Economic Analysis of Improving Cold Tolerance in Rice in Australia

Rajinder P. Singh[1], John P. Brennan[2], Tim Farrell[1], Robert Williams[1], Russell Reinke[1] Laurie Lewin[1] and John Mullen[3]

[1]*NSW Agriculture, Yanco Agricultural Institute, PMB, Yanco, NSW 2703*
[2]*NSW Agriculture, Wagga Wagga Agricultural Institute, PMB, Wagga Wagga, NSW 2650*
[3]*NSW Agriculture, Locked Bag 21, Orange, NSW 2800*

Abstract

The occurrence of low night temperatures during reproductive development is one of the factors most limiting rice yields in southern Australia. Yield losses due to cold temperature are the result of incomplete pollen formation and subsequent floret sterility. Researchers have found that in 75% of years, rice farmers suffer losses between 0.5 and 2.5 t/ha. Research is being undertaken to identify overseas rice varieties, that are cold tolerant under the local weather conditions and by using those genotypes as parent material, develop cold tolerance varieties of rice. A yield simulation model was used to measure reduction in losses due to cold at different minimum threshold temperatures, while the SAMBOY Rice model was used to measure the costs and returns of a breeding program for cold tolerance. The results of the economic analysis reveal that new cold tolerant varieties would lead to significant increase in financial benefits through reduction in losses due to cold, and an increase in yield from the better use on nitrogen by the cold tolerant varieties. The returns to investment on the research project are estimated to be high.

Key words: Rice, cold, yield loss, breeding

1. Cold Tolerance in Rice

The rice industry is a major contributor to Australia's agricultural production. Although the Riverina region, located in the South Eastern Australia, is among the highest yielding rice-growing regions in the world, rice production is subject to climatic risk. The occurrence of low night temperatures during reproductive development in rice is one of the principal yield-limiting factors of rice growing in the region. Yield losses due to low temperatures are the result of incomplete pollen formation and subsequent floret sterility. Yield losses occur when the temperature falls to 18° C and lower.

Management strategies such as timely sowing of rice and less than optimal rate of nitrogen application are being followed to minimise the losses due to cold. The most common and effective practice to minimise these losses is increasing the depth of standing water once the rice has reached the panicle initiation stage (Williams and Angus, 1994).

Analysis of the information on long-term weather trends show that the warmest time of the year, from the end of January to early February, has an average minimum temperature of 17° Celsius (Russell Reinke, personal communication). Thus in most years some degree of crop damage and yield losses occurs especially to the rice that is not protected by deep standing water. Deep water (between 20–25cm) is usually 6° to 7° C warmer than the night temperatures, and greatly helps to protect rice from damage at the cold sensitive early pollen microspore stage. Research at Yanco Agricultural Institute revealed that moderate water depth of 15 cm in an average year leads to a yield loss of up to 0.7 t/ha due to cold damage, while in the worst 20% of seasons, yield losses were found to be between 1.5 to 2.5 t/ha.

Under uncertain weather conditions, another strategy to protect the crop from cold damage is to apply nitrogen at less than the optimum level. Although this helps to protect the crop from cold because the plant is smaller and more likely to be protected by water, low nitrogen also leads to low yield.

There is little opportunity to escape cold damage by adjusting sowing time. Sowing time recommendations for varieties of all maturity classes are based on ensuring that the cold-sensitive stage occurs during the warmest period of the season. Therefore, there is a need to incorporate cold tolerance into local Australian rice varieties of all maturity groups.

The Cooperative Research Centre for Sustainable Rice Production is pursuing a multi-faceted approach to understanding the cold tolerance mechanisms present at the plant, organ, cell, protein and genetic level. Research has been undertaken in the CRC Rice funded research project (Project 2201) on “Cold physiology at the plant level” to identify genes responsible for cold damage and to select varieties with increased tolerance to cold. The specific objectives of the research on cold physiology under that project are:

- To test and identify rice varieties brought from overseas which perform better than the Australian varieties under the local weather conditions during the early microspore stage of rice production; and

- Using those genotypes as parent material, to develop varieties that are cold tolerant and at par with the local commercial varieties in terms of yield and quality of the rice grain.

This study reports an economic assessment of the likely benefits and costs of the investment by the CRC and its partners in this research. More specifically, the economic analysis was undertaken with the following aims:

- To measure yield or productivity losses in rice due to cold in different years and at different minimum threshold temperatures;
- To measure the cost of a breeding program for developing cold tolerant varieties; and
- To estimate the returns on R&D investments by incorporating the total costs involved in research and extension and the flow of benefits from the new cold tolerant varieties.

2. Economic Cost of Cold Tolerance

There have been large variations in the area, yield, production and price of rice during recent years. An average of the past 5 years for area, yield and price of rice was used in the analysis. On that basis, the total average area under rice was 154,600 ha, the average price of rice used in the analysis was $208 per tonne, and the long-term yield potential of the rice industry was estimated at 9.3 t/ha.

For most of the rice varieties grown in Australia, the critical temperature for cold damage to occur during the reproductive stage is 18° C (R. Williams, Pers. comm.). However, it is difficult to identify the extent of the losses due to cold temperature from the existing information available on crop yield in different years.

In the absence of precise data on the extent of yield losses to the rice farmers or to the rice industry, researchers at the Yanco Agricultural Institute developed a yield simulation model for Australian rice varieties. The model incorporated weather data from 1955 to 1999 to estimate the extent of yield losses due to cold during this period. Genotypic parameters for the model were developed for the variety Amaroo, using the yield and meteorological data from 1987 to 1999. Amaroo is a medium-grain variety widely grown across the rice belt since its release in 1987. It is a long duration variety of good grain quality with a high yield potential (R. Williams, Pers. comm.). To measure the yield potential and yield losses due to cold damage, the following nine parameters were considered: Time of planting, time of physiological maturity, efficiency of conversion of radiation into yield, sensitivity to low temperature, start of cold sensitivity stage, threshold minimum temperature for cold damage, daily solar radiation data, and daily minimum temperature. The model assumed that yield potential was a function of the daily accumulated-radiation over the study period (Farrell 2001). Simulated yield was worked out by subtracting yield losses based on mid season cold weather conditions from the potential yield (Table 1). Table 1 shows that during the study period, the productivity losses due to cold varied from 0.0 t/ha to 2.5 t/ha with an average yield loss of 0.89 t/ha.

Table1: Observed and simulated grain yield for Amaroo, 1987 to 1999

Year	Observed yield (t/ha)	Simulated yield (t/ha)	Yield potential (t/ha)	Cold loss (t/ha)
1987	6.6	7.4	9.9	2.5
1988	8.1	7.9	10.4	2.4
1989	8.8	9.0	9.5	0.5
1990	9.1	8.4	9.6	1.2
1991	9.8	9.7	10.2	0.5
1992	9.5	8.5	9.4	0.9
1993	8.3	8.8	8.8	0.0
1994	8.8	8.8	9.2	0.4
1995	9.5	9.4	9.9	0.5
1996	6.7	7.1	9.5	2.4
1997	9.0	10.0	10.0	0.0
1998	9.6	9.6	9.8	0.2
1999	9.7	9.7	9.7	0.0
Mean	**8.73**	**8.78**	**9.67**	**0.89**

Source: Farrell *et al.* (2001)

Using this model, we measured the extent of productivity losses due to cold and the probability of occurrence of such weather conditions during the critical microspore development stage over the period 1955 to 1999 (Table 2). We also estimated the probabilities of yield loss that would occur if rice were to become more tolerant by 1 to 3 degrees because of the genetic material introduced from cold tolerant varieties. Table 2 shows that between 1955 to 1999 with the existing levels of threshold temperature the rice industry suffered a maximum loss of 2.5 t/ha once in ten years, whereas in 50% (0.29 + 0.22) of the years the industry suffered yield losses of up to 1.0 t/ha. The analysis further revealed that at the current threshold temperature, the probability of a cold year was 0.73 and that declined to 0.64, 0.40 and 0.27 with the reduction of the threshold temperature by 1°, 2° and 3° C respectively (Table 2).

Table 2: Probability of rice yield losses due to cold at different threshold temperatures

Yield losses	**Probability of yield losses at threshold temperature**			
(t/ha)	***Current***	***Current-1°C***	***Current-2°C***	***Current-3°C***
More than 2.5	0.00	0.00	0.00	0.00
Between 2.0 - 2.5	0.11	0.00	0.00	0.00
Between 1.5 - 2.0	0.02	0.02	0.00	0.00
Between 1.0 - 1.5	0.09	0.07	0.00	0.00
Between 0.5 - 1.0	0.29	0.22	0.09	0.02
Less than 0.50	0.22	0.33	0.31	0.24
Total cold years	33	29	18	12
Total years	45	45	45	45
Probability of cold year	0.73	0.64	0.40	0.27

Source: Estimates from data provided by R. Williams

The results presented in Table 3 show that on average farmers suffered productivity losses from cold of 0.72 t /ha. At recent average price of $208 per tonne this is valued at $150/hectare per year. Using this information and the total area under rice, the study found that on average the rice industry suffers a loss of $ 23 million per year due to cold damage.

Further, the benefits of improving cold tolerance in the local commercial varieties were estimated by reducing the threshold temperature by 1° C steps to 3° C. The results (Table 3) show that cold tolerant varieties would lead to a reduction in losses from $150/ha to $71, $29, and $8 per hectare per year at 1°, 2° and 3° C lower threshold temperature, respectively. In other words a cold tolerant variety with 1° C lower threshold temperature would lead to a gain in productivity of $79 per ha ($150 - $71), whereas new cold tolerant varieties with 2° and 3° C lower thresholds would lead to $121 and $142 gains in productivity per ha, respectively.

Table 3: Productivity losses due to cold damage, from 1955 to 2000

Yield losses	**yield losses at threshold temperature**			
	Current	***Current-1°C***	***Current-2°C***	***Current-3°C***
Average losses (t/ha/yr)	0.72	0.34	0.14	0.04
Value of average losses ($/ha/yr)	150	71	29	8
Average area under rice (000ha)	154.6	154.6	154.6	154.6
Value of total losses ($million/yr)	23.2	10.9	4.5	1.3
Maximum losses (t/ha/yr)	2.5	1.6	0.9	0.3
Value of maximum losses ($/ha/yr)	520	333	188	62

Source: Estimates from data provided by R. Williams

3. Economics of Breeding Cold Tolerant Varieties

3.1 Breeding for cold tolerance

The project "Cold physiology at the plant level" aims to identify cold tolerant rice varieties/genotypes that may be used as parent material by the rice breeders for developing cold tolerant varieties. Approximately 140 varieties of more cold tolerant genotypes (compared to the local varieties) were brought from overseas and tested for their adaptability and performance under the local agro-climatic conditions.

Of those varieties tested, seven genotypes consistently performed better than the Australian cultivars in withstanding low temperatures during the reproductive stage. The results of the experiments revealed that low temperatures lowered the harvest index[1] of the overseas

[1] Harvest index, defined as the ratio of grain yield to total dry matter production, is an indicator of the effect of cold temeperatures.

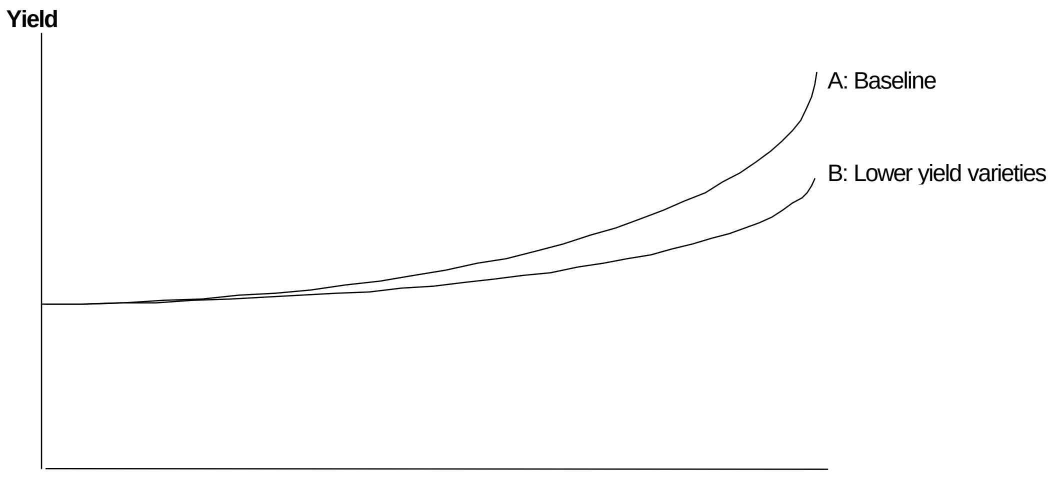
varieties by an average of 20% compared to 50% for the typical Australian cultivars (Farrell and Williams, 2001). But the yield and quality of those varieties are low compared to the local commercial rice varieties. Hence the intent of a breeding program is to use the cold tolerance genes of the overseas varieties with well-adapted local varieties to develop new varieties that combine cold tolerance with high yield and grain quality.

Progress in plant breeding depends on the number of lines and the probabilities of identifying a line with superior yield (or other characteristics) compared to the current varieties. Any reduction in numbers caused by selecting for an additional characteristic will reduce the probability of finding such a superior line for release, unless additional resources are made available to expand the number of lines in the earlier stages of the program. As the lines are brought through the stages of the program, any reduction in numbers at one stage of the program impacts on the likely numbers and the characteristics of the materials flowing through to the subsequent stages of the programs in the following years. Thus, the impact of adding another selection character will be felt through the impact on the flow of new varieties released over a number of years.

The impact of slowing the rate of varietal yield improvement in non-cold years is illustrated in Figure 1. Without the additional selection for cold tolerance, the value of rice production would progress along line A. With the additional selection, the slower rate of progress in yield potential (line B) is followed. The cost to the industry in terms of the loss of progress in yield potential is the difference between the two lines.

The benefits of selection for increased cold tolerance in rice need to be compared with those costs. As selection is made for increased cold tolerance, costs from susceptibility to cold fall because of the saving in yield losses in cold years. The key question addressed in this analysis is the extent to which the benefits of improved cold tolerance are greater than the losses imposed by the reduced selection for, and thus slower progress with, yield potential.

Figure 1: Impact of Slowing in the Rate of Varietal Improvement



The analysis of the breeding for improved cold tolerance was made using the SAMBOY-rice model (Brennan, Singh and Lewin, 1997). The model was modified to focus only on medium-grain rice, and the costs were adjusted by the Consumer Price Index to convert them from 1994 to 2002 values. Specific data and assumptions used in the analysis of medium-grain rice are given in Table 4.

Table 4: Data and assumptions used in analysis of different breeding programs

Parameter	Value
Average area under medium grain rice (ha)	108400
Average yield of medium grain rice (t/ha)	9.36
Average production of medium grain rice (million t)	1.02
Average price of rice ($/t)	208
Accounting period (years)	32
Discount rate (%)	7

These parameters and assumptions were used to measure the value of the breeding programs. The model was initially run using these industry parameters for the current selection program, without any specific selection for cold tolerance to work out cost of breeding program for yield improvement only (the “baseline” run). The model was then run with selection for cold tolerance included, to work out cost of breeding program for yield improvement and selection of cold tolerance. These results were compared to those of the “baseline” run to find out the additional cost of the breeding program with selection for cold tolerance. The following assumptions were made:

- Testing for cold tolerance is undertaken in a glasshouse at F_3 stage
- The best 50% of lines for cold tolerance were selected following that evaluation
- The cost of testing 3,000 lines per year for cold tolerance is $61,000
- As 50% of lines were discarded (because of cold tolerance) after F_3, fewer lines progressed through the later stages of the program
- As a result, it takes longer to develop a variety with the same yield advantage (5%) in non-cold years as in the baseline program.
- The first cold tolerant variety would be released in 2013, one year later than the equivalent non cold tolerant variety. Subsequent varieties with cold tolerance will achieve 5% yield gains every 9 years compared to every 6 years for non tolerant varieties
- This selection program for cold tolerance would lead to 1° C[2] reduction in the minimum threshold temperature.

The results of the simulation model were used to measure the potential benefits from developing a variety that could withstand cold temperature 1° C below the current minimum threshold temperature for the existing varieties. In Table 5, the average annual benefits from developing a medium grain variety of rice that could withstand cold temperature 1° C less than the current threshold are 0.38/ha, which at the current price of rice of $208/t are valued at $79/ha/year. In any year the benefits are $79/ha times the area under cold tolerant varieties.

[2] This is judged by the breeders to be achievable. Larger reductions in the minimum threshold temperature may be possible, but would require additional resources and involve greater time lags, and may not even be feasible given current resources and genetic materials without affecting yield and quality.

The total annual benefits from reduced cold losses for medium grain rice would depend on adoption of the new cold tolerant variety.

Table 5: Average benefits from breeding a medium grain rice variety with improved cold tolerance

Measure	Value
Yield losses at current minimum threshold (t/ha/year)	0.72
Less yield losses at 1° C lower than threshold temp. (t/ha/year)	0.34
= annual benefit with reduction of 1° C threshold (t/ha/year)	0.38
Average price of rice ($/t)	$208
Annual value of benefits ($/ha/year)	$79

3.2 Impact on productivity gains from breeding program

The breeding program, whether or not it includes selection for cold tolerance, leads to an increase in yield. The value of a 5% productivity gain from the breeding program is shown in Table 6 as $98 per hectare. Where there is no selection for cold tolerance, this increase can be achieved in approximately six years. Where selection for cold tolerance is incorporated into the program, this increase can only be achieved in nine years.

Table 6: Value of productivity gains from medium-grain rice breeding program

Measure	Value
Average yield of the existing varieties (t/ha)	9.36
Yield of a new improved variety (t/ha)	9.82
Increase in yield (t/ha)	0.47
Value of increase in yield ($/ha)	$98

3.3 Benefits from additional use of nitrogen with cold tolerance

Currently most rice farmers apply less than optimal levels of nitrogen to minimise cold damage. The new cold tolerant varieties would help growers to increase the use of nitrogen to optimum levels which would further increase crop yields by at least 5%
(L. Lewin, Pers. comm.). Benefits from the increase in yield from the additional use of nitrogen are estimated to be $84 per hectare (Table 7).

Table 7: Productivity gains from additional use of nitrogen in cold tolerant rice varieties

Measure	Value
Increase in use of nitrogen (kg/ha)	25
Cost of nitrogen used ($/t)	$14
5 % increase in yield (t/ha)	0.47
Value of increased yield ($/ha)	$98
Net value from additional nitrogen use ($/ha)	$84

3.4 Impact on cost of breeding new varieties

Using the SAMBOY-Rice model, the costs involved in developing a medium grain variety both for existing breeding program and the breeding program with selection of cold tolerance have been estimated (Table 8). The costs are $6,414 higher where there is selection for cold tolerance. In addition, the time required to release a variety with 5% yield increase would be 6 years under existing breeding program and 9 years with selection of cold.

Table 8: Annual costs of breeding a medium grain cold tolerant rice variety

Measure	Value
Cost of breeding cycle of existing breeding program	$186,912
Cost of breeding cycle with selection of cold tolerance	$193,326
Increase in cost of breeding cycle	$6,414

4. Estimating the Benefits of the Project

The economic analysis was undertaken to measure the returns from the development of cold tolerant rice varieties, and to provide a basis for establishing priorities for research in rice. Benefit-cost analysis was used to compare the potential benefits arising from new cold tolerant varieties with the costs of the research to develop such varieties. The criteria used include the Net Present Value of the project (NPV), the Benefit-Cost Ratio (BCR), and the Internal Rate of Return (IRR).

4.1 Key Assumptions

To undertake a benefit-cost analysis of the project, the benefits estimated above have to be scaled up to reflect the rate and extent of adoption of the technology, lags in the development and adoption of the technology and an estimate of when the technology will become obsolete. The impact of new technologies can be spread over many years. Since it takes a long time to develop a new variety, in this analysis, the period over which benefits and costs of the proposal were accounted for was 32 years; that is, from 2002 to 2034. After 2034 it is anticipated that the technology used to develop such varieties would be replaced by new technology from future research and development.

For the purposes of this analysis, the benefits of the project are defined as follows:

Benefits = benefits from reduced cold losses,
less the cost of a slower rate of yield improvement,
plus net benefits from additional nitrogen that can be used with cold tolerant varieties
less additional costs of breeding cold tolerant rather than non-tolerant varieties.

As low temperature prior to flowering is one of the most serious issues in sustainable growth of rice, adoption of the new cold-tolerant rice varieties would be faster and higher compared to the non cold-tolerant varieties of rice. Our assumption is that a cold tolerant variety's adoption reaches a peak of 40% of the area in 4th year after release and stay at the same level until a new variety is released and then declines for the following seven years (Table 9).

Further we assumed that a new variety in the base line scenario would be available every 6 years whereas a cold tolerant variety would be released every 9 years. As each new variety is released yields increase by five percent per year. In discounting, all benefits and costs were expressed in 2002 dollars, which required past expenditures to be expressed in real 2002 dollars, then compounded forward at the discount rate to 2002, while all future returns and costs were discounted to 2002. We assumed that Australia is a price taker in the world rice market and hence changes in production in Australia as a result of this new technology will have no effect on world price.

The information given in Table 9 illustrates how we estimated the stream of benefits and costs over time. A new medium grain cold tolerant variety with one degree C increase in cold tolerance would lead to total annual potential benefits of $10555, $8570 and $9108 thousand from yield increase, reduction of losses due to cold and productivity gains from additional use on N respectively. We measured flow of benefits taking into account the rate of adoption and time lags in development and adoption. These benefits and costs were then discounted at 7% discount rate, to get net present value of benefits and costs as shown in Table 11.

Table 9: Flow of Benefits from Breeding for Tolerant Varieties

	Current Breeding Program						Cold Tolerance Breeding Program								Net benefits of breeding for tolerance
	Adoption %					Benefits from yield improvement	Adoption %				Benefits from:				
Year	1	2	3	4	Total		1	2	3	Total	Yield improvement	Cold tolerance	Nitrogen use	Total	
2002															
2003															
2004															
2005															
2006															
2007															
2008															
2009															
2010															
2011															
2012															
2013	5				5%	528									-538
2014	11				11%	1161	11			11%	1161	943	1002	3106	1945
2015	22				22%	2322	22			22%	2322	1885	2004	6212	3889
2016	31				31%	3272	31			31%	3272	2657	2824	8753	5481
2017	31				31%	3272	40			40%	4222	3428	3643	11294	8022
2018	31				31%	3272	40			40%	4222	3428	3643	11294	8022
2019	26	5			31%	3800	40			40%	4222	3428	3643	11294	7494
2020	24	11			35%	4855	40			40%	4222	3428	3643	11294	6438
2021	15	22			37%	6227	40			40%	4222	3428	3643	11294	5066
2022	9	31			40%	7494	40			40%	4222	3428	3643	11294	3800
2023	7	31			38%	7283	31	11		42%	5594	3600	3825	13020	5737
2024	5	31			36%	7072	20	22		42%	6765	3600	3825	14181	7109
2025	4	26	5		35%	7494	11	31		42%	7705	3600	3825	15131	7636
2026	3	24	11		38%	8866	5	40		45%	8972	3857	4099	16928	8061
2027	2	15	22		39%	10344	4	40		44%	8866	3771	4008	16645	6301
2028	1	9	31		41%	11822	3	40		43%	8761	3685	3916	16363	4541
2029		7	31		38%	11294	1	40		41%	8550	3514	3734	15798	4504
2030		5	31		36%	10872	0	40		40%	8444	3428	3643	15516	4644
2031		4	26	5	35%	11188	0	40		40%	8444	3428	3643	15516	4327
2032		3	24	11	38%	12877	0	31	11	42%	10027	3600	3825	17453	4576
2033		2	15	22	39%	14460	0	20	22	42%	11188	3600	3825	18614	4153
2034		1	9	31	41%	16149	0	11	31	42%	12138	3600	3825	19564	3414

4.2 Expenditure on research associated with the cold tolerance project

The analysis considered both direct expenditure by the Rice CRC on research and the in-kind contributions from NSW Agriculture to the project over the five-year period from 1997-98 to 2001-02. All the costs were expressed in 2002 dollars after inflating expenditure in early years by the Consumer Price Index (Table 10). The expenditure by the CRC was 61% of the total expenditure of $1.37 million over the five years of the project.

Table 10: Cash and In-kind Expenditure on the Cold Tolerance Project

	Project Expenditure		
Year	**CRC**	**In-kind**	**Total**
1997-98	$21,774	$106,174	$127,948
1998-99	$207,708	$147,005	$354,714
1999-00	$201,238	$108,766	$310,003
2000-01	$198,441	$113,420	$311,861
2001-02	$202,657	$61,000	$263,657
Total	**$831,818**	**$536,365**	**$1,368,183**

4.3 Benefit-Cost Analysis Results

The results of the benefit-cost analysis of the project are shown in Table 11. The results indicate that the Net Present Value (NPV) of the program, which is expected to increase cold tolerance by 1° C, is $26.6 million with a Benefit-Cost Ratio of 17 and an Internal Rate of Return of 22%.

Table 11: Results of Benefit-Costs Analysis of the Cold Tolerance Project

Measure	**Results**
Present value of benefits ($000)	28,215
Present value of costs ($000)	1,663
Net Present Value ($000)	26,552
Benefit-cost ratio	17
IRR (%)	22%

Therefore, even at conservative assumptions about the likely adoption of cold-tolerant varieties, the project has a high economic return. The incorporation of selection for cold tolerance, which can now be undertaken as a result of this project, is a profitable change for the breeding program. Selection for cold tolerance in the rice breeding program would increase the net returns to the breeding program, and lead to substantial benefits to the industry.

5. Conclusions

Low temperature, prior to flowering, is one of the most serious issues for sustainable growth of rice industry. In 75% of the years, rice farmers suffer losses ranging from 0.5 to 2.5 t/ha. To protect the rice crop from cold damage, most farmers apply nitrogen at less than the optimum level. The aim of the Rice CRC funded project on cold tolerance was to test overseas genotypes under local weather conditions, to identify varieties that are more cold tolerant than the local varieties. Using those genotypes as parent material, initially the rice breeders would develop cold-tolerant varieties of medium grain rice. The new cold-tolerant varieties would not only lead to reduction in yield losses due to cold but would also help to increase yield from better use of nitrogen.

A simulation yield model was used to measure reduction in losses due to cold at different minimum threshold temperatures, while the SAMBOY Rice model was used to measure the costs and returns of breeding programs both with and without the selection for cold program. The results of the economic analysis show that a 1° C increase in cold tolerance expected from the current project leads to a significant increase in financial benefits through reduction in losses due to cold, and an increase in yield from the better use of nitrogen. If the breeders were able to develop varieties that could withstand cold conditions 2° to 3° C below the current threshold, the returns to investment on the project could be expected to be even higher.

Thus, the Rice CRC project on cold tolerance, by enabling these advances to be incorporated into the rice breeding program, is likely to produce a high return on the funds invested in it.

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