GENETIC EXPLOITATION OF THE ENVIRONMENT - FIELD CROPS AND PASTURES

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INTRODUCTION

Genetic exploitation of the environment encompasses many activities, organisms, concepts and disciplines. In the context of this paper, it implies the development and use of populations of plants which are genetically superior for the needs of agricultural producers. In practice, however, improvements in agricultural and pastoral productivity depend on the concurrent manipulation of both the plant and its environment. Although aspects of improved plant and soil management are being considered in separate papers, they form an integral part of the plant improvement process.

This paper is not a formal review. Rather, it is an overview of field crop and pasture plant improvement in the Australian agricultural environment.

Agricultural development in Australia is a classic example of the escalation of genetic exploitation of the environment by man. A clear pattern may be recognized. Exploitation of any suitable native species has been followed by a series of activities best described as crop adaptation; viz. exploitation of chance introductions, planned introduction of new cultivars and species, limited local breeding for specific aspects of adaptation, and finally, large scale national breeding programs. There has been a progressive improvement in adaptation through both genetic and environmental modification, and this has been the chief concern of agriculture since first settlement.

Today, particular species occur at different stages of this adaptation cycle, largely as a result of the historical or conceptual importance of each species in Australia. No native crop species were domesticated by the first settlers. Thus from the earliest days, Australian field crops have been exotic in origin, and in many species genetic improvement has now reached a high level. By contrast, exploitation of the massive resource of native pastures has been vital to pastoral development in Australia, and this still supports large numbers of sheep and cattle. Extensive degradation of native pastures has occurred throughout Australia, but improved management techniques have allowed continued exploitation. Efforts to genetically upgrade the native plants have rarely been considered worthwhile. Rather, pasture plant breeders have concentrated their efforts on introduced pasture plants, particularly legumes, which have often simply been oversown into native grassland. Substantial genetic improvement through breeding has occurred in a number of pasture species, but in general, pasture plant breeding has received less emphasis than, and has lagged behind, crop plant breeding.

Plant introduction has played a major role in the development of Australian agricultural systems. Most of the early introductions were relatively poorly adapted to Australian environments; for example, the early wheat introductions which originated in temperate Europe were narrowly adapted to the cooler and wetter coastal and sub-coastal regions. Recognition of the genetic differences among introductions and the development of an understanding of plant geography, led to planned plant collection and introduction. While introduction remains a major tool in plant improvement, its role varies with the level of species development and adaptation. For non-adapted species, the objective is to

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introduce whole genomes, as lines with direct or indirect potential as cultivars. For species already well adapted to Australian environments, the usual objective is to introduce specific genes or characters required in further breeding.

The importance of germplasm collections (gene banks) is widely recognized, and substantial collections are maintained. Some centralized Australian national collections exist (e.g. wheat and various pasture species), and there is a trend towards generalizing this approach. The international network of plant improvement centers for the major crop plants (Table 1) has provided impetus to germplasm collection and exchange, and to plant breeding. Most major Australian field crops are charter species at one of the centres, and collaboration with those programs can assist Australian scientists to make better progress with limited local resources.

TABLE 1. Some international plant improvement centres

Centre and site	Crops
International Maize and Wheat Improvement Centre (CIMMYT), Mexico	maize, wheats, triticale, barley
International Rice Research Institute (IRRI), Philippines	rice
International Center for Tropical Agriculture (CIAT), Colombia	field beans, cassava, tropical pasture species.
International Institute for Tropical Agriculture (IITA), Nigeria	root and tuber crops, grain legumes
International Potato Center (CIP), Peru	potato
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India	sorghum, pearl millet, pigeon pea, chickpea, peanut
Asian Vegetable Research and Development Center (AVRDC), Taiwan	soybean, gram, vegetable crops
International Centre for Agricultural Research in the Dry Areas (ICARDA), Lebanon	chickpea, lentil, broad bean, durum wheat, barley

Breeding programs involving hybridization and selection have been established in many species in Australia, but they are often restricted in size, duration, objective or region of inference, in part because of the diversity of crop and pasture species used and their relatively small individual areas. Because of this, practical plant improvement with many species depends directly on introduction of genetic material developed or collected elsewhere. We regard continued introduction and exchange of material to be essential in all species because of the dangers of working in isolation.

IMPROVED USE OF CURRENT RESOURCES

The land resources of Australia are relatively unexploited agriculturally; that is, there is a substantial gap between actual and potential production. Although there are many reasons for this, it is true that greater genetic exploitation of the Australian environment can result from better use of our current genetic resources. Rapid expansion of certain crops including cotton, sorghum, sunflower, soybean and lupin during the last 10-20 years demonstrates the dynamic changes that can occur, and emphasizes the need for a flexible infractructure capable of anticipating and rapidly reacting to such changes.

Although there are clear biophysical constraints to plant growth (Gifford *et al*. 1976), production could be expanded considerably using present technology. Nix (1974) estimated that dryland agriculture could be extended by a further 25 m ha, approximately equally divided between northern and southern Australia, after allowing for constraints due to fertility and topography. Most Australian agriculture is dryland but Haigh (1963) estimated that it should be possible to treble the irrigable area, particularly in northern Australia where the most voluminous and most unexploited water resources exist.

In Australia we have a relatively recently developed agriculture in a wide range of diverse environments which must accommodate dynamic changes in demand. A responsive research infrastructure and effective extension and adoption of research findings are crucial to the improved exploitation of the agricultural environment. Investment in research is considerable, with Australia ranked third of 19 countries surveyed in terms of the percentage of gross rural product expended on rural research and development (Anon. 1976). The need for research into the development of better plants is particularly important, and the extension worker has a key role to play in improving the use of both existing and improved cultivars. Effective communication between extension and research personnel is essential.

EXPANDING GENETIC POTENTIAL

In this section, we consider some of the opportunities for genotypic improvement, through removing some limitations to production, preventing loss from biotic factors or by lifting product quality.

(a) Limits to production

(i) Establishment and persistence

Poor establishment is one of the most important and basic limitations to production, and reduces or negates much of the value of other inputs to development. Establishment failures are common in sown pastures, particularly in low input systems, and may pose an absolute barrier to development. Considerable research has occurred in this area but much remains to be done. Similarly, persistence of sown species is crucial in permanent pasture systems and has received considerable attention, but there is need for further improvement. For example, a major deficiency of the scrambling tropical pasture legumes is lack of adaptation to, and persistence under, close grazing and this commonly necessitates management designed to protect the pasture rather than to optimize production. Research into the genetics of adaptation to grazing is vital. Factors such as hardseededness and dormancy which influence the reserve of seed in soil are important, and innovative approaches to improving persistence may be possible (e.g. the introduction of geocarpy into Siratro from *Macroptilium geophilum*).

Establishment has posed few genetic problems in most cereal crops although improved sowing technology has had considerable impact on production. In contrast, major establishment problems exist in many oilseed and protein grain crops, and genetic manipulation of tolerance to weathering and physical damage, and of storage life, may be warranted. Furthermore, new cultural practices can pose additional genetic requirements; for example, greater seedling vigour is required in wheat to ensure establishment in stubble-mulched or zero tillage systems, and genetic sensitivity to particular herbicides and insecticides has been recorded in a number of crops.

(ii) Phenological adaptation

Selection for phenological adaptation to Australian environments remains one of the major objectives in genetic improvement in all crop and pasture species. Two general objectives exist, viz. stress avoidance by tailoring plant growth to avoid absolute environmental limits and/or to schedule the most sensitive phases of growth during favourable seasonal periods, and optimization of production by designing agronomic systems to complement phenology.

Phenological modification has been used widely in wheat improvement but further changes may be desirable, either in the direction of even earlier maturity or towards winter habit. Similar genetic manipulation of phenology has occurred in most crop plants, with a range of maturity types being developed to provide flexibility of rotation and adaptation to particular soil and climatic conditons. In many tropical legume crops, phenological change due to photoperiodic response can be accommodated by agronomic techniques and this can extend the range of usefulness of elite cultivars. Genetic insensitivity to daylength exists in some of these crops and can be used to reduce crop duration and expand the potential area of cultivation of the crop.

In pasture species, phenology has basic influences on productivity and persistence. A striking example of the benefits which can flow from attention to phenology is the development of early flowering lines of subterranean clover, which has greatly extended the area of cultivation of this important legume. Similar examples exist in *Phalaris*, *Stylosanthes humilis* and many other species.

(iii) Production and distribution of biomass

Massive differences exist between and within species for biomass production. Commonly, these are related to differences in phenology. In certain cases, such as sugarcane, cassava and pasture plants, biomass is a direct component of the economic product and substantial genetic advances are possible. However in most crops harvested for seed, biomass *per se* is relatively less important than its partitioning into seed and non-seed components (harvest index, HI). Substantial genetic differences in HI have been demonstrated in some crop species and have been exploited heavily in some cases e.g. semi-dwarf wheats. In soybean and pigeon pea, genetic differences in phenological response can be used to manipulate HI. In a different context, the development of high oil sunflower and improvement of sugar content in sugarcane are outstanding examples of genetic improvement in dry matter distribution.

With pasture plants, seasonality of biomass production is also important. Pasture growth varies during the year depending on seasonal climatic conditions. Appropriate management of both pastures and animals enables feed requirements to be met, usually at some cost to the producer, but overall stocking rates are often dictated by the feed available at critical periods. Thus, an increase in herbage yield at certain times of the year may be much more valuable than at other times. Clearly, climatic factors will set a limit to the genetic improvement of fluctuating growth rates, but plant breeders have made some useful contributions; for example, cultivars of perennial Mediterranean grasses such as *Phalaris* with superior winter growth. Seasonality of feed quality may be equally critical; in particular, the production of a small amount of green leaf during the summer in southern Australia, or the winter in northern

Australia, can have disproportionate effects on animal production. Similarly, a small genetic improvement in frost resistance of a tropical grass, as in Narok *Setaria*, can have a dramatic effect.

(iv) Plant morphology

In most crop and some pasture plants, domestication and subsequent improvement has involved significant re-design of plant morphology and habit, both to increase productivity and improve harvestability. Examples include dwarfing genes to improve lodging resistance in wheat and sorghum; lodging and shattering resistance in soybeans; seed retention in *Phalaris*; and creeping rooted lucerne for improved persistence under grazing. Some of these modifications involve quite fundamental changes in plant morphology, one of the more extreme cases being the genetic re-design of canopies of the field pea to remove most of the leaf tissue.

Examination of new plant characters is a valid experimental aim in breeding. Although an experimental modification of morphology may not directly improve productivity for a variety of reasons, it may add significantly to our knowledge of plant behaviour. Breeding for new and often unconventional characteristics involves considerable imagination and far-sightedness by the breeder, and involves recognition by him of the limitations of existing plant morphology and/or the need for different types of traits for special applications. Accomplishment of the modification and demonstration of its results may involve a long term program, and continuity of support is necessary. Australian programs currently exist to develop uniculm cereals, photo-insensitive pigeon peas for mechanized harvesting, improved seed characters in buffel grass, and shrub types of *Leucaena*. In many of these cases, the morphological changes are substantial and there is a need to redefine the agronomic practices relevant to such material. For example, uniculm wheats and short season compact soybean lines will require relatively intensive management by specialist growers, and their adoption requires close collaboration of breeders, agronomists, extension workers and producers.

Breeders may be excessively conservative in designing and implementing morphological changes, both to avoid problems of acceptance and in an attempt to produce plants which compensate for inefficiencies in cultural practices which are commonly avoidable. Breeding of plant habits designed for more specialized production regimes is likely to be accelerated in the future.

(v) Stress resistance or tolerance

Excessively low or high levels of any environmental factor may impose a stress on growing plants, and in Australian environments complex stresses commonly arise from the interactions of many factors. Some of these stresses are controllable, or may be reduced; for example, fertilizer may be applied to minimise nutritional stress, or waterlogged soils may be drained. However in practice, any field crop or pasture will experience some unavoidable stresses, particularly due to extremes of climate.

Plant breeders have attempted to breed for resistance to climatic stresses in many species. Among the many Australian examples which could be noted are the progress being made towards frost resistance in wheat and the release of drought resistant pasture grasses in southern Australia. The outstanding challenges for future improvement include the genetic modification of grain legumes, sorghum, rice and other crops in tropical Australia. Some of this genetic improvement will flow from stress avoidance due to better phenological adaptation (e.g. suitable flowering times and habits), but genetic resistance *per se* to drought and/or high temperatures is likely to be critical to the success of many of these crops. Past experience suggests that achieving such resistance will not be an easy task in most crop plants.

In complex field environments, where it may not be possible or even sensible to isolate the independent effects due to one of a number of interacting stresses, techniques pioneered in Australia enable the breeder to improve the overall level of adaptation to the environment. These techniques (joint linear regression analysis and pattern analysis) make it possible to identify and describe, and thus genetically manipulate, any systematic variation in the response of genotypes to a range of environments.

(vi) Nutritional adaptation

There is evidence that differences between plants in reaction to nutrient availability are genetically determined, and that it is possible to select for response to improved nutrition. In most cases, the greatest genetic improvements in yield are obtained in high input systems. For those crops grown under irrigation or in the higher rainfall areas, gross mineral deficiencies may be corrected and genotypes selected which are able to respond to improved nutrition.

However, most Australian crop and pasture production occurs in dryland agriculture with low and erratic yield largely related to the degree of moisture stress. In this situation, nutritional problems are often complex and labile, and difficult to define and handle genetically. However, there have been some successes; for example, species of *Stylosanthes* have been identified which thrive on low phosphate soils in the tropics. In this case, resolution of the plant genetic problem has created a new problem in animal husbandry and agronomy because of the poor utilization of the legume by the animal - a good example of the need for a multi-disciplinary approach to complex agricultural problems.

In principle, we regard breeding for nutritional adaptation to be a complex area which should not be entered lightly. Where specific problems are identified, genetic resolution should be considered as one alternative, but not in isolation.

(vii) Genotype x environment interactions

A common breeding objective is to develop cultivars with high and stable yield over a range of production environments. Stability of performance is desirable for producers and consumers, but the form of that stability may vary substantially.

Breeders must sacrifice performance in some environments in order to attain an acceptable level of overall adaptation i.e. broad adaptation involves specific sacrifices, and limits are placed on performance in particular environments because of the range of environments which the breeder must consider. Thus the objectives of broad versus narrow adaptation are basically incompatible.

As indicated previously, techniques exist which allow definition and manipulation of genetic differences in adaptation. Where those differences are relatable in part to particular locations, they can be exploited by the development of regional programs if adequate resources exist. However, year-to-year variation at a single location is more complex and necessitates a broader approach to adaptation.

Despite the environmental diversity in Australia and the consequent genotype x environment interactions, breeding at centralized breeding centres can be effective provided it is supported by active regional testing. The success of wheat breeding throughout Australia and soybean breeding in sub-tropical Australia for the lower latitudes shows what can be done.

(b) Biotic factors

Breeding for pest and disease resistance has been one of the most successful activities of Australian plant breeders. The emphasis on protective breeding is not surprising: the problems are economically significant, the objectives are easily defined, and selection can be conducted in discrete programs. Genetically resistant varieties have many advantages over other forms of control. However, genetic resistance may break down and this leads to a continuing requirement to identify and incorporate new sources of resistance, which diverts resources from other breeding problems.

The comprehensive program for stem rust resistance in wheat has effectively prevented any major loss of yield within the northern wheat belt for over 25 years. A national program of rust control has been established involving all wheat breeders in Australia. Numerous smaller but effective programs have been mounted in other species. Nevertheless, many continuing disease problems require attention e.g. Alternaria in safflower, anthracnose in Stylosanthes, Rhizoctonia and rust in Macroptilium, rust in peanuts, black leg in rapeseed, Verticillium wilt in cotton, etc. Demand for disease resistant cultivars is certain to increase in the future.

Few advances have been made in breeding for insect resistance, despite instances of major problems. However, some programs show promise e.g. resistance to Sitona weevil in medics, aphids in lucerne, root knot nematodes in Macroptilium and cereal cyst nematode in wheat. Host plant resistance is part of integrated pest management research in cotton and soybeans.

Beneficial biotic factors have received only limited breeding attention. The effectiveness of the legume host - Rhizobium symbiosis has been improved in many species, and this has extended the usefulness and area of production of certain species e.g. Lotononis and soybean. Despite this, breeding for improved symbiosis is little emphasized, and most progress has resulted from selection between Rhizobium strains. A program of breeding for promiscuity of nodulation in Stylosanthes guianensis is in progress. Similarly, beneficial association with mycorrhizae exists in certain species, but has received limited genetic attention to date.

(c) Breeding for product quality

To the breeder of field crops, product quality refers to any genetic characteristic which influences the market price and acceptance of the product. Breeding for quality is receiving greater attention due to a growing discrimination by processors and consumers, and is stimulated by the increased technical capability available to breeders. Significant advances have occurred in milling and baking quality of wheat, malting quality of barley, fibre quality in cotton, sugar content in sugarcane, and oil and protein composition of oilseeds and protein grains.

There is a continuing demand for such genetic advances, but emphasis on quality has a hidden cost because it retards genetic improvement in other characters. There is a finite limit to selection pressure. In addition, market forces for quality can impose restrictions on the use of genetic resources in breeding. For example, Australian wheats must be white grained, and this prevents exploitation of the superior weathering resistance of red wheats. The genetic base of Australian barley cultivars is very narrow, mainly because of the requirements for malting quality. Similar constraints exist in most crops.

Processors and consumers tend to resist varietal change, often use subjective parameters for quality tests, frequently give conflicting assessments, and are reluctant to establish premiums for quality. Conversely, it is not unknown for breeders to ignore real quality defects in their material or to be unresponsive to new quality requirements. Close liaison of the industry and breeders is necessary in order to use breeding resources most efficiently; that is, to ensure that quality criteria reflect the real needs of the market and are in balance with other objectives.

In pasture plants, quality is determined by factors such as the content of mineral nutrients, freedom from toxic or anti-nutritive compounds, digestibility, intake and the efficiency with which digested nutrients are used by the animal. It is possible to breed for each of these components, but in practice it is difficult to achieve an overall improvement in quality which is reflected in animal production. New developments are required in this area, especially in reliable laboratory techniques for predicting intake. However, significant advances have been made in Australia for aspects of nutritional quality for which laboratory testing is possible e.g. low isoflavone subterranean clover, low alkaloid *Phalaris*, non-bitter lupins etc. Further work is warranted in some species e.g. for low mimosine in *Leucaena* and low indospicine in *Indigofora*. Bloat is a major problem with many of the temperate legumes and deserves close attention. However, it is not simply a genetic problem and Australian breeders may benefit substantially from the outcome of existing international research.

IMPROVED BREEDING PROCEDURES

(a) Expansion of genetic variability

There is increasing recognition of the importance of access to genetic diversity in the cultivated and wild forms of agricultural species, and of the need to conserve vanishing germplasm (see our earlier comments). Large international collections exist for many of our major crop plants, but much more collection is required in some crop and most pasture species. In particular, further collection within the important tropical pasture genera is needed.

Unfortunately, plant breeders probably make insufficient use of plant collections. In part, this results from lack of coordination and from inadequate communication regarding the content of collections but there is also a need for improved procedures for obtaining, recording and using data from such large collections. Current moves towards national collections of particular species should result in improved storage and documentation, which will encourage their use as working collections. Innovative approaches to quarantine are required in order to facilitate rapid access to exotic germplasm.

With the exception of subterranean clover and lupin, artificial mutagenesis has been little used in Australia despite extensive use overseas and the ready availability of facilities and expertise in Australia. This may indicate that appropriate genetic variability has generally been available, and a recognition that mutation breeding programs are equally expensive to conduct.

Recent progress in tissue and haploid culture in some agricultural plants, and in somatic hybridization in other organisms, suggests that genetic engineering may have future application in plant breeding. However, in view of the complexity of environmental adaptation and merit in agricultural plants, we consider that these approaches have limited contemporary relevance. Most plant breeders eagerly await practical developments in this area.

Most breeders recognize the limited extent of recombination in breeding populations, and various procedures are used to increase this (e.g. wide crossing within species, recurrent selection, genetic male sterility, rapid cycling of breeding populations, interspecific hybridization and multiple or composite crossing. Pasture plant breeders have found interspecific hybridization to be promising in a wide range of genera e.g. *Phalaris*, *Medicago*, *Leucaena*, *Desmodium*, *Cenchrus*, *Setaria*, *Digitaria* and (potentially) *Stylosanthes*. There is great interest in attempts by New Zealand breeders to cross *Trifolium repens* with *T. semipilosum*, and in the successful production of ryegrass hybrids in New Zealand and the United Kingdom.

(b) Utilization of diversity

Choosing parents is a key decision in any breeding program and remains a major obstacle, particularly in self-pollinated species and for quantitative characters. Various methods of predicting the usefulness of parents are used, including parental performance, phenotypic stability, estimation of combining ability, multivariate analyses and various biochemical assays, but none has shown general utility. Better guides are necessary. In sugarcane, the 'proven-cross' method involves continued exploitation of particular crosses in proportion to their comparative usefulness in breeding, and has proved effective.

Numerous breeding systems can be applied, each involving different strategies of selection and recombination and quite different logistical and genetical implications. Relatively few comparative studies exist to guide the choice of breeding system. However, each breeding system has been effective in particular situations, and it is possible that quite contrasting approaches can sometimes be effective in the one species; for example, both wide bi-parental crossing followed by regional field testing and limited-generation backcrossing with glasshouse evaluation have proved effective in wheat improvement. Improved guidance on the relevance of different breeding systems is necessary, and maintenance of diversity of breeding strategies is probably desirable in view of the complexity and range of breeding problems.

(c) Utilization of heterosis

Hybrid vigour has been exploited effectively in maize, sorghum, and sunflower. F_1 or other heterozygous hybrid cultivars are not used in many other field crops for various reasons, including absence of a suitable system of pollination control (soybean, cotton), inadequate hybrid vigour (tobacco) and cost or unreliability of seed production (wheat). Relatively few hybrid cultivars of pasture species have been released except for forage sorghum. The 'Sabrina' cultivar of ryegrass in the U.K. is an allopolyploid of *Lolium perenne* x *L. multiflorum*, and certain interspecific F_1 hybrids of *Phalaris* show promise.

The prospect for greater use of hybrid cultivars in field crop and pasture production in Australia is problematical. The applicability of hybrid cultivars in pasture species, either annual or perennial, is uncertain and requires close consideration. Extension to further crop species depends on effective systems of pollination control and sufficient heterosis to justify the investment. However, hybrids do provide protection of the product, and in the absence of plant variety protection legislation this has encouraged investment from private sources in practical plant improvement.

(d) Rapid generation turnover

The length of most breeding programs (up to 10 or more generations) adversely influences their cost and effectiveness. Techniques which accelerate generation turnover allow more rapid determination of the value of crosses and lines and make programs more responsive to contemporary demand. Examples for self-pollinated species include the conduct of limited generation backcrossing in glasshouses, use of off-season nurseries to turn over generations with or without selection, and the single seed descent system or its modifications to produce random near-homozygous lines for evaluation. In population improvement of out-breeding species, family selection can effectively reduce the length of a breeding cycle in comparison with progeny testing.

Reducing the duration of a breeding cycle commonly involves a compromise. For example, single seed descent allows earlier evaluation of fixed lines and avoids bias in selection in the early segregating generations, but it is labour intensive, invests resources in deriving and testing inferior random lines, and does not allow early generation selection where this is feasible.

In some species (maize, tobacco, barley), homozygotes may be derived rapidly by diploidization of haploid individuals. This technique appears to have merit, but techniques of haploid culture have yet to be developed in most field crop and pasture species.

(e) Testing procedures

Multi-environmental evaluation of breeding material commonly involves inter-organizational collaboration regionally or nationally. Such tests are essential but expensive. Analyses and interpretation of such data vary but generally are restricted and provide inadequate information to guide discrimination among the entries. Improved techniques of analysis exist which extract more relevant information from these important trials. In pasture species, the need for repeated measurements inevitably increases the duration and expense of such trials.

While breeders recognize the importance of genotype x environment interaction in assessing the relative performance of cultivars and breeding lines, its significance in the conduct of early generation testing is less well appreciated. Close evaluation of the effects of specific test environments is required. Better understanding of environmental adaptation may allow development of more effective and reduced or phased testing programs.

(f) Varietal release and pure seed production

Procedures for release of cultivars vary considerably within Australia, depending on the State, the breeding institution and the species, ranging from statutory control with or without a requirement for genetic purity to uncontrolled free release. Regardless of the scheme, all seed must meet statutory requirements for purity, germinability etc, and these vary in different States. There is no independent testing authority but the relevant State Departments conduct annual regional trials and issue recommendations based on those tests.

The failure of political and agricultural borders to coincide can cause transitory difficulties in release and recommendation of cultivars. The general absence of statutory requirements for seed certification in most species, and the relatively informal procedures for release, are probably constructive and supported by most agricultural scientists. Nevertheless, this can lead to excessive proliferation of cultivars, and there is a clear need to improve the standard of genetic purity of cultivars in certain species.

ASSOCIATED RESEARCH DISCIPLINES

Advances in any technology depend upon continued progress in the underlying sciences from which it is derived. Plant breeding practice is a technology and by definition problem-solving and mutli-disciplinary; since the barriers to genetic improvement are generally complex, breeding technology requires the integration of knowledge in genetics, biometry, physiology, chemistry, pathology, entomology and other sciences. Thus, while plant breeders must maintain a strong disciplinary base and contribute to the advancement of knowledge in their own research, they generally depend heavily on associated research.

The form of research collaboration required depends on the problem and its perception, and may alter substantially over time; for example, genetic advance is generally relatively easy to attain in non-adapted species and in previously unselected traits, largely because genetic variability is available. In new crops, the difficulty is in definition of clear breeding objectives, to adapt the genetic material to different ecological and agronomic circumstances. Similarly in tropical pasture plants, questions may arise before formal breeding commences regarding the relative potential of different genera and species, and the relevance of and requirements for breeding for particular objectives. The many possible objectives for non-adapted species are often overlapping or contradictory, and there is a clear need for associated research to assist in problem definition. The primary questions are not simply genetic in form, although certain basic genetic information on ploidy, reproductive biology etc. is necessary and the need for quantitative genetic knowledge rapidly arises. In contrast, improvement objectives for an established species within its area of adaptation are generally more specific and easier to define e.g. rust resistance and quality in wheat. However, greater in-depth research will then normally be required in order to make progress

Possibly the best plant improvement research flows from close association of multi-disciplinary theoretical and applied workers, preferably in species or regionally orientated groups. This occurs in a number of the international plant improvement centres, but has rarely been implemented in Australia. Without a close association, much theoretical research into associated disciplines which should be related to plant improvement is divorced from the breeder or largely irrelevant to existing breeding problems. The problem of coordination of scientific resources for plant improvement is complex, and is discussed in the next section.

IMPROVED RESOURCE ALLOCATION

While Australia expends considerable resources on rural research and development (2.4% of the gross rural product; Anon. 1976), crop research is supported relatively poorly compared with the livestock and horticultural industries. Approximately one-quarter of the total professional research activity on crops is devoted to breeding and varietal evaluation (Table 2), and distributed over a large number of crops quite disproportionately relative to their gross value (Table 3). Crops differ greatly in the proportion of research devoted to genetic improvement (Table 3), reflecting the diversity of crop species grown, the importance of particular crops and problems, the stage of crop development, and the economics of scale possible in research into the major crops.

The basic rationale for, and tangible product of, plant breeding is the development of improved cultivars. On a cost/benefit basis, plant improvement is more effective than most other fields of agricultural research, and Australia may be under-investing in this area. Despite this, achievement of varietal improvement receives little public or private recognition, and carries little influence in appointment or promotion in most institutions.

Four aspects of plant improvement programs deserve comment, viz. funding, cost, optimal size and organization. Most plant breeding in Australia is publicly funded, but private investment should increase when plant variety protection legislation is enacted. Despite a basic inconsistency due to seasonal and market influences, the industrial research funds have made important contributions to plant improvement research, and the levy system should be expanded. However, plant improvement programs are particularly susceptible to inconsistency of support, and improved funding procedures designed to provide continuity are required, regardless of the source of the support.

Breeding programs commonly are considered to be large and expensive relative to other disciplines. Dissection of costs among disciplines within multi-disciplinary teams is difficult and not very constructive. Most breeding programs emphasize labour and field facilities relative to laboratory and equipment costs, and we doubt the validity of the general perception of breeding as a relatively high cost exercise.

TABLE 2. Professional man-year equivalents in crop research (modified from Plant Production Committee of the Standing Committee on Agriculture, report PPC 6:9).

Crop	Breeding & Varietal Evaluation				Agronomy	Crop Protection	Physiology and Biochemistry
	State*	T.I.**	CSIRO	TOTAL	TOTAL	TOTAL	TOTAL
Cereals							
Wheat	35.4	5.4	2.4	43.2	42.9	50.4	36.9
Oats	3.1	-	0.1	3.2	0.6	1.1	0.3
Barley	9.0	2.0	0.5	11.5	1.4	4.2	5.7
Rye	0.1	0.4	0.4	0.9	0.2	-	0.7
Triticales	1.0	1.5	-	2.5	0.2	-	0.4
Maize	4.0	1.3	-	5.3	3.6	2.1	1.7
Sorghum	3.5	0.3	1.0	4.8	7.4	4.1	5.2
Rice	1.7	-	0.2	1.9	3.3	1.9	2.3
Millets	-	-	-	-	0.2	-	0.2
TOTAL	57.8	10.9	4.6	73.3	59.8	63.8	53.4
Oilseeds							
Sunflower	2.4	0.5	1.6	4.5	12.3	1.8	5.5
Safflower	0.2	-	1.5	1.7	0.4	0.4	0.1
Rapeseed	5.0	0.6	-	5.6	2.8	1.3	2.1
Linseed	1.2	-	-	1.2	0.7	0.4	0.1
Other	0.4	-	-	0.4	0.4	-	0.5
TOTAL	9.2	1.1	3.1	13.4	16.6	3.9	8.3
Protein Grains							
Soybean	3.8	1.3	0.9	6.0	7.3	10.7	6.0
Lupins	5.2	0.2	1.0	6.4	11.0	2.8	14.7
Peas/beans	4.7	2.4	0.9	8.0	4.5	2.4	7.6
Guar	-	-	-	-	-	0.3	-
TOTAL	13.7	3.9	2.8	20.4	22.8	16.2	28.3
Fibre Crops							
Cotton	2.5	0.2	2.0	4.7	7.3	15.9	1.5
Kenaf	0.2	-	0.7	0.9	1.0	0.2	0.2
Pennisetum	-	-	-	-	1.0	-	-
TOTAL	2.7	0.2	2.7	5.6	9.3	16.1	1.7
Other Crops							
Sugar Cane	12.6	-	-	12.6	10.0	8.6	4.6
Potatoes	5.3	-	-	5.3	8.6	5.5	3.6
Tobacco	5.3	-	-	5.3	7.7	4.8	2.0
Peanuts	0.4	-	-	0.4	2.6	1.8	1.4
Jojoba	-	-	-	-	-	-	0.1
Cassava	-	-	-	-	5.6	-	2.0
Others	0.8	-	0.1	0.9	0.7	-	0.1
TOTAL	24.4	-	0.1	24.5	35.2	20.7	13.8
TOTAL	107.8	16.1	13.3	137.2	143.7	120.7	105.5

* Includes Department of the Northern Territory, Bureau of Sugar Experiment Stations and CSR Ltd.

** Tertiary Institutions.

TABLE 3. Crop research and productivity in Australia.

Crop	% total gross[1] value of crop production (mean 1976/77 to 1978/79)	Professional man-year[2] equivalents in research		Genetic research input per[3] unit of production
		Genetic improvement	Total	
Wheat	46.2	43.2 (25)[4]	173.4	0.9
Sugarcane	14.6	12.6 (35)	35.8	0.9
Barley	9.7	11.5 (50)	22.8	1.2
Potato	3.4	5.3 (23)	23.0	1.6
Oats	2.9	3.2 (62)	5.2	1.1
Sorghum	2.4	4.8 (22)	21.5	2.0
Rice	2.3	1.9 (20)	9.4	0.8
Cotton	2.0	4.7 (16)	29.4	2.4
Tobacco	1.8	5.3 (27)	19.8	2.9
Sunflower	1.1	4.5 (19)	24.1	4.1
Peanut	0.7	0.4 (6)	6.2	0.6
Soybean	0.6	6.0 (20)	30.0	10.0
Maize	0.4	5.3 (42)	12.7	13.2
Lupin	0.2	6.4 (18)	34.9	32.0
Safflower	0.2	1.7 (65)	2.6	8.5
Linseed	0.1	1.2 (50)	2.4	12.0
Rapeseed	0.1	5.6 (47)	11.8	56.0

[1] Bureau of Agricultural Economics

[2] Plant Production Committee of Standing Committee on Agriculture; PPC 6:9 (Table 2)

[3] Professional man-year equivalents per percentage unit of total gross value of crop production

[4] Percentage of total research input devoted to breeding and varietal evaluation

In view of the diversity of agricultural problems being researched genetically, it is impossible to nominate an optimum or threshold size of plant breeding program or an optimal structure and organization. Nevertheless, plant improvement in Australia tends to be fragmented, and some reorganization of research into centralized species or commodity orientated research teams is justified. The structure should combine individual initiative with integrated problem-orientation, and a model based on the international plant improvement centres may allow more effective deployment of staff, utilization of germplasm, national evaluation programs, and an adequate scale of program including associated disciplines. We do not conceive creation of monolithic organizations - rather some centralized facilities with limited permanent staff, with scientists on secondment from relevant organizations working either at that facility or elsewhere on defined problems, possibly under a form of contract research. Collaboration with satellite test centres is vital. We advocate continued review of programs, to provide more objective definition of the prospects for, and benefits from, alternative projects.

The degree of centralization necessary to mobilize and coordinate resources may vary. For the large cereal programs, regional centres may be adequate. However, where the total research resource available or justified is small, as in oilseeds, protein grains and pasture species, centralized combined facilities have attractions. We believe that the most effective plant improvement is done by motivated scientists working in well serviced, integrated, multi-disciplinary teams which specifically include extension officers. There is a trend in Australia towards such structures, and we urge that it be accelerated.

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