An Economic Analysis of Potential Changes to a Rice Breeding Program

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ABSTRACT

Rice breeders and their administrators face difficult decisions regarding the most appropriate methods and approaches to use in their breeding programs. In this paper, economic principles are used to evaluate and compare the gains from different plant breeding programs or differently structured programs. By identifying the costs of potential changes and estimating the expected returns from proposed programs, investment criteria are used to evaluate the efficiency of shifts in resources within the breeding program. The information generated enables the rice breeders at Yanco to adjust the existing breeding program to provide the Australian rice industry with relatively higher returns.

Keywords : Research, evaluation, breeding, rice.

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1. Introduction

Plant breeding is one of the major components of agricultural research. Studies such as Blakeslee and Sargent (1982), Zentner and Peterson (1984), Nagy (1984), Gardiner, Sanders and Baker (1986), Brennan (1989) and GRDC (1992) have identified high average returns on investment in breeding and varietal improvement. However, such research is time consuming and requires huge amounts of investment, in terms of both the resources used and the value of research that could have been carried out if that particular research were not funded (opportunity cost).

If research were costless, each environmental niche would have a unique technology (Boyce and Everson, 1975) and each marketing niche would be fully researched and developed. Those allocating research funds in rice breeding are faced with scarce resources, and have to determine how to allocate the limited research resources across different types of rice to meet the changing market requirements with a view to maximising returns to the industry as a whole. Within the limited funds, the rice breeders are being asked not only to produce varieties with improved productivity, but also to ensure that such increased production is sustainable.

Because the resources available to the Australian rice breeding program are less than the resources needed to address all breeding issues, choices have to make between competing uses of resources. Some empirical research investigations like Brennan (1992) have identified the threshold industry size for different wheat breeding programs, but no information is available for rice. In the absence of any economic information to help making these decisions. the breeders and decision makers have to depend on judgements of the appropriate outcomes rather than objective analyses.

In the present study, an attempt has been made to estimate the impacts of some potential changes to the Australian rice breeding program at Yanco, NSW, with a view to providing an economic basis for rice breeders and decision makers to determine the research priorities in a better way.

The specific objectives of this research paper are to:

i) estimate the costs and benefits of the existing rice breeding program; and
ii) estimate the impacts of some potential changes to the Australian rice breeding program.

2. Analytical Model Used

2.1 Basis of model

Investment of resources in rice breeding can be considered as one of a number of alternative publicly-funded projects in which investments could be made. Brennan (1989) has developed

a spreadsheet model to estimate the cost and benefits from wheat breeding program in Australia. In the present study, the same model has been further developed to produce a dynamic deterministic (certainty) model to study the impacts of potential changes in existing rice breeding program at Yanco on various financial and physical parameters.

The profit function of the rice breeding program for society over n years can be expressed as:

$$\sum_{t=i}^{n} P_t = \sum_{t=i}^{n} R_t - \sum_{t=i}^{n} C_t \qquad (1)$$

where P_t, R_t, and C_t refer to the respective profit, returns and costs in year t, expressed in real term, and where costs include annualised capital and overhead costs.

2.2 Costs of breeding

There are a number of categories of costs that need to be included in an evaluation of the breeding programs. The costs detailed in this study can be classified into:

i) costs of the breeder's activities; and

ii) costs of quality testing.

The cost of disease evaluation is not important in this study, because the Australian rice industry is currently disease free. That disease-free status is maintained by strict quarantine regulations.

Following Brennan (1989), the costs of society's profit function include more than these direct costs of the rice breeding program itself. Additional costs that are part of the costs to society of the breeding program include the costs of comparative evaluation with the existing cultivars, the costs of information regarding agronomic requirements, the cost of extension over and above that required for the existing cultivars, the costs for growers of seed or additional inputs over and above the existing cultivars, and the cost of release or registration procedure. Those costs are not incorporated in the analysis reported in this study.

2.3 Returns from a breeding program

Because of the long period between the initial cross and release of a new cultivar, there will be no returns from the first several years of a new breeding program or to a new breeding approach.

While there is always uncertainty of outcomes in plant breeding research, the expected rate of genetic gain from selection can be estimated from information about the variability of the original population, the heritability of the selection character, and the intensity of selection (Simmonds 1979). A given selection program determines the rate of expected genetic improvement in each selection character, as:

$$G_i = k_i D_i (h^2)_i \qquad (2)$$

where G_i is the genetic advance under selection for character i, k_i is the selection differential

for character i, D_i the standard deviation for character i, and $(h^2)_i$ the heritability for character i (Simmonds, 1979). From this equation and comparison with current cultivars that have already been subjected to selection, the expected rate of genetic progress through selection can be estimated. The economic returns from the genetic gains in a breeding program depend on the gains from the cultivars, the adoption of that cultivar, and the economic value of each of the traits (Brennan 1989).

In economic terms, the yield increasing effects of a new rice variety result in a downward shift in the supply curve (Linder and Jarrett, 1978, Norton and Davis 1981, Edward and Freebairn 1984 and Brennan *et al.* 1994), while the quality-improving effects can be represented as an upwards shift in the demand curve (Unnevehr 1986). For this model, the approach developed by Brennan *et al.* (1994) has been used. The following assumptions are implied in the analysis:

i) Increase in rice production from any new variety are assumed to be sufficiently small that there will be no decline in the price in the marginal market. If prices would decline, then the benefits are likely to be overstated.
ii) A new variety is assumed to lead to higher output with no increase in inputs.
iii) Possible increases in production that can take place because rice becomes more competitive with alternative enterprises are ignored, so the benefits are likely to be understated.

A detailed description of the model used for estimating the returns from each breeding cycle is given in Brennan (1989). The spreadsheet model developed can estimate the time required to release a new variety from the start of crossing program, additional time required to develop every new cultivar, requirement for the various physical parameters like area, and number of lines required to be handled over the years before the release of a new cultivar. Benefit-cost ratios have been worked from the estimates of discounted costs and benefits to economically evaluate and compare the results.

3. Australian Rice Breeding Program

3.1 Current breeding program

The past growth and future development in Australian rice industry are closely linked to the rice breeding program, being undertaken by the scientists of NSW Agriculture at Yanco Agricultural Institute, Yanco, NSW. The program has a long history of providing new cultivars at regular intervals. NSW Agriculture has for many years developed and supplied the total technology package for rice production in this temperate region, and has conducted local agronomic research and extension in rice growing since the early 1930s. However, it is only since the late 1950s to early 1960s that adequate professional staff have been available to enable a local breeding team to develop.

The current rice breeding program has two rice breeders and a cereal chemist, along with other technical and support staff and is led by Dr Laurie Lewin. The operations of this program are illustrated in Figure 1. The rice breeding operations are carried out at three

locations, namely Yanco, Deniliquin and Jerilderie, to represent the whole rice growing area in NSW. At present, virtually all of the rice in Australia is grown in southern NSW.

The overall program is currently made up of 9 sub-programs, each aiming to produce varieties with different quality characteristics. The sub-programs are shown in Table 1.

Table 1 : Resource use pattern and progress of rice breeding program at Yanco

Rice Type	Sub-program began	Varieties released	First variety released	Average no. of years/variety		Existing resource use
				From start	New variety	
Standard Medium Grain	1958	6	1958	1	6	30%
Standard Long Grain	1958	6	1967	9	6	30%
Specialty Types:						
Fragrant Jasmine	1975	2	1991	16	10	15%
Medium Grain Japanese	1980	1	1995	15	15	10%
Long Grain Firm Cooking	1970	1	1989	19	25	5%
Arborio	1980	3	1981	1	5	4%
Fragrant Basmati	1988	0				3%
Medium large	1987	0				2%
Waxy	1970	0				1%
- Sub-total Specialty		7				40%
Total		19				100%

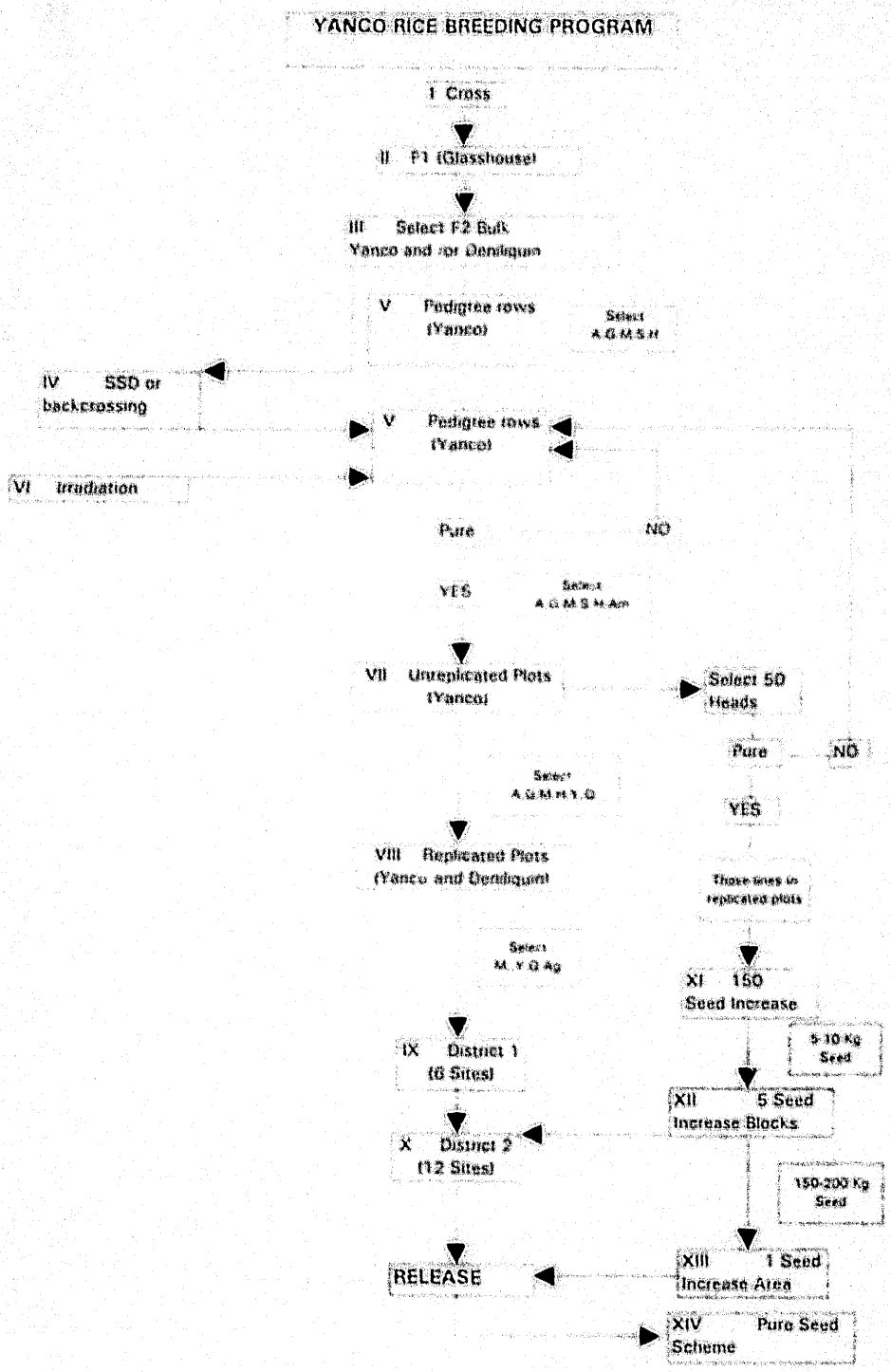
3.2 Progress and existing resource use

The progress and existing resource use pattern of various sub programs of the Australian rice breeding program at Yanco are presented in Table 1. The allocation of resources within the rice breeding program along with comparative performance of Australian rice industry for different types of rices is also presented in Table 1.

Sixty percent of the resources are used for the mainstream breeding programs including standard medium and long grain types. For these types the breeders apply strong selection pressure, which means comparatively fewer lines are allowed to move from one generation to the next depending up on selection for yield, maturity and various quality parameters. This has direct impacts on gains from breeding program and sustainability of new varieties.

The remaining 40% resources are shared among the specialty types. Fragrant jasmine gets 15% followed by 10%, 5% and 4% of total resources available for breeding by Japanese, firm cooking and arborio types respectively. A moderate selection pressure is applied for the

Fig 1: Details of the Operations of Australian Rice Breeding Program, 1994-95



A : Agronomic M : Maturity G : Grain type S : Grain appearance (brown/white) Am : Amylose content H:Height Y : Yield Q: Milling Quality Ag : Amylograph

breeding of these types. Third group includes basmati (3%), medium large grains (2%) and waxy (1%). During the breeding process, a relatively high proportion of lines is allowed to go from one generation to the next for these types, i.e. weak selection pressure is applied. The aim is to build a sufficiently large base of late generation lines in these rice types so as to be able to release a variety quickly if there is an urgent request from the industry.

Calrose, a medium grain variety from U.S.A. was tested and introduced during 1958 in NSW and it remained the major medium grain variety up to the release of Amroo during the year 1987. From the early 1960s, efforts have been made to develop long grain rice varieties for which there is a price premium. The long grain varieties developed were generally lower-yielding than Calrose (Kennedy, 1977), although current long and medium grain varieties out-yield Calrose. More recently there has been a concerted effort to develop specialty rices, such as fragrant, Spanish (arborio) and Japanese to meet higher-priced niche markets and newly developing markets.

To date, six varieties each of standard medium and long grain types have been released. Different specialty rice sub-programs including fragrant jasmine, Japanese, firm cooking and arborio were started over the years beginning from 1970 onwards. Because of less resource use on these types in the past, it took 15-19 years to release the first variety in some of these rice types. A total of seven new specialty varieties including Bahia, an arborio type which was introduced from Spain during 1981, have been released by the rice breeding program for cultivation in NSW. However, no variety has yet been released for basmati, medium large grains and waxy types.

The details of the performance of Australian rice industry by types of rices during 1994-95 is presented in Table 2. A total of 127,500 hectares of rice was grown which produced 1.13

Table 2: Performance of Australian rice industry during 1994-95

Rice Type	Area ('000 ha)	Yield (t/ha)	Production ('000 t)	Gross value ($million)	% of total Area	Yield	Production	Gross value
Medium Grain Standard	86.7	9.20	797.5	133.2	68%	104%	71%	67%
Long Grain Standard	28.5	8.30	236.9	46.3	22%	94%	21%	23%
Specialty:								
- Fragrant Jasmine	5.7	6.18	34.9	9.2	4%	70%	3%	5%
- Medium Grain Japanese	1.8	8.58	15.8	2.8	1%	97%	1%	1%
- Long Grain Firm Cooking	4.0	9.53	37.9	7.0	3%	107%	3%	3%
- Arborio	0.8	10.45	8.3	1.4	1%	118%	1%	1%
- Fragrant Basmati	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
- Medium large	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
- Waxy	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
- Sub-total	12.3	7.90	96.8	20.4	10%	89%	9%	10%
Total	127.5	8.87	1131.19	199.9	100%		100%	100%

million tonnes of different types of rices with an average yield of 8.87 t/ha. The gross value of production was estimated out by using the average price premium for each rice type over medium grain standard varieties, which was taken as $167/t. The dollar value of the total rice produced in NSW was estimated at $200 million during the year 1994-95. A comparison of existing resource use and gross value of production for different types of rice (Table 1) indicates that there is a need for some economic basis for better allocation of resources by the breeders anticipating the future changes in different market requirements.

4. Cost and Benefits of Rice Breeding Program

4.1 Costs of rice breeding program

The nominal costs of each operation in the representative breeding program, including labour, operating capital and overhead costs, were estimated. The cost of each generation were calculated once the operations being carried out and the number involved in the program were determined. The cost structure of the whole of a complete cycle of the rice breeding program is presented in Table 3. The total cost of operating the overall breeding program for one year is estimated as $471,000 excluding the overhead costs as incurred by the NSW Agriculture for providing support services and maintenance of the station, etc. The cost of breeding program is relatively very small in the early phases and increases as the program advances. It is only 1.5% of the total cost in year 1 and increases to 19.4% during year 7. Of the total cost, 52% is spent by the breeders and 48% by the cereal chemist for conducting quality testing operations during various generations.

Table 3 : Cost Structure of Rice Breeding Program[a] ($'000)

	Year	Breeder	Quality testing	Total ($'000)	(%)
	1	7.2	0.0	7.2	1.5
	2	22.9	0.0	22.9	4.9
	3	21.6	0.0	21.6	4.6
	4	11.0	46.1	57.0	12.1
	5	25.9	44.8	70.7	15.0
	6	39.8	37.4	77.2	16.4
	7	43.9	47.5	91.4	19.4
	8	34.4	28.3	62.7	13.3
	9	38.2	22.2	60.4	12.8
Total		244.8	226.3	471.1	100.0
Per cent		52%	48%	100%	

a: Excluding administrative overhead costs

4.2 Benefits from existing rice breeding program

The benefits from the Australian rice program have been estimated by using the past performance of varieties developed and released for cultivation. The estimated benefits (undiscounted) from the program for different types of rice over their life span are presented in Table 4. On average, a medium and long grain standard type variety developed by the breeding program has a life of 15 years. An average medium grain variety has contributed 56,000 tonnes of additional production over the previous cultivars and the gross value of this production at $167/t is estimated at $ 9.4 millions over the life span of a variety. Similarly, the gross value of benefits over the whole life of an average long grain and specialty type rice variety are estimated at $20.7 million and $0.25 million respectively. These calculated benefits are based on the past performance of the varieties and depend on the base level yield used for calculating additional benefits. The base level yield in case of long grain rice varieties was relatively low and that is one reason that gross returns from an average long grain variety have been estimated so high.

Table 4 : Benefits of Rice Breeding Program
('000 $/variety)

Type	Average life (years)	Additional Production (000 t)	Price ($/t)	Value (Undiscounted) ($'000)
Medium grain	15	56.1	167	9,368
Long grain	15	106.1	195	20,688
Speciality	5	0.9	282	248

In the case of specialty varieties, the benefits estimated are based on the average performance of the whole range of specialty types. Most of the program in these types of rice was in its initial stages and the variety developed so far have just been enough to meet the *ad hoc* market requirements. Because of this and market limitations the total area covered by the specialty types, and hence the total benefits, have been very small.

However, it is anticipated that in future the benefits from the main-stream long grain varieties would be more like medium grain varieties except for the price premium. For the specialty varieties, it would be different for each specialty type depending upon resource use pattern for the breeding of that type and the market requirement. But it is certain that as these sub-programs stabilise, the returns would increase from an average variety.

4.3 Benefit-cost analysis

For the purpose of benefit-cost analysis of different types of rice varieties, the total cost of the breeding program for one year was apportioned on the basis of time spent for the breeding of relevant type. The apportioned costs were then added for the number of phases as required for the release of a new variety in that type. For instance, it has taken 6 years to release each additional variety in medium and long grain rice types (Table 1). Hence, these costs have been added over 6 phases asssuming that second phase starts with crossing in year 2, and so on. The details of benefit-cost analysis are presented in Figure 2.

The estimated costs and benefits have been discounted at 8%. To develop an average variety in medium and long grain mainstream rice breeding program it costs $503,000 over several years. For an average specialty rice variety, the total discounted costs were $43,000. On the basis of past parameter values, the benefit-cost ratio for long grain rice was estimated at 16.2, with 7.6 for medium grain and 3.3 for specialty varieties.

It is expected that in future flow of the benefits from the long grain varieties would follow the same trend as that of medium grain varieties except for the difference of price premiums. Therefore, the gaps between the benefit-cost ratios would narrow. The resource use for specialty type rices has relatively increased over the past, which would help to develop better and more stable varieties in future yielding higher returns and affecting the benefit-cost ratio positively.

5. Impacts of Potential Changes to Rice Breeding Program:

The Australian rice breeding program is continually being adjusted to develop new varieties for specific markets. At present, the world rice market is undergoing continuous and sharp changes because of opening up of new markets like Japan and Korea. The Australian rice industry has a location advantage and is targeting these new markets for increasing future returns. As a result, rice breeders are especially keen to ensure that they can assess which of the alternative options for their program will provide the greatest pay-off for the rice industry.

One application of the model has been to estimate the sensitivity of various financial and physical parameters to shifts in resource use in standard medium-grain varieties (Table 5). This application provides an illustration of the many alternative breeding options that can be analysed with the model.

Fig. 2 : COSTS AND BENEFITS OF RICE BREEDING:
Costs (current), Benefits (based on past experience)

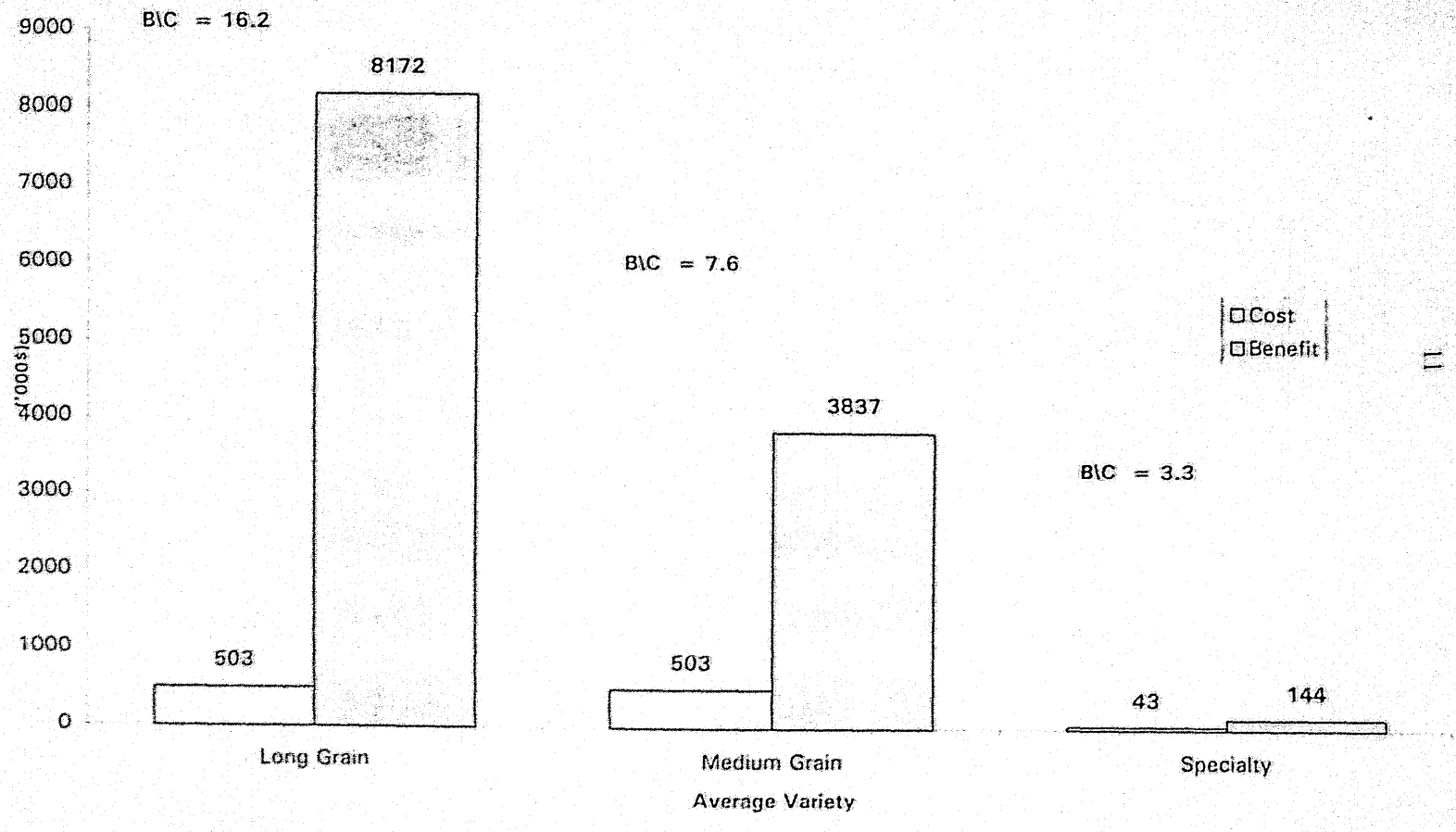


Table 5: Impacts of Shifts in Resource Use for Standard Medium Grain Rice Varieties

	% of the total resources				
	30%	25%	20%	15%	10%
Financial Parameters					
Total Discounted Costs ($'000/variety)	349	294	296	271	236
Total Discounted Benefits ($'000/variety)	2,857	2,857	2,645	2,449	2,100
Net Present Value ($'000/variety)	2,508	2,563	2,350	2,178	1,864
Benefit-cost ratio	8	10	9	9	9
Physical Parameters					
Expected yield of new cultivar (t/ha)	10.81	10.81	10.81	10.81	10.81
Gap in release of new variety (years)	3	3	4	5	7
First variety released from start of program (yrs)	11	11	12	13	15
Area required (ha)	18.25	15.49	15.88	15.25	14.04
Number of lines handled for release of variety	28813	24012	25610	24011	22412

The current resource use for standard medium-grain rice is 30% of the total breeding resources. In the table, the trade-off between resource use and different financial and physical parameters is illustrated. The detailed analysis provides considerably more information than that summarised in the above table. The information provided can help the breeders to determine the annual area requirement and annual work load of handling different generations under different levels of resource use. The detailed information would help them to make better resource allocation decisions.

With the existing 30% resource use for the breeding of standard medium-grain varieties, the model estimates $349,000 (discounted at 8% real rate of discount) as the cost of producing a new variety every three years, with a benefit-cost ratio of 8. This estimated benefit-cost ratio is very close to what an average medium grain variety has yielded in past, providing a verification of the model's findings. A 5% lower use of resources for breeding this type of rice does not affect the time of release of a new variety and total discounted benefits but has lower discounted cost ($294,000). Consequently, the benefit-cost ratio increases from 8 to 10. This implies that 5% of resources can be shifted away from standard medium-grain varieties and be used in some other part of the breeding program without reducing the benefits for this segment of the market.

However, any further shift of resources away from this type of rice delays the release of each new variety, which changes the flow of costs and benefits and their timing. For example, at 20% resource use for standard medium-grain varieties, there is a one year delay in the release

of a new rice variety and the benefit-cost ratio falls to 9.

6. Summary and Conclusions

The model developed and described in this paper provides a means of economic evaluation of the resources used in Australian rice breeding program. By identifying the costs of each operation in the current program and potential changes, and estimating the expected returns from proposed programs, benefit-cost analysis is used to evaluate the efficiency of shifts in resources within the breeding program. Any proposed change in the program can be accommodated, and information based on economic principles can be made available to the decision makers for better resource allocation. The model also provides information about the time required to release a new variety from the start of crossing program, additional time required to develop each new cultivar, requirements for the various physical parameters like area, and number of lines required to be handled by the program before the release of a new cultivar.

There are many issues which can be addressed with the model described in this paper. These include an analysis of: (a) different structure and size of breeding programs; (b) effects of the increased selection pressure in the breeding of specialty rices; (c) effects of shifts in resource use pattern, (d) effects of use of alternative breeding techniques like molecular biotechnology or tissue culture in rice breeding, (e) whether to establish new laboratories or to have collaboration with other research organisations having these facilities, etc.

However, as the use of the model becomes more specific, there is a need for further physical data on a number of aspects of the rice breeding program. For other analyses, the model requires information from breeders on heritability and variability in the original breeding populations for different types of rice, selection pressure used in the breeding of different types of rice, etc. For some specific question regarding use of alternative breeding techniques, the relevant data needed involve costs and benefits from techniques such as the savings in total time for release of a new variety, or the additional increase in yield or quality as a result of the use of these alternative techniques. Once these data are available, more extensive alternative breeding programs can be analysed with the model that has been developed.

Breeders and their administrators are able to use this analytical model to analyse the expected economic gains from changes to their breeding programs. This can provide a means of improved economic efficiency in the allocation of resources with a breeding program, as well as providing a means of identifying the possible gains from future changes within the current rice breeding program.

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