Improved production - the scientist's role

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Introduction

Agricultural research, as we know it today, began some 150 years ago with Lawes and Gilbert, who were the first to apply rigorous scientific methods and thinking to crop production. Their work, relating soil chemistry and plant nutrition with crop growth and yields, provided the catalyst for a much greater effort on agricultural research embracing many problems and disciplines. Scientists have since made numerous and varied contributions to agricultural research which, directly or indirectly, have helped to improve agricultural production; they include the development of concepts which have advanced our thinking and changed the direction of our experimental programmes, the establishment of principles with broad application, a better understanding of the effects of factors, and the solution of problems, limiting output in particular environments, and a whole range of experimental methods, techniques and items of equipment integral to the increase of our knowledge.

In choosing examples of the contributions of the scientist to increasing production, a physiologist might discuss work on the efficiency with which solar energy is converted to dry matter, highlight the finding of the C3 and C4 processes of CO_2 fixation and their relationship to the structure, adaptation and performance of temperate and tropical grasses, or talk about studies on crop canopy and light interception, how temperature affects photosynthesis, respiration and growth, and the extent to which such effects might be manipulated in crop breeding and production. A cytogeneticist could point to the value of the knowledge we have gained on the evolution of crop plants as a basis for incorporating desirable genes into present crops and developing new crops, and the significance of genetic engineering and tissue culture in breeding programmes.

The examples I have chosen relate more closely to the adaptation of crops, including grassland, to the prevailing environment. Many factors can affect the levels of production of such crops or the output from grassland. Some - solar radiation, temperature and rainfall - determine the potential of the environment for dryland production, i.e. whether the level of output which can be achieved is high or low, reliable or variable. Man can do little to change these factors but he can quantify them and determine or predict their effects on plant performance. Further, within any climatic constraints, he can do a great deal to ensure good production levels - by choosing plants well adapted to the conditions, achieving a vigorous even stand of his crop, providing the nutrients necessary for good growth, using available water efficiently, preventing competition from weeds, eliminating pests and diseases and harvesting at the right time.

Because crop performance is so dependent on the local environment, individual factors which are vital in one region or agricultural system may have little consequence in another. Nevertheless there are some topics which are fundamental in studying crop production or grassland output and a brief mention will be made of the scientist's contribution to a few of these, prior to examining his broader achievements on field performance. I make no claim for completeness or balance in the examples quoted; if they are biased towards predicting or improving crop performance rather than interpreting it, or too many are taken from temperate areas in Britain and Australia, or from grassland, I can only plead that such developments are where both my experience and real interests lie. have also made a deliberate decision not to separate too rigidly either science from technology or research from development.

Specific topics

Crop Water Use

It would be difficult to select a more significant contribution than that of Penman (1). His demonstration that the loss of water from a growing crop was a function of its physical environment - mainly radiant energy and the saturation deficit of the air - has had far-reaching effects on our thinking, experimentation and practice in the whole field of climate/soil water/crop growth relationships.

Penman showed that when soil moisture was non-limiting and during that part of the day when the stomata were fully open, the amount of water passing through a crop was equal to that evaporated from an open water surface and could be determined accurately by formulae based on climatic data on energy and relative humidity. From measurements of crop water loss in such non-limiting conditions (i.e. its potential evapotranspiration - Et) it is possible to show a relationship with the water lost from a free water surface (E_a) (Et is generally considered to be 80% of E_a from a standard Australian open pan, though the relationship varies somewhat with the conditions prevailing) and from crops where moisture is limiting.

A knowledge of the water holding capacity of the soil, Et and rainfall provides the basis of rational irrigation. In addition to their use in planning and executing such irrigation, Penman's widely tested conclusions form the basis - the world over - of the hydrological management of catchments and are fundamental to the characterisation of environments and the prediction of crop performance therein.

Control of Pests, Diseases and Weeds

Conservative assessments put the loss in world crop production due to pests, diseases and weeds at 1/4 to 1/3 before harvesting, in addition to a further 15% after harvest (2); there is thus no doubt of their importance in our arable agriculture.

The introduction of DDT in 1940, the first of a new generation of pesticides, provided, first, fresh opportunities, and subsequently major problems for the scientist and farmer alike. They were (a) biological - emergence of strains of pests and pathogens insensitive to pesticides or virulent against the resistance factors; (b) economic - crop production became more costly because frequent application of pesticides led to a build up of resistant strains, and thus the need to spray more often to maintain some degree of control; even so such measures are not always successful and could not save cotton production on the Ord River; and (c) environmental - pollution has emerged as a major problem following the use of high levels of pesticides and of herbicides and fertilisers.

While there seems little doubt that fungicides and pesticides will be needed in intensive agriculture in the foreseeable future at least, the above developments have changed our thinking on their use. Data on the relationship between weather conditions and fungal spore levels, and their likely movement in the air, now provide the basis of a forecasting service on the spread of some diseases, e.g. potato blight and barley mildew in the U.K. Estimates of pest populations, based on a knowledge of their life history and behaviour, are being used to indicate when application of pesticides is necessary to prevent economic crop loss, e.g. Myzus persicae (the insect vector of yellow virus in sugar beet) and Heliothis, with its potentially disastrous effect on cotton production. Such measures help prevent unnecessary spraying.

Weed control has also been revolutionised during the last 40 years. The introduction of 2,4-D and other hormone-like herbicides provided the first opportunity for successful weed eradication from crops other than by fallowing or hand removal. By enabling broad-leaved weeds to be controlled, such herbicides completely changed cereal cropping in Britain in the 195Os. Subsequently, newer herbicides extended selectivity to enable control of grass weeds, e.g. black grass and wild oats, in cereals - a major achievement.

The availability of such selective herbicides, coupled with the increased use of fertilisers possible on the newer cereal varieties, made it less necessary to grow grass for its land cleaning and soil fertility building properties, as part of a crop rotation. As a result a change has occurred in the agricultural use of land in Britain.

Cereal production has been concentrated in the south and east with its better climate, topography and soil, with land in the wetter more undulating and less fertile north and west being permanently under grass.

(c) Direct Drilling

Herbicides have had a further significant influence on our agriculture. The introduction, in the 1960s, of bipyridyl herbicides, with their ability to kill all green plants whilst leaving no active residue in the soil, made possible the direct drilling of crop seeds into a narrow band of soil in an otherwise undisturbed surface. Such drilling, with zero or minimum cultivation, provided a new concept for studies of soil management and fertility, and had practical advantages for crop production (3).

The practice of direct drilling reduces the sharp interface between the cultivated horizon and the sub-soil characteristic of many traditionally cultivated soils, and removes the adverse effects of ploughing on soil organic matter content and structure built up by the previous crops. Immediate advantages to the farmer include a reduction in the risk of erosion in some cropping situations - important in Australia - saving of fuel and time and the fact that crop yields are as high or higher on many soils than those obtained using traditional cultivation. In 1979, 325,000 ha of crops were sown by direct drilling in Britain.

The Concept of Metabolizable Energy (ME)

Measurements of herbage yields and quality, valuable though they are in describing grassland production, go only some way towards measuring such output in meaningful terms, i.e. as meat, or milk or wool. A big step towards achieving this objective has been the development of the concept of Metabolizable Energy (ME) and the so-called ME system (4). This system is particularly significant because it enables both the feed value of herbage and the energy requirements of ruminants to be expressed in common terms; it is thus now possible to calculate not only the ME requirements of ruminants in different enterprises but also the proportion of such energy needs which can be supplied by forage.

For example, Fig. 1A shows a typical lactation curve in an autumn- calving dairy cow, yielding 6000 kg milk. The ruminant can eat only a limited amount of forage, and this sets a ceiling to the contribution which such forage can make to the animal's ME requirements. Peak daily intake of silage is some 2.5% body weight, reached approximately 12 weeks after calving (Fig. 1A). It is clear (Fig. 1B) that a large proportion, but not all the ME which the dairy cow needs to maintain milk yield during early lactation, can be supplied by good quality silage; whilst the animal obtains a limited amount from body reserves, the bulk of the balance must be met by concentrates (5).

The ME concept has helped unify grassland research which, in many parts of the world, had become separated into distinct plant and animal camps, and made at least some such research more relevant to important production problems.

Experimental Methods, Techniques and Equipment

There are many examples of the contribution of experimental methods, techniques and items of equipment to our knowledge on improving production. For example, one significant development in field studies resulted from the experimental designs, devised by Fisher and Yates in the late 193Os, which enabled an estimate to be made of the precision of the results obtained, allowed several factors to be studied in one experiment, their effects to be measured simultaneously and any interactions investigated; such designs proved a major stimulus to field experimentation and investigations of farming systems. Specialised equipment such as the electron microscope and the neutron moisture meter, and new techniques such as X-ray diffraction, chromatography and the use of isotopes have made possible more detailed examinations of,

and increased the quantitative precision in, the study of many processes and situations. But it was the advent of the computer which has had perhaps the biggest single influence on our agricultural research in recent years, making possible rapid recording, retrieval and analysis of large quantities of data. It has been fundamental to the considerable increase in modelling which has characterised our recent investigations and has enabled better prediction of production, and the development of more efficient crop management systems.

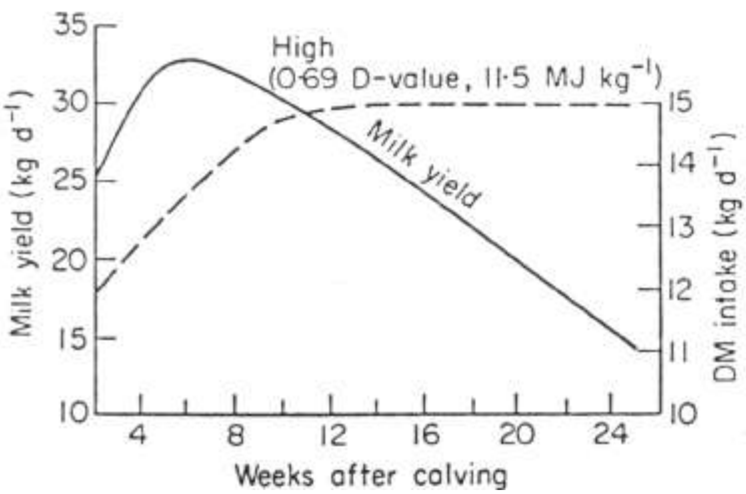


Fig. 1a. lactation curve and silage dm intake of a 6000-litre autumn-calving cow (from GRI data)

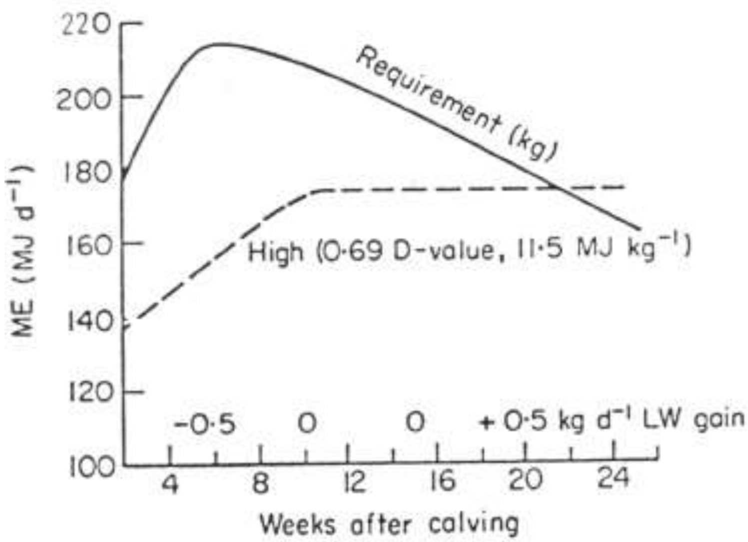


Fig. 1b. contribution of high-quality silage to energy requirement of a 6000-litre autumn-calving cow (from GRI data)

The crop and the environment

Choosing the Right Plants

Practically all Australian crop plants have been introduced, initially many as foreign varieties (e.g. wheat) or by chance (e.g. subterranean clover). The scientist can claim little credit for plant introduction until the studies of Hartley (6), who identified the world centres of distribution of the important grass tribes and related the climatic conditions of such areas with those of various regions of Australia. Such work provided a more scientific basis for plant introduction, methods for which have been developed most for pasture plants; the present collection of some 16,000 forage and 5,000 crop accessions, held by the

CSIRO Division of Tropical Crops and Pastures, includes the world's largest assemblage of tropical forage germplasm.

Selection and adaptative breeding are normally necessary before introductions can be released for agricultural practice, whilst achievement of specific breeding objectives, e.g. to increase or stabilise yield, improve quality or provide agronomic convenience, often requires hybridisation between populations from widely different environments. Farrer, who made the first - and perhaps the greatest - single step in improving wheat production in Australia, used varieties from three continents in his breeding programme which achieved 'a degree of successful matching between genotype and environment, unknown in the previous 100 years' (7).

Farmer's varieties combined in some measure the characters of his parent plants; their features - little cold requirement or winter dormancy, insensitivity to daylength, better yielding and a somewhat higher protein content than previously grown varieties, and sufficiently early maturing to escape stem rust and drought in most years - have become typified in the so-called Australian wheat types.

The rapid increase in land under wheat - from 2M ha at the turn of the century to 12M ha in 1915 - would not have been possible without Farrer's varieties, the best known of which, Federation, released in 1901, was the country's most widely grown variety between 1910 and 1925.

Achievements of Australian plant breeders, though considerable, have not matched the spectacular success of some overseas programmes, e.g. the performance of hybrid maize, first bred in the USA; the effect of semi- dwarf wheat selections from CIMMYT in Mexico in alleviating carbohydrate shortage in many developing parts of the word; and the breeding at IRRI in the Philippines of indica rice varieties with three to five times the yield potential of the older indica varieties. Such developments have resulted in considerable movements of germplasm throughout the world; however, the improved varieties only perform near their potential under favourable, and fairly specific, growing conditions. It is perhaps not surprising, therefore, that semi-dwarf wheats have not produced any spectacular improvement in the yields of the Australian crop, grown in our widely varying environment.

Finlay and Wilkinson (8) succeeded in measuring the adaptation of crop populations to such differing growing conditions. Their technique which can be incorporated directly into a breeding programme has had a big impact on plant breeding in Australia. They grew a large number of barley populations for three years at three sites in southern Australia, under widely varying conditions of rainfall (122 to 625 mm between sites and seasons) and some soil fertility differences. Mean yields of all varieties at each site for each year were then used as a quantitative measure for the growing environment (Fig.2).

Two of the varieties illustrated (Atlas and BR 1239) had a stability similar to that of the population mean in all environments, though Atlas had above average yields at all sites, i.e. showed good general adaptability, and BR 1239, with below average yields, was poorly adapted to all environments. In contrast two other varieties - Provost and Bankuti Korai - showed clear genotype x environment interaction. Provost, very sensitive to environmental change and therefore of below average stability, yielded poorly in low yielding environments; as the growing conditions improved its yield increased more rapidly than that of the crop mean and it was one of the highest yielding varieties under most favourable growing conditions. Bankuti Korai, with more than average stability, changed little in yield however good or poor the growing environment.

Thus, by growing a fairly large, and representative, number of populations of a crop in the different environments for which improved varieties are sought, a breeder can be provided with a good estimate of the genetic variation within the crop, without the need to define the environment or analyse the effects of its varying inter-acting factors on crop production. The method also indicates how far the breeder is likely to achieve his objectives as well as the populations of most value in his breeding programme.

A quantitative measure of the contribution of the plant breeder to increased production is dependent on separating the effects of improved variety from changes in agronomic practice - applications of higher fertiliser levels, increased use of agrochemicals and modification in cultivation and harvesting methods -

no easy task. However, results from a U.K. trial (Table 1) showed modern wheats to yield 40% to 50% more than those available before World War II (irrespective of the level of N applied); such yield increases were associated with a reduced straw length and a higher harvest index (9).

Table 1: Comparisons of varieties of wheat of different ages in a trial at the Plant Breeding Institute in 1977/78 (Riley, 1981)

Variety (Year of Introduction)	Grain Yield (t ha^{-1})	Height (cm)	Harvest Index %
Little Joss (1908)	6.2	142	36
Holdfast (1935)	5.9	126	36
Maoris Huntsman (1972)	7.8	106	46
Norman (1980)	9.0	84	51

Fig. 2. Linear relationship of individual yields of four varieties and population mean of 277 varieties of barley grown at different sites and seasons (after Finlay and Wilkinson, 1963)

Studies incorporating data on the proportion and relative yields of each variety of wheat grown in the U.K. crop between 1947 and 1975, and comparing such information with rolling five-year-average yields, suggest that some 60% of the yield increase of 2.04 t ha which occurred during the period was attributable to variety (Fig. 3). Similar calculations indicate that about 45% of the mean barley yield increase during the same period was a result of variety. Such figures equate to a contribution to farmers' returns of *100* ha^{-1} (1980 prices) made by the breeder during the period.

The plant breeder has also been responsible for changes in land use. For example, the area under barley in the U.K. increased from 898,000 ha in 1953 when Proctor was released, to 2,411,000 in 1966. High yielding, stiff-strawed, good quality, disease resistant varieties such as Proctor and Rika helped barley dominate British agriculture more than any other crop had ever done previously, such that in 1966 it occupied more than half the land under the plough (Fig.4).

(b) Improving Pastures - A Regional Example

Pasture improvement on the Northern Tablelands of New South Wales proceeded apace between 1950 and 1965, the area of land fertilised and sown with improved pasture species - mainly from the air - increasing by more than 17 fold from less than 35,000 to more than 600,000 ha during the period. Livestock numbers increased from 4.9 to 8.3M D.S.E. and annual wool production from G 9M to 72OM kg, - 83% attributed to pasture improvement (10).

The technology used worked well - until the drought of 1964-65, when its deficiencies for the Northern Tablelands became apparent. The commonly sown plants, perennial ryegrass and white clover, were unable to withstand the severe moisture stress then experienced, especially when combined with over-grazing. As a result, the pastures, deprived both of sown grass and nitrogen input from white clover, quickly deteriorated, native grasses and broad-leaved weeds soon dominating the vegetation. Failures in pasture establishment became increasingly common whilst pasture development, expected to progress to a grass dominant stage (Fig. 5) became arrested at the clover dominant phase, with its adverse effects on pasture stability and an increase in the incidence of bloat in beef cattle.

The experimental programme devised to study the pasture problems involved a combination of controlled environment, glasshouse and field experiments with associated property trials. Investigations did little to provide a better legume and thus a more predictable nitrogen supply to the pasture, so vital for its continued productivity. However, phalaris and tall fescue were much less affected by moisture stress than either white clover or perennial ryegrass (11, (12), whilst tall fescue was also shown to be fairly resistant to severe defoliation, and to have a better seasonal distribution of growth than phalaris (13).

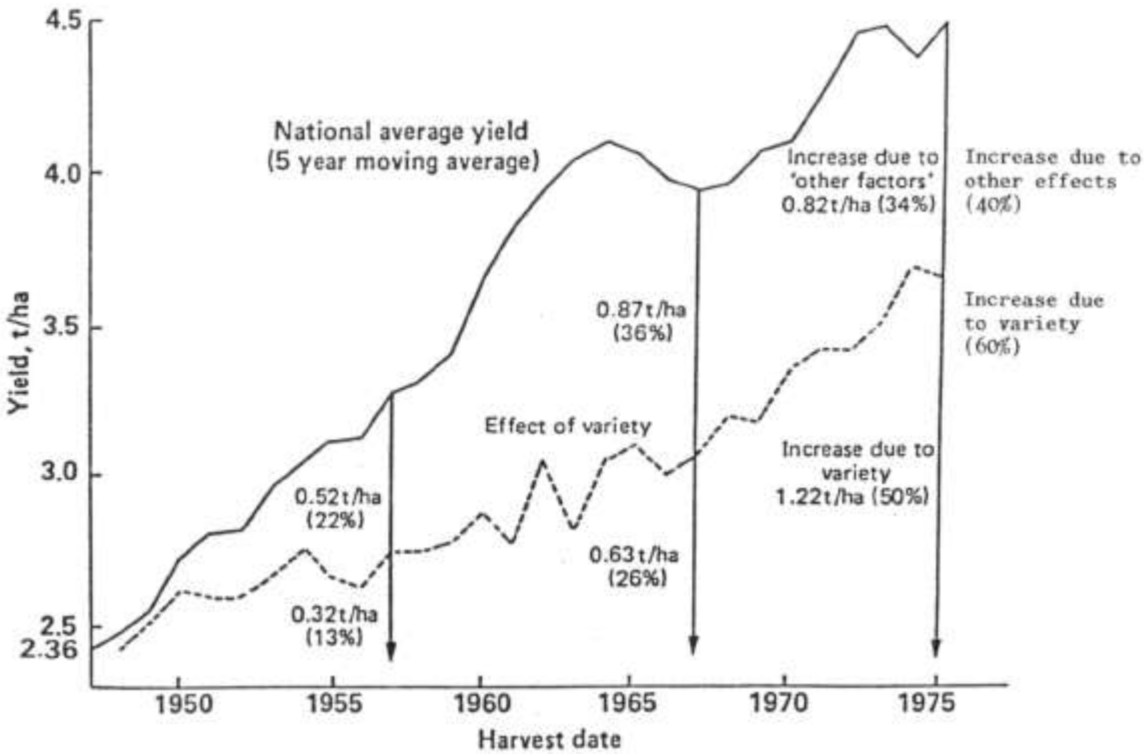


Fig. 3. the increasing average yield of whet in England and Wales expressed as the 5-year moving average (t ha) and the estimated effect of variety on the increase (after Mrs. Valerie Silvey, National Institute Of Agricultural Botany)

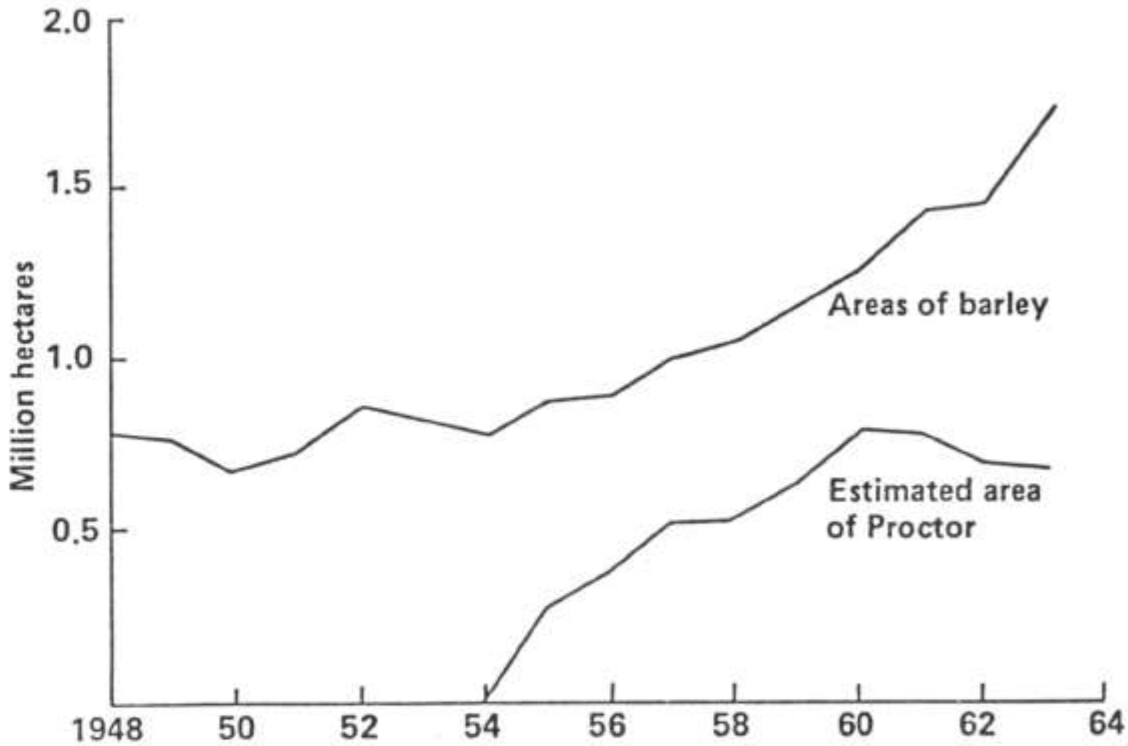


Fig. 4. the area occupied by barley in the d.g. and the association between the increase in area and the availability of the variety proctor (Riley, 1981)

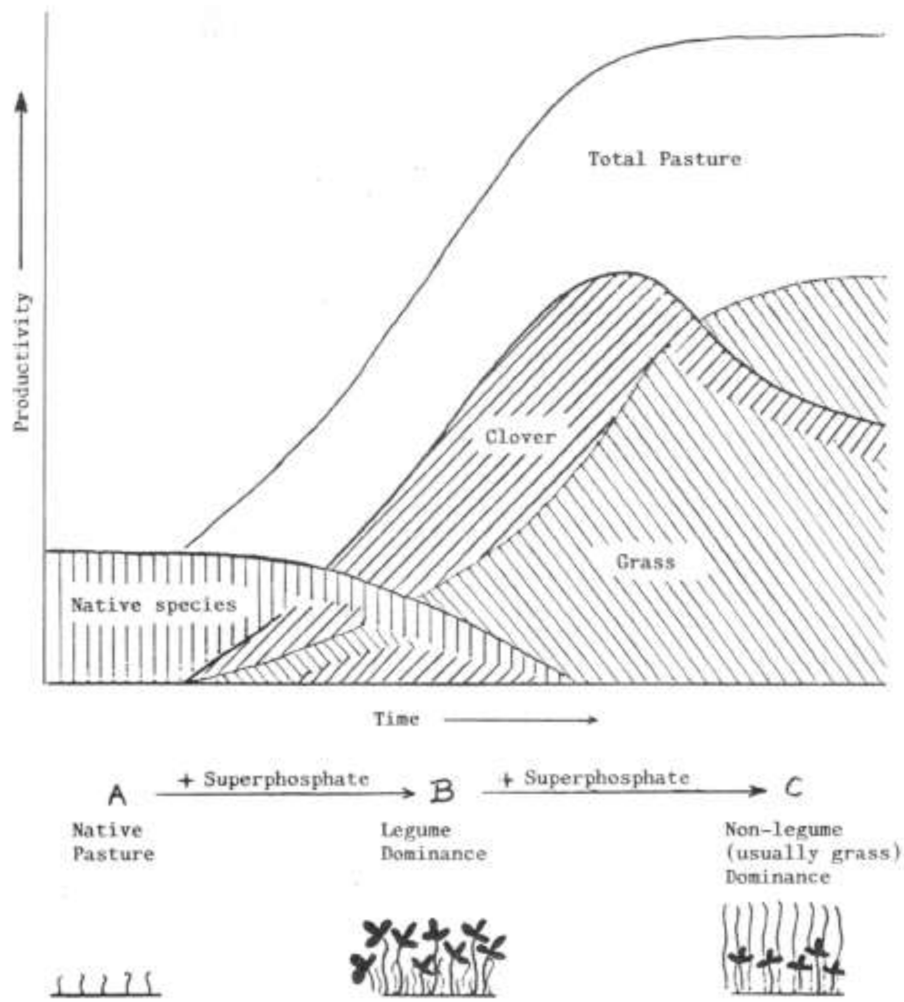


Fig. 5. stages of pasture improvement (after Wolfe)

Studies on pasture establishment showed moisture conditions on the soil surface to be the major factor affecting germination of the aerially sown seeds and the early establishment of seedlings (14), and to be most favourable in the June to August period (15), when there is also least competition from native pasture species. Convincing field data (16) subsequently showed winter seeding to *be* more reliable for successful pasture establishment than sowing in autumn or spring, the times previously recommended (17).

The rate of pasture development was shown to be largely dependent on the level of superphosphate applied (especially P and to a lesser extent S) - nitrogen, grass species sown or sowing rate all having little or no effect. Increasing by up to three-fold the annual rate of superphosphate normally applied (i.e. from 100 to 300 kg ha^{-1}) both hastened such pasture development and made it more certain, whilst grasses sown with the clover established successfully in low fertility conditions and survived until such fertility increased (18), (19).

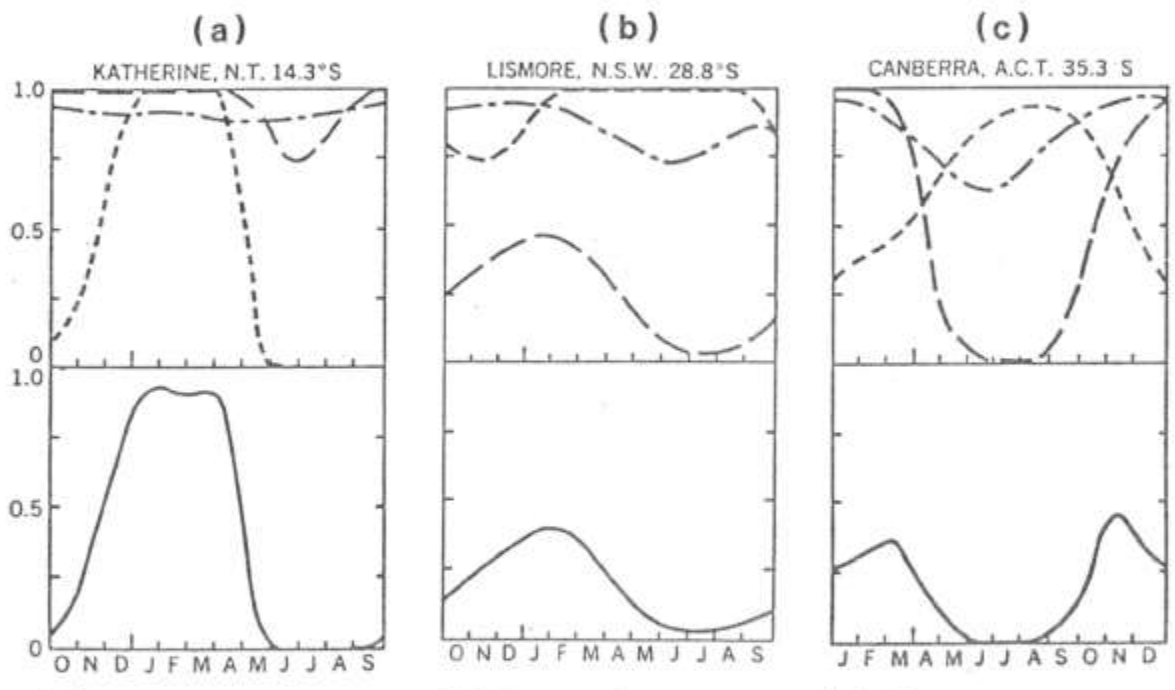
As a result of the R & D, tall fescue is more widely used in pasture improvement on the Northern Tablelands than in 1965, whilst winter seeding is normal with grass being sown together with clover at the beginning of the improvement programme rather than some years later. Heavier rates of superphosphate are applied in the early stages of pasture improvement on some properties, a practice which has helped achieve the more stable grass dominant stage of pasture development.

The examples discussed so far have emphasized contributions made through well-established methods and techniques; I now turn to some of those made by the modeller. The confidence that one can have in any model can only be a reflection of the reliability of the data on which it is based; all models need testing in real situations and refining, if necessary, as more experimental or firm data become available.

(c) Australian Climate and Plant Growth

Fitzpatrick and Nix (20) sought to evaluate Australian environments for the growth of pasture plants through the development of a simple model - the so-called Growth Index (GI). Using theoretical concepts, experimental data and a water balance model as basic information, they based their GI on the concept of fractional dry matter production (i.e. the rate of dry matter production at a given level of a climatic variable, relative to that when the factor is non-limiting) for solar radiation (LI), temperature (TI) and available moisture (MI) such that
GI = LI x TI x MI

Climatic data for a 30-year period taken from 277 stations throughout Australia were meaned on a weekly basis and, together with estimates of evapotranspiration, used to characterise various environments in terms of GI values for three plant groups - temperate grasses and legumes, tropical grasses and tropical legumes. Predictions were made of the performance of the plants in the different environments throughout the year, and the effects on growth of radiation, temperature and available water were separated - a major breakthrough in characterising Australian environments (Fig.6).



(a) Tropical legumes at Katherine

(b) Tropical grasses at Lismore

(c) Temperate grasses and legumes at Canberra

Fig. 6. annual trends in light, thermal, moisture and growth index values for tropical and temperate grasses and legumes (after Fitzpatrick and nix, 1970)

Katherine (mean annual rainfall 926 mm) is typical of much of the better watered areas of northern Australia. The dominating influence on growth is that of the rainfall which is very seasonal; there is little effect of light and not much of temperature.

Lismore (mean annual rainfall 1323 mm) is characteristic of much of the humid coastal lowlands in northern New South Wales and southern Queensland. Atypical for Australia, moisture is generally favourable, though somewhat limiting in spring and early summer. Whilst the temperatures are below optimum for tropical grasses and retard their growth even in summer, such grasses are grown widely for summer feed.

Canberra (mean annual rainfall 992 mm) has a climatic pattern fairly similar to that of the Southern Tablelands of New South Wales, southern Victoria and the lowlands of Tasmania. When the temperature conditions are favourable for growth, moisture is in short supply, and when water is available, it is too cold. Thus whilst temperate pasture species are sown, their performance in this relatively unfavourable environment is much lower than their potential.

The effects of mean climatic data only have been considered so far. A comparison of the effects of long term mean and actual weekly data, collected over a three-year period, on TI, MI and GI values for tropical legumes at Bileola, Queensland (Fig. 7) shows that whilst temperature regulates seasonal growth of tropical legumes such that little production occurs in winter even when moisture is plentiful, it is rainfall which accounts for much of the short and longer term variation on growth in the main growing season; this situation is characteristic of most pastures in the Commonwealth, and makes their growth unpredictable.

Nix (21) used the GI model to characterise wheat growing environments in Australia, relating the prevailing climatic conditions, together with any water stored in the soil outside the growing season, to the crop's requirements at different stages of its growth and development, i.e. from seeding to floral initiation, floral initiation to anthesis, and from anthesis to maturity.

Whilst the seasonal water cycle sets absolute limits to the timing and duration of the crop in Australia, the success of wheat production depends on how well the pattern for growth and development of varieties can be fitted in with four constraints, namely (i) the timing of rain which affects date of sowing, (ii) the duration of mid-winter depression in temperature and radiation values, (iii) the timing of the earliest safe ear-emergence date as determined by frost conditions, and (iv) a rapid increase in the temperature and evaporation during spring and early summer, i.e. whether sufficient water is likely to be available for the crop to ripen.

Given data on the site, water and management, Nix (21) suggests that it is now possible to predict the performance of any variety of wheat at any location in the Commonwealth.

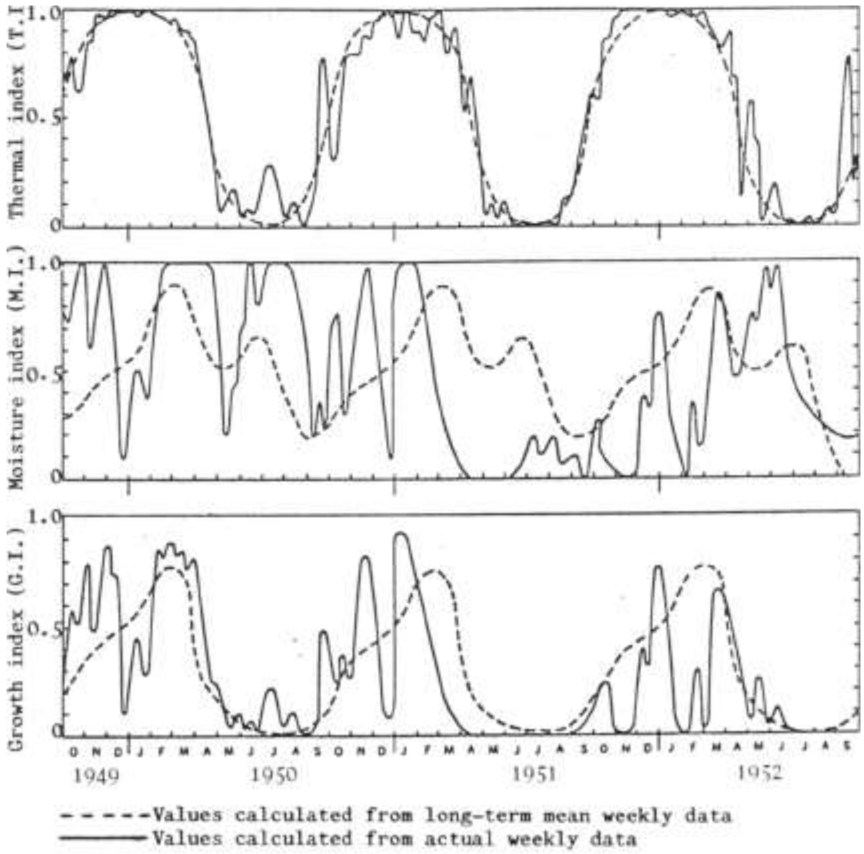


Fig. 7. comparison of estimated actual weekly values with long-term mean weekly values of thermal, moisture, and growth indices for tropical legumes at Biloela, central Queensland (Fitzpatrick and nix, 1970)

(d) Predicting Optimal Areas for Sunflower Production in Australia

Traditionally, lengthy and costly agronomic trials have been used to determine how well any new crop is adapted to the prevailing conditions. In the late 197Os, a study was undertaken at the University of New England to test Nix's proposition (21) that such adaptation could be predicted using a systems approach (22). A multiple regression model, based on the effects of radiation, temperature and available moisture on the growth and yield of sunflower (cv Peredovik),was developed from data, collected from a time of sowing trial and other experiments, validated against crop performance in two contrasting environments, and refined to include constraints for the crop's susceptibility to low temperatures (between bud emergence and its last anthesis) and a range of pathogens (under conditions of high relative humidity).

Mean weekly climatic data from 455 stations throughout Australia were then used for prediction of likely crop performance. A crop system spanning three years was simulated by beginning with fallow and sowing at four-weekly intervals throughout the year, provided the critical soil water level had been reached. The highest yield achieved in the three years was used to estimate the yield potential of every location, an estimate specific for a given level of stored soil water and an initial soil water level at seeding.

The predicted yield distribution for sunflower on soil with a maximum water storage of 200 mm and an initial store of 150 mm at seeding, indicates prime areas for production - based on climatic factors only - in south east Queensland, north east New South Wales (the two present prime production areas), the Southern Tablelands of New South Wales and Victoria and central Tasmania (Fig. 8).

Commercial production also occurs in the second and third yield zones which contain many of the large farms and best growers. However, the success of sunflower production in these areas is more dependent on moisture stored in the fallow than in Zone 1. For example, a major increase in the prime areas of production was predicted when the maximum soil moisture was increased to 300 mm and the initial water level to 150 mm, and a sharp reduction when contracted to 100 and 50 mm respectively (Fig. 8). Stored soil water was thus shown to be a very important factor in the successful sunflower production in many dry- land areas.

The model, though accounting for 75?0 of the observed variation in ten commercial crops growing in a wide range of environments, needed validation against year to year variations in crop yield at any one site because of the importance of such variability in determining risk and thus the farmer's decision-making. Incorporation of year to year variation in rainfall indicated that later sowings are less risky than

early sowings in the northern areas of the central highlands of Queensland, there is less risk at the beginning and end of the summer period in southern areas of Queensland, whilst in more southerly parts of Australia early sowings are less risky than late sowings (23).

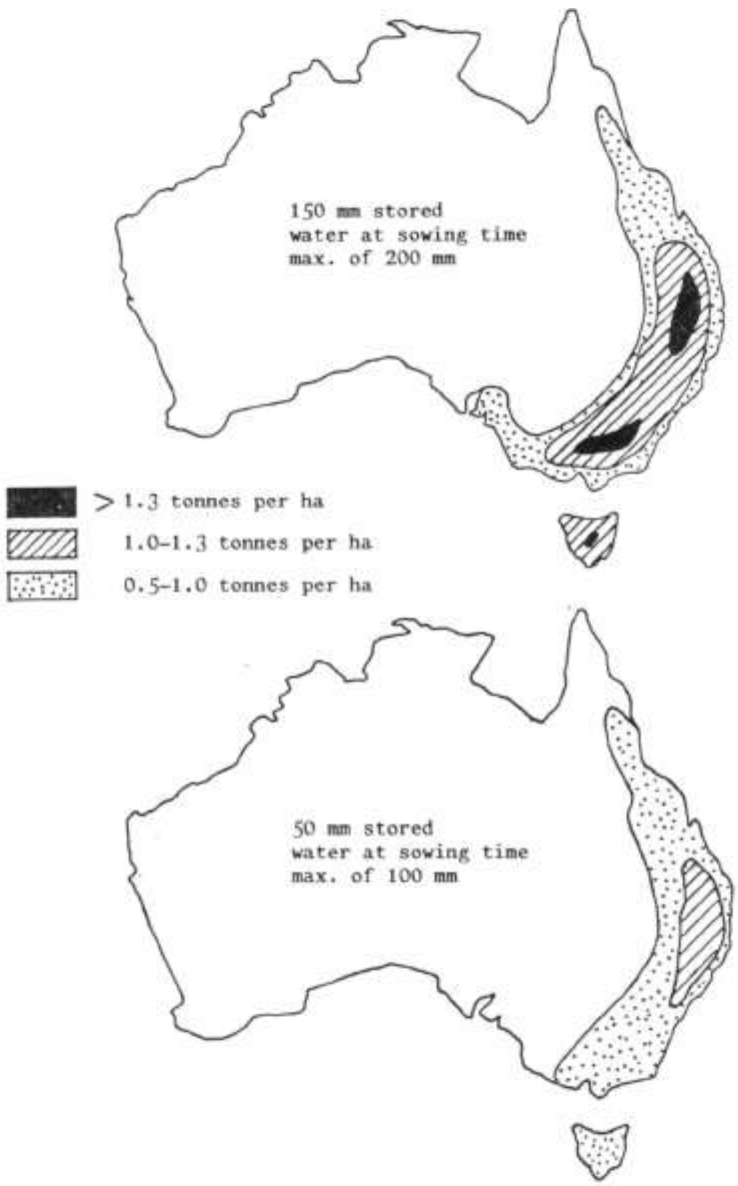


Fig. 8. soil water and sunflower yields (after Smith et.al. 1978a)

(e) Computer Management in Agriculture : SIRATAC : Management System for Cotton

SIRATAC - a multidisciplinary co-operative research programme involving CAIRO Divisions of Plant Industry and Soils, the New South Wales Department of Agriculture, the University of Queensland and the Department of Primary Industry in Queensland - was designed to develop a set of objective procedures for more efficient management of the cotton crop within an economically and ecologically viable production system.

As insect pests are the most significant factor limiting successful cotton production, the major focus of work has been on the entomology of the cotton system - defining more accurate methods of estimating the size of insect populations, probing the life histories of major pests,

predicting effects of beneficial insects, and determining the effectiveness of different chemical and biological insecticides - activities complemented by a plant breeding programme to evaluate the role of certain plant characters in insect attacks.

Conventional breeding work designed to improve yield and quality of fibre, reduce the length of the growing season and introduce resistance to various diseases, and agronomic research on nitrogen and water use and the interaction of cotton with various insect pests at different stages in its growth, also form part of the overall programme.

SIRATAC is now used to manage about a third of the cotton grown in Australia, i.e. 33,000 ha in 1983-84 with an annual commercial value of $30OM (24), (25) (Fig.9).

The system is updated progressively as research results become available, knowledge gaps being filled by common sense or replaced by experimental results which are subsequently confirmed or modified.

The programme incorporates a series of management principles - maximum use of the natural mortality of pests, the use of specific and non- residual insecticides wherever possible, the concentration on the prevention or reducing damage only on fruit which will mature and using economic levels of insecticide.

Decisions on any necessary spraying are taken by the grower on the basis of advice - available every three days - and based on insect numbers, fruit numbers, weather data, any previous spraying, crop growth stage and potential yield and the likelihood of pests exceeding threshold numbers (Fig. 10), the softest option being recommended first.

The considerable value of the system includes: financial benefits to the grower (because of fewer and more economical spraying schedules), significant biological impacts (delaying the development of pest resistance to pesticides), and important ecological effects (minimising environmental pollution). Further, the considerable data bank on crop growth and development, and on insect numbers, damage and control probably exceeds that for any other crop in Australia.

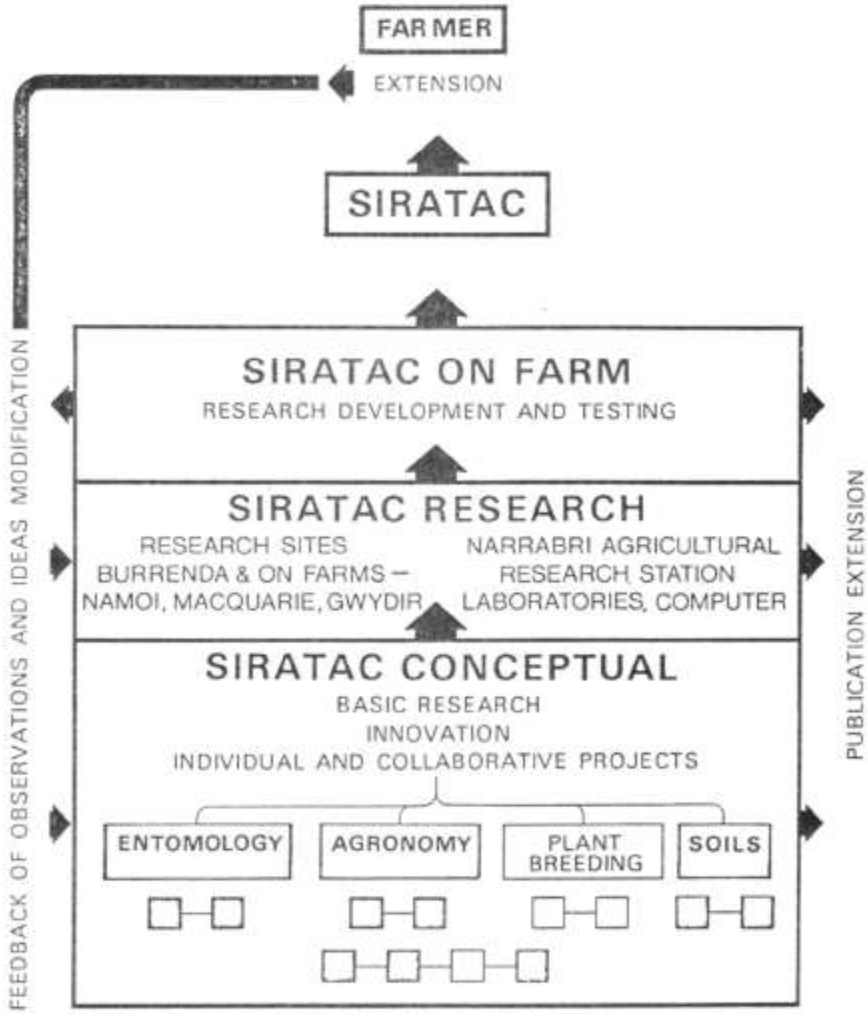


Fig. 9. SIRATAC and its interactive research programmes (Peacock, 1980)

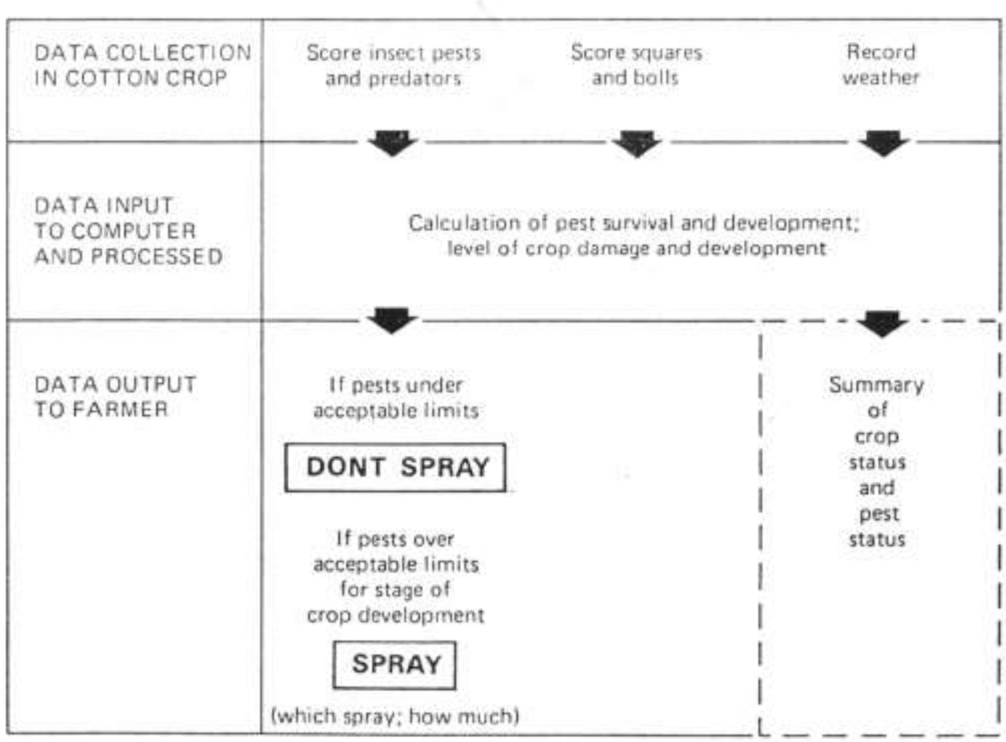


Fig. 10. SIRATAC data collection, computerisation and output to farmer (Peacock, 1980)

A logical extension of SIRATAC is SIRAGCROP, started in 1983, with objectives initially of better management of irrigated wheat, and ultimately to provide crop management systems for irrigated areas in south east Australia, and providing farmers with alternative

cropping systems which use water more efficiently and reduce problems associated with rising water tables and increasing salinity (25).

(f) Maximising the Use of Grassland for Milk Production

Achieving high output from grassland requires a more complex management system than that needed for good crop yields; nevertheless modelling has helped determine efficient management practice for some animal systems based on grass. For example, the data of Morrison et. al. (26) provide the basis for accurate prediction of dry matter production and metabolizable energy (ME) in intensive grass x N systems in Britain.

Production can be related to the growing conditions, especially summer rainfall and the water holding capacity of the soils (27).

Growing grass is one thing; using it efficiently for animal production is another. The seasonal cycle of grass growth varies so much more than do animal requirements (Fig. 11). Nevertheless, a good grass farmer should be able to use for animal feed about 75% of the grass which is grown, i.e. to achieve a level of utilised metabolizable energy (UME) of some 75% of that produced - provided all his grassland management, i.e. grazing, conservation and the integration of grazing and conservation in his system, is of a high standard.

Good quality grazed grass is needed throughout the growing season (7OD or 11.5 Mi kg^{-1} DM) and grazing management must ensure that there is sufficient grass present to enable animals to eat to appetite (equivalent to approximately 2i% of the body weight per day, i.e. 15 kg of dry matter per day for a

600 kg animal, thus supplying some 170 Mi energy); when intake falls so does animal production but if the pasture is under- grazed, nutrients are wasted. Grazing studies have enabled a relationship to be determined between sward canopy height and intake as a basis for management decisions - minimum sward heights of 9 to 10 cm and 7 to 8 cm on the rotationally and continuously grazed ryegrass pastures respectively are required for full intake for dairy cattle (28).

The increase in our understanding of fermentation processes in silage production (29) and the development of means of controlling them (30) have resulted in the identification of the causes of deterioration both within the silo and when the face is exposed for feeding (31). This has enabled the development of a technology for making silage of predictable quality (32) and has resulted in a rapid increase in the amount of silage made in the U.K. (from 1.5 MT in 1966, only 17% of the total conserved forage, to some 7.6 MT in 1980 - 14% more than the DM conserved as hay), a very significant factor in making the best use of grass for milk production.

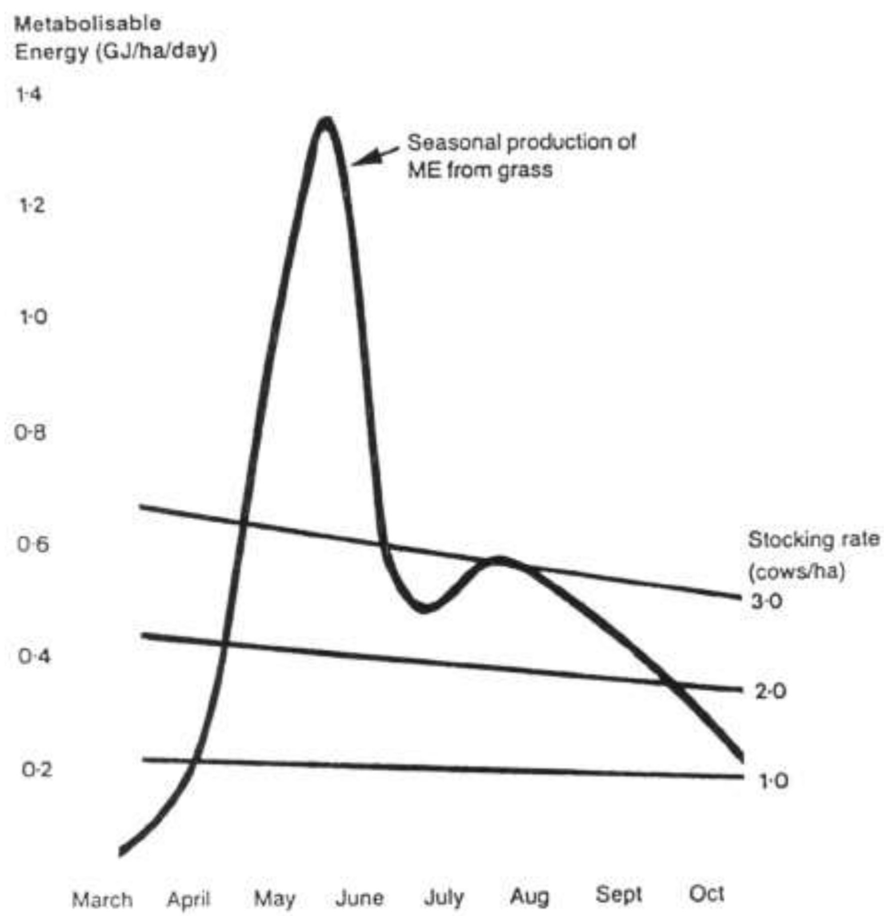


Fig. 11. the me requirements of spring-calving cows at three stocking rates compared with the seasonal production of metabolizable energy from grass (Thomas and Young, 1982)

Just as the farmer has an option on the level of nitrogen he can apply and thus of the dry matter production, so he has a choice on the quality of his silage which is determined largely by the frequency of cutting (e.g. low quality - 60 D material with approximately 9.5 MJ energy kg $^{-1}$ to high quality - 69 D - 11.5 MJ kg $^{-1}$; with a negative correlation between bulk and quality). However, conservation serves not only to provide feed for the dairy cow in winter but also to help in the management of grass for grazing during the rest of the year. Thus the number of cuts influences not only the yield and quality of the silage, but the amount of grass available for grazing over the season. Cutting two, three or four times during the year makes more efficient use of grass for grazing and is more profitable - even allowing for the extra costs of more frequent cuttings (33).

In producing his milk, then, a dairy farmer has a range of interrelated options - level of nitrogen to apply, stocking rate, and the amount of concentrates to feed which provide the basis for determining the efficiency of his management. He can calculate how much energy he should get from his grass, relate this to his herd's requirements for a given level of milk production and then determine the role of grass in his feeding policy - i.e. whether he will seek to use it to provide essentially only the maintenance needs of his stock or to supply, in addition, a large part of the energy needed by his animals for milk production. Targets are thus provided for grass output from farms on differing quality land. These targets, already approached by the best British grassland farmers, are being used increasingly in intensive grassland enterprises.

A comparison of the top and bottom 25% milk producers in the biggest British national scheme shows that the amount of milk produced from forage, the stocking rate, and UME, are all higher on the better milk producing farms; further, higher margins over feed and forage are also generally associated with the ability to obtain more milk from grass (34).

Concluding comments

As I indicated at the beginning, I have emphasised some of the contributions of the scientist which have influenced production in the field, starting with specific topics and concluding with an example where a whole range of factors are involved, not least the farmer's standard of management.

In a sense such increasing complexity has paralleled the applied researcher's activities - initially his objectives were to solve relatively simple problems, e.g. identifying the nutrients limiting production or selecting a crop plant which performed well in a particular environment, but now, increasingly, he is concerned with providing information on situations requiring a multidisciplinary effort, typified by the example of computer-aided management of cotton, where the grower makes day to day decisions on the basis of advice which is continually updated.

I perhaps have not emphasised as much as I might have the extent to which our research objectives have changed over time. No longer are we concerned solely with maximising production; yield levels now need to be achieved more efficiently, thus enabling crops to be grown as cheaply as possible and preventing waste of, say, plant nutrients. Further, the role of the applied scientist is increasingly to provide options to the farmer, who has also to be aware of the possible effect of his farming operations on the environment. Nevertheless, I hope I have not only given you a glimpse of the many achievements which the scientist has made in improving our agricultural production, but also made clear my confidence in his continuing role in highlighting things that really matter in making our agricultural enterprises both more efficient and ecologically acceptable.

Finally, it is a pleasure to record my thanks for the helpful comments of Dr J.J. Yates during the preparation of this paper.

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