ful collaborative research on relevant vaccines would have advantages and benefits for both countries.

4. Virological Research —— Arboviruses

As Australia is free of the serious endemic viral diseases, the main research has been on the detection and classification of what viral diseases we do have, in particular the arboviruses and their insect vectors (St. George and Kay 1982). Ephemeral fever, a viral disease also present in Africa, has attracted a considerable research input by the CSIRO and University of Queensland. The aim of the research has been to understand the viral taxonomy, the epidemiological characteristics, and pathogenesis of the disease. Areas of research that are in need of attention in ephemeral fever as listed by St. George (1981) are (a) biochemical methods to detect the virulence or virulence status of the virus, (b) biochemical changes and mechanisms of the action of the virus in the vertebrate host, (c) behaviour of the virus in the intermediate host, (d) identification of vectors in Africa and Australia, and (e) the study of ephemeral fever in tropical countries to determine the cost of the disease.

Collaborative research into any of the above aspects would assist a greater understanding of the disease, particularly the identification of vectors. Although ephemeral fever is important in Australia, African scientists will have to make a priority judgment whether it is important enough to warrant an African scientific resource input, in view of other disease constraints.

Bluetongue Infections of Sheep

In 1977, Australia was informed that a viral isolate from insects, CSIRO 19, was indistinguishable from bluetongue. Since that day, all sectors of the animal health community, both Commonwealth and State, have been involved in an active research program to identify the spread, significance, and pathogenicity of the ‘new disease’. The impact of this news in 1977 on Australia's export trade was significant and it took 3 years before most trade restrictions were lifted.

Bluetongue is endemic in Africa. The discovery of the virus in northern Australia triggered off intensive research into the viral classification of bluetongue strains and of other closely related arboviruses in the orbivirus genus. The taxonomy of the virus is still under intensive investigation, using both biochemical and serological methods. The taxonomy of the intermediate host, a Culicoides sp, and its role in the spread of CSIRO 19 virus, is also currently under investigation.

Research on bluetongue in Australia requires a high security laboratory, as the only suitable laboratories are outside the endemic area. All bluetongue research is carried out at the Commonwealth Serum Laboratory, Melbourne and at the CSIRO Long Pocket Laboratory in Brisbane. For the record, 3 sero-types of bluetongue virus (BTV20, BTV1, BTV21) (Anon. 1982) and 7 other sero groups of orbiviruses are subclinically present in certain areas of Australia. The research emphasis on viral taxonomy is required, due to serological cross-reactions that are caused by orbivirus subgroup members in cattle tested for bluetongue. There are many field viral isolates that have yet to be identified.

Fortunately, the subtle relationship between bluetongue viruses and other subgroup members of orbiviruses is becoming clearer. One administrator involved in bluetongue investigations in Australia pronounced that the orbiviruses were 'conceived by biochemists, manufactured by virologists and promoted by entomologists'. Because of the antigenic relationship of bluetongue viruses to other members of the orbivirus genus, there will be a considerable ongoing research input to clarify the taxonomy. In spite of the fact that no clinical bluetongue disease has been associated with Australian viruses, the importance of bluetongue in other parts of the world, such as Africa, necessitates continued research and vigilance.

Research on Akabane Virus

Akabane virus is another arbovirus that is endemic in northern Australia without causing any obvious economic problems. However, in the southern, more productive areas, it has caused significant losses in cattle herds and sheep flocks due entirely to its adverse effect on developing foetuses. When akenbene virus first appeared, it caused the loss of 5,000 calves due to abortion, stillbirth, and teratogenic effects, (Lehane 1982-83). At present, research is concentrated on the tax-
Ovary of the akabane virus, and the pathogenesis of the disease in sheep and cattle with particular reference to the virus crossing the placental barrier.

5. Research on Bacterial Diseases

Foot Rot of Sheep

The most important infectious disease affecting Australian sheep is foot rot caused by *Bacteroides nodosus*. Other bacterial diseases, such as those caused by *Clostridia*, are routinely controlled by vaccination and are not important production-limiting constraints. The major bacterial disease of cattle, bovine pleuro-pneumonia, has been eradicated.

Intensive research on foot rot has resulted in the production of a commercial vaccine, which was based on the earlier immunological results of a CSIRO research project. There is considerable interest by State Departments of Agriculture and CSIRO for an improved vaccine, using purified antigen and a basic study of the humoral and cellular components of the ovine immunological reaction. Currently, there are three teams investigating which *Bacteroides nodosus* strains are present, in order to incorporate them in the vaccine. There is also a major research input into the differentiation of benign and virulent foot rot caused by strains of *Bacteroides nodosus*.

Bovine Trichomoniasis

*Trichomonas foetus* is a protozoan that causes infectious infertility in bovines resulting in low reproductive returns. The disease is endemic in Northern Australia and can cause significant losses through reproductive failure (Ladds et al. 1973). In some areas, the current management control is to use only 2-3 year old bulls, which show a much lower carrier status control than older bulls. However, under extensive management conditions, this practice is difficult. Research is underway to purify the antigenic fractions of the protozoan *Trichomonas foetus*. The chance of success in devising a protein vaccine is reasonable as cows appear to be resistant to adverse effects after initial infection.

Bovine Brucellosis Eradication Scheme

Bovine brucellosis has been a most expensive disease in Australia, with control measures having cost several million dollars to date, although it should be noted that on current epidemiological models, successful eradication is close. The research input for the scheme was carried out a long time ago. During the final stages of the eradication process, there is a demand for more specific, more sensitive, and cheaper serological tests by field operators.

The presence of non-specific serological reactions in bulls and calves has proved to be a more difficult problem than anticipated. The CSIRO and some State Departments have been investigating new serological procedures and their results suggest that the ELISA (Enzyme-Linked Immuno-Sorbent Assay) has many advantages over the current Complement Fixation Test. The low cost, opportunities for automation, and increased accuracy are attractive features of the brucella ELISA test.

6. Research on Parasites of Livestock

The Cattle Tick

The cattle tick is the major disease-associated problem of cattle in northern Australia. Its economic effects range from the spread of infectious disease to the depression of the host growth rates through general debilitation. The tick has previously been controlled by use of acaricides; however, chemical resistance has occurred. Crossbreeding between *Bos indicus* and *Bos taurus* has increased tick resistance, but physiological changes of lactation and pregnancy do lower such resistance levels.

As the tick is a major pathogen vector in Australia, research is currently being carried out by the CSIRO, State Departments of Agriculture, and universities. Current areas of research are:

1. Identification of tick resistant cattle — the search is on for a simple immunological method to estimate the degree of tick resistance and the role of host compatibility antigens as genetic markers.

2. Immunization of vaccination against the cattle tick using natural tick tissue culture and adult tick antigens. The tick vaccines have shown some effect on the intestinal cells of adult ticks and have resulted in a lower tick egg viability.
Tick-borne Diseases

Vaccination methods against *Babesia* are well known; however, they do have considerable disadvantages, such as the spread of the organism, short-shelf life, and occasional breakdowns.

Research at the Long Pocket CSIRO Laboratories in Brisbane is currently directed to the possibility of using non-live vaccines. The approach is to use antigens from *Babesia*-infected cells and encouraging results have been obtained. However, further work is required to remove excess non-specific red cell antigen before the vaccine can be recommended for general use. Other research underway involves recombinant DNA methods, mono-clonal antibody techniques, and biochemical analysis of tick enzymes.

Internal Parasites of Livestock

Australian scientists have been aware of the importance of internal parasites as a cause of poor animal health status and resultant economic loss. Indeed, scientists such as Dr. Hugh Gordon have made a significant contribution to the ‘knowledge bank’ of parasitism. There are several laboratories where the ecology and population dynamics of helminth infections of grazing livestock are studied, ranging from a basic biological approach to that of an applied nature. The overall aim is to improve strategic control methods by manipulation of the susceptible stock and the infective stage larval population.

Anthelminthic Resistance to Helminths

Resistance by parasites to antihelminthic drugs has been of serious concern to the Australian livestock industry, particularly in the more settled subtropical areas of northern Australia. Currently, there are pockets of multidrug resistant populations of *Haemonchus* and *Ostertagia*, which have given urgency to the research efforts to gain an understanding of the mechanisms involved.

Current research endeavours are focused on the host-parasite mechanism of development of resistance and the intra-host regulation of nematode populations. Basic knowledge of the genetic make-up of drug-resistant *Haemonchus* species and genetic parameters of host susceptibility are being investigated by the CSIRO and University of New England, Armidale, New South Wales. In addition, there is a search for markers of resistance to parasitism of a relatively simple nature for animal breeding purposes. Preliminary results suggest that bovine lymphocyte antigens may be of use as such markers. Detection methods for anthelmintic resistance are the cumbersome drug response trials, however improved *in vitro* methods are also being intensively studied.

The current situation in Australia is that there are populations of trichostrongyles that are resistant to both of the available anthelmintic compounds, i.e. the benzimidazole and levamisole groups. The limiting range of available anthelmintics, plus the increasing animal populations in areas of Africa and Australia, have precipitated a considerable reallocation of research resources in this area. Fortunately, it appears that the new compound Ivermectin (R) may be effective against all current resistant populations. Another encouraging result is that infective larvae from resistant worm populations are found to be more susceptible to environmental desiccation than larvae from non-resistant populations.

Additional approaches to the drug resistance problem are (a) pharmokinetics of anti-parasite drugs, (b) host-physiological response to parasites, (c) respiratory mechanisms of developing nematode eggs and adults, (d) protein synthesis by the host and protein loss due to the parasites, and (e) hereditability of sheep resistant to *Haemonchus*.

In the northern areas of Australia, epidemiological studies have shown that the pathogenic parasites *Haemonchus placei*, *Oesophagostomum radiatum* and *Cooperia* sp are present all year round. The infective stage larvae survive in the dung pads, thus limiting the effect of control grazing. To offset the estimated 25% production loss due to parasitism, efforts are being made to stimulate artificially, the acquired immunity of cattle. Ultimately, it is hoped that a vaccine, possibly with antigens from irradiated larvae, may be developed.

Should parasitism be considered a priority for research by African scientists, there are many potential areas for collaborative research, which would be of importance to Africa and Australia.

7. Immunological Research

In the immunological field, Australia has a world-
wide reputation for achievements made. The two centres that are actively carrying out immunological research are the Walter and Eliza Hall Institute and the Australian National University. The latter group has been involved in exploring the possibility of identifying immature cattle that have inherited protective immunological responses to specific factors such as ticks and internal parasites, and to establish the genetic patterns of such responses with the eventual aim of breeding fitter cattle. The association between inheritance of histo-compatability genes and susceptibility to diseases has been described (Dorf 1981).

The Walter and Eliza Hall, in conjunction with the University of Melbourne, has spent the last 5 years on a study of immunological processes of cysticercosis and taeniasis in domestic animals. This group have had considerable success in being able to reduce the incidence of *Cysticercus bovis* by using inert vaccine. This points the way to the possibility of immunizing stock against the intermediate stages of tape worms, and of protecting the meat-eating human population.

Other scientists have built on the knowledge gained from basic immunological research to develop improved diagnostic methods for infectious animal diseases. The ELISA test, which was mentioned earlier, appears to offer considerable advances in disease control schemes by providing a cheap, accurate test that has the dual advantage of being able to detect both the antibody as in a serological test, or the antigen, i.e. the disease-causing agent. Detection of the antigen by this system could remove the need to carry out the isolation procedures involved in bacteriology and virology.

There is considerable enthusiasm for this test in the more remote parts of Australia that do not have adequate diagnostic facilities or are too far away from a diagnostic laboratory. The benefits in terms of easier management and disease control of 'on the spot' ELISA tests for the extensive cattle systems of northern Australia are considerable. At present, research resources are being directed to establishing suitable test systems for viral diseases of poultry, and certain bacterial diseases of pigs and sheep.

In the framework of the disease priorities established by the African countries, there could be areas of collaborative research into an ELISA test for animal disease diagnosis that should be useful to regional laboratories and field staff. Provided adequate research inputs are available, the ELISA test has exciting prospects for the future control of animal diseases.

**Conclusion**

To sum up, the areas of animal health research areas in which collaborative programs may be of interest to both African and Australian livestock authorities and scientists are as follows:

1. Viral antigenic relationship as a taxonomic guide.
2. Immunological studies on internal nematode parasites and cattle tick.
4. Methods of disease control.
5. Improved diagnostic methods and reagents such as the ELISA test.
6. Economic research on animal diseases, using the epidemiological model.

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Research and Development Aimed at Genetic Improvement of Livestock

R.R. Howe*

The recent establishment of the Animal Breeding and Research Institute in Western Australia and its program of research and development are indicative of the priority and nature of Australian applied research efforts in animal genetics. A discussion of its objectives and program with appropriate reference to other Australian work should therefore provide a useful background to this subject matter.

The Western Australian Animal Breeding and Research Institute (ABRI), universities and colleges, CSIRO, and all other State Departments of Agriculture are engaged in a significant research effort aimed at genetic improvement of livestock thereby indicating the potential that is still seen in this area. Cost-benefit analyses of animal breeding programs have been an important area of study because of the unique nature of genetic gains—small but cumulative and permanent over time.

Man has practised selection as a means of modifying the properties of animals from prehistoric times. Yet only in the last half century has a real study been made of the theory of inheritance (on which the selection theory is based). Attempts were being made in the late 18th century to explain heredity in mathematical terms. Little progress was made however until the concept of ‘particulate’ inheritance, based on the work of Gregor Mendel in 1865 was accepted. Little basic knowledge existed prior to the beginning of the 20th century. There was a period of some three decades during which Mendel’s work was ignored due to the preoccupation with the theory of evolution and Darwin’s work in relation to it. Furthermore Lamarckism (briefly, inheritance of acquired characters) was still in fairly strong favour relative to evolutionary theory.

Animal breeding practices up to this time involved the unconscious use of genetics and was aimed at the ‘ideal’ animal within a particular breed and species. This approach to animal breeding is still evident today.

Australian research in animal breeding really began only after World War II. A brief historical account of the history of animal breeding in Australia is given by Barker (1979). However, in general the nature of applied research in animal genetics has been either verification of the theory or the estimation of the many parameters required in designing or understanding breeding systems. While much of the work in both theoretical and empirical studies was motivated by the desire to understand evolutionary processes, increased productivity of domesticated species was also a major motivation. The latter is most relevant to this discussion.

In virtually all domestic species of livestock there is an aim to increase efficiency of production genetically per unit of food intake. In most cases this can be achieved by selection for high production per head without measuring intake. In either case, studies so aimed must be relevant to the livestock industry concerned. This discussion will concentrate on the sheep industry.

Institute Role and Objectives

The establishment of the Institute was based on the clear recognition that there could be substantial benefits from genetic improvement of livestock and that there was a substantial research and development requirement for this to be achieved.

The Sheep Industry

The Western Australian sheep industry, like the Australian sheep industry as a whole, is based on apparel wool and meat production. The former is largely an export industry high on the list of foreign exchange earners. The latter is about

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equally balanced between local consumption and export, export being considerably expanded in recent years with the development of markets for mutton in the Middle East.

Wool, being largely Merino type (some 75% of sheep in Australia are Merinos) contributes largely to the high quality end of the market. Although wool yarn forms only a small proportion of total apparel yarn, its price on the world market has been reasonably maintained.

Meat production is essentially in two forms. First, specialty prime lamb production is based on a fecund, crossbred dam (Merino x British breed) and a meat-type terminal sire (British breed) where all the progeny are slaughtered. Crossbred dam production forms a secondary industry with male progeny also sold as prime lambs. Second, there is mutton production from surplus stock in wool producing flocks, though the development of mutton exports has provided incentive for more specialized production for this market. A small carpet wool industry is developing, based on imported breeds from New Zealand. This is the only country from which live sheep, semen, or embryos can currently enter Australia although protocols are currently being examined at Government level.

The Australian sheep population of about 137 million is distributed in large flocks—the average being about 1 000 head. The most important aspect of its distribution though, is its breeding structure. Generally this is ideal for implementing genetic change programs, as only a small proportion of females are allowed to produce potential sires. These are the so-called 'stud' sheep which are either in parent or closed studs breeding their own sires, or in open studs which rely on parent studs for sires and are simply ram multipliers. With the exception of a proportion of sheep bred outside this structure, the genetic change in the Merino population is effectively in the hands of the small number of closed or parent studs (Short and Carter 1955; Roberts et al. 1975).

Recent developments outside this structure include house-breeding of rams on large properties, and co-operative breeding groups which are used in Australia and which could be especially valuable in countries where flocks are small. Group Breeding Schemes, as they are called, provide for superior breeding stock to be screened from many (small) flocks on a regular basis to form a ram breeding nucleus. Rams from the nucleus are supplied back to the contributing flocks. An optimum structure is about 5-10% of ewes in the nucleus and about half the ewe replacements come from contributing flocks but exact details depend on reproduction rates, age structure, male/female ratios, etc. Additional tiers for ram multiplication may be warranted in large populations. Such programs could be very useful within small nomadic flocks.

**Past Research Results**

Much of the important genetic theory has already been validated in sheep breeding. Also, studies in most of the important characters have provided estimates of parameters enabling design of optimum breeding programs and gains. Turner and Young (1969) provide a most comprehensive review of all aspects of sheep breeding research results. With only a few exceptions, favourable genetic changes of the order of 5-8% per generation are possible from selection in most economically important characters, provided these characters are measured. Some exceptions are low genetic variation (e.g. some fertility traits) and antagonistic genetic correlations (e.g. wool weight and crimp numbers, where this is used to estimate wool quality. If wool quality is judged on measure fibre diameter, the genetic correlation with wool weight is much lower).

Such responses are small compared with other typical input-output relationships (e.g. plant growth response to fertilizers). However, in the evaluation of a selection program, the cumulative and permanent nature of gains help the long-term benefits. Gains from each cycle of selection are additive and when selection is ceased the cumulative gains are not lost. In evaluating a particular program in dairy cows where costs per cow far exceeded the actual annual benefit, it was not until year 18 of a 20 year program that benefits were seen, but still the benefits of the whole program were very favourable.

Benefit-cost analyses of genetic research are thus more favourable than they might initially appear.

**Breeder Acceptance**

In addition to economic justification for such
Research and development, there is the benefit from improved adoption of optimum breeding programs. Studies of industry statistics suggest that the current rate of genetic improvement in wool production is low (Ferguson 1976). On the other hand, heritability estimates and selection responses in experimental populations suggest ample genetic variation. It would therefore appear that traditional breeding methods are relatively inefficient and adoption of modern, more efficient programs is poor.

Similarly, the more traditional objectives of breeding programs are based on show ring fashion rather than real economic benefits. However, the acceptance of economic breeding objectives might seem to be improving given the increasing proportion of rams that are measured for production (Savage and McGuirk 1976; Beetsen 1976). Also the accuracy of selection using indirect characters and visual appraisal may be better than earlier thought (e.g. Napier and Jones 1979). The fact remains that selection differentials for the important characters are probably well below potential.

The industry itself would not equate this information to poor genetic progress but to the scientist's different concept of objectives. The scientist, on the other hand, would see this difference between so called 'traditional' and 'scientific' thinking as the major limitation to genetic progress in the industry. Continued research and development should provide increased credibility and thus adoption by industry.

Technical Limitations

Limitations of a technical nature are those that prevent optimum design and efficient operation of breeding programs. Research aimed at reducing these limitations is warranted:

1. Genetic Parameters

Optimum selection program design requires good estimates of phenotypic and genotypic parameters such asheritabilities and correlations. Estimates are available for many important traits but the range of estimates for each is large and high standard errors apply to most. There are other traits of importance for which only few or no estimates are available (e.g. staple formation, fertility, and skin morphology traits).

The sensitivity of selection programs to changes in these parameters warrants attention (Ponzoni 1979). Considering the poor precision of estimates available and the relevance of these to widely varying environments, flock management systems, and seasons under which the ram breeding flocks operate, there is cause for concern. In particular, knowledge of differences in the parameters among breeds, strains, and individual flocks, not to mention changes over time (several generations) is even more limited.

2. Genotype By Environment Interaction

The flocks making up the ram breeding industry operate over diverse environments, management systems, and seasons. Of particular importance is the fact that a high proportion of rams are bred under more favourable conditions than the commercial flocks purchasing them. Improvement in ram breeding flocks may not fully carry over to the less favourable environments of commercial flocks.

Some evidence exists for significant interactions in sheep (King and Young 1955; Dunlop 1962) but Turner and Young (1969) concluded that they are unlikely to be important in animal breeding plans. On the other hand, they have been implicated in apparent plateaux in selection response in some experimental flocks (Pattie and Barlow 1974).

3. Measurement Procedures

The accuracy of selection is clearly increased where objective measures of a character are available. Resistance by breeders to measurement vis a vis visual appraisal is a complex problem but it is greater where expensive and complex measurement techniques are necessary.

Although measurement of mean fibre diameter is now reasonably cheap, a quicker and cheaper method would increase its acceptance. Interest in skin morphology and other characters such as wax/suint ratio, staple diameter variation, etc. will not become widespread while their measurement is so expensive.

4. Production Traits

Ponzoni (1979) points out that selection objec-
tives in ram breeding flocks should include those characters influencing monetary returns in commercial flocks since the latter produce virtually all the wool and sheep meat.

Given the absence of obvious faults, such as pigmented fibres, a simple list of characters is fleece weight, fibre diameter, number of lambs weaned, and adult body weight that would apply to varying forms and combinations depending on breed. The acceptance of these by the ram breeding industry is low but a wide range of other characters are accepted. Research continues in some of these. For example, characters such as crimp definition and staple formation may be important in fleece protection (Turner 1976).

Most of these 'traditional' characters however, are either only indirectly related to production objectives or are concerned with the aesthetic appearance of the sheep or fleece. Their importance in the industry has been strongly reinforced by the show and sale ring as well as by the trade (both wool and meat), which itself has only recently adopted objective marketing technology. However, both breeders and the trade are changing.

The Australian Merino Society and the Association of Performance Recording Merino Breeders represent significant bodies of breeders adopting a more objective approach. Also, in the last wool selling season about 90% of wool was sold on measurement of fibre diameter and yield, encouraging objectivity in breeding programs.

**The Major Research Projects**

A brief description of the major projects either in progress or planned at the Institute will serve to illustrate the nature of Australian animal breeding research.

**Fertility Screening Project**

Using the technique of endoscopy, the project team screened maiden ewes within the top ram producing studs to identify those with twin ovulations at mating. Only stock considered suitable by the breeder with regard to body size, wool quality and production, conformation, etc. are selected.

Twin ovulating ewes are transferred after mating to the Animal Breeding and Research Institute where individual lambing records are obtained. The four-tooth ewes are joined with high fertility rams selected on the basis of dam fertility record (ovulation at 18 and 30 months of age), testicular development, wool production, and growth rate.

A nucleus high-fertility breeding flock of 600 ewes has now been established at the ABRI from the flocks of 76 co-operating Stud Merino breeders (about 20% of registered Merino breeders in Western Australia). This establishment phase has been extremely successful.

The next phase of the project involves selection of ewes to form the studs' own 'fertility families' and infusion of fertility nucleus genes into these families so that they can offer for sale, flock rams bred for high fertility.

Twin bearing ewes from within each stud flock are identified using the ultra sound technique to form the studs' own 'high fertility' family. The best rams from the fertility nucleus flock will be used in these families by intra-uterine artificial insemination (laparoscopic) of frozen semen.

In 3 years, the 'fertility families' within each participating flock will have been established and will essentially be self-replacing. The artificial insemination program will be the only remaining service to be offered to the participating breeders on a regular basis.

Measurement of genetic difference achieved by screening and subsequent selection has yet to be made but even if heritability is low (say 10%) the 'elite' flock should be well above the average due to its intensive selection.

**Base Merino Flocks**

Twelve of Western Australia's biggest studs have each provided 100 stud ewes that although run as one flock will remain linked to the stud by annual purchases of sires. The 12 flocks are made up of 4 in each of the major Merino strains—Peppin, Bungaree, and Collinsville. Those flocks will provide the basis for:

1. Estimation of heritabilities and phenotypic and genetic correlations in all the important traits with sufficient precision to examine differences between strains in these parameters.
2. A study of the relative magnitude of between strain and stud differences.
3. Monitoring genetic change, if any, being made at stud level.

Complete pedigree records are kept from these flocks.
Strain x Environment Interaction Studies

A genotype x environment interaction (GEI) occurs when different genotypes respond differently to changes in environment or where their relative performance alters in different environments. Here 'response' refers to the actual phenotype in a particular character. 'Environment' in this context can cover a myriad of factors affecting phenotypic expression but we are concerned here with external physical influences such as nutrition, temperature, and the presence or absence of any stressful condition.

The GEI can be in the form of either a change in ranking of genotype or a change in the difference between genotypes. Whichever type of interaction is present, there will be some influence on the effectiveness of selection decisions. If GEI is significant in important characters then the present ram breeding system may be suboptimal.

Investigations of GEI have not been attempted in Western Australia, hence advice to breeders can be extrapolated only from other results. The climate in this State is more Mediterranean than elsewhere in Australia and therefore recommendations based on Eastern States' research where GEI has been shown to be relatively insignificant, may be inappropriate.

Ewe flocks of each strain will be established in each of four widely differing locations. Sires of each strain will be sampled from rams bred in the base flocks, and distributed to each location. The rams will either be rotated to each site in sequential years, or lambing will be staggered within years to allow the same rams to be used at all locations.

Selection for Dermatophilosis Resistance

Dermatophilosis (mycotic dermatitis or lumpy wool) is a condition that can be important in predisposing Merino sheep to fly strike.

The objectives of this work are:

1. To determine whether the culling of dermatophilosis-affected sheep is effective in reducing the incidence of this disease in affected flocks. It would be necessary to clarify whether culling is effective because of the removal of susceptible types or simply because of the removal of reservoirs of infection.

2. To derive values for the realized heritability of resistance to dermatophilosis and measure correlated changes in production characters (e.g. fleece weight, reproductive performance, liveweight, etc).

The condition occurs following wet, warm conditions but the nature of infection is not well understood. The condition being an all or none trait, with a level of incidence variable between seasons and locations, an artificial procedure was used.

A flock of 700 ewes and 100 rams from a very dry environment and thus no previous contact with the condition were treated. The first 20% infected were chosen as susceptible and the 20% remaining when 80% became infected, were chosen as resistant. Differences in the incidence of the condition in the progeny will indicate a genetic response and will provide an estimate of realized heritability.

Body Weight Screening

The objectives of this project are:

1. To screen stud Merino flocks for superior genotypes based on 12-month body weight and to use outstanding sheep as the basis of a selection flock. Establishment of a control flock will enable estimation of the initial genetic difference caused by screening at a defined intensity.

2. To provide a source of superior 12-month body weight sires for participation, hence enabling them to supply rams designed to meet a specific marketing requirement for young, heavy lambs.

The heaviest 2% of one year old ewes together with a random sample will be chosen from each contributing flock. Rams with the highest deviation in standard units will be chosen from among all flocks. An elite flock of about 300 breeding ewes will be established over three years with a similar control flock.

The areas of study are:

1. Correlated Responses

Comparisons between the control and selection flocks will enable the estimation of correlated
changes in other productive traits; for example, some breeders believe that concentration on body weight will lead to poorer quality or quantity of wool. The correlated response in reproduction rate is also an important and obvious study area.

2. Parameter Estimates

Genetic and phenotypic parameter estimation will be possible in the control flock. In particular, the genetic correlations between part records and full records are of interest, where full record is 12-month weight.

3. Components of Efficiency

Selection at 12-months of age should have the effect of identifying those animals that are most efficient at maintaining body weight during the dry summer period.

Booroola Project

Breed development is one of the major functions of the ABRI. Within this context, improvement of reproduction rate is seen as a high priority. Improvements in the State lambing percentage (70) can be achieved by crossbreeding using known high fecundity breeds. In Australia, the outstanding breed available for this purpose is the Booroola Merino, with a reproduction rate similar to the best of the exotics from Europe (Turner 1978).

Research reported by Piper and Bindon (1981) strongly suggests that a single dominant major gene (named the F gene) is implicated in the outstanding reproduction rate of the Booroola. It should therefore be possible to isolate the gene in a non-Booroola background genotype. Wool production and live weights of Booroola crosses have been shown to be inferior to non-Booroola Merinos.

The objectives of this project are therefore to:

1. Isolate the Booroola gene in a non-Booroola background genotype by backcrossing.
2. Provide animals homozygous for the F gene but differing in the proportion of non-Booroola background genes, as a resource for studies into genetic components of wool and growth production parameters.
3. Breed F gene carriers, which are registerable and hence acceptable to the stud Merino breeding industry.

Booroola rams will be crossed over Merino ewes to produce F₁ progeny. These progeny will be inter se mated to generate F₂ progeny, a quarter of which are homozygous for the F gene and half will be heterozygous. Ram lambs that are progeny tested will be mated to large numbers of ewes (up to 100 each) by artificial insemination. The top 25% of rams on progeny test will be used to initiate round 2 that follows the same pattern as round 1. Round 3 sees the production of crossbreds that are only one-eighth background Booroola genotype.

Wool Growth Studies

Tenderness in wool is a particular problem in Western Australia, accounting for losses of $5-$10m per year. Tenderness is probably caused in Western Australia by poor nutrition over the later summer/autumn period coupled with the trauma of low temperature following the break of the season.

There is no information on the relationship between other wool characteristics and tenderness, nor is it known what proportion of differences between sheep in resistance to tenderness are genetic in origin. Heritabilities and the correlation structure are required before selection against tenderness can be included in formal breeding programs. Also, stud flocks are bred under conditions of ample nutrition through supplementation. The nutritional conditions that determine the incidence of tenderness may not be imposed and selection would therefore be ineffective.

Two flocks of 300 ewes are to be established, one managed under stud conditions, the second run similarly to a commercial flock. The same rams will be used in both flocks so that genotype x environment interactions can be assessed. Full pedigree records will be maintained. Periodic wool growth will be measured by dyebanding at 2-monthly intervals, and a wide range of other wool traits recorded including fleece weights, yield, fibre diameter average and distribution (at each dyeband and along the staple), tensile strength, wool growth, etc.

The Future

All of the areas of research, current and planned,
referred to above fit the pattern of verifying genetic theory or measuring parameters or responses in breeding systems. It is all based on genes that are already available in Australia (and New Zealand).

There have been reports on the potential importation of exotic genes for most of the livestock industries. In sheep (Anon. 1979) a wide range of breeds currently unavailable in Australia have been recommended should current import restrictions be lifted. This Institute is particularly interested in studying some fat-tail breeds and their crosses with the Merino as a means of improving mutton production. Where such studies are prevented by import restrictions some studies could conceivably be carried out in the country where the required breeds exist if no import restrictions exist there. That is, Australian breeds, which would be crossed to exotics, would be taken to the country of origin, although this would leave some uncertainties, particularly in the area of genotype x environment interaction.

This possibility would provide mutual benefits in both countries and thus provides a basis for collaborative research.

References


Australian Broadleaved Species in Fuelwood Plantations and Agroforestry Systems

L.D. Pryor*

Australian woody vegetation consists mainly of endemic species some of which are in large genera such as Eucalyptus and Acacia. In other groups, Australia is the centre of species diversity and is thus the main source of propagating material. This flora has developed over a long period and in isolation from the rest of the world. It possesses features that are not shared to the same extent with trees of other continents, and is especially adapted to resist water stress and fire, and to endure conditions of low nutrient status.

In the past, use has concentrated particularly on Eucalyptus, which has been highly successful in cultivation in many parts of the world providing a range of produce such as fuelwood, building poles, sawlogs, industrial wood, and other products.

Not only is it possible to extend the use of species in this genus, but there are other important genera that have scarcely been examined at all, and two of these, namely Casuarina and Acacia, are able to fix atmospheric nitrogen actively. To the extent that they have been used, species in these genera have been found to grow quickly and produce fuelwood, especially in places where there is a shortage of fuel and building material.

The correct identification of species, the collection of seed true to label and from specific provenances as well as establishing the best silvicultural practices are areas in which considerable research is necessary to permit the full use of this resource, which can play a highly significant role in meeting the woody plant needs of the developing countries.

Fuelwood

Fuelwood used directly or as charcoal is a basic need upon which enormous numbers of people depend for cooking, warmth, and thus survival in many parts of the world. Great shortages are predicted before the end of the century (Spears 1978), which will add to the markedly deficient situation that already exists, especially in developing countries in warmer regions (Arnold and Jongma 1978). At present this material is derived largely from overcutting in accessible woody vegetation either forest or woodland, leading to accelerating degradation of the land producing it, diminishing supply, and pushing the surviving resource beyond the limits of accessibility to many communities.

Fuelwood is relatively heavy and of low value. Most users cannot afford the price that results from long haulage distances and many communities are limited to exploiting an area within a radius determined by the distance of half a day's walk.

Unless there are some radical innovations in present practices the situation can grow only rapidly worse as populations increase and resources become still more limited. To this must be added the loss resulting from the deflection of animal dung and agricultural wastes from further crop production, to fuel. Some reversal of the trend has been achieved here and there by the establishment of plantations aimed solely at producing fuelwood. Since these must be near the users, small community forests or farm woodlots are often appropriate and close integration with the practices of the society concerned is essential. Agroforestry methods also offer considerable promise in meeting this need.

Some Essential Features of Fuelwood Plantations

In order to fill the need, fuelwood plantations must be quick growing species and produce wood of reasonable calorific value bearing in mind that generally the denser the wood and therefore the higher the calorific value, the more slowly the tree grows.

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It is important that the wood produced should have good burning qualities and especially be free of spitting and noxious smoke. Some adjustment from preferred traditional needs by the users may be possible and desirable, according to circumstances.

Usually, crop renewal by coppicing for at least several rotations is essential. Also, several other features are often desirable such as resistance to eating by domestic stock, adaptability to a wide range of sites, ability to thrive on sites of low nutrient status or on difficult habitats, and other features.

Ideal conditions seldom exist and most adopted practices will be a compromise aimed at securing the best available result in the prevailing circumstances.

**Agroforestry**

The development of agroforestry practices, often by the extension of traditional methods, offers considerable promise in helping to alleviate shortcomings in some areas (B. Lundgren, pers. comm., 1982). There is no sharp boundary between community or social forestry and agroforestry, but the latter gives special emphasis to using multiple purpose woody plants and includes shrubs and trees. Nitrogen fixation is likely to be especially important in this situation.

In one way or another, woody plants in agroforestry systems can contribute to soil stabilization, provide shade, shelter and fodder, produce some fuelwood and building poles, and add to the nitrogen balance. Some species yield products such as honey, tannin, essential oils, fibre, etc. Of course not all things will be provided by all species at all times.

**The Eastern Africa Situation**

The foregoing generalized statements can be applied without modification to many parts of Eastern Africa. Translation to programs of development must of course take account of specific regional conditions in deciding on the precise steps for implementation. In many cases, foregoing research is still necessary before developmental operations can be properly planned and implemented.

**The Role of Australian Germplasm**

Australian material has a special place in future fuelwood and agroforestry programs. Past experience has shown that many Australian species perform particularly well as exotics in other countries. While this role has often been directed to industrial wood production and involved the use of certain *Eucalyptus* species, there is no doubt that similar benefits will continue to flow from the use of additional eucalypt species as well as from species of other Australian genera.

The larger genera of Australian trees display a great range of adaptation to different environments, both in climatic and soil conditions in which they thrive. Australia, which is continental in extent, ranges from tropical regions to cool temperate zones and from well watered places to very arid sites. The soils are often sandy and acid, sometimes are calcareous, other sites are saline, and a number are swampy. Often within this array there are species adapted to particular sites that may suit the needs in developing countries.

The reasons for the excellent performance of the Australian material are believed to involve their ability to thrive on sites of low nutrient status (like so much of their homeland), their freedom from parasites in exotic environments (which may not last forever), and the fact that in a given ecological situation large plants result from Australian material in comparison with local species. In many parts of the world, local species in particular sites are smaller and grow slower than their Australian counterparts.

Although the Australian species in their homeland often have parasites and pests, they are in balance and are seldom of critical importance for successful growth. When introductions to other countries are made by seed these pests are always left behind. It is important to avoid introductions of vegetative material except under the most stringently controlled conditions, and national plant quarantine services should take account of this situation. Where insect pests have been introduced there have been some spectacular instances of later biological control but this is costly and not always immediately applicable. It is wise to avoid situations that may require biological control. It is comforting to note that there is very little attack on Australian plants by pests indigenous in other countries.
There are strong reasons for taking advantage of the benefits offered by such species. At the same time, the view expressed in the National Academy of Sciences publication Firewood Crops (1980) as to certain risks involved in the introduction of exotics is acknowledged. However, the dictum therein that 'In any trials of fuelwood plantations local species should always be given first priority' should be viewed with reserve. It would seem more appropriate to suggest that indigenous species should be given equal priority in trials. In this context it is worth noting that where there has been extensive site degradation, exotics at present are often by far the best species to use in rehabilitation programs even though the indigenous species may take a place finally as the preferred species once a degree of stability has been established.

Australian species are pre-eminent for their fast growth, general healthy condition, nitrogen fixation, yield of other products, and provision of shade and shelter.

While most experience to date with Australian species relates to *Eucalyptus* there are many other species, especially in the genera *Acacia* and *Casuarina*, that offer great promise for such use (Boland and Turnbull 1981).

**Eucalypts**

Australian trees are probably best known internationally through eucalypts (FAO 1979). The genus is large, with some 500 species, the majority of which have been tested at least once experimentally outside Australia. The primary purpose has usually been the search for industrial wood with other uses taking second place.

In many species there is a considerable geographic distribution in natural occurrence and thus marked provenance differences within the species. This variation has been examined in a few species but for the genus as a whole, it is a study in its infancy. Further research is warranted not only with species but also on provenances within species. For fuelwood production, the genus is less explored since the species with a higher wood density and therefore in general better burning qualities have (as a rule) a slower growth rate in volume. Partly for this reason they have been set aside in the search directed to ends other than fuelwood production.

The significance of this aspect is illustrated by a recent paper (Kaumi 1983) on trials at Mugugu, Kenya. In a study of two eucalypt species over two rotations, *E. saligna* was found to be nearly 10% higher in wood density than *E. grandis*, which has been favoured because of its value in producing industrial wood. In selecting species for fuelwood production, the benefit of higher density makes the same volume production more valuable in the species with the higher density so that some growth loss can be accepted without that being inferior economically. There are also benefits in the transport of higher density material because it occupies a smaller volume. In this particular experiment, volume production was also found to be higher in *E. saligna* than *E. grandis* in the fourth rotation (reversing earlier trends) so that on both grounds *E. saligna* was indicated as the species.

However, neither of these two eucalypt species is top class as fuelwood and if more species were investigated along the same lines it is likely that distinct advances would be made in selecting other species and other provenances for particular locations. For example, on the site where the above species are favoured, both *E. microcorys* and *E. decepta* would thrive and produce wood of considerably higher density. There are a limited number of trials with these species but their unsuitability for industrial wood has generally led to their being ignored for extensive use. However, for fuelwood they could well be superior, especially if an adjustment for density difference is made when assessing the economic situation.

As a group, the eucalypts have great value not only because of their desirable features for use in fuelwood plantations, but also because they are especially suited by their physiological characteristics for growing in the drier and warmer tropical and subtropical regions of the world, in which fall the broad climatic characteristics of many developing countries.

Apart from a closer survey of the genus in its natural habitat and from complementary experimental work under managed plantation conditions, there is a future prospect for still greater developments via tree improvement methods. Although these methods have been established, they are still probably beyond the reach of the facilities available for many urgent undertakings. These developments will often involve interspecific hybridization and vegetative propagation of...
planting stock. These procedures have already begun in plantations for industrial use where the value of the product is higher than in fuelwood production. However, basic need may establish an economic value of wood for this purpose when produced from plantations properly located that is high enough to merit fully the use of such techniques.

The special needs of agroforestry, particularly as they are more precisely defined, are likely to be especially responsive to such improvements. An examination of the economic elements involved in such possible developments would be worth exploring in-depth. Amongst other things, it may lead to central specialized nurseries associated with appropriate storage and transport systems.

Eucalypts have many advantages for the previously mentioned uses, but they also have shortcomings. For example they do not fix nitrogen so far as is known. Their water consumption is high although it is believed that (a), wood production per unit of water consumed is also high and (b), they are amongst the most efficient plants in wood production in relation to water consumption. Planning the use of resources should allow a balanced decision as to the extent of eucalypt planting in any given situation in order to keep water consumption to appropriate levels. In some agroforestry situations, species other than eucalypts will be favoured on this ground alone so that combinations of tree and crop plants will be more practical than would be the case if such mixtures were attempted with eucalypts alone.

**Casuarinas**

As with eucalypts, the casuarinas are almost an Australian biological monopoly but not quite to the same extent because there are more *Casuarina* species outside Australia than is the case with the eucalypts. Casuarinas have already attracted considerable attention, but their use to the present has been concentrated largely on three or four species and on limited provenances of those species, whereas the resource is very much broader.

The importance of *Casuarina* has been recognized in various ways including at the international workshop that was held in Australia in 1981 (Midgley et al. 1983). Apart from being a vigorous grower (although not quite to the extent that is shown by the eucalypts) it actively fixes nitrogen and rivals that of herbaceous legumes and the best of other tree species in this category. As a group, *Casuarina* produces superb fuelwood and in its native habitat it was preferred in earlier years by bakers for fuelwood for the exacting process of bread-baking. Special contracts were arranged for supplies of wood for this purpose in eastern Australia at least until 1939.

The selection of species for these uses presents special problems, the first of which is the basic taxonomy. Recent treatment proposes that the genus be separated into four separate genera each of which stands in considerable genetic isolation from the other. Moreover several of the potentially most important species extend into regions of Australia (some are in Papua New Guinea). They are relatively little explored and are not readily accessible. The result is that a considerable amount of research remains to be done on screening and exploring provenances of the best adapted species.

To date only about four or five species have been widely used and of these *Casuarina equisetifolia*, *C. cunninghamiana* and *C. glauca* are the most widespread in plantations. Amongst these, *C. equisetifolia* has been especially important. It has been very successful as a sand binder and wood producer on coastal sands in many areas in India near Madras and on the central coast of Vietnam.

In Thailand a single clone, which is derived from *C. junghuhnuana*, has been widely planted while in Egypt a spontaneously occurring hybrid of *C. cunninghamiana* and *C. glauca* has shown considerable promise for agroforestry use in that country (El-Lakany 1974). Examples such as these, point to some ways in which future development may proceed with benefit.

Some species can be propagated readily by stem cuttings (as in Thailand), which is a method that opens the way for clonal culture and which is likely to be of special importance in agroforestry situations. Traditional use of *C. oligodon* in Papua New Guinea has exploited this feature and there is a related practice in Timor with the local species.

The extent to which interspecific hybridization will be feasible remains to be explored. It is known that marked chromosomal differences
occur between different groups and that there will certainly be barriers to interspecific hybridization between some pairs of species.

The capacity of species of *Casuarina* to fix atmospheric nitrogen has been known for some time. This is mediated by the actinomycete *Frankia* in association with root nodules. All species have been found to possess nodules, but they are not invariably present on all sites and it known that nodules can be present without there being much active nitrogen fixation. Sometimes, poor performance of seedlings and young plants has been observed, which suggests that either *Frankia* inoculation is absent or that the strains available are inappropriate. In view of the importance of nitrogen fixation, especially in agroforestry, the benefits of a thorough understanding of the biology of the system in *Casuarina* is very desirable and would help in planning more effective use of this group of trees.

Apart from this characteristic, some species display a capacity to tolerate considerable salinity. *C. glauca* and other species will withstand quite calcareous conditions; however genotype habitat interactions have not yet been systematically studied.

Various *Casuarina* species range in size from shrubs to 30 m trees. Many will coppice readily and the well known ones are easy to handle in the nursery either as seed or cuttings. Many provide fodder for stock when needed under conditions of stress although this feature may make problems for protection during establishment. Not all species share all these characteristics and this calls for further research.

It is evident that *Casuarina, sensu latus*, is a genus of great importance for fuelwood and agroforestry programs in widespread areas of the developing world.

**Acacias**

As defined at present, the genus *Acacia* extends round the world in the warmer latitudes. From taxonomic studies, some persons consider that most of the species occurring in Australia, and which are mostly phyllodinous, merit elevation to a genus of their own. Whether this view has universal support or not, it does emphasize that as a group they have features that separate them from other species in the genus and especially from those that occur naturally in Africa and Asia.

The Australian group is a very large one with some 700 species—larger than *Eucalyptus*. The distribution of some acacias extends further from Australia than eucalypt species, e.g. as *A. koa* in Hawaii and *A. confusa* in Malaysia. In Australia, species are still being described at a rapid rate. Acacias in Australia are predominantly shrubby, but a few species grow as trees to 30 m high.

In the main, Australian species develop phyllodes instead of normal leaves; these leaf-like structures are derived morphologically from petioles associated with a largely complete suppression of the pinnate foliage characteristic of the genus as a whole. The phyllodes are often remarkably similar to eucalypt leaves so that acacias and eucalypts in Australia tend to have a somewhat similar appearance in the mature trees in the field. Almost everywhere in the natural habitat where there is a species of eucalypt there is an accompanying species of acacia.

A few species have been planted extensively outside Australia. In this regard, *Acacia mearnsii* (syn. *mollissima*) is widely known as a producer of tanbark and latterly of useful wood either for fuel, pitprops, or pulp. In common with other Australian species this has grown very well as an exotic in suitable localities—there are extensive plantations in east and southern Africa. *Acacia melanoxylon* has also been quite widely used in various places as a timber producing tree and at times reaches more than 30 m in height. Other species have been sought as ornamentals of which one of the most striking is the mimosa of southern France, which is based on a hybrid of the two species *A. podalyriaefolia* and *A. baileyana*. This in turn has been grafted as a clone on to stock of another phyllodinous species, i.e. *A. retinodes*, which is resistant to calcareous soils that are characteristic of much of the region in which its cultivation is sought on the Mediterranean coast.

This historical experience in relation to ornamental horticulture indicates the possibilities for further domestication of the genus as its use is extended.

In tropical areas *A. auriculiformis* has been used and more recently, *A. mangium*. The latter is somewhat larger and has a better stem form than the former. Some provenance trials with this species are presently being commenced on an international basis.
It is known that a range of species exists that merits introduction to cultivation, a first step in which is field survey and seed collection where they grow naturally. Such collections will commence in 1983. Acacias of these types are generally very fast growing when young and are often short-lived, viz. 10-20 years. Others grow much longer. Many produce excellent fuelwood as well as timber of high value. Some will coppice and some also make good animal fodder. The position is that the value of the resource is recognized but at present is being little tapped.

In common with other legumes, the phyllodinous acacias fix atmospheric nitrogen and display root nodules. However, less is known about the details of the process, its efficiency, and implications in cultivation. Research to provide more information in this aspect is desirable.

The potential for use of Acacia species is great, both in meeting fuelwood needs as well as in agroforestry situations.

**Melaleucas**

Interest in this genus of paperbarks centres on the species that were known formerly as *M. leucadendron* but which are now spread over a dozen or so species, which are confined to the Australian region, with one or two closely related ones in SE Asia.

Basic taxonomic work in the group is still incomplete but there is evidence that trees in a range of sizes, which endure adverse conditions such as swampy sites, salinity, and aridity, are found. In some localities, species of the group have become weedy in exotic habitats and this feature must be assessed when their use is contemplated.

Compared with the foregoing groups, assessment of their potential is still at an early stage but there is considerable promise implied from the existing information.

**Other Australian Species with Potential for Use.**

The biological resource in Australia is unique, diverse, and of incalculable value where needs for fuelwood and agroforestry are to be met in much of the developing world. This is not confined to the four groups mentioned above but extends to considerably more genera, each with a few species. Some that are likely to be significant have been mentioned recently by Boland and Turnbull (1981). Further reviews of such species are to be expected in the future.

The opportunities for taking advantage of this resource will be extended by programs of the Australian Centre for International Agricultural Research (ACIAR) in the cooperative programs that it is developing.

**Summary**

The demand in developing countries for fuelwood and for introducing the benefits of developments in agroforestry is large and urgent. Australia has a biological resource of major value in these fields and one which is still largely unexplored in *Eucalyptus, Casuarina*, phyllodinous *Acacia, Melaleuca*, and other genera. Research to employ this resource more fully is a need of high priority and one which should involve especially the nitrogen fixing role of both *Casuarina* and *Acacia*.

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Flooded Gum, Eucalyptus grandis, coppiced i.e. cut for fuelwood at 7 years of age, in Eastern Africa.

S. J. Midgley*

Australian tree species have become an integral part of the rural landscape of Kenya, Tanzania, and Zimbabwe since plantings were first made there towards the end of the last century. These trees are now grown in the three countries over a wide range of soils and climates—from fertile uplands at 2 000 m to infertile semi-arid areas and to the tropical coast. There have been introductions of probably 150 species of Australian origin and the eucalypts, the wattles (Acacia spp), and Grevillea robusta are the best known (Anon. 1957; Perry and Willan 1957; FAO 1979; Mullin 1982). The Australian Centre for International Agricultural Research (ACIAR) realized the increasing social importance of Australian species in the region and commissioned an assessment from June-September 1983 of their current use and potential so that better use can be made of the Australian genetic resource.

Eucalypts

They were first introduced as fast-growing trees to meet projected demands for railway fuelwood and, until replaced by oil and coal, they made a significant contribution to the development of Zimbabwe and Kenya. Today the eucalypts are a vital source of domestic fuel in many areas of the Eastern Africa Region and are commonly used as posts, poles, and small-scale building material. In Kenya and Zimbabwe they are also being grown for industrial cellulose. They are widely grown in commercial plantations, in small villages, on farm woodlots, and for ornamental or amenity plantings. Total areas under eucalypts are given in Table I. Most plantings are on the better quality lands at higher altitudes and are dominated by E. grandis and E. saligna but many plantings, mainly E. camaldulensis and E. tereticornis, have been established on harsher sites. Other species planted commonly include E. paniculata, E. microcorys, E. globulus and E. citriodora. Evaluation of other eucalypts for the more marginal sites in the Region is in progress.

The prime reasons for continued popularity of eucalypts among the rural populations include fast growth, superior form of production of building materials, great coppicing ability, ease of management, lack of weeding, and their value as a fuel. In some quarters concern is being expressed as to possible environmental consequences of eucalypt planting, including soil impoverishment, increased erosion, disturbance of the soil-water regime, and possible allelopathy. Although some eucalypts on some sites under particular conditions of management may contribute to such problems, the benefits of planting eucalypts clearly outweigh such shortcomings.

Acacias

The most successful and widely planted Australian acacia, Acacia mearnsii (wattle), is grown primarily for tannin, which is extracted from its bark. A decreasing world demand for tannin has prompted extensive conversion of wattle plantations to other land uses over the past 20 years but significant areas remain (Table I). Wattle cultivation benefits rural employment and provides significant quantities of fuelwood and charcoal, posts, and building materials. From one district with some 8 000 ha of wattle plantation, the East African Tannin Extract Co (EATEC) of Kenya produces about 10 000 tonnes of charcoal annually with an estimated wholesale value of 6 million Kenyan shillings i.e. approximately US$440 000

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Table I. Current total areas (ha) under eucalypts and *Acacia mearnsii* in Zimbabwe, Tanzania, and Kenya.

<table>
<thead>
<tr>
<th>Genus</th>
<th>Zimbabwe</th>
<th>Tanzania</th>
<th>Kenya</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eucalypts</td>
<td>30 970a</td>
<td>3 000b</td>
<td>24 000c</td>
</tr>
<tr>
<td><em>A. mearnsii</em></td>
<td>13 920a</td>
<td>23 300d</td>
<td>14 000e</td>
</tr>
</tbody>
</table>

a. Forestry Commission, Harare.
b. Estimated total, Forestry Division, Dar es Salaam.
c. Forestry Dept, Nairobi, pers. comm.
d. Sherry (1971). (Figures now out of date and possibly an overestimate).
e. Heuvelop et al. (1982).

(M.J. Gichuru, pers. comm. 1983). In populated areas a maize crop is sometimes grown between the rows of wattle during the first year of the rotation. EATEC has also recorded nitrogen fixation rates of 50 kg ha⁻¹ yr⁻¹ under vigorous stands of wattle (Kirit Patel, pers. comm. 1983).

Despite its obvious success in many areas, the use of wattle is restricted by its inability to coppice and its potential to become a weed under some conditions. In areas converted from *A. mearnsii* to *Pinus patula* it has, in some cases, taken up to 10 years to totally remove the wattle from the site. In Zimbabwe, because the wattle plantations are remote from the centres of populations and the people have no cultural affinity towards charcoal, some 70 000 tonnes of wattle are burnt to waste annually (J. Wiltshire, pers. comm. 1983).

Other Australian acacias introduced to Africa are *A. decurrens* and *A. dealbata*, which are closely related to *A. mearnsii* and *A. melanoxylon* (well known as a furniture timber), but these are not as widely used as is *A. mearnsii*. Acacias from an expanded range of Australian environments will be included in future species-assessment trials. Fast growing species, from arid, semi-arid, and seasonally dry tropical zones, that can compete with weeds, fix nitrogen and provide fuelwood and charcoal are of particular interest.

**Other Australian Genera**

*Grevillea robusta* was introduced to East Africa early this century primarily as a shade tree for tea and coffee. *G. robusta* will continue to be planted at many sites as an ornamental, in shelterbelts, in boundary plantings, and intercropped with agricultural crops. Small plantations of this species in Kenya and Tanzania suggest that its reputation for autotoxicity when planted in monoculture is not fully deserved. It is currently a much sought-after tree for inclusion in agroforestry systems in Eastern Africa as it produces a favourable mulch and does not compete strongly with agricultural crops (ICRAF, pers. comm. 1983).

Other Australian genera, which have been planted to a lesser extent, include *Araucaria, Callistemon, Callitris, Casuarina, Melaleuca*, and *Macadamia*. They are more commonly planted as ornamentals in arboreta or in small trial plantations. *Casuarina equisetifolia* is an exception in that it has become almost naturalized in coastal sites of Eastern Africa. It is said to have been introduced by Arab dhow captains to mark harbour entrances (Perry and Willan 1957) and produces straight strong, durable poles highly prized for building and firewood, and occasionally used as masts. The ability of this casuarina to fix nitrogen, to help stabilize dunes, and to establish on impoverished sites has made it very popular on the coast of Kenya, and indicates that further trials of the casuarinas, particularly *C. cunninghamiana* and *C. glauca* are warranted. Both these species have demonstrated a potential for success on semi-arid, saline, or waterlogged sites.

**Management of Australian Species**

Australian species have presented few problems in the nursery, planting, or establishment stages.
Propagation material (primarily seed) is readily available and easy to work with, and the species have generally offered flexible silvicultural and management options. Their properties are such that it is possible to utilize the timber, whatever the size, at almost any time during the rotation. This is well demonstrated in Uganda where, over a period of 50 years, the end use target of the E. saligna plantations changed six times (Marten 1981). Thus, if priorities in end-use change, the management of these species, particularly the coppicing eucalypts, can be altered accordingly. Their regeneration capacity from either seed or coppice is such that re-establishment after harvesting is generally cheap and technically straightforward.

**Future Directions in the Use of Australian Trees**

Forestry authorities in the countries visited have expanded their objectives from an almost total commitment towards industrial wood production to a substantial additional commitment towards domestic fuelwood supply. This conscious policy shift will have far-reaching effects upon the future utilization of Australian tree species. The governments in all three countries have firm policy commitments towards forestry in general and to village afforestation in particular. As a consequence of enlightened political patronage, this commitment is supported by generous resources in Kenya through the Rural Afforestation Extension Scheme (RAES), in Tanzania through the Village Afforestation Scheme (VAS) and in Zimbabwe through the Rural Afforestation Scheme (RAS).

The prime objectives of all three schemes are to provide for the wood needs (primarily fuelwood and small building materials) of a rapidly growing rural population and to maintain a suitable environment for sustained agricultural production. The estimates of annual fuelwood consumption for Kenya of 20 million m\(^3\) (Speich 1983), for Tanzania 40 million m\(^3\) (Kaale 1983), and for Zimbabwe of 5 million m\(^3\) (Banks 1980) are placed in perspective by comparing them with total roundwood removals from Australian forests in 1981-1982 of 16 million m\(^3\), which included wood for paper, building materials, reconstituted products, and chips for export.

Agricultural demands upon the better quality highland areas of Kenya and Tanzania are increasing rapidly and plantation forestry, which has been a prominent land use in these areas, is being pushed to more marginal sites. There is now an urgent need to identify species that can grow in harmony with intensive agriculture or can better utilize marginal and arid, or semi-arid sites. It is for these reasons that research in afforestation on arid and semi-arid lands and on farm forestry (including social forestry, community forestry, and agroforestry) is being given high priority and has attracted support from foreign donors (IDRC, USAID, World Bank, FAO, NORAD, GTZ, Swiss Government, SIDA and others).

In this new direction for forestry, all the ingredients for success are present including funds, expertise and political and administrative commitment. However, there are constraints. Many rural inhabitants are not yet convinced of the gravity of the fuelwood problem and there are shortages of suitably qualified staff to implement projects. Technical questions, the main one of which is the choice of suitable species to meet local objectives, still have to be answered.

Those called upon to implement fuelwood or agroforestry programs find that many of the traditional forestry constraints to species choice are no longer relevant. Attributes such as stem form, fibre length, wood colour, and sawing qualities become subordinate to qualities such as fast growth, burning properties or mulching ability and the range of potentially suitable species is consequently increased. The end result is that the tree planter is confronted with a bewildering array of largely untried species from which to make a choice. It is no coincidence that many projects are concerned with species assessment. There are two projects in Zimbabwe, four in Tanzania, and in Kenya the problem is tackled by four ministries, twelve donor agencies and probably twenty non-government organizations. Lack of coordination and communication between these projects is leading to duplication and fragmentation of effort.

In the past, problems in seed procurement have limited many species trials (Nkaonja 1980). The Canadian IDRC has recognized the problem of communication and duplication of effort especially with regard to supply of tree seed and has proposed to support a Regional Tree Seed Centre based in Zimbabwe (Scott, pers. comm. 1983).
Such a centre will be a natural focus for information on species assessment and would overcome many shortcomings of tree seed supply. Kenya, Tanzania, and Zimbabwe have climatic and soil conditions that are likely to suit many of the 1300 Australian species of eucalypts, acacias, and casuarinas. Some of these are suitable for fuelwood and agroforestry (Boland and Turnbull 1982) and can often tolerate particularly harsh site conditions including aridity and high levels of salt and soil alkalinity. Mullin (1982) concluded that 'with this vast array of species to choose from, and the already proven success in Zimbabwe of many eucalypts and one casuarina, there seems little reason to look beyond Australia for trees to meet our fuelwood needs'.

Despite long experience in dealing with Australian species, many foresters in Kenya, Tanzania and Zimbabwe particularly the first two named were unaware of the enormous variation that exists between provenances (different seed origins) of some Australian species. Lack of experience in the taxonomy of Australian species has led to problems associated with incorrect identification. This inexperience with the Australian flora is seen as a major constraint to its effective use. There exists in the region a wealth of data, literature, and experience with a significant, but by no means exhaustive, range of Australian tree species; however, much of this information is not readily available.

Conclusions and Recommendations

The crisis of domestic energy supply will ensure that forestry activities are afforded high priority in the future development of Kenya, Tanzania, and Zimbabwe. Australian species have the potential to play a unique role in the future of African forestry. Careful introduction, systematic trial work, and careful assessment are essential to ensure the effective use of these species.

This would be facilitated by establishing projects designed to:

1. Increase the local expertise and knowledge of Australian woody species.
2. Assist in the selection and evaluation of additional species.
3. Encourage effective use of successful Australian species through efficient distribution of authentic seed and positive support for the proposed IDRC-sponsored Regional Tree Seed Centre.
4. Gather, evaluate, and publish relevant data on the performance of fast growing species for fuelwood or agroforestry in the eastern and southern regions of Africa.

Summary

Current use and management of Australian woody species in Kenya, Tanzania, and Zimbabwe are discussed. A shift of emphasis of governmental policies from forestry for industrial wood supply to forestry for domestic energy supply is noted. Future directions in rural reforestation, the role that Australian species may play and constraints to their effective use are described. Recommendations for donor assistance are made.

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Session 3

Farming Systems and Socio-Economics
One could easily gain the impression, given the spate of recent literature, that the farming systems approach to research was only discovered in the past decade or so. Until the 1970s, little was heard of it. Since then it has had no shortage of either powerful proponents or opponents in those various national and international forums where the organization, programming, and budgeting of agricultural research are decided——a sign, no doubt, that farming systems research (hereafter FSR) is significant and revolutionary. Yet, farming systems have necessarily existed since farming began. Likewise, it is inconceivable that agricultural research can ever have been conducted without some appreciation of the farming system context to which it related. Indeed, with hindsight, one may argue that much successful agricultural research historically has been that which was conducted with an implicit farming systems orientation. Nonetheless, it is also a fact that institutional research specifically organized in terms of farming systems is relatively new, dating perhaps from no earlier than the 1950s. Only in the past decade has FSR gained formal recognition via the sanctioning of budget appropriations and designated program activities within a variety of research agencies and in terms of the research literature. For instance, the journal *Agricultural Systems* only began in 1976.

As a formal framework for the conduct of agricultural research, the farming systems approach is still, for many people, ill-defined and unproven. Certainly, being so new in its modern formal incarnation, it is true that the concepts, terms, and methods of FSR are young and evolving. Thus some have found it:

1. To suffer from problems of definition.
2. To involve activities that seem to lack specificity of purpose.
3. Not to have a codified set of methods for its implementation.
4. To involve a bewildering array of activities.
5. To be difficult to evaluate in benefit-cost terms.

Perhaps heroically, against such a background, in this paper we attempt to outline the farming systems approach, appraise its relevance and consider its implications for research organization and management in the context of agricultural development.

### The Farming Systems Approach

What is the farming systems approach to research? Certainly it does not imply the use of some new independent science. Rather, it involves the application of knowledge available from the physical, biological, and social sciences (i.e. from the standard pool of knowledge used in traditional agricultural research) but with the difference that it uses a systems approach (Couger and Knapp 1974) in its inquiry. Thus FSR is holistic in outlook and is both multi and interdisciplinary. Reflecting its systems orientation and consequent need for realism and practicality (expressed in part by an understanding of farmers' existing systems), the activities of FSR include both working at the farm level and at the research station level, often with less control than is usual in traditional research with its focus on a particular discipline or commodity.

Basic to FSR is an appreciation of the farm as a system whose *modus operandi* is specified by some particular farming system of which the farmer is an integral part. Defining what is meant by the term 'farming system' is not easy, as is indicated by the following statement (Dillon et al. 1978, p.8):

*A farming system is not simply a collection of crops and animals to*
which one can apply this input or that and expect immediate results. Rather it is a complicated interwoven mesh of soils, plants, animals, implements, workers, other inputs and environmental influences with the strands held and manipulated by a person called the farmer who, given his preferences and aspirations, attempts to produce output from the inputs and technology available to him. It is the farmer’s unique understanding of his immediate environment, both natural and socio-economic, that results in his farming system.

More directly, Shaner et al. (1982, p.16) have defined a farming system as:

‘a unique and reasonably stable arrangement of farming enterprises that the household manages according to well-defined practices in response to the physical, biological, and socio-economic environments and in accordance with the household’s goals, preferences, and resources. These factors combine to influence output and production methods. More commonality is found within the system than between systems. The farming system is part of larger systems—e.g. the local community, and can be divided into subsystems—e.g. cropping systems’.

Thus a farming system involves complex interaction between a variety of interdependent components both physical and psychical which, in turn, may often be viewable as subsystems. Central to the system is the farmer himself.

Following Norman (1980), Figure 1 is a schematic representation of the determinants of a farming system. The environment is seen as having two elements; human and technical. The technical element, specified in terms of available technology and climate, defines production possibilities. The human element involves exogenous factors (including the socio-economic and cultural environment) that influence the farmer’s decision making as to what farming system he will use in face of the technical and resource constraints that he faces.

In such terms, FSR can be viewed as research that: (a) views the whole farm as a system; (b) is conducted with a recognition of and emphasis on the interdependencies and interrelationships that exist among elements of the farm system, and between these elements and the farm system’s environment; and (c) is aimed at enhancing the efficacy of farming systems through the better focusing of agricultural research so as to facilitate the generation, testing and adoption of improved technology.

To these ends, the major activities involved in FSR oriented to a particular target group or region are:

1. To develop a clear statement and agreement on initial objectives of the team.
2. The collection and analysis of base line data.
3. The study of existing farming systems.
4. The design of new system components, subsystems, and/or farming systems.
5. Farm systems experimentation.
6. The evaluation and monitoring of new components and/or new or modified farming systems.

Some Examples of FSR

The span of application of FSR, ranging from simple system adjustment through revision to replacement by a virtual new system, is illustrated by the following three examples.

1. **System Adjustment in Brazil**

Wheat, which would otherwise be very well suited, suffers from the high aluminium level of the soil in the Cerrado of central Brazil. Recognizing this, EMBRAPA and CIMMYT are cooperating on a wheat breeding program to develop wheat varieties resistant to aluminium toxicity. When available, this new germplasm will, as a simple adjustment to the prevailing system, replace the existing wheat germplasm.
Figure 1. Schematic representation of some determinants of a farming system (After Norman 1980).

From a FSR view, this is not a complicated matter—though the breeding research may be quite complicated (as may also be the research needs opened up when Cerrado farmers, through the income generated from the new wheat germplasm, have the potential for further elaboration of their farming systems).

2. System Revision in the Philippines

IRRI's Cropping Systems Program has focused on rice-based systems of small farmers in rainfed areas. One avenue of assistance to these farmers was seen to be increased cropping intensity (Zandstra et al. 1981). For areas with a growing season of intermediate length, appraisal indicated that the effective growing season might be lengthened. The following methods, either alone or in combination, were proposed: (a) the use of shorter duration varieties, (b) techniques allowing earlier planting at the start of the rainy season, (c) overlapping of growing periods by relay cropping and intercropping, (d) use of drought-tolerant crops, (e) improved soil moisture usage, and (f) use of supplementary irrigation.

Thus, for example, research into rainfed rice systems in the Iloilo region of the Philippines showed that new short-duration rice varieties in combination with direct seeding techniques would enable other upland crops to be planted before or after rice and, in lower-lying areas, the production of two rice crops in a single season. When IRRI began this work in 1975, 82% of the rainfed land in the Iloilo region was planted to a single-crop rice fallow pattern. Today, in contrast, some 75% of the region produces two or more crops per season. With this revision to the farming system, a significant increase in the region's cropping intensity was achieved in two years.

3. System Replacement in India

Perhaps the most significant application of FSR to date has been ICRISAT's development of virtually a new farming system for the Vertisol sub-region of India having a soil depth of at least one metre and a mean annual rainfall above 750
mm. The new system appears suited to implementation on at least 5 million and perhaps as much as 12 million ha of this subregion of 73 million ha in India's semi-arid tropics. Currently, this area of rainfed agriculture is left fallow during the rainy season and cropped for wheat, chickpea, sorghum or safflower in the postrainy season.

The essence of the new system (Swindale 1981; Kampen 1982; Reddy and Willey 1982) is the growing of an extra rainy-season crop on the lands presently left fallow, thereby raising cropping intensity from its present level of around 100% to around 200%. Development of the new system has involved multidisciplinary on-station team research at ICRISAT Center near Hyderabad since 1974. Central to this work has been the use of operational-scale watersheds and subwatersheds of from 1-5 ha in size. The technology options considered have been of a moderate-input nature based on bullock power and, assuming that some economies of size can be achieved in the manufacture of implements, lie within the reach of the small farmer. They are technology options that will create employment and are thus socially relevant.

Within the context of the small watershed (which will typically involve some 6 to 20 farmers), components of the new system are (Ryan et al. 1982):

1. Cultivation of the land immediately after the previous postrainy-season crop when the soil still contains some moisture and is not too hard.
2. Improved drainage with the aid of field and community channels and the use of graded broadbeds and furrows constructed with a bullock-drawn wheeled tool carrier.
3. Dry seeding of crops (such as sorghum or maize in a sequential or intercropping system with legumes, such as pigeonpea or chickpea) before the monsoon rains arrive.
4. The use of improved varieties and moderate amounts of fertilizers.
5. Improved placement of seeds and fertilizers; and attention to improved plant protection, particularly for legume crops.

While any one of these components, with the exception of fertilizer, gave only a small effect on production, all of them together produced spectacular results. This is shown in Table 1 from Ryan et al. (1982, p.8) for the case of a maize-pigeonpea intercrop system in 1976-77—a system, which in research station trials over the years 1976-77 to 1980-81, gave an average annual yield of 3.85 t/ha of food grain production without irrigation. Economic analysis of these on-station experiments has been made by Ryan and Sarin (1981). The new improved system using all the devised technology gave annual profits averaging US$365/ha, compared with only US$50/ha from the simulated traditional system. The ICRISAT Center study suggests that, for an extra annual cost of US$120/ha, a farmer changing from the traditional to the improved system can earn an additional profit of about US$310/ha per year. This represents a rate of return on the increased operating expenditure of 260%.

To provide on-farm verification of the proposed new system, ICRISAT conducted a farmer-managed trial in 1981-82 in a village chosen to be representative of the deep Vertisol region with assured rainfall. A watershed of some 15 ha involving 14 farmers was used for the experiment. Some assistance by way of wheeled tool carriers, power sprayers and surveying of the watershed was provided but other required resources were paid for by the farmers. Advisory input from ICRISAT scientists amounted to 1.4 man years. The farmers were also guaranteed that they would not earn less than they could have expected by using the traditional system. To this end, nearby plots representative of the traditional system were also monitored. Using information provided by ICRISAT, the farmers made their own crop choices—this resulted in nine different crop combinations, including the crops of one farmer who decided not to change.

The results of this farmer-managed trial have been summarized by Ryan et al. (1982) and Ryan and von Oppen (1983). Averaged over the nine cropping systems on the improved watershed, the profits were US$306/ha compared with US$165 for the traditional system. This implied an average rate of return of 240% on the farmers' extra annual expenditure and confirms the experience at ICRI SAT Center (even though atypically high prices for postrainy-season sorghum grain led to unusually high profits in the traditional
Table 1. Synergistic effect of variety, soil management, and fertilizer application in a maize-pigeonpea intercropping system on a deep Vertisol at ICRISAT Center, Patancheru, A.P., India, 1976-77.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (kg/ha) Maize</th>
<th>Pigeonpea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize variety: Local</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional inputs and management</td>
<td>450</td>
<td>320</td>
</tr>
<tr>
<td>With improved soil- and crop-management alone</td>
<td>600</td>
<td>610</td>
</tr>
<tr>
<td>With fertilizer application alone</td>
<td>1,900</td>
<td>450</td>
</tr>
<tr>
<td>With improved soil-crop management and fertilizer</td>
<td>2,610</td>
<td>840</td>
</tr>
<tr>
<td>Maize variety: Improved/hybrid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional inputs and management</td>
<td>630</td>
<td>500</td>
</tr>
<tr>
<td>With improved soil- and crop-management alone</td>
<td>960</td>
<td>640</td>
</tr>
<tr>
<td>With fertilizer application alone</td>
<td>2,220</td>
<td>540</td>
</tr>
<tr>
<td>With improved soil-crop management and fertilizer</td>
<td>3,470</td>
<td>600</td>
</tr>
<tr>
<td>L.S.D. (5%)</td>
<td>470</td>
<td>220</td>
</tr>
</tbody>
</table>

a. Pigeonpea variety was the same in all cases.

The Need for a Farming Systems Approach

If agricultural research aimed at the improvement of technology is to be fruitful, it must generate knowledge that is actually used by agricultural producers. Otherwise, if the research has no impact, it implies wasted effort and loss of other opportunities (including those foregone because research has earned itself a bad name).

The need for FSR and its usefulness lie in the degree to which traditional research approaches of a disciplinary or commodity nature fail to produce results that are actually used by farmers. Such failure of traditional research can be usefully related to the FSR concepts of system adjustment, revision, and replacement. Traditional research whose impact, from the farmer's view, is merely system adjustment has *ceteris paribus*, the greatest chance of adoption. Thus we have the success of well adapted new, especially Green Revolution, varieties since they
only require the farmer to make minimal adjustments to his existing farming system. In contrast, system revision is more difficult to implement, and system replacement, from the farmer’s view, is the most difficult of all.

Traditional disciplinary or commodity research results whose potential impact lies in system replacement are highly unlikely to be adopted because, by the nature of traditional research, such results will have been generated without due regard to the realities of the farmer’s situation and the difficulties he faces in system replacement. Thus it is inconceivable, for example, that the current implementation of ICRISAT’s Vertisol technology could have occurred without its having been developed in an FSR context. Indeed, it is most unlikely that a traditional research approach would have been able to generate such a technology.

The results of traditional research may fail to be adopted for two reasons: on the one hand, the research may be misdirected because the researchers misperceive the farmer’s situation through lack of understanding of his desires, perceptions (especially of risk) and constraints or, on the other hand, because the farmer cannot perceive the relevance of the research results due to inadequate information. Through its orientation to the farmer, emphasis on the understanding of his existing farming system and its context as its starting point, and its follow-up activities, FSR aims to ensure that these two difficulties are overcome, in turn ensuring more rapid adoption of the new technology that it generates than would otherwise be the case. At the same time, because of its system orientation, FSR is more likely to ensure consideration of the whole system within which agricultural production takes place, and thereby give due weight to both the needs of farmers and of society at large, as well as more effectively identifying and suggesting solutions to institutional constraints to agricultural development.

Without doubt, the greatest need for an FSR approach is in the development of improved technology for the masses of small farmers in the less developed countries. This opportunity arises, first, because such farmers, who are of overwhelming numerical importance in the Third World, generally do not have either the educational or information services to enable them to act as good integrators of new scientific information; and, second, because traditional research in such countries (a) has generally overemphasized biological potential and yield considerations without sufficient attention to other relevant criteria, (b) has been based on priorities decided by government or by researchers without the involvement of small farmers, and (c) has been carried out on experiment stations in isolation from small-farmer conditions. To a significant degree, these difficulties reflect the inadequacies of traditional institutional arrangements for agricultural research—a matter to be further pursued below.

To the extent that farmers are capable integrators of new scientific information, have influence in the choice of research that is to be conducted, and rely on sole cropping and monoculture, the need for a formal FSR approach is reduced. There still remains, however, the argument that FSR, by virtue of its holistic approach, provides a more complete approach to agricultural research than the traditional disciplinary or commodity approaches with their reductionist philosophy of research (Dillon 1976). Thus it can be argued that most successful agricultural researchers have, in fact, had an appreciation and understanding of the farming systems relevant to their work, even though their research was conducted with a disciplinary or commodity focus.

**Methodology of FSR**

While there is still much discussion over various points of detail, the general methodological framework of FSR is no longer a matter of contention as evidenced by the general consensus to be found between, for example, Collinson (1982), Dillon et al. (1978), Gilbert et al. (1980), Norman (1980), Shaner et al. (1982) and Zandstra et al. (1981). In this section we follow these authors in suggesting what should be done in FSR without elaborating precisely how it should be done. There is much ambiguity about the latter and the unresolved questions about it constitute a prevalent weakness in the practice of FSR.

Following Collinson (1982), Figure 2 depicts the overall framework of FSR. Broadly, seven activities are involved. To a degree, particularly in the initial stages, these activities will be sequentially cyclical as shown in Figure 2. However,
Once an ongoing FSR program is established, all the activities will likely be going on simultaneously with forward and backward interactions across them all. Relative to each activity, the following points may be made:

**Choice of Target Area or Group**

Selection of the target area or group (sometimes referred to as the recommendation domain) should: (a) attempt to be compatible with social needs and priorities, (b) be such as to give a fair chance of obtaining tangible results in reasonable time, and (c) be broad enough to spread costs (Perrin et al. 1976). The most satisfactory delineation is likely to be based on the relative homogeneity of the farming system currently used or, in terms of potential, on the basis of agroclimatic zoning. The aim should always be to strike a satisfactory balance in terms of the economic trade-off between decreased intra-group variability (or increased inter-group variability) and the problem of location specificity, which reduces the domain of impact (Menz and Knipscheer 1981).

Both in the delineation of the target area and in its further specification once chosen, there will be a need for base line data analysis. Time and cost considerations may often imply the use of secondary data. The relevance of data should be judged in terms of their contribution to the delineation and understanding of existing farming systems, their constraints, and opportunities for modification. Base line data will involve both physical factors such as land, soil and climate, and socio-economic factors such as population, culture, and infrastructure. Generally, base line data analysis will be carried out as a desk study. It will, of course, also make use of any micro information that is already available from prior surveys or research into existing farming systems.

**Diagnostic Survey**

Having delineated a target area or group, it is necessary to gain an understanding of the existing farming systems and farmers' motivations in using them. The main aim of this activity is to provide an assessment of farmers' priorities, decision criteria, resource availabilities, constraints, and possible development opportunities. The survey will also, if need be, provide a basis for delineating separate recommendation domains of farmers within the overall target area group. These domains may be based on natural factors such as soil or topography; cultural factors such as food preferences; or institutional factors such as tenure and market access.

Two broad types of surveys have been used for diagnostic purposes, i.e. reconnaissance or exploratory surveys, and formal surveys (Byerlee and Collinson 1980; Byerlee et al. 1980; Gilbert et al. 1980). The former are relatively informal and of low cost. They typically involve a week or so of field travel through the target area by a small multidisciplinary FSR team (e.g. an agronomist and an economist) who talk with representatives of policy-making and farmer-contact agencies, community leaders, and a small sample of farmers and their families. Formal surveys, in contrast, typically involve some considered form of sampling and prespecified sample sizes.
designed questionnaires and an orientation to traditional scientific standards of accuracy. In contrast to informal exploratory surveys, they are likely to be time consuming and costly. This will be particularly so if the formal survey is of a multi-visit panel nature with field recording of production factors.

If time and resources permit, and the need is seen, both exploratory and follow-up formal surveys will be conducted. In terms of gaining an understanding of existing systems and opportunities for change, they are complementary and perhaps best seen as relating to different stages of an FSR program. Initially, the rough and ready information of an exploratory survey may suffice; later, particularly if systems modelling (e.g. mathematical programming analysis) is used, more detailed information obtainable only via formal survey procedures may be needed.

Identification of Possible Changes and Operational Research

From appraisal of the survey information (and also from operational research), judgements can be made as to system changes that might be feasible and relevant. This experiment-station (or sometimes farmer's-field) based design, and operational research activity should generate a few sets of improved practices for possible testing at the farm level and suggest a number of technical problems or more major system changes needing deeper research. More risk-averse researchers may want more rather than a very few sets.

Criteria suggested as relevant (Gilbert et al. 1980) to the initial choice of possible changes for farm-level testing have been that they:

1. Involve, as experimental variables, practices in which farmers' management is flexible (perhaps due to underutilized resources) and where ex ante evaluation suggests the possibility of increased productivity (perhaps due to limiting resources).

2. Assume few changes in the existing institutional framework relating to input supply and product marketing.

3. Take as parameters in the experimental process those factors not potentially subject to manipulation, their level being set so as to be as representative as possible of practical farming conditions.

In the longer term, more drastic system changes become more feasible and the above strictures may be relaxed.

The design stage of identifying possible system changes for on-farm testing may involve experiment station trials of an operational research nature and should always involve ex ante economic appraisals as, for example, discussed by Anderson and Hardaker (1979), Banta (1982), Ghodake and Hardaker (1981), and Ryan et al. (1979). Generally, the greater the body of existing knowledge pertinent to the system under study, the shorter will be the time required on the experiment station to complete the design stage and the more valuable is panel survey work.

System changes considered at the design stage may involve incremental or 'single trait' changes or more extensive 'packages' of practices. While incremental changes are doubtless easier to design and extend, packages will often have the advantage of capturing complementary or synergistic effects between components.

On-farm Testing

Farm-level evaluation via both researcher-managed and farmer-managed trials is a crucial element of FSR methodology. The evaluation criteria should be the same as those used by farmers, whatever they may be, as ascertained in the diagnostic survey. Performance of the improved technology, of course may drop as it is moved from the artificial conditions of the experiment station to the farm level, particularly under farmer management where it is being fully tested for compatibility with the existing system.

Research-managed farm trials can cover more treatments than farmer-managed trials and should be aimed to screen proposed technologies from the design or experiment-station stage, to fine-tune them to local conditions, and to evaluate their potential for local and regional coverage. All this is, of course, easier said than done, and refinement of the operational details for successful practice remains the key challenge in FSR.

Farmer-managed trials are the strongest form of testing. These trials should be on sufficiently large plots and involve as many farmers on a continuing basis as is practicable to provide valid information on the new technology itself and on
its compatibility with other parts of the farmer's system, and should be replicated over time with any modifications deemed necessary from the ongoing appraisal.

Choice of farms for farm-level testing is important as it bears on the question of farmer-research team interaction and technology transferability. To foster transferability, sites should, if possible, be representative of large areas, particularly with regard to landscape position. To foster farmer-researcher interaction, the more cooperative better farmers will tend to be preferred as collaborators. However, these are not representative farmers. Use of 'average' farmers, while decreasing interaction, may give a more satisfactory appraisal of the proposed system changes.

-associated with and growing out of the on-farm testing activity are extension, monitoring, and evaluation activities. Extension workers should be involved directly in the on-farm testing activities so as to be fully informed. They, along with other member of the FSR team, should monitor the spread and evaluate the performance of the newly introduced technology so as to provide feedback to policy makers and sponsors, if there are any, on any relevant issues. In this sense, monitoring and evaluation should be made from the various perspectives of farmers, researchers, and society as a whole.

Identification of Technical Problems

Arising out of the diagnostic survey and identification of possible system changes, a variety of technical problems (e.g. diseases, market difficulties, etc.) can be identified. The feasibility, potential benefits and priority of attacking these problems need to be established as a prior step to undertaking research aimed at their solution.

Component Research

Having decided on the portfolio of technical problems to be researched at greater depth, commodity or disciplinary research on the relevant system components can be conducted on the research station. This research may be oriented to single or multiple components and may involve quite basic research, although to ease subsequent transfer, conduct on farms will be preferred where possible.

Single component research, which aims at improving individual components, will generally help elucidate 'principles' and 'processes'. It includes such topics as, e.g. identifying suitable genotypes for a particular cropping system, examining factors effecting runoff, etc.

Multi-component research constitutes the initial integration of modified or new components developed from disciplinary research into the system. It includes aspects such as the integration of cropping systems with labour availability, soil fertility management, and watershed management.

Use of Existing Scientific Knowledge

Particularly in the experiment station sequence from component research to operational research, use will be made of the existing body of scientific knowledge of both a general nature and specific to the target area or group and its farming systems.

Organization of FSR

The broad organizational lines of FSR spanning on-farm adaptive ('downstream') research and station-based technical ('upstream') research are depicted in Figure 2. Much debate has occurred over the separation and overlap of these activities—see, e.g. Dillon et al. (1978), Norman (1980), and Gilbert et al. (1980). Such debate, however, has been rather fruitless. A complete FSR approach will involve full integration of on-farm and station-based research with the same researchers working, as appropriate, in both activities. Thus ICRISAT, for example, has emphasized the complete integration of on-farm and station-based research via its designated Farming Systems Research Program which, as shown in Figure 3, exists alongside and interacts with the ICRISAT commodity (germplasm) and economics programs (ICRISAT 1983). A similar approach has been taken at ICARDA.

Compared with a traditional organization of research on the basis of disciplines and/or commodities, FSR has strong implications for research organization and management.

By virtue of its holistic approach to the problems of agricultural production, FSR is mul-
tidisciplinary in nature. It should be organized so as to provide a means by which multidisciplinary teams of researchers can examine problems of the relevant farming systems, including the complementary and competitive relationships between enterprises. The characteristics of FSR thus transcend those of conventional disciplinary research, in that FSR through a multidisciplinary team effort with a systems orientation, aims to develop new technology that is compatible with farmer goals and that will enhance system productivity.

The organization of FSR should thus be such as to encourage effective interdisciplinary interaction, which is the key element in FSR and is best encouraged by purposive leadership and voluntary cooperation rather than by attempted institutionalization through structure and formalities. Flexible procedures and mechanisms have to be developed to facilitate interdisciplinary research. Individual initiative in the competition for ideas should not be sacrificed. Sharing of experiences through networks can be very helpful and, as IRRI has shown through its cropping systems research network, can be especially useful in training FSR workers.

The successful operation of FSR programs places great demands upon the scientists involved. Coordination must be frequent and be undertaken by the people directly concerned. Team work is essential. Most importantly, the intra-institute organizational structure for FSR must be flexible; as the research task changes, so too, if need be, should the team and its leadership also change. Team leadership should not respect seniority. A high standard of professionalism is required which, in turn, requires that personal professional goals must be realizable within the system and the team.

One implication unique to FSR is that scientists should be involved in all steps of agricultural research. Scientists do not stop at one stage and hand over their research product to someone else for its further development and testing, but rather should participate in all stages of the problem-oriented research. Research with a conventional approach is usually much more compartmentalized across time and space.

At the more macro institutional level, the implementation of farming systems approach implies significant changes to the organizational structure of research found in many developing countries. First, it implies a shift away from commodity or disciplinary-based research institutes or divisions to a multidisciplinary farming systems orientation. In many countries this would perhaps be best expressed by a shift away from a system of research institutes or stations each having responsibility for a specific commodity to a system emphasizing regional responsibilities (but within which, of course, component research would still be undertaken as needed). Second, it implies a high degree of flexibility in the research, with considerable devolution of decision making and responsibility to those actually doing the work. Third, it implies a far higher degree of integration between research and extension activities than is usual. Extension personnel should be part of the FSR team and, ideally, there should be no institutional break between research and extension. Otherwise, the adoption of an FSR approach may lead to a new set of extension activities being carried out, and the consequent isolation of the traditional extension agency. Fourth, FSR implies a far greater role for farmers, through both formal and informal avenues, in the determination of research agendas. Fifth, through its orientation to farmer reality and the total environment of agricultural production, FSR implies an integral role for social

Figure 3. Organization chart of ICRISAT's Farming Systems Research Program (After ICRISAT 1983).
scientists, particularly agricultural economists, in its activities. So important and so often misunderstood is this role that we take it up separately.

**FSR and the Social Scientist**

In the post-euphoric phase of the Industrial and Green Revolutions, the importance of human, social, and economic factors in farming systems is so widely recognized that it does not need further elaboration here. Research administrators, whether they be in regional, national, or international organizations have generally responded by ensuring that social scientists are represented in research structures.

The form of their representation varies widely, reflecting such things as the prejudices of the administrators and their influential scientific advisers (especially from other than the social sciences) and the availability of social scientists with backgrounds and interests in agriculture. The range extends from a token and peripheral appointment or two, through specialized service divisions of social sciences, to complete integration of social scientists in multidisciplinary research and problem-solving teams. In spite of the diversity, we might chance the generalization that the institutional incorporation of social scientists becomes more haphazard, the more local is the level of organization. Thus, for example, social scientists are pervasively involved in the International Agricultural Research Centres but, at the other extreme, can be almost non-existent at the regional agricultural research stations of the Third World where priorities have usually been given to activation of biological research. Perhaps it is the political sensitivity of socio-economic research findings (e.g. on income distribution issues) that have slowed the advancement of social sciences in Third World agricultural research. Fortunately, however, the situation is improving rapidly in most such countries.

What is it that social scientists have to offer in farming systems research? Surely, it is not simply informing someone that beans have a higher market price than barley, or working out costs of production! It can be many things, and will doubtless vary from scientist to scientist, accordingly to disciplinary training and experience. Among the most important matters that will be addressed are: (a) the social milieu in which farm decisions are made, including customs of sharing and bequest, (b) the institutional setting and policy environment in which farming is conducted, including land reform, credit, and taxation, (c) the economic environment of farms, including long-term market prospects for inputs and outputs and, most importantly, an understanding of the opportunity costs and transactions costs faced by farmers, and (d) the attitudes and personal constraints of farmers, including their desire or otherwise for change, for leisure, for education, for different foods, and so on, and their human and other capital.

Data on such matters are not assembled for their own sake nor for the professional gratification of the social scientists concerned. Rather, the purpose must be to assist in the identification of effective changes to and designs of practices, techniques, enterprises, activities and policies that are acceptable to and appreciated by the target groups in FSR. The days of the 'quick' technological 'fix' have probably gone and progress now must be won in the context of the full reality.

Understanding the wider reality of farming systems does not come easily. Ideally, social scientists glean their knowledge of such systems through long and close contact with the people of the systems. Horton (1983) documents such a recent successful endeavour in Peru. The ideal, however, rarely obtains and more formal methods of description and understanding must be sought. The most widely used approach is a survey that garners detailed information on what happens in the village and on farms, to whom and when. Profiles of labour availability, cash flow, work demands, prices received, etc, can be built up in this way and, if the collections run for a sufficiently long period, the variability over time, especially in response to natural hazards like flood, drought and fire, can also be quantified.

Many elements sought in survey activities are subtle and/or sensitive. Particular skills are required to ensure faithful description of reality. For instance, some transactions costs such as bak-

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2. A referee has suggested another possibility, namely, that biological science administrators see a contribution from social scientists as being less useful than that from biological scientists!
sheesh to public irrigation managers or to fertilizer distributors may not be readily forthcoming in simple interviews but may involve considerable inflation of factor costs. Production levels may be systematically understated if farmers fear linkage between FSR workers and taxation authorities. For a final example, attempts to elicit information on farmers' attitudes to risk are fraught with the danger of interview bias clouding the sought information. Such anecdotes underscore the costs of reliable FSR survey work. In short, it is (a) time consuming, involving repeated contact both to develop confidence on the part of farmers and to gain an understanding of intertemporal effects, and (b) demanding of a high degree of professionalism on the part of those in direct contact with the farmers. Senior social scientists themselves must be actively involved in the direct contact even if this is (perhaps linguistically) difficult. Minimally, interviewers should be conversant with the theoretical underpinnings as well as the empirical applications of the collected data.

The roles charted above for social scientists in FSR could be interpreted as a blueprint for integrative scientific supermen and it is as well to reflect on just how well such roles are executed, at home and abroad. To focus on Australia for the moment, a distinguishing feature of most social scientists engaged in work that could be broadly described as FSR is their basic facility in the technology of agriculture. Following British tradition, most of them have a first degree in agricultural science (or agricultural economics), which makes for their ready appreciation of the technical issues in FSR, as well as predisposing more ready peer acceptance from their colleagues in physical and biological sciences. This contrasts with, say, the situation in the U.S.A. where most economists, sociologists, etc. who work in agriculture do not have the same sort of background in agricultural sciences, and may explain, in part, the fairly high proportion of Australians among FSR social scientists working in the International Agricultural Research Centres.

On the organizational side, FSR-type work is conducted primarily in the Australian State Departments of Agriculture. These are partitioned into research and extension units and the structure of research is typically on disciplinary lines. However, there is usually a high degree of collaboration across disciplines, and between research and extension workers. Sometimes the cooperation is formalized in problem-solving teams but usually it works from bottom-up joint activities—especially at regional research centres. Such free-wheeling farm-level interdisciplinary research contrasts strongly with the prevalent arrangements and practices in most African countries, for example, where typically research agencies are rigidly structured and administered so that there is little collaboration between social and other sciences, and extension services are relatively weakly staffed and are bureaucratically and operationally divorced from the research agencies.

Given the rigidity of African bureaucracies, perhaps the best way to foster FSR generally, and its social science components in particular, is to introduce new bureaucratic entities such as 'FSR Coordination Units' wherein the leads being facilitated by, say, CIMMYT in East Africa, ILCA in Ethiopia, and ICARDA in Tunisia might be implemented in national programs of rural research and extension.

Problems in Adopting the FSR Approach

A variety of problems must be met in implementing the FSR approach. First, commitment of scientists to the approach is essential. To be effective and to operate successfully, the systems approach requires participants to adopt a more altruistic attitude to their work than is conventionally required. Unless participants are committed to the approach, there may be problems in generating the attitudes required for its successful operation.

Second, scientists may often be inadequately prepared to operate effectively in integrated research, either because they did not receive a formal 'systems' training or because the training was theoretical and/or inadequate for practical use. Because most agricultural research units are shortstaffed, the temptation may be merely to shift 'conventional' researchers to an FSR group without restaffing the more conventional disciplinary areas. This 'robbing Peter to pay Paul' philosophy should be avoided if at all possible, even granted the shortage of research resources in developing countries.

Third, there may be problems relating to the evaluation and reward of scientific merit. Con-
ventional evaluation and reward systems that do not adequately recognize the scientific ability of an individual in terms of his or her contribution to the achievement of group, rather than individual research, are not conducive to integrated research of the type required in FSR.

Fourth, there may be problems of definition and focus. In its efforts 'to do good', FSR may run the risk of becoming too loosely focused and degenerate into overly site-specific research characteristic of 'rates and dates' agronomy. At the other extreme, as exemplified by Nielsen and Preston (1981), FSR may be excessively systematic and attempt to design ideal farming systems that have little probability of adoption. A practical farm-oriented perspective has to be maintained throughout the conduct of FSR. As already noted, the difficulty of implementation increases significantly as the research orientation moves from system adjustment, to revision, and to replacement. Concomitantly, the development of completely new systems will be much more demanding of research resources and a far more difficult research task than the development of system adjustments or revisions.

Fifth, there is the question of who sets research priorities and for whom. The establishment of formal forums for the interchange of ideas for setting up research priorities and discussion of multidisciplinary tasks is essential. Determination of priorities is not an easy matter and the scientific staff must be well informed if they are to participate effectively in the decision-making process. There may be political obstacles to overcome in some instances, since some governments maintain a deliberate bias against some groups, e.g. against small farmers outside cooperative groupings. If resource reallocation should become necessary, extensive background briefings will be needed. As noted above, it may be necessary for an institution to establish a coordinating unit for its FSR. The functional nature and composition of such a coordinating unit need to be clearly defined. Steps should also be taken to ensure effective liaison and equilibrium between any such FSR coordinating unit and the subject matter areas of research. The unit should continuously evaluate the present status of the FSR multidisciplinary effort and formulate goals and priorities for the immediate future. Additional means to assist this unit may be required.

Sixth, established reward systems based on equating only reductionist activity with good science may cause difficulty. In the context of FSR, such difficulties are aggravated by problems associated with multidisciplinary targeted research. Reporting and presentation of FSR data tend to follow a step-by-step and seemingly fragmented structure that often times provides little stimulation for evaluating the integrated results of the program as a whole. No doubt due to the relative newness of FSR, there are as yet an insufficient range of forums for presentation, discussion, and evaluation of FSR research. It also seems that insufficient importance is attached by FSR workers to such activities. All members of multidisciplinary research teams must be especially cognizant of the need to accord recognition to those who contribute to the scientific success of such teams. Clear guidance for administrators that effective participation in multidisciplinary projects is recognized would seem to be very important.

Seventh, in terms of implementation problems, there is the question of whether FSR can be superimposed on an existing conventional program. The answer is definitely yes. FSR and conventional research are not mutually exclusive. They are complementary, as implied in Figure 2. To be successful, any FSR program requires both basic and applied research. Conventional research programs are often 'project-oriented' or 'departmental-oriented' with individual scientists attached to each department carrying out a specific piece of disciplinary research relevant to the project under consideration. In this approach, which is akin to component research in FSR, individual components are not, however, defined relative to some holistic view. FSR would enable such precise definition and provide for time-bound achievable goals. However, the following organizational needs related to the structure and conceptual framework of FSR should be clearly understood:

1. There should be a satisfactory mechanism for establishing the goals, priorities and allocation of resources within the FRS program.

2. The definition and coordination of research activities, particularly those of an integrated nature, designed to meet FSR goals should be as complete as possible.

3. Sufficient flexibility to respond to chang-
ing circumstances and the introduction of new ideas should be well ensured.

4. Adequate encouragement of activities and communication among subdisciplines, and between FSR and other major activities of the institute, is desirable and necessary.

In terms of introducing the FSR approach into a conventional research institute, the best first step would probably be to introduce or foster on-farm testing as a normal activity of researchers, perhaps through encouraging them to take greater interest in work outside their particular specialities. The second step would be to provide a flexible institutional structure within which researchers can come together to tackle problems on a systematic basis. The third step could be to provide loci for base line analysis, base line surveys and diagnostic research which, along with on-farm testing, would generate enhanced awareness of the need for a FSR approach.

Finally, in terms of implementation problems, some points of caution are necessary. First, it must be recognized that FSR is, to a greater or lesser degree, location-specific (Kalirajan 1981; Menz and Knipscheer 1981). The more complex the system under study, the more location-specific it is likely to be. The constraints defining location-specificity are physical, biological, economic, and social. Physical and biological constraints are the most intractable. They define the limits of improvement that are possible. To define these limits, to assess physical location-specificity and to enable technology transfer, certain minimum sets of data must be obtained on-station and on-farm. Social and economic constraints are less intractable than resource constraints and are more time-dependent. Second, multidisciplinary research can tend to be ‘weak in theory and soft in quality’ (Schultz 1979). It may be easy to jump on the bandwagon but it is important for the disciplines concerned to steer the wagon in the right direction and at the right speed. Third, and most important of all, it must be recognized that FSR is no more than one of many facilitators to development. Of itself, it is not a panacea.

With particular reference to African farming systems, two features of most systems contribute to their complexity in a very significant way. It happens that they are both strongly paralleled in most Australian farming systems so that Australian experience and expertise may have particular value in collaborative work. First, livestock play a central and pervasive role in the functioning and success of such systems. Second, climatic variability (especially rainfall amounts and inter-temporal distribution) is high on world standards, (but not Australian). Witness the present devastating drought affecting southern Africa.

The conjunction of these features is a greatly under-researched field. FSR workers face the prospect of many surprises and insights as they untangle and comprehend the many complementary interactions among livestock and cropping activities and the buffering effects that these have in assisting farmers to cope with turbulence in their environment, whether it arises from natural, economic, or political sources. One of the challenging aspects of such work is to discover and deal with the attitudes towards risk, food insecurity, and wealth held by African farmers. These must be understood much better than they presently are before investigators could, with any confidence, propose ‘improved’ tactics and strategies for farmers managing in such highly variable environments.

Perhaps the greatest single problem in FSR for Africa, and, indeed, for any alternative model of agricultural research, is the diversity of farming systems. We have alluded to this above in the context of location-specificity. Another issue for researchers to grapple with is the allocation of their scarce investigatory resources among so many competing systems of diverse importance, especially when importance is judged by such things as the contribution to the economic growth and welfare needs of more or less neglected groups. We know of no easy solution to this difficulty but, minimally, research decision-makers must be sensitive to the tendency to concentrate resources on farm people already favoured relative to those in less accessible areas. The price of social relevance may be that work that is more difficult and less scientifically satisfying should take precedence over opportunities that are easier and more comfortable. Special funding may be required in some instances and, with the growing recognition of FSR among donors, this may be increasingly obtainable.
Summary

The FSR approach can be summarized (Shaner et al. 1982, p.4) as farmer based, problem solving, comprehensive, interdisciplinary, complementary, iterative and dynamic, and socially responsible. It is:

1. Farmer based because FSR teams seek an understanding of farmers' conditions and integrate farmers into the research and evaluation process.
2. Problem solving in that FSR teams seek researchable problems and opportunities for improving existing farming systems.
3. Comprehensive in that FSR teams consider the whole farming system in the context of all its environmental influences so as to learn how to improve the farmer's welfare while evaluating results in terms of both farmer and societal interests.
4. Interdisciplinary in its team approach involving scientists and extensionists with different disciplinary backgrounds who work together to identify problems and opportunities, to search for solutions, and to implement and monitor the results.
5. Complementary because it draws on and feeds back to disciplinary and commodity-based research.
6. Iterative and dynamic in that FSR follows a cyclical pattern of research and testing that leads on to further research and testing.
7. Socially responsible in that FSR teams aim to keep public interests, both present and future, in mind, as well as those of the farmer whose farming system is being studied.

Many of these features are, of course, common to the more traditional approaches of disciplinary and commodity research. The combination of them all, however, distinguishes the FSR approach.

References


Kalirajan, K. 1981. The contribution of location specific research to agricultural productivity. Indian Journal of Agricultural Economics 35: 8-16.

Kampen, J. 1982. An approach to improved produc-


The paper focuses on small-farm systems. The justification for ignoring commercial farmers is that small farmers make up 80-90% of the total populations of the Eastern African countries, and their development dominates national political and economic priorities.

Figure 1 models the characteristics of a farming system. The farmer reacts to his circumstances by decisions to allocate resources to crop and livestock enterprises that meet his priorities. Natural circumstances, particularly of climate, but also of soil and biology, bound the production opportunity set open to him. Economic circumstances, marketing systems, prices, and policy modify the usefulness of this opportunity set to the farmer. His resource base dictates how, and how far, he can exploit these sets of circumstances and how well his activities satisfy his priorities. Differences in circumstances, in farmers' resource bases, or in farmers' priorities can result in different farm systems represented by different patterns of crops and animal enterprises and different methods of production. With wide diversity in climate, social background, and market development in Eastern Africa there is a parallel diversity in farming systems. The paper attempts to identify only the most important sources of variation, to discuss the effects of these sources on East African farming systems, to example two common types of systems and, finally, to discuss priority areas of research for these two types.

Farmers' Exogenous Circumstances

Natural Circumstances

Categories of circumstances that can influence

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* Economist, CIMMYT, Nairobi. Kenya. The views expressed in this paper do not necessarily represent those of CIMMYT.
Table 1. Areal distribution of given rainfall regimes in Eastern Africa (Morgan 1969).

<table>
<thead>
<tr>
<th>No. wet months</th>
<th>Land area %</th>
<th>No. Wet months</th>
<th>Sequence of seasons</th>
<th>Land area %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wet season</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Dry season</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Wet season</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dry season</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>1.8</td>
<td>7</td>
<td>4 -</td>
<td>0.2</td>
</tr>
<tr>
<td>11</td>
<td>3.7</td>
<td>7</td>
<td>4 -</td>
<td>1.0</td>
</tr>
<tr>
<td>10</td>
<td>3.5</td>
<td>6</td>
<td>5 -</td>
<td>1.0</td>
</tr>
<tr>
<td>9</td>
<td>6.9</td>
<td>5</td>
<td>2 -</td>
<td>2.3</td>
</tr>
<tr>
<td>8</td>
<td>3.2</td>
<td>4</td>
<td>2 -</td>
<td>3.5</td>
</tr>
<tr>
<td>7</td>
<td>12.3</td>
<td>4</td>
<td>2 -</td>
<td>2.0</td>
</tr>
<tr>
<td>6</td>
<td>16.4</td>
<td>4</td>
<td>2 -</td>
<td>3.5</td>
</tr>
<tr>
<td>5</td>
<td>22.7</td>
<td>3</td>
<td>2 -</td>
<td>0.2</td>
</tr>
<tr>
<td>2</td>
<td>2.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>14.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

87.9 12.1

Table 2. Percentage of land area receiving selected amounts of annual rain in 4 years out of 5 (Morgan 1969).

<table>
<thead>
<tr>
<th>Rainfall</th>
<th>Kenya</th>
<th>Tanzania</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 20&quot; (&lt; 500 mm)</td>
<td>72</td>
<td>16</td>
</tr>
<tr>
<td>20-30&quot; (500-750 mm)</td>
<td>13</td>
<td>33</td>
</tr>
<tr>
<td>30-50&quot; (750-1 250 mm)</td>
<td>12</td>
<td>47</td>
</tr>
<tr>
<td>&gt; 50&quot; (&gt; 1 250 mm)</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Thus Kenya, much the most poorly served of the East African trio, receives a reliable 760 mm over only 15% of its land area. Altitude differences affecting the length of the growing season, are an additional, important natural source of variation in East African farming systems, though secondary to rainfall. Maize, for example, will mature in 100 days at sea level but will occupy land for 300 days at 2 500 m. The effect of this extreme variation in the length of the growing season on farming systems is tempered by the fact that most of the East African land area has only a single annual growing season, and over 50% has a 5-7 month dry season. Thus the sheer length of the growing season at high altitudes is not an extraordinary disadvantage. Though, when combined with prolonged exposure to hazards of frost and unreliable rainfall in particular situations, it greatly compounds uncertainties.

Economic and Social Circumstances

The dominant socio-economic source of variation between farming systems in Eastern Africa is population density. As Figures 2 and 3 (Kenya and Tanzania only) demonstrate there is a close correlation between rainfall and population. On the whole the best rainfall areas were farmed first and populations have since been pressured out into poorer conditions. This general pattern is modified by historical tribal dominance, and by low population densities of the relatively well watered areas in the west and south east of Tanzania.

Overall population densities are modest but irrelevant, due to the large proportion of land areas unsuitable for agriculture. Local specific populations reach very high densities for dryland farming, e.g. over 500 persons (70-80 families)/km² in parts of western Kenya in the higher rainfall areas of the Lake basin. This contrasts with very low densities, i.e. below 10 persons (1-2 families)/km² in well watered parts of west and south east Tanzania (760-1 270 mm per year, 4 years out of 5). Such variations in population density are closely related to other economic circumstances, especially market opportunities and
Figure 2. Zones of average annual rainfall (mm) in Kenya and Tanzania (Reproduced with the kind permission of B. Lundgren, ICRAF, Nairobi, Kenya).
Figure 3. Administrative boundaries and population density in Kenya and Tanzania (Reproduced with the kind permission of B. Lundgren, ICRAF, Nairobi, Kenya).
infrastructure development. High densities form market opportunities and allow the cost-effective development of roads and assets to service the concentrated populations. As a corollary, some of the most successful re-settlement efforts have been based on the principle of providing infrastructure and market opportunities to motivate people to settle in the area.

Finally, specific basic starch foods are often a strong tribal tradition. Where subsistence foods are a major part of the farming system, variations reflecting different cultures are a strong modifier to the pattern. There are over 120 recognized ethno-cultural groupings in Eastern Africa and basic starches include grain, plantain, and root crop types.

A wide range of natural, economic, and social circumstances make up the farmers' production environment. Rainfall, altitude, population density (and related features of market opportunity and infrastructural development), and traditional tribal starch foods seem the most important exogenous sources of variation between Eastern Africa farming systems.

Farmers' Endogenous Circumstances

Farmers' Priorities

Farmers' priorities change as they develop. The smaller the farm, the more limited the resource base and the more do subsistence needs dominate resource allocation. Farmers with limited means place an overriding priority on producing food, day in day out, for their families. Increased market contact and exchange are a prerequisite for farm development. As contact increases, production rises and the farming system expands until output for the market parallels and then overtakes subsistence production. During this process, production for the market will begin to dominate resource allocation.

Further steps in this sequence of changing priorities are the farmer turning to the retail market to purchase food for his family, and specializing in cash crop production. While all stages of this development sequence can be found among Eastern African small-holders, home food production probably dominates resource allocation in the majority of small-hold-}

ings in the region. Four stages are listed below with the second stage being the dominant one:

1. Wholly subsistence production with surpluses locally exchanged or used for increased social activity when available.
2. Dominant subsistence priorities with (a) deliberately produced surpluses for sale locally or centrally, and (b) with a cash enterprise 'tacked on' to the subsistence system and management subordinated to food supply priorities.
3. Dominant cash enterprise(s) but with basic food requirements still produced on the farm; food shortfalls or special preferences are supplemented by purchases.
4. Wholly cash enterprises and mainly family goods purchased (except for specialities).

Stage 1 is characteristic of systems in areas of low population density with poorly developed infrastructure. Such situations are limited in Eastern Africa. Most of Eastern Africa's small-farmers probably fall into Stage 2. Table 3 is a list of farm enterprises that are managed for subsistence and for the market, in the region.

In subsistence priority systems, the energy requirements of the family dominate resource allocation and the starch staple is usually the largest enterprise. The management requirements of cash crops are subordinated to those of the foods. Where rainfall reliability is low, farmers' management strategies centre on ensuring a family food supply. Market reliability also plays a major part in the development sequence. Farmers in areas where purchased food supplies are unreliable or for which prices are highly variable continue to grow foods. Similarly, where cash crops markets are unreliable, where there is no guarantee that crops will be purchased, or where cash may not be available on crop delivery, farmers will persist in subsistence production.

Very few small-farming systems have reached Stage 4 where farmers rely on cash earnings for food purchase. This may be limited to some densely populated areas in the central highlands of Kenya with effective and reliable marketing channels for coffee, tea, and dairy. In such cases, where cash flow problems are minimized by the nature of the enterprises, some but by no means all farmers, under pressure from population increases, have begun to specialize in these cash crops.

Most Eastern African farmers operate systems
Table 3. Major farm enterprises of Eastern Africa.

1. Major Source of Energy—Starch Staples:
   Maize, sorghum, millets, cassava, Irish potato, sweet potato, plantain, wheat, rice.

2. Major Vegetable Protein Sources:
   Beans, cowpea, groundnut, chickpea, gram, pigeon pea, bambara.

3. Major ‘Relish’ or ‘Food Flavour’:
   Groundnut, cabbage, kale, tomato, onions; and fruits and/or leaves of cowpea, bean, cassava, pumpkin.

4. Cash Crops:
   Export and Local Industry:
   Cotton, coffee, tea, sugar, pyrethrum, tobacco, cashew, sisal, groundnut, sunflower, sesame, soya, castor, coconut, fruits.
   Urban Food Supplies:
   Maize, wheat, beans, groundnut, cassava, plantain, sugar, fruits.

5. Livestock:
   Milk, meat for subsistence and sale, draft power, manure, security, traditional uses.

oriented to family subsistence. Innovations, to be relevant and thus acceptable, will have to be focused in one of three ways:

1. To improving the efficiency of resource use in food production, without sacrificing food supply reliability, and releasing farmers’ resources for market production.

2. To improving the reliability of food supply and releasing resources from food insurance management strategies for orientation to market production.

3. To improving the efficiency of resource use for marketed crops without jeopardizing the supply and reliability of food supplies.

**Small-holders’ Resource Base**

Relative land scarcity is the most important resource factor causing variation between farming systems in Eastern Africa. A direct effect of population density, it can be related back to differences in rainfall. Land is scarcer in the areas most favourable for farming. Availability ranges from about 1 ha per family in some of the very high potential areas, to 50 ha per family in some low medium potential areas. (This range excludes those semi-arid and areas occupied by pastoral people dependent on their herds and nomadic in character).

Two other resource factors interact with land scarcity to cause variations between farming systems, i.e. cash availability and power resource. Small holders spend between 10-25% of their gross cash revenues on farm inputs ranging from hired labour and tractors through to the intensifying inputs of fertilizers and insecticides. Farm expenditure on the majority of small holdings is in the range of US$10-250 usually reflecting the level of market contact of the system. Cash requirements and the returns to cash are often key criteria in the selection or development of innovations because of low cash incomes, and low farm expenditures, in many Eastern African small-farm systems. Returns to the use of cash can be very high in small farm systems—well over 10:1 on the early increments. This falls off as extra cash is invested. Table 4 shows the levels of cash costs and the returns to cash found on local farms and experienced on a trial small-holding in Tanzania in the 1960s. Returns on new technology that demand cash outlay have to compete with returns to existing uses of cash in the system for the innovations to be attractive to small farmers.

Power source for land preparation is a further resource factor interacting with land scarcity in Eastern African small-farming systems. Methods of seedbed preparation range from the handhoe, requiring 50 plus man days per ha, through oxen, requiring 5 team days per ha, to tractor hire, that is used on a limited scale to supplement hand or ox power. Small farmers often continue preparing and planting lands for two or three months at the start of the rainy season. If we assume three work units per family and take an average work period of 50 days at the start of a season, this limits families working with handhoes to 3 ha cultivated, and families with a single ox team and plough to some 10 ha cultivated.
Table 4. Returns to increasing levels of cash expenditure on a trial small holding (US$) (Collinson 1969).

<table>
<thead>
<tr>
<th>Factor (US$)</th>
<th>Local farmers</th>
<th>Trial Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Best</td>
</tr>
<tr>
<td>Level of farm costs</td>
<td>17</td>
<td>23</td>
</tr>
<tr>
<td>% net returns on all cash used</td>
<td>793</td>
<td>130</td>
</tr>
<tr>
<td>% net returns on extra cash used</td>
<td>–</td>
<td>1</td>
</tr>
</tbody>
</table>

a. Over that used on the average local farm.
b. Over that used in the previous year.

Three points for research relevance emerge from these generalized scenarios; they focus on the extensive or intensive use of land as a production factor:

1. Although fertility maintenance problems emerge much earlier on most soils, land does not become absolutely scarce (i.e. there is less available than farmers could cultivate during the season) until population density has reached about 200 people/km² of cultivatable area under handhoe systems and about 50 people/km² under ox plough systems.

2. Even when land becomes absolutely scarce and the 50 days work period assumed for planting reduces, crops will continue to be established at suboptimal times because of the low rates of work for both ox draft and particularly hand power.

3. With long periods taken for seedbed preparation the initial areas prepared need weeding before later areas are planted. With dual demands on limited labour, weeding is often subordinated to further land preparation.

Research and extension have failed to recognize that the extensive use of land is logical and will persist until holding sizes are very small due to the low levels of power at the disposal of small farmers. It has often been said that small farmers are irrational by not planting at the right time as it is a ‘costless’ recommendation. Nothing could be further from the truth. Exhorting the small farmer to ‘plant everything in the first week of good rains’ is tantamount to asking him to reduce his production levels by 80%. Even on holdings with 1 ha of cultivated area, where the traditional hand seedbed preparation sequence is used, the last plantings will be 3 weeks after the start of the rains. Experiments have shown that yield potential may be halved by such a delay. Clearly the economics of fertilizer use alter radically.

If we look at ‘the extra acre’ prepared by hired power at modest yield levels, the return to cash employed is very high. (Say US$20 for a hired tractor for an acre realizing 800 lbs of cotton at US$0.20 = US$160 or 8:1 on the investment). It takes major crop responses to intensifying inputs to equal such returns and this is why the extensive working of land persists. The delayed times of planting forced by lower power availability, the choice of further seedbed preparation over early weeding, the low quality of seedbed preparation and rapid methods of seeding to offset labour scarcity, all interact with the classic intensifying inputs and inhibit their efficient use. (Farmers have said ‘we need high levels of fertilizer to make sure the demand from weeds does not take too much away from the crop!’ ——they may right).

Two Common Types of Eastern African Farming Systems and some Research Implications

Two common types of farming systems are described and implications are drawn for some research priorities in the light of the needs of these systems. The examples used are dictated by areas in which CIMMYT’s Economics Program has cooperated, relatively recently, in diagnostic survey work and which are representative of difficult situations for increasing numbers of Eastern African small farmers.

First, from the south part of Chibi District in Zimbabwe, an example of the type of system with
a single season of unreliable rainfall and the use
of animal draft under increasing population pres­
sure is described. The example highlights the
importance of food security in local farmers’
resource allocation decisions, and the increas­
ingly common clash between human and animal
food needs in Eastern and Central Africa.
Second, from Kakamega in western Kenya, an
example of systems in better rainfall areas with
very high population densities, dependent solely
on the handhoe for land preparation, is outlined.

Semi-Arid areas, Unreliable Rainfall,
Animal Draft Dependence and
Increasing Populations— a
Zimbabwe example (Collinson
1982).

Rainfall and Soils
Annual average isohyets in south Chibi range
from 600 mm in the north to 850 mm in the
south. Rain falls from mid-October to mid-April.
There is a 20% probability of a 15 day period with
less than 45 mm of rain at most times in the
growing season. This mid-season dry period is
devastating when it occurs while maize is tassel­
ing and silking from late December to early
February.
Soils are granitic sands, do not retain moisture
well, and have a poor nutrient status. Table 5
shows how dry periods occurred in the 1981-82
season, the first catching early maize plantings at
3-4 weeks and delaying later plantings until
January. Then the second dry period subsequent­
ly devastated these with the season virtually
finishing in late February. Rainfall totalled less
than 470 mm for the season.

Population Density and Market
Infrastructure
Population density is about 75/km². With eight
persons in the average family this is about 11 ha
of land per cultivator. Probably below 50% of the
available land is arable; farmers presently
cultivate some 3 ha each. Although the area
is bisected by a main tarmac road, feeder roads
are few and poorly maintained. Some local
retail storekeepers have been appointed as
Maize Board agents but there is no Board depot in
the area. The nearest reliable source of purchased
inputs is 100 km from most of the area. Exchange
transactions are dominated by the informal mar­
ket within the community.
Increasing population pressure has created a
clash between arable needs to produce human
food and grazing needs to feed animals. It has
reached a crucial stage reducing livestock num­
bers and consequently squeezing draft animal
resources.

Farmers Resource Base and Performance
Table 6 sets out the resource base and some
rough measures of performance for our two
groups of farmers in south Chibi; cattle owners
and non-owners, this difference in control over
power source has been used to separate the
groups.
Significantly, as is common in Zimbabwe,
parts of Zambia, Malawi, and southern Africa,
most cash is earned from non-farm sources. At
these low levels of cash income, farmers priori­
ties are to achieve enough food production to
meet family requirements. Surpluses of maize
and groundnut are sold off locally. Finger millet is
either sold for local beer making or brewed on the
farm and sold as beer. Although farmers are not
cultivating all the land available, new families are
being forced to crop poorer land that was formerly
used only for grazing. This is growing to a crisis
for the area.

Constraints on the System
Historically the major challenges to farmers have
been the unreliable rainfall and the low soil

<table>
<thead>
<tr>
<th>Table 5. Rainfall (mm) at the Chibi District Office, 1981-82 (north of and drier than the actual project area).</th>
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</thead>
<tbody>
<tr>
<td>Oct</td>
</tr>
<tr>
<td>------</td>
</tr>
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<td>34</td>
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</tbody>
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