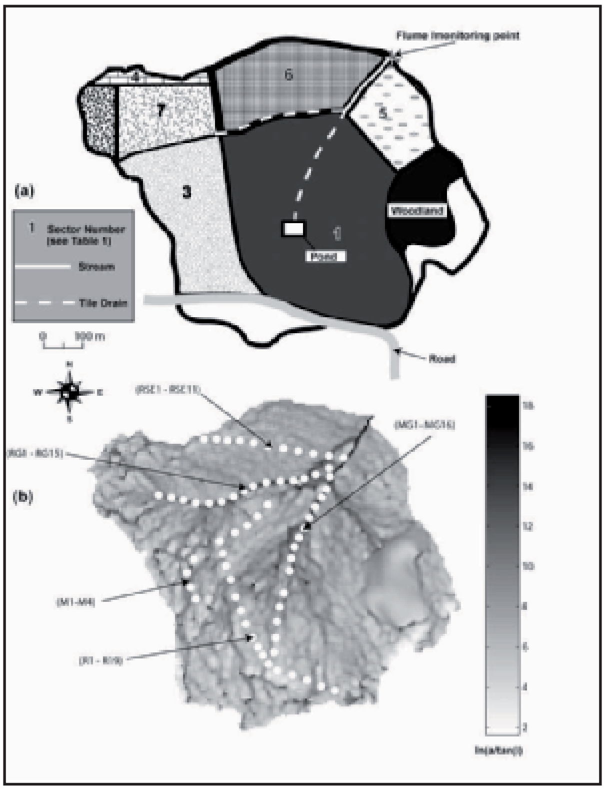


*Shallow injection of slurry into grassland*

A further stage in the systems approach to understanding nutrient flows was the development of the North Wyke 'farmlets' with a range of new managements imposed on the Rowden experiment and also at a contrasting freely-draining soil at De Bathe Cross (some 1–2 km away). The treatments now combined further components of grassland management within one-hectare areas so that cutting for silage, grazing, manure/slurry return and different approaches to fertiliser management and effects on nitrogen behaviour were incorporated within the same experimental areas. This large-scale system approach to nitrogen management was sustained for six years with replicated treatments. As well as providing the primary objectives of demonstrating the effects of conventional and novel management regimes throughout an annual production cycle, and their interaction with supplies from manures, the effects on the two vastly different soil types also provided test-beds for model development and validation.

The farm-scale system approach was also developed further in other studies, off site. In the first major interaction between BBSRC, NERC and ESRC, funding was acquired to follow some of the key nutrient and biodiversity impacts of the conversion phase of organic farming at the Duchy farm at Tetbury: this involved IGER North Wyke and Aberystwyth with Rothamsted Research, CEH, and the University of East Anglia. This provided novel information on the changes that occurred during the transition from conventional to organic

*Measuring water flow in the Denbrook catchment*




*Plan of Denbrook catchment showing boundaries and drainage*

**The Mini Catchment Work at North Wyke**

Research on Rowden at North Wyke helped to demonstrate that significant quantities of water-polluting substances (nitrate, phosphorus, sediment and faecal organisms) were transferred from experimental plots into drains. However, in the early 2000s, new policy pressures came from the European Union's Water Framework Directive and it became clear that we needed to address the issue of 'delivery' from the edge of the plot or field to the river. We thus needed to scale-up our understanding and so, around 2000, I set about trying to find locations that were suitable. It was a challenge, because we needed small enough 'headwaters' for us to have a reasonable chance of seeing a response and also to avoid other confounding issues, such as inputs from septic tanks or point source pollutants. We also had to have 'friendly' farmers on-board who would allow us access to monitoring equipment. I recall many pleasurable hours poring over maps and roaming the roads of Devon with Tim Harrod, Neil Preedy and Adrian Joynes. I think on one occasion my wife Anne and new-born son Matthew joined in the catchment hunt. Eventually, we settled on two local livestock farms, Drewston close to Chagford on the edge of Dartmoor, and Denbrook, closer to North Wyke and adjacent to the Railway Inn.

More recently we started to monitor the River Taw on the North Wyke estate. These catchments have served as demonstrations for Defra and other visitors (some international), a learning platform for students and a meeting point for collaboration. They have also helped us re-conceptualise issues of grassland-soil hydrology: by going to 'real' catchments we had relinquished our reductionist control, but we had opened the door to a new wave of empirical observations that has helped us to learn about grassland management in different ways, embracing complexity and model uncertainty. Such holistic and integrated studies drew strong parallels with systems biology, which usually focussed on cells, not catchments, and helped us to remind BBSRC of the importance of landscape and soil science.

*Phil Haygarth, North Wyke 1993 – 2008*

### $SIMS_{DAIRY}$: A Novel Modelling Framework to Specify Routes Towards Sustainability for UK Dairy Systems

Since the 1980s dairy farming has been challenged with mitigating its pollution of water and the atmosphere to within internationally agreed limits while at the same time struggling to maintain profitability. Come the 21st Century, the list of sustainability criteria has grown further to encompass management and usage of multifunctional landscapes. $SIMS_{DAIRY}$, a farm-scale, nutrient flow modelling framework, was developed to explore to what extent these production, environmental and societal goals might be reconciled.

$SIMS_{DAIRY}$ includes dynamic linkages between existing and new models of system components describing animal feeding, pasture, stock and manure management, farm economics, emissions of greenhouse gases and ammonia and losses of nitrate and phosphorus to water. It also incorporates novel 'score matrices' for other system attributes, including biodiversity, landscape aesthetics, animal welfare, product quality and soil quality. It can optimise and rank systems against sustainability criteria.

It has been used to:

- specify a range of new dairy systems for UK agriculture and to track the trajectories of current systems towards sustainability through practical and affordable stages.
- show that research on genetics and breeding would be more cost-effective than that on improved farm managements in the evolution of more sustainable dairy systems.

We now hope to incorporate energy and carbon flows into the framework, to broaden its spatial scale and to extend the range of land uses simulated.

*David Scholefield, Hurley 1977–86, North Wyke 1986–2007*
*Agustin del Prado, North Wyke 2002–08*

management. Another Defra study followed this in the same geographical area but was specifically focussed on nitrogen management and losses, this time based on a conventional mixed farming system on the freely-draining soil of the Cotswolds (with Rothamsted Research and Royal Agricultural College) at Cirencester. A North Wyke contribution was also made to an ADAS study of dairy-farming management systems based at ADAS Bridget's in Hampshire. All of these studies were key in demonstrating the opportunities that there were for developing new or improved managements with practical approaches derived from these and other recent research findings in order to change nitrogen use to reduce emissions.

*Farmlets at Rowden involving integration of cutting and grazing, manure and fertiliser management with assessments of production and nutrient cycling*

The importance of integrating natural and social sciences was recognised in the more recent Rural Economy and Land Use (RELU) programme, with North Wyke being successful in becoming a major partner in projects concerned with aspects of microbial contaminants of waters and of biodiversity. This was a reflection of not only the specific expertise required to undertake these projects but also of the capability of the research scientists to integrate individual component effects and to synthesise systems. Under the directorship of Chris Pollock, there was an active encouragement for all to involve other key components of aspects of the Institute programme into a 'bigger-scale' thinking. From this, the notion of 'research platforms' evolved from the discussions of the group of senior scientists tasked with taking the next phase of IGER's research forward. This very much involved the Rowden Experiment, and the initial discussion of a whole farm platform at North Wyke started to emerge. The possibility was also investigated at this time with colleagues in INRA, France, of obtaining funding for the establishment of a European network of large systems-scale experimental platforms such as Rowden to provide a wide base of research opportunity over bigger spatial and longer temporal scales. This has subsequently developed into a European-wide project (ANAEE) which is an important development in providing a chain of observations and research opportunities.

Development of understanding phosphorus loss to waters and its control also required a bigger system scale appreciation than previously acknowledged. The Rowden platform again formed a key initial stage and provided a huge step forward in quantifying and understanding phosphorus losses from typical grassland soils into surface waters. Once this had been done and some of the more fundamental processes had been identified and understood, the next stage was to move up-scale so that effects in a local surface-water drainage system could be followed, a key necessity for compliance with the Water Framework Directive. The research thus required a scale beyond the farmlet system scale and linkage with a catchment to integrate management effects over the bigger scale. Under the leadership of Phil Haygarth, the on-farm monitoring of a primary stream catchment at the nearby Denbrook and another local small catchment on the edge of Dartmoor was an important step forward.

*Discussion on slurry use with delegates to international conference on Controlling Nitrogen Flows and Losses organised by North Wyke staff in 2003*

As with other phases of the Institute's research, and hand-in-hand with experimental systems, models of nutrient flow have also been a key feature of the outputs from Hurley and North Wyke. The NCYCLE suite of models constructed by David Scholefield and others has already been noted but the extension of these by David Scholefield and Agustin del Prado to a complete systems dairy model ($SIMS_{DAIRY}$) produced a novel modelling framework to specify routes towards sustainability for UK dairy systems and extended the capability to looking at other environmental and managerial issues. Another important facet of the modelling activity was the synthesis of experimental and on-farm information together with model outputs to define realistic and typical whole-farm systems descriptions of nitrogen in hypothetical dairy farming systems in the first instance. This approach was extended to estimate the flows on real farms, to derive phosphorus balances, determine greenhouse gas emissions and to provide estimates of the effects of practical options to change managements to improve nutrient use and reduce the environmental footprint. This again helped to reinforce the need to provide an integration of effects at this scale and underlines the importance of the current research thrust of the North Wyke farm platform to take this forward.

### Key Outputs

Key outputs have included:

- An evaluation of the status of managed grassland swards throughout England and Wales.
- Comprehensive understanding of the regulatory factors restricting the restoration of biodiversity of grassland.
- Delivery of practical managements for the restoration and/or maintenance of biodiversity.
- The development of practical management options for beef, dairy and sheep production.
- Practical models to aid decision making for farmers and their advisors.
- Mechanistic models to describe individual components of grassland systems and their integrated effects.
- Improved understanding of complete nutrient flows in dairy and other grassland-based livestock systems.
- Development of practical on-farm options to improve the environmental footprint of livestock farms.

*Steve Jarvis*

## CONTRIBUTIONS OF HURLEY AND NORTH WYKE TO GRASSLAND SCIENCE

Grassland sciences are relatively young research disciplines that emerged mainly after the Second World War. The development of grassland research was dictated by the ‘green revolution’ for an increase in herbage production and animal outputs. Great Britain played a leading role on a world scale at this time through its two major research centres: GRI at Hurley and WPBS at Aberystwyth, the first being more specialised in ecophysiology, agronomy and grazing ecology, while the second was devoted to genetics and plant breeding. The contribution of GRI Hurley was very important in several domains:

- Applied Plant Physiology, in particular plant and canopy photosynthesis and growth regulation of nitrogen fixation by legumes and nitrogen nutrition.
- Grassland Agronomy, in particular the management of nitrogen fertilisers, the soil-plant interaction and the optimisation of herbage harvest and conservation.
- Grazing Ecology, in particular the pioneering research on plant-animal interactions which open the door for grazing behaviour studies, and all the work on grazing management.
- Environment, in particular the pioneering research on greenhouse gas emissions conducted first in Hurley and then in North Wyke, and the biogeochemical cycles of carbon, nitrogen and phosphorus and groundwater quality.
- Grassland Ecology and Biodiversity, mainly developed from North Wyke on natural grassland areas but with a vision of landscape ecology.

For all these contributions, Hurley and North Wyke were considered as the leaders at world-wide levels and their scientific output were much disseminated around the planet. Although not central to my own research area, I am aware that scientists at Hurley also carried out ground-breaking research on herbage quality and ruminant nutrition. The closure of Hurley in 1992 was accompanied by a partial transfer of scientific staff to North Wyke with the clear objective to develop research targeted more at a grassland ecosystem level, rather than an agrosystem only. Once again this strategy was pioneering and now North Wyke appears as an advanced international research centre for grassland ecology and environment. The attempt to link more intimately the ecosystem research at North Wyke with the genetic research in Aberystwyth was not totally successful despite the great interest for using genomic tools for an evolutionary genetic approach to grassland biodiversity dynamics. Nevertheless, the new links of North Wyke with Rothamsted Research offer the opportunity for studying the interactions of grassland areas and animal production systems with arable cropping areas for more sustainable land-use and management systems. The old concept of ley-farming, at the base of GRI Hurley’s philosophy at the time of its creation, has to be re-used and adapted to current landscape ecology and environment studies. Thus the scientific heritage of Hurley can now be recycled within the more integrated approach of agro-ecosystems services.

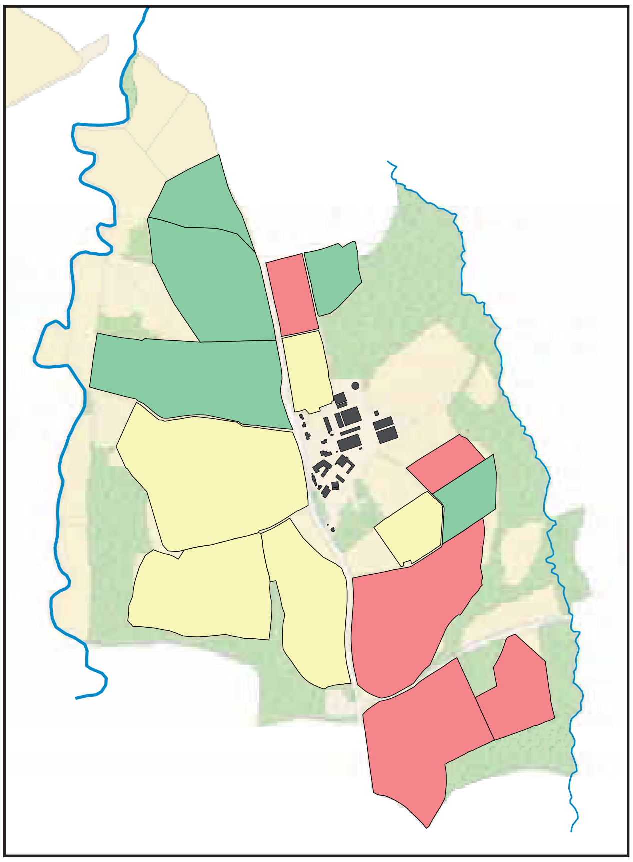
*Gilles Lemaire, Director of Research, INRA, France*

## NEW DIRECTIONS FOR GRASSLAND SCIENCE AT NORTH WYKE RESEARCH

There was great change at North Wyke in 2006, with a new Head of Site being appointed just as it was being hit by redundancies resulting from cuts in Defra funding. Since then the change has only increased, as North Wyke split from IGER to have a brief period as a distinct research institute, North Wyke Research, before its merger with Rothamsted Research in 2009.

The research environment has changed even more, even though funding continues to get tighter. The biggest change of all is the new international concern about food security. Les Firbank, the Head of North Wyke Research, was a member of the International Assessment of Agricultural Science and Technology for Development that was looking at the future of global agriculture, in the context of attempts to reduce poverty and address the increasingly damaging effects of environmental degradation on agriculture. In 2007, a spike in oil prices triggered steep rises in the prices of agricultural commodities, resulting in food shortages in several parts of the world. This could be a sign of things to come; the current Government Chief Scientist, John Beddington, says that there are real risks of food shortages by 2030. No one wants to go back to the days of old-style intensive agriculture, wasteful in energy and nutrients and harmful to wildlife. It’s clear that we need to develop productive agriculture that contributes positively to environmental quality.

A key challenge is to understand how farmers can better manipulate flows of carbon, nutrients, energy and water through soils, plants and animals in and around fields. Around the world, new research infrastructures are being established to look at the underlying processes at new levels of detail, whether in the laboratory, field or controlled environment, to help predict and manage agricultural and other ecosystems in the face of climate change and the new demands for more intensive production. We can probe soil function as never before, by using stable isotope and chemical signatures to track changes in soil chemistry and link them directly to changes in the function of soil organisms as revealed through changes in enzyme levels and gene function. Environmental sensors are now capable of monitoring water flows, water quality and greenhouse gases at very fine scales, allowing us to identify what causes spikes of greenhouse gas emissions or water pollution. We can bring these data together by applying advances in computing and informatics to help us develop the detailed models needed to develop a new generation of precision agriculture. North Wyke Research is in the forefront of this kind of thinking. To give but one example, North Wyke has taken the lead in assembling the national greenhouse gas inventories for methane and nitrous oxide from agriculture. However, the current inventories are very crude. In particular, they do not look at the highly variable nature of emissions, according to soil conditions and land use. Our research seeks to understand the processes in the soil that give rise to different levels of emissions at a fundamental level. This involves work in highly controlled environments, allowing the research teams to explore what happens under these defined conditions to influence emissions. Research also increasingly involves field measurements on new experiments that are looking at a variety of farm management systems, allowing us to investigate in more detail the potential trade-offs, for example, between water



*Allocation of land to different treatments for the North Wyke Farm Platform*

pollution and greenhouse gas emissions. The science is complex, but the outcome is clear: high quality advice to farmers and more accurate evidence to policy makers.

The range of field experiments at North Wyke has increased remarkably in recent years. In the early 2000s, the main field experiments on site were the Rowden Drainage platform, large-scale slurry/manure management studies, grazing animal behaviour studies and experiments looking at biodiversity. Now there are new projects looking at different ways of managing field edges to buffer against diffuse pollution, the potential for new grass varieties to reduce the flow of water through the soil in order to better manage flood risks, the performance of wood chip corrals for cattle housing, and ways to improve the botanical diversity on improved grassland. Increasingly, experiments are interdisciplinary, looking at multiple environmental impacts. The new Highfield experiment at Rothamsted brings together scientists across both sites to address the biological response to major changes in land management on parts of the classic experiments, a very visible sign of the scientific benefits that are coming about from our merger.

The next phase at North Wyke Research will take this approach to a whole new level. The North Wyke Farm Platform will create a new farm-scale basis to look at a whole range of processes under different management systems over many years. Scientists from across the UK and beyond will be able to pool ideas, experimental resources and data, working with our partners (Duchy College, Exeter and Plymouth Universities) in the Peninsula Partnership for the Rural Environment (PPRE) to embed the research findings into training and knowledge exchange in the South West. At the same time we are developing collaborations around the world for mutual benefit.

North Wyke was founded to conduct research into productive agriculture. The programme then encompassed and developed research into environmental protection and enhancement. It is now at the forefront of conducting research to enable both agricultural production and delivery of ecosystem services in a world of rising populations and changing climates. This was important, challenging, exciting work then, and will be even more important, challenging and exciting in the future.

*Les Firbank*

## BOOK LIST

The numerous scientific, technical and advisory publications by staff at Hurley and North Wyke are detailed in the Institute Annual Reports, hard copies of which were published until 1999. IGER Annual Reports for the years 2000–06 are on the internet at: www.aber.ac.uk/en/ibers/publications/iger-archive/annual-reports/ and information on North Wyke at www.northwyke.bbsrc.ac.uk. Some books published by the Research Stations or written by members of staff are listed below.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## ABBREVIATIONS

ADAS – Agricultural Development and Advisory Service
AFRC – Agricultural and Food Research Council
AGRI – Animal and Grassland Research Institute
ARC – Agricultural Research Council
BBSRC – Biotechnology and Biological Sciences Research Council
BGS – British Grassland Society
CEH – Centre for Ecology and Hydrology
Defra – Department for Environment, Food and Rural Affairs
DM – Dry matter
ESRC – Economic and Social Research Council
GM – Grassland Manuring
GRI – Grassland Research Institute
IBERS – Institute of Biological, Environmental and Rural Sciences
IGAP – Institute for Grassland and Animal Production
IGER – Institute of Grassland and Environmental Research
LAI – Leaf area index
MAFF – Ministry of Agriculture, Fisheries and Food
NAAS – National Agricultural Advisory Service
NERC – Natural Environment Research Council
NIRD – National Institute for Research in Dairying
PPRE – Peninsula Partnership for the Rural Environment
SoilCIP – Cross-Institute Programme for Sustainable Soil Function
WPBS – Welsh Plant Breeding Station