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GENETICS OF, AND BREEDING FOR, RUST RESISTANCE IN WHEAT IN INDIA AND PAKISTAN

ACIAR Projects CS1/1983/037 and CS1/1988/014

John P. Brennan and Kathryn J. Quade
NSW Agriculture, Wagga Wagga
April 2004

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Genetics of, and breeding for, rust resistance in wheat in India and Pakistan

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Foreword

Wheat is one of Australia's major agricultural exports and is also an important crop in India and Pakistan. Vital to the success of the industry is the availability of varieties resistant to major diseases such as rust. Recognising that integrated research would benefit all three countries, ACIAR has supported collaborative projects to increase the level of understanding between plant breeders in India, Pakistan and Australia.

These projects were designed to help improve the nature and extent of variability within rust pathogen populations and the genetic basis of rust resistance in the wheat cultivars currently grown in the three partner countries. Scientists also studied the genetic basis of resistance in potentially useful cultivars and genetic stocks grown in countries other than Australia, India, Pakistan and China.

The objectives were to develop a wider genetic base of wheat varieties. Each country will profit from new sources of resistance discovered in the course of research. These new resistance types will also be shared with other countries through The International Maize and Wheat Improvement Center's (CIMMYT's) international nursery evaluation program.

At the end of the project, new lines with enhanced resistance were distributed to national breeders, to make further selections in the light of their own requirements or to use as rust-resistant parents for further crossing programs.

Another outcome of the projects was the opportunity for scientists and technicians from both India and Pakistan will have opportunities for 'hands-on' experience in Australia at some time during the project's three-year span, following the highly successful training program of the previous project.

ACIAR commissioned this report as part of its impact assessment series to provide a quantitative analysis of the value of this research to Australia and other countries. The report is also available on our website, <www.aciar.gov.au>.

Peter Core
Director
Australian Centre for International Agricultural Research

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Details of projects evaluated

ACIAR projects CS1/1983/037 and CS1/1988/014	Genetics and breeding for rust resistance in wheat
Collaborating organisations	Plant Breeding Institute, University of Sydney, Australia (PBI); Indian Agricultural Research Institute (NARI); Pakistan Agricultural Research Council (PARC)
Project leaders	Professor Bob Macintosh, PBI; Dr Vidya Gupta, Plant Molecular Biology Unit, National Chemical Laboratory, NARI; Dr S. Nagarajan, Crop Diseases Research Institute, PARC
Linked programs	National Wheat Rust Control Program, Australia; All-India Wheat Improvement Project, Punjab Agricultural University; Wheat Improvement Program of the International Maize and Wheat Improvement Center (CIMMYT)
Duration of ACIAR projects	1 September 1984 – 31 December 1987; 29 July 1988 – 29 July 1991
Total ACIAR funding	AUD1,152,304
Project objectives	• To determine the genetic basis for rust resistance in wheats grown in India and Pakistan • To use the genetic information in advising breeders in widening the current levels of genetic diversity • To introduce and incorporate new sources of rust resistance into adapted and important local cultivars • To increase the capacity of Indian and Pakistani scientists in rust pathology and the genetics of rust resistance in wheat

Summary

In the late 1980s and early 1990s, ACIAR funded two related projects (CS1/1983/037 and CS1/1988/014) on the genetics of, and breeding for, rust resistance in wheat. The key organisations involved in the projects were the Australian Centre for International Agricultural Research (ACIAR), the Indian Council for Agricultural Research, the Pakistan Agricultural Research Council and the University of Sydney.

The main objectives of the projects were to investigate and enhance the sources of rust resistance in wheat in India and Pakistan, and to provide training for Indian and Pakistani rust scientists at the National Wheat Rust Control Program (NWRCP) at the University of Sydney.

The two related ACIAR-funded projects produced a number of outputs, including the training of scientists in rust resistance for wheat. Eight scientists came to the NWRCP during the projects to receive detailed, hands-on training. Each scientist returned to his own country to put into practice the skills learned in that training. While it is difficult to value the outcomes of such projects, this study has estimated the value of the training received in Australia by Indian and Pakistani scientists.

That training led to increased research capacity in wheat rust resistance in both countries, and the higher research capacity has, in turn, increased the outcomes in terms of rust resistance for both India and Pakistan. As a result, both countries have higher levels of rust resistance in place at present than would have been the case without that training. Hence, the value of the two ACIAR-funded projects is estimated as the value of that improvement in rust resistance.

On the basis if the analysis undertaken, those benefits are estimated at $A2.20 million per year, with India receiving the majority of the benefits. Given that those benefits are likely to be received until 2014, the present value of the benefits ($A57.2 million) is much greater than the present value of the project costs ($A3.3 million), giving a benefit–cost ratio for the projects of 17.3. This result indicates that the funds invested by ACIAR in the projects on rust resistance provided a high economic return on that investment.

These results are sensitive to the assumptions made in the analysis, particularly the extent and timing of the impact on research and development capacity in India and Pakistan. However, even with the least optimistic assumptions, the projects gave a benefit–cost ratio no lower than 8, indicating a project with robust economic benefits.

1 Introduction

Wheat is one of the most significant crops in both India and Pakistan, and is critically important to the food supplies in both countries. In each of these countries, there has been strong yield growth since the 1960s, following the green revolution. With the spread of the high-yielding varieties of wheat in developing countries, there was concern that the disease resistance in that material might break down. Given the considerable degree of commonality in the genetic backgrounds of these varieties, there was a danger of a major disease outbreak that could have serious consequences for wheat production and hence food security in the developing world.

One of the most serious disease threats in each country to wheat production in past decades has been the presence of epidemics of rust diseases, namely stem rust (*Puccinia graminis*), leaf rust (*Puccinia recondita*) and stripe or yellow rust (*Puccinia striiformis*). Crop yield losses of 30–55% from leaf and stem rust have been reported in susceptible wheat cultivars in Australia (Keed and White 1971; Rees and Platz 1975). McIntosh et al. (1995) reported that severe rust epidemics have occurred in India since the 1800s (Joshi 1976), and that a severe outbreak in Pakistan during 1978 was estimated to have caused economic losses of $US86 million (Hussain et al. 1980).

The two means of control of rust diseases in wheat are the development of varieties with genetic resistance to the pathogen, and the use of fungicides in some instances. Brennan and Murray (1998) found that, while current losses from rust diseases in Australia were between $A2 and $A11 million per year, the genetic resistance to these rusts was currently worth $A99 million per year for stem rust, $A85 million for leaf rust and $A161 million for stripe rust. In contrast, fungicides contributed control valued at only approximately $A12 million per annum across the three rusts in Australia.

Rust pathogens can mutate to overcome the existing resistant genes. Therefore, breeding for rust resistance needs to focus on maintaining current levels of resistance and on developing new and improved sources of resistance. The maintenance of rust resistance involves a continuing search for, and development of, new forms or combinations of resistance, to ensure that the varieties in farmers' fields have effective genetic resistance against the current strains of the pathogens. To ensure that rust does not cause economic losses, breeders need to have an understanding of cultivar susceptibility, the rust pathogens and a sense of the resistance genes available for use.

Research into the genetics of rust resistance has been carried out in India at the Punjab Agricultural University at Ludhiana, the India Agricultural Research Institute in New Delhi, and the Wheat Rust Research stations at Simla and Mahabaleshwar. In Pakistan, rust research has been undertaken at Islamabad, Murre and Karachi, as well as at regional institutes at Tarnab, Tandojam and Faisalabad. Rust research has been undertaken at the University of Sydney's Plant Breeding Institute since the 1920s. Since 1973, the (Australian) National Wheat Rust Control Program (NWRCP) has been operated at the University of Sydney. Each year, more than 1000 rust samples are examined and classified, over 15,000 breeders' lines are screened using seedling tests, and 15 gene sources are backcrossed to 30 recurrent parents. The NWRCP provided an opportunity for training of scientists from India and Pakistan in wheat rust resistance.

2 ACIAR-funded projects CS1/1983/037 and CS1/1988/014: description of activities and outputs

2.1 Project description

In the late 1980s and early 1990s, ACIAR funded two related projects on 'Genetics and breeding for rust resistance in wheat' (projects CS1/1983/037 and CS1/1988/014). The key organisations involved in the projects were the Australian Centre for International Agricultural Research (ACIAR), the Indian Council for Agricultural Research (ICAR) and the Pakistan Agricultural Research Council (PARC). These two projects involved collaboration between the University of Sydney, the All India Wheat Improvement Project, Punjab Agricultural University, the Indian Agricultural Research Institute, and the Pakistan Agricultural Research Institute. In addition, the work was closely linked to work being undertaken at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico. Approximately $A1.2 million was invested in the two ACIAR-funded projects.

The main objectives of the original project were:

1. to determine the genetic basis for rust resistance in wheats grown in India and Pakistan, to show the degree of genetic diversity currently deployed and thus indicate the vulnerability to future short-term changes in the pathogen populations

2. to use the genetic information in advising breeders in widening the current levels of genetic diversity

3. to introduce and incorporate new sources of rust resistance into currently adapted and important local cultivars

4. to permit Indian and Pakistani scientists to gain first-hand experience in the Australian laboratory responsible for the National Wheat Rust Control Program.

At the conclusion of the first ACIAR-funded project (CS1/1983/037), a follow-on project (CS1/1988/014) was also funded. The follow-on funding enabled genetic materials to be further progressed into the breeding programs, and further evaluation of the resistance status of the material to be undertaken. As well, it provided further hands-on training for Indian and Pakistani researchers. It also made funds available for the extension of the information, through the development of workshops for scientists and the production of a book.

A subsequent review of the projects concluded that the projects were ‘highly successful’ in identifying the genetic diversity of rust resistance in wheat from southern Asia, and in providing training for Indian and Pakistani scientists. However, given that the principal benefit of the projects was enhancing the research capacity of the partner organisations, the review concluded that it was too difficult to quantify the economic benefits of the projects. The purpose of this evaluation is to attempt to quantify those benefits.

2.2 Visiting scholars and scientists

At the start of the projects, both India and Pakistan had well-trained wheat breeders and pathologists and good facilities for research. The thrust of the project was to enhance and build on that training and to achieve close research collaboration in developing more-durable rust resistance in wheat. The skills-enhancement component of the project involved the transfer of advanced research and breeding techniques, joint planning on research objectives, and access to the research expertise and experience on rust genetics that existed in Australia. In addition, the interchange and evaluation of genetic material was planned, to build a better basis for rust resistance in spring wheats for all three countries.

Given the differences between the participating countries in, for example, field and greenhouse environments, it was desirable that these differences be appreciated and well understood in the early phases of the project. That was achieved by having visiting scientists from India and Pakistan working with the Australian group for periods of up to one year when the various seasonal activities of the rust laboratory were observed and experienced. In addition, mutual short-term exchange of senior scientists was undertaken, to facilitate planning and discussion of results.

In all, eight visiting scholars from India and Pakistan came to Australia under the project (see Table 1). They each spent between 10 and 12 months at the University of Sydney.

Table 1. Visiting scholars from India and Pakistan to Australia (1985 – 1991)

Project No.	Country of visiting scholar	
	Pakistan	India
CS1/1983/037	Mr M. Hussain	Dr R.G. Saini
	Mr A.A. Hakro	Mr S.K. Nayar
	Mr S.J. Hamid	
CS1/1988/014	Dr A.K. Khanzada	Mr J.B Sharma
		Dr M. Prashar

In addition, several senior scientists from India and Pakistan visited Australia for shorter times during the project, to familiarise themselves with the project and the work being undertaken in Australia. As well, several brief visits were made to India and Pakistan by Australian scientists involved in the projects.

2.3 Breeding populations

In order to ensure that work on the improvement of resistance in India and Pakistan was more soundly based and able to be undertaken consistently at different locations, some fixed-line breeding populations were developed in the project. Fixed-line breeding populations allow replicated testing of pathogens and isolates to be done in different countries such that there is confidence that the results will be comparable.

Fixed-line breeding populations were developed by ‘single seed descent’. Under this method, one or two random plants from each F_2 plant are grown to F_3 generation One seed from each plant is advanced to the next generation and the procedure is repeated for 3–4 cycles, by which time (F_5 or F_6 generations) the lines are highly inbred and homozygous. Each line then behaves as a 'cultivar' and can be increased to any desired quantity. For international work the main advantages are:

- a core population can be maintained and stored long-term at one site
- as few as one grain per line can be grown for seed increase, research and study at any number of sites without the risk of significant genetic changes
- the growing of as few as one grain per line allows efficient use of plant quarantine facilities through which populations may need to pass when entering some countries
- standard statistical procedures can be used for analysis of data from such populations
- there are few problems with heterozygosity and segregation.

Once the fixed-line breeding populations were developed, they were made available to India and Pakistan as well as Australia. These breeding populations were then used to identify the strains of the different rusts present in each country, and for comparison with other local lines and varieties. More recently, molecular markers have to some extent superseded fixed-line breeding populations.

2.4 Glasshouses and research facilities

Two quarantine glasshouses were built for the project at Castle Hill, west of Sydney, to ensure that the seed-transmitted diseases such as Karnal bunt were not introduced into Australia as a result of the project. The glasshouses were later transferred to the new location for the NWRCP at Cobbity, southwest of Sydney. These glasshouses enabled larger populations of quarantine material to be handled at these facilities.

Plant growth facilities were also provided in Pakistan as part of the project. Funds were provided for a greenhouse and associated back-up generator at the Pakistan Agricultural Research Council laboratories in Islamabad.

Although the project was not seen as a major provider of equipment, to enhance project effectiveness, money was also provided for car refrigerators for rust surveys, a liquid nitrogen refrigerator, and an ultra-low-temperature deep freeze for rust spore storage.

2.5 Technical workshops

In the proposal for the later phase of the ACIAR-funded project CS1/1988/014, two workshops were planned:

- a small workshop in March 1989, in either Pakistan or Nepal
- a larger workshop was held in New Delhi in February 1991, as part of the project review.

3 Description of outcomes of the projects

3.1 Visiting scholars and scientists

There were several outcomes from the hands-on training that the Pakistani and Indian visiting scholars received at the National Wheat Rust Control Program. An overarching outcome was the creation of a group of rust pathologists with training in advanced knowledge about rust diseases, such as rust genetics and resistance genetics, and deployment of a mosaic of cultivars. That training is likely to yield both short- and long-term benefits.

Through their training, the visiting scholars gained a better understanding of the genetic bases for rust resistance in wheats grown in India and Pakistan. These scientists also improved their capacity to analyse and develop improved levels of disease resistance in wheat. This is likely to translate into improved genetic information being given to breeders in widening current levels of genetic diversity. Once these improvements were in place, the likely longer-term outcomes would be improved rust resistance in wheat in India and Pakistan, and an increased level of diversity and reduced vulnerability in rust resistance in wheat in both India and Pakistan. An increased capacity to identify, analyse and develop improved levels of disease resistance, as well as increasing the cooperation, and communication between rust scientists in India, Pakistan and Australia, were also important short-term and long-term outcomes. These developments are likely to ensure that the benefits from the project continue well into the future.

The visits by senior scientists from India and Pakistan to the Australian laboratory responsible for the NWRCP were likely to have similar outcomes to those of visiting scholars. An added advantage of this collaborative research was that they were able to become familiar with procedures and techniques at the Castle Hill facility, assisting the exchange of comparable research results.

For Australian scientists and technicians visiting India and Pakistan, the short-term outcomes may be summarised as an increased effectiveness in training visiting scholars from India and Pakistan, and an increased understanding of the genetics of wheat rusts. Longer-term outcomes are likely to be improved rust resistance in Australia, as the researchers would have obtained improved information about the nature of rust diseases and the applicability of the different methods of overcoming them in a range of environments. Increased knowledge and experience with the host–pathogen systems on the Indian subcontinent increased international knowledge and supplemented information obtained during the 1970s by international gene virulence surveys.

3.2 Breeding populations

The development of populations of fixed lines for rust research enabled rapid identification of rust resistance in India and Pakistan, and a more rapid identification of rust resistances in Australia. The likely longer-term outcome of that more-rapid accurate identification is improved rust resistance in wheat in India, Pakistan and Australia.

3.3 Glasshouses and research facilities

The construction of new glasshouses at Castle Hill and Pakistan had important outcomes for both collaborating countries. For Australia, in the short-term there was an increased capacity to import more lines from India and Pakistan for assessment in projects. The long-term outcome of this activity was that larger populations could be handled in the NWRCP at Cobbity, leading to faster progress with resistance in Australia. In addition, some superior attributes of Indian and Pakistani cultivars, such as larger seed size, could be introduced into the University of Sydney wheat-breeding program.

For Pakistan, the short-term outcome was the capacity to undertake rust strain evaluations in a high-standard glasshouse, while in the longer –term, the construction of the glasshouse is likely to have led to more rapid progress with rust resistance. However, it is unclear to what extent the glasshouse was subsequently used for that purpose.

3.4 Publication of book on rust genes

The project facilitated the publication of the book *Wheat rusts — an atlas of resistance genes* (McIntosh et al. 1995), which has improved world-wide dissemination of information on resistance genes. This book illustrates the types of seedling or adult plant response associated with as many as possible of the known genes for resistance to leaf rust, stripe rust and stem rust. The information provided on the various features of the individual resistance genes is likely to make an important contribution to an improved understanding of the extent of and limitations of rust resistance in wheat around the world.

3.5 Summary of activities, outputs and outcomes of projects

The activities, outputs and outcomes of the project are summarised in Table 2.

4 Impacts of projects

4.1 Analytical framework for evaluating capacity building

The impact of the training in rust resistance is essentially aimed at improving the research and development (R&D) capacity in both India and Pakistan. Investment aimed at building research capacity can be an important component of R&D investment, as it enhances the productivity of R&D resources.

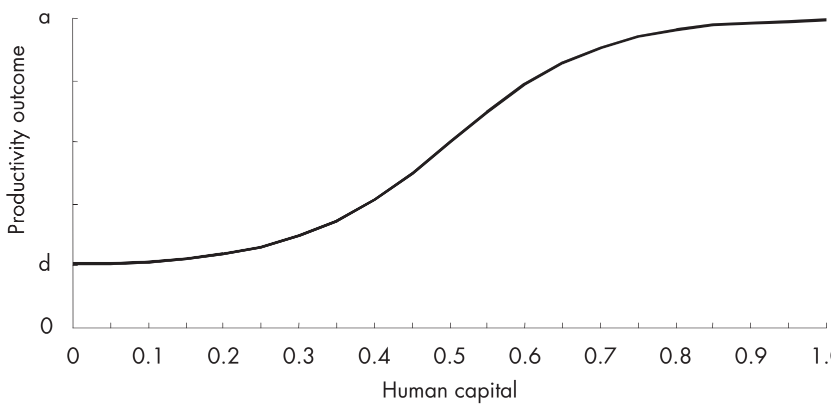
Investment aimed at building research capacity can have an effect through increased productivity, or increased maintenance research{?}, or both. Given the presence of research spillovers from one environment to another (Alston 2002), there can be some productivity enhancement and maintenance{?} in a particular environment without any R&D capacity in that environment, though generally both require some direct R&D capacity (Maredia and Byerlee 2000). The larger the capacity, the larger is the potential productivity enhancement and maintenance research{?}, and hence the larger the potential economic outcomes.

Table 2. Activities, outputs and outcomes of wheat rust projects

Activities	Outputs	Short-term outcomes	Long-term outcomes
Training for visiting scholars from India and Pakistan at the Australian laboratory responsible for the National Wheat Rust Control Program	• Eight Indian and Pakistani scientists with hands-on experience of rust control activities in Australia • Rust pathologists with training in advanced knowledge about rust diseases, such as rust genetics and resistance genetics, and deployment of mosaic of cultivars	• Better understanding of the genetic bases for rust resistance in wheat in India and Pakistan • Increased capacity to identify, analyse and develop improved levels of disease resistance in wheat • Improved genetic advice to breeders on widening current levels of genetic diversity • Increased cooperation, and communication between rust scientists in India, Pakistan and Australia	• Improved rust resistance in India • Improved rust resistance in Pakistan • Increased capacity to identify, analyse and develop improved levels of disease resistance in wheat • Increased diversity of rust resistance in India and Pakistan • Continuing cooperation, and communication between rust scientists in India and Australia
Visits by senior scientists from India and Pakistan to the Australian laboratory responsible for the National Wheat Rust Control Program	• Indian and Pakistani scientists with increased awareness of rust control activities in Australia	• Better understanding of the genes being used for rust resistance • Increased capacity to identify, analyse and develop improved levels of disease resistance in wheat	• Improved rust resistance in India • Improved rust resistance in Pakistan • Increased diversity of rust resistance in India and Pakistan • Increased capacity to identify, analyse and develop improved levels of disease resistance in wheat
Visits by Australian scientists and technicians to India and Pakistan.	• Australian scientists with increased awareness of rust problems and control activities in India and Pakistan	• Increased effectiveness of training provided to visiting scholars from India and Pakistan • Increased effectiveness of understanding of genetics of wheat rusts	• Improved rust resistance in Australia
Development of a population of fixed lines for rust research	• Population of fixed lines for rust research	• Rapid identification of rust resistances in India and Pakistan • More rapid identification of rust resistances in Australia	• Improved rust resistance in wheat in India, Pakistan and Australia
Building of new glasshouse at Castle Hill	• Additional quarantine standard glasshouses at Castle Hill (now at Cobbity)	• Capacity to import more lines from India and Pakistan for assessment in the projects	• Larger populations being handled in the NRCP/ACRCP at Cobbity, leading to faster progress with resistance in Australia
Building of new glasshouse in Pakistan	• High-standard glasshouse available in Pakistan	• Capacity to undertake rust strain evaluations in Pakistan	• More rapid progress with rust resistance in Pakistan (if still being used for that purpose)
Assembling of information on resistance genes for wheat	• Publication of the book *Wheat rusts – an atlas of resistance genes* (McIntosh et al. 1995).		• Improved world-wide dissemination of information on resistance genes through the book *Wheat rusts – an atlas of resistance genes* (after 1995).

An analytical framework for evaluating the benefits of improving the R&D capacity is developed, and that framework is applied to the training in Australia of wheat pathologists for the management of rust resistance in wheat in India. At low levels of human capital (HC) in a given region, productivity outcomes (PO) will be determined by technology 'spill-ins' from other regions (Figure 1). As HC is further developed, the rate of increase of PO will increase, but as HC is increased even further, PO will reach diminishing marginal returns so that ultimately additional HC will not increase PO.

Figure 1. Relationship between human capital and productivity outcomes, with technology spill-ins.



Following Alston et al. (1995, p. 357) in their work on adoption curves, the logistic curve can be specified as:

$$y = \frac{a}{1 + e^{-(b+cx)}} \tag{1}$$

where y is the (observed or estimated) productivity outcome in a target region, x is the level of the component of R&D capacity, and a, b and c are parameters to be determined. The parameter a represents the value of y that can be achieved at full human capacity, and b and c are parameters that define the path of the response that asymptotically approaches the maximum.

With spill-ins of d where $x = 0$, $y = d$, the maximum level (ceiling) of the logistics/response curve is then $(a - d)$. Thus, equation (1) becomes:

$$y' = \frac{A}{1 + e^{-(b+cx)}} \tag{2}$$

where

$$A = a - d \tag{3}$$

and

$$y = y' + d \tag{4}$$

where d is the level of productivity that results from the technology spill-ins from other regions when there is no R&D capacity in the target region; y' is the productivity outcome from R&D capacity within the region; and A is the parameter of the logistic curve.

The question then is how to elicit values that will define the parameters of the logistic curve. Considering the case of human capital improvement (through training, for example), while all other components are fixed, x can represent the years of scientific experience in a region, and y can represent the rate of crop yield improvement per year. The maximum level of yield improvement, a, can be determined from experimental or expert information. If the level of human capital in an area of scientific expertise within a particular region were zero, then productivity outcomes would rely on technology spill-ins from other regions or farmer experimentation.

As the curve is asymptotic to the floor set by the spill-ins, we can set $y = y_0$ when x{?} = 0, where y_0 is an arbitrarily small positive number. Thus, from equation (2):

$$y_0 = \frac{A}{1 + e^{-b}} \tag{5}$$

so that

$$A = \frac{y_0}{1 + e^{-b}} \tag{6}$$

This can be re-arranged to give:

$$b = -\ln\frac{A}{y_0 - 1} \tag{7}$$

Substituting equation (7) into equation (1) and rearranging, we get:

$$c = \frac{1}{x}\left(\ln\left(\frac{A}{y_0} - 1\right) - \ln\left(\frac{A}{y} - 1\right)\right) \tag{8}$$

Thus, given a and d (that is, A) and y_0, we can calculate b. If we define one other point on the curve for which both x and y are known, we can then calculate c, and hence define the entire logistic curve.

Once the curve has been defined, changes in x represent a movement along the response curve. Thus, we can then calculate the expected change in y for a given change in x, and then place an economic value on changes in R&D capacity.

4.2 Units of measurement of parameters

For any relationships to be useful in assessing the value of specific R&D capacity-building activities, the units of measurement of R&D capacity and the productivity outcomes need to be defined carefully. For example, there are a number of ways to measure the human capital component of a training program, such as cumulative years of professional experience, years of experience post-training, years of post-graduation work, the number of workers with a particular qualification, or other measures of research-worker intensity.

The human capital inputs need to be scaled to the production that is being targeted by the R&D since, for example, two qualified workers in a small region may well be adequate to allow productivity to be maximised, whereas that would be inadequate for a very large, diverse region with 100 times as much production. Thus, the human capital measure needs to be a measure of research intensity (see, e.g., Scobie et al. (1991)), expressed as 'years of experience for each hectare of crop sown in the target region'.

The productivity outcomes used in the analysis need to be defined in terms of a measurable outcome, such as wheat yields per hectare, or the annual value of disease resistance in each region. The productivity measure used needs to reflect the differences in outcomes that will occur with a change in the level of R&D capacity.

4.3 Valuing rust resistance in India and Pakistan

Following Brennan and Murray (1998), the potential losses from diseases that could have been controlled by resistance can be calculated. In addition, estimates are also available of the current losses that occur in the presence of the current levels of resistance in place. These two figures can be combined to determine the extent to which current use of resistance is successful in controlling the diseases. When expressed as a percentage of potential losses, the current level of control represents a measure of the success of the R&D capacity in relation to wheat disease resistance. Where other forms of control can be used as well as genetic resistance (see Brennan and Murray 1998), only that proportion relating to resistance is to be included. The measure of productivity outcomes from disease resistance capacity can therefore be defined as:

$$y_i = \Sigma_j(\mathrm{r}_j\,(P_{ij} - A_{ij})/P_{ij}) \tag{10}$$

where y is the productivity outcome in region i, r_j is the relative contribution of disease resistance to the control of disease j, P_{ij} is the potential economic losses in region i from disease j (in dollars) and A_{ij} is the actual current economic losses in region i from disease j (in dollars) given current controls.

4.4 Data used

For the purposes of data collection on wheat rust diseases in India, five key wheat production regions were defined (Table 3). The Northern Plains was the dominant wheat production region, although Central and North-eastern regions were also significant producers. Similarly, for Pakistan four wheat-growing provinces were analysed. The main production is in the Punjab and the Sindh provinces.

Table 3. Regional wheat data for India and Pakistan (average of five years to 2001–02).

	Area ('000 ha)	Yield (t/ha)	Production ('000 t)
India			
Southern Hills	256	0.74	190
Central	6,025	1.76	10,590
Northeastern India	2,601	2.05	5,323
Northern Plains	15,682	3.01	47,259
Northern Hills	1,558	2.06	3,212
- Total	26,122	2.55	66,574
Pakistan			
Sindh	1,015	2.50	2,533
Punjab	6,081	2.42	14,702
NWFP	824	1.29	1,060
Baluchistan	337	2.02	681
- Total	8,257	2.30	18,976

Source: Indian and Pakistani governments' official statistics.

Data on the productivity outcomes for rust resistance in wheat were obtained from a survey of wheat pathologists in India (R.G. Saini, pers. comm.) and Pakistan (Dr Iftikhar Ahmad). Scientists were first asked to estimate the incidence and severity of each of the three main rust diseases (stem, leaf and stripe rust) for each of the main wheat production regions in each country. The results are shown in Table 4.[1]

Table 4. Scores for disease severity and incidence for rust diseases in India.

	Stem rust			Leaf rust			Stripe rust		
	Severity		Incidence	Severity		Incidence	Severity		Incidence
	Potential	Present		Potential	Present		Potential	Present	
India									
Southern Hills	4.5	2.5	4.0	4.0	2.5	3.5	3.5	2.5	3.0
Central	4.5	1.0	2.5	3.5	1.5	2.0	0.0	0.0	0.5
Northeastern India	1.5	0.0	0.5	3.5	2.0	2.5	1.0	1.0	0.5
Northern Plains	0.5	0.0	0.0	2.5	1.5	2.0	4.5	1.5	3.0
Northern Hills	1.5	0.0	0.0	4.0	1.5	3.0	4.5	1.0	2.0
Pakistan									
Sindh	5.0	1.0	1.0	4.0	1.0	1.0	3.0	1.0	1.0
Punjab	4.0	0.0	1.0	5.0	2.0	2.0	4.0	1.0	1.0
NWFP	3.0	0.0	0.0	5.0	1.0	1.0	5.0	2.0	2.0
Baluchistan	3.0	1.0	1.0	4.0	1.0	1.0	4.0	1.0	2.0

Source: Based on a survey of Indian and Pakistani wheat pathologists.

For each of the rusts, there are regions in each country where the potential (uncontrolled) level of severity in the event of a disease outbreak is given a score of 4.0 ('severe') or 4.5 ('severe'/'very severe') or 5.0 ('very severe'). However, given current controls, the present severity of the diseases in these regions is 2.5 ('light'/'moderate') or lower. The incidence scores indicate that environmental conditions for the rusts are such that the rusts are generally 'localised' (scores 2–3), although in some regions the scores are 1.0 ('rare') or 4.0 ('widespread in some seasons'). In each of the regions, at least one, and generally more than one, rust has the potential to cause serious losses if not controlled.

From these scores, using the methodology outlined in Brennan and Murray (1998), estimates were obtained of the total value of resistance to each of the three diseases (Table 5). These values show that, in India, stem rust causes annual losses of $A0.51 million, leaf rust $A4.06 million and stripe rust $A4.86 million. In aggregate terms, the control of stripe rust through resistance contributes $A245 million per year in losses avoided, with resistance valued at $A47 million per year for stem rust and $A43 million for leaf rust.

[1]In each country, scores were also given for other regions (Peninsular India and Northern Areas in Pakistan), but because production is so small in those regions they are not included in this analysis.

In Pakistan, potential losses are approximately half of those in India, but present average annual losses are $A1.51 million per year for leaf rust, $A0.29 million per year for stripe rust and $A0.03 million for stem rust. The value of the control provided by resistance is therefore $A75 million per year for leaf rust and $A24 million per year each for stem and stripe rust.

Aggregating across the three rusts, for India as a whole, resistance to the three rusts has the potential to provide benefits of $A344.3 million per year (Table 5). At present, benefits of $A335.3 million are being provided, so that the productivity outcome in terms of rust resistance is 97.4% (= 335.3/344.3) of potential. For Pakistan, the three rusts have the potential to provide benefits of $A124.3 million per year, with current benefits of $A122.6 million, or 98.6% of potential. Thus, the productivity outcome for rusts in India is that resistance is providing 97.4% of the potential benefits, and for Pakistan it is 98.6% of potential. These are used as a measure of the current level of productivity achieved through rust resistance in each country.

4.5 Valuing rust resistance capacity building in India and Pakistan

The issue now is to determine the human capital inputs that have brought about that outcome. Craig et al. (1991) and Pardey et al. (1991) used the number of full-time equivalents in research, defined by educational status, as their measure of the human capital input into agricultural research. Pardey et al. (1991) acknowledged the practical difficulties associated with qualification levels, expatriate researchers and research managers in constructing a measure of human capital in developing countries. Such difficulties are inherent in this study as well.

In measuring the level of human capital in the area of disease resistance in a region, the most appropriate measure appears to be a combination of the level of educational status and the total cumulative years of postgraduate experience among the plant pathologists in wheat diseases resistance. Given the need to scale the measure, it is expressed as ‘years of experience per million hectares of wheat sown’.

The information on personnel working on wheat pathology in India was obtained from personal contact with Dr R.G. Saini, wheat pathologist with Punjab Agricultural University, Ludhiana, India. Detailed data were available on the individuals involved in rust resistance work at present. The human capital involves 32 scientists, contributing a total of 20.2 full-time equivalents (FTEs) on wheat rust resistance. Similar data were obtained from Dr Iftikhar Ahmad of the Institute of Plant and Environmental Protection, National Agricultural Research Centre, Pakistan. The data on the qualifications and experience of the staff involved in wheat rusts in each country are summarised in Table 6.

A number of alternative methods for estimating the total human capital involved as a single parameter were considered (Brennan and Quade 2004). The method of measuring the human capital for wheat rust resistance used in this report is the total years in study and years of experience.

Table 5. Productivity outcomes for wheat rust resistance in India and Pakistan

	Potential costs ($A'000)	Present costs ($A'000)	Value of controls ($A'000)	Percentage control by resistance	Resistance potential ($A'000)	Resistance actual ($A'000)	Resistance as percentage of potential
India							
Stem rust	47,638	512	47,126	100.0	47,638	47,126	98.9
Leaf rust	49,414	4,059	45,355	95.0	46,944	43,087	91.8
Stripe rust	262,814	4,858	257,956	95.0	249,673	245,058	98.2
All rusts	359,866	9,429	350,437	95.7	344,254	335,272	97.4
Pakistan							
Stem rust	24,179	32	24,147	100.0	24,179	24,147	99.9
Leaf rust	80,055	1,514	78,542	95.0	76,053	74,615	98.1
Stripe rust	25,341	292	25,049	95.0	24,074	23,796	98.8
All rusts	129,575	1,838	127,737	95.9	124,305	122,558	98.6

Source: Derived from Table 4.

Table 6. Scientists working in rust resistance in wheat in India and Pakistan

	Scientists	Years of experience			
Educational status	(FTE)	0–5 yrs	6–10 yrs	11–20 yrs	21–30 yrs
India					
Master's degree	3.5	2	2	0	0
PhD	16.7	7	7	8	6
– Total	20.2	9	9	8	6
Pakistan					
Master's degree	16.9	5	12	11	6
PhD	1.2	0	0	3	4
– Total	18.1	5	12	14	10

Source: Dr R.G. Saini (pers. comm.) and Dr Iftikhar Ahmad (pers. comm.).

In this study, the years of experience for each individual are summed linearly. In assessing the years in study, the values allocated to different levels of education are shown in Table 6. A basic degree is taken as three years, a Master's degree as two additional years, and a PhD an additional four years. Thus, a scientist with a Master's degree is taken to have five years of study, and one with a PhD nine years of study, in addition to their years of working experience. Allowing for the proportion for the time each individual allocates to rust resistance, by this measure the current human capital for wheat rusts is 326 years for India and 270 years for Pakistan. The current level of human capital for wheat rust resistance per million hectares of wheat sown in India is therefore 12.5 years, and in Pakistan it is 32.7 years.

In addition, given that spill-ins are likely to be high for a characteristic such as rust resistance in India, 50% technology spill-ins are allowed in the analysis, so that resistance is 50% of potential if there is no local human capital. We use the value of $y_0 = 1\%$ when x is zero (given that y is asymptotic to the horizontal axis). Where there are spill-ins, $y_0 = 50\%$.

From equation (2), the relationship between human capital for rust resistance and outcomes for wheat rust resistance in India is estimated. Each specification provides a separate estimate of the relationship. From each relationship, an estimate of the value of a change in human capital can be estimated (ignoring any lags inherent in the system). Using each of these specifications of human capital and spill-ins, equations (8) and (9) are used to estimate the required parameters. The relationship determined from these data for India and Pakistan is illustrated in Figure 2.

4.6 Valuing training in rust resistance

On this basis, the value of programs to build human capacity through training or further education can be estimated. While there are likely to be many qualifications to any such estimates, they provide a first step in the process of quantifying the value of R&D capacity building.

In determining the effect of bringing three Indian wheat pathologists to Australia for training at the National Cereal Rust Control Program at the University of Sydney, some further assumptions are required:

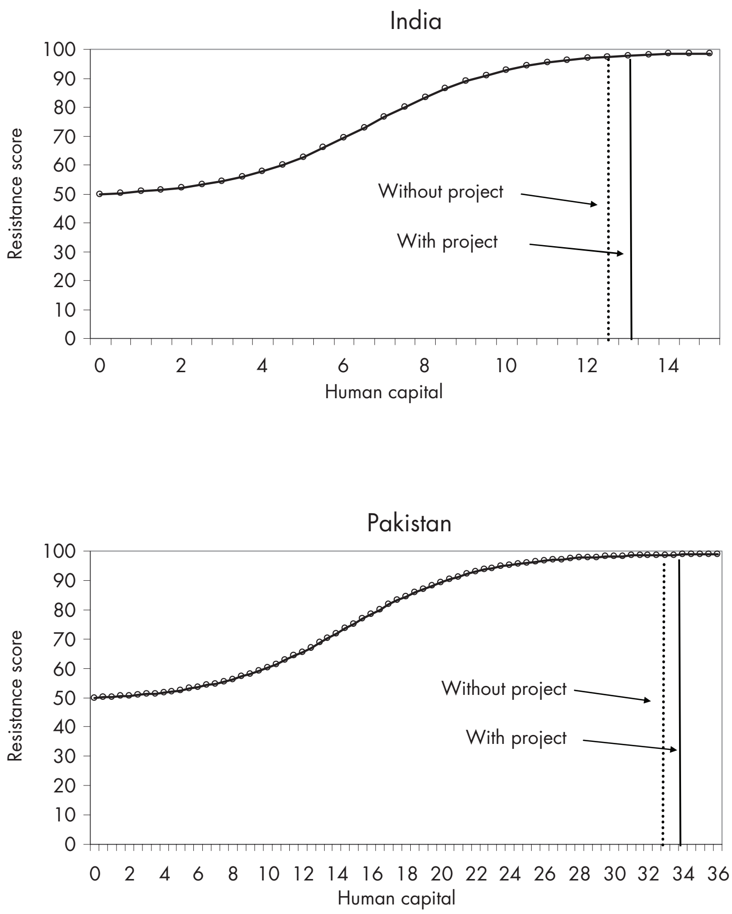
- each round of training lifts the human capacity of that individual for a number of years

- the additional human capacity for each year is equivalent to one-half of a FTE of additional experience

- trainees were employed for 10 years after training, so that the training has a 'life' of 10 years in terms of improving human capacity of that individual.

Thus, for each plant pathologist trained, the human capacity in each country increases by a total of 5 years. With three Indian scientists trained under the project, the aggregate human capacity at present is 15 years higher than it would have been without that training. Similarly, in Pakistan, with four scientists trained under the project, the aggregate human capacity at present is 20 years higher than it would have been without that training.

Figure 2. Effect of human capital on rust resistance in India and Pakistan.



Inserting that shift in the equation for each set of parameter estimates, the productivity outcome without that additional human capacity is estimated (Table 7). The annual gain in productivity outcome is estimated as 0.57% in India, which is valued at $A1.96 million per year. In Pakistan, the annual gain in productivity outcome is estimated as 0.19%, valued at $A0.24 million per year. The aggregate gains per year are $A2.20 million (in 2003 dollars).

Table 7. Value of training plant pathologists in rust resistance (50% spill-ins).

		India	Pakistan	Total
Human capital (*x*)				
– with training	years/m.ha.	13.24	35.13	
– without training	years/m.ha.	12.48	32.71	
– gain from training	years/m.ha.	0.77	2.42	
Productivity outcome (*y*)				
– with training	%	97.96%	98.79%	
– without training	%	97.39%	98.59%	
– gain from training	%	0.57%	0.19%	
Value of productivity gain	$m	$A1.96m	$A0.24m	$A2.20m

5 Impact on poverty alleviation

Agricultural research is increasingly called upon to address equity issues, especially poverty reduction. Research that generates broad-based productivity increases is one of the most-effective means of reducing poverty through rural employment and income generation. One major impact of agricultural research is increased availability of and lower prices for food; this is especially beneficial to the poor, who spend a large share of their income on food.

Nagarajan and Joshi (1975) discuss the extent to which rust epidemics in India in the past have led to famines. They concluded that the failure of the monsoons and the associated 'Kharif' summer season crops are the main cause of past famines. As a result, they argue that 'rust epidemics or pandemics can aggravate famine conditions, if occurring prior to, or after a poor monsoon' (Nagarajan and Joshi 1975, p. 32).

There has been a considerable amount of research conducted into rust resistance in the developing world. For these countries, there are great social consequences from not having resistance to rust. Many of these farmers and societies rely extensively on their wheat crop for their livelihood, and large-scale fungicide treatment may not be a feasible option for them. Hence, the issue of rust resistance has a direct influence on poverty alleviation.

Given that rust resistance is incorporated into the seed, the marginal costs of improved resistance are minimal for poor farmers. Therefore, improvement in rust resistance is an effective way to provide benefits to the poor, though they only receive benefits in proportion to their production.

6 Benefit–cost analysis of the projects

6.1 Evaluation framework

The costs of the projects are assessed from 1985 and the benefits commence in the final year of the second project, namely from 1991. As a 30 time horizon is used, the costs and benefits are measured from 1985 to 2014. After 2014, the benefits are assumed to decline to zero. Benefits and costs are converted to 2003 Australian dollars using the consumer price index. A 5% discount rate is used, so that future benefits are discounted and past benefits and costs are compounded to 2003.

Investment criteria used for the analysis are net present value (NPV), benefit–cost ratio (BCR) and internal rate of return (IRR). A positive NPV, a BCR greater than one and an IRR greater than the discount rate (5%) indicate that real project benefits are greater than real project costs.

6.2 Project costs

Costs associated with project activities in India, Pakistan and Australia are detailed in Table 8. Over the seven-year period from 1985 to 1991, ACIAR allocated $A1.05 million to projects CS1/1983/037 and CS1/1988/014. Other costs include contributions from the commissioned organisation (University of Sydney) and from ACIAR for review activities. In 2003 dollars, over $A1.60 million was invested in the two projects.

Table 8. Annual project costs.

Year	Costs nominal ($A)	Consumer price index (2003 = 100)	Costs real (2003 $A)
1985	93,304	50.0	186,461
1986	60,873	54.2	112,216
1987	174,934	59.3	294,806
1988	141,231	63.7	221,737
1989	163,004	68.3	238,509
1990	212,247	73.8	287,581
1991	204,296	77.7	262,875
Total	1,049,889		1,604,186

6.3 Key assumptions

The key assumptions used in the analysis are:

- an average price of wheat of $A200 per tonne (in 2003 dollars)
- there are no lags from the end of the project until the first benefits are received; the project benefits start to flow in the final year of the second project (1991), and continue until 2014, after which they fall to zero
- average production for the five years to 2001–02 is representative of the full period of benefits
- the estimated annual benefits are constant for the full period
- each round of training lifts the human capacity of that individual for a number of years
- the additional human capacity for each year is equivalent to one-half of a FTE of additional experience
- the training has a 'life' of 10 years in terms of improving human capacity of that individual
- spill-ins from other regions provide 50% of the total potential benefits even if there were no rust resistance capacity in India or Pakistan
- a real discount rate of 5% per annum is used.

All prices and costs are converted to 2003 dollars.

6.4 Results

For the economic analysis of the project, we assume no lags from the end of the project, with benefits beginning in 1991, and remaining at the peak level for 24 years (until 2014). The stream of benefits and costs for the 30-year period from 1985 to 2014 is shown in Table 9. Using a real discount rate of 5.0%, the stream of discounted benefits and costs is also shown. The present value (in 2003 dollars) of the benefits is $A57.2 million, and the present value of the costs is $A3.3 million.

The results of the benefit–cost analysis are as summarised in Table 10. The NPV of the projects is $A53.9 million, the BCR is 17.3, and the IRR 51%. Thus, the analysis shows that the project provided a substantial economic return on the funds expended.

6.5 Sensitivity analysis

The results are likely to be sensitive to changes in a number of the parameter values assumed in the analysis. A sensitivity analysis is presented in Table 10, where the benefit–cost ratios for alternative assumptions for spill-in levels, the impact of training on individuals, length of benefits and discount rates are shown. The results are found to be very sensitive to the extent to which training influences the capacity of the individual, and the length of time that the trainee continues working in the system, as well as the discount rates used. On the other hand, the results are not very sensitive to the level of spill-ins or the length of time of the benefits to the system. Nevertheless, even with less-optimistic values for each parameter, the results indicate that the project provided a significant economic return.

It is also likely that different specification of human capital can lead to significant differences in the results of the benefit–cost analysis (see Brennan and Quade 2004), although those issues are not explored in this report.

Table 9. Stream of benefits and costs to India and Pakistan from rust resistance projects (50% spill-ins)

	Real (2003 dollars)			Discounted to 2003		
Year	Benefits ($A'000)	Costs ($A'000)	Net benefits ($"000)	Benefits ($A'000)	Costs ($A'000)	Net benefits ($A'000)
1985	0	186	–186	0	449	–449
1986	0	112	–112	0	257	–257
1987	0	295	–295	0	644	–644
1988	0	222	–222	0	461	–461
1989	0	239	–239	0	472	–472
1990	0	288	–288	0	542	–542
1991	2,196	263	1,934	3,944	472	3,472
1992	2,196	0	2,196	3,757	0	3,757
1993	2,196	0	2,196	3,578	0	3,578
1994	2,196	0	2,196	3,407	0	3,407
1995	2,196	0	2,196	3,245	0	3,245
1996	2,196	0	2,196	3,091	0	3,091
1997	2,196	0	2,196	2,943	0	2,943
1998	2,196	0	2,196	2,803	0	2,803
1999	2,196	0	2,196	2,670	0	2,670
2000	2,196	0	2,196	2,543	0	2,543
2001	2,196	0	2,196	2,422	0	2,422
2002	2,196	0	2,196	2,306	0	2,306
2003	2,196	0	2,196	2,196	0	2,196
2004	2,196	0	2,196	2,092	0	2,092
2005	2,196	0	2,196	1,992	0	1,992
2006	2,196	0	2,196	1,897	0	1,897
2007	2,196	0	2,196	1,807	0	1,807
2008	2,196	0	2,196	1,721	0	1,721
2009	2,196	0	2,196	1,639	0	1,639
2010	2,196	0	2,196	1,561	0	1,561
2011	2,196	0	2,196	1,487	0	1,487
2012	2,196	0	2,196	1,416	0	1,416
2013	2,196	0	2,196	1,348	0	1,348
2014	2,196	0	2,196	1,284	0	1,284
2015	0	0	0	0	0	0
Total				57,150	3,297	53,853

Table 10. Benefit–cost analysis of rust resistance projects (50% spill-ins)

Present value of benefits	($Am)	57.1
Present value of costs	($Am)	3.3
Net present value	($Am)	53.9
Benefit–cost ratio		17.3
Internal rate of return	(%)	51

Table 11. Sensitivity of results to key parameter assumptions.

	Benefit–cost ratio
Spill-in levels without R&D capacity in region	
30%	18.7
50%	17.3
80%	13.1
Training increases capacity for individuals by (years):	
0.2	7.9
0.5	17.3
1.0	28.4
Trainee continues working for (years):	
5	9.6
10	17.3
15	23.5
Benefits last for (years):	
20	15.7
24	17.3
28	18.7
Discount rates:	
0%	32.9
5%	17.3
10%	10.3

7 Conclusions

The two related ACIAR-funded projects on enhancing the rust resistance of wheat in India and Pakistan led to a number of outputs in those countries and in Australia, in addition to the training of scientists in rust resistance for wheat. Eight scientists came to the National Wheat Rust Control Program at the University of Sydney during the projects to receive detailed hands-on training. Each scientist returned to his own country to put into practice the skills learned in that training. While it is difficult to value the outcomes of such projects, this study has estimated the value of the training received in Australia by Indian and Pakistani scientists.

That training led to increased R&D capacity in rust resistance in both countries, and the higher R&D capacity has in turn increased the outcomes in terms of rust resistance for both India and Pakistan. As a result, both countries have higher levels of rust resistance in place at present than would have been the case without that training. The value of the two ACIAR-funded projects is estimated as the value of the improvement in the levels of rust resistance.

On the basis if the analysis undertaken, those benefits are estimated at $A2.20 million per year. Of those benefits, India receives an estimated $A1.96 million and Pakistan $A0.24 million per year. Given that those benefits are likely to be received until 2014, the present value of the benefits ($A57.2 million) is well in excess of the present value of the project costs ($A3.3 million), giving a benefit–cost ratio for the projects of 17.3. This result indicates that the funds invested by ACIAR in the projects on rust resistance provided a high economic return.

These results are sensitive to the assumptions made in the analysis, particularly the extent and timing of the impact on R&D capacity in India and Pakistan. However, even with the least-optimistic assumptions, the projects gave a benefit–cost ratio of at least 8, indicating a project with robust economic benefits.

Thus, the results provide a useful analysis of the impact of the project, and provide a basis for concluding that such training has been clearly a worthwhile and productive use of funds for agricultural research and development.

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