Economic Impact Analysis of Marker-Assisted Breeding in Rice

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(ABSTRACT)

Abiotic stresses such as salinity and phosphorous (P) deficiency are major yield-limiting factors for rice, particularly on marginal lands. Marker-aided backcrossing (MAB), enabled by advances in genomics and molecular mapping in recent years, is said to be a more precise, time-saving, and cost-effective way to develop rice varieties that can withstand these abiotic stresses than conventional breeding. The study employs the economic surplus approach to measure the benefits of MAB for salinity tolerance in rice for Bangladesh, India, Indonesia, and Philippines, and for rice with tolerance to P-deficient soils in Indonesia. At a 5% discount rate, the benefits over 15 years of planting salt-tolerant varieties amount to $226.9 million in the Philippines, $3.666 billion in Bangladesh, $4.848 billion in India, and $895.7 million in Indonesia. The gains from growing varieties that can withstand P deficient soils in Indonesia amount to $2.070 billion. The incremental benefits from completing the salt-tolerant and P-deficient tolerant breeding cycles 2 years earlier are $340.5 million in Bangladesh and $192.1 in Indonesia, respectively. In India, $227.0 million is gained even if MAB develops salt-tolerant varieties just a year earlier. The additional gains from completing the salt-tolerant rice breeding cycle 4 years earlier are $40.3 million in the Philippines and $158.9 in Indonesia. In general, the gains from saline- (Bangladesh, Indonesia, Philippines) and P-deficient (Indonesia) tolerant rice are reduced by 5%, 9%, 14%, and 18% when MAB breeding cycle is delayed by one, two, three, and four years, respectively. In India, there is 3%, 7%, 10%, and 13% loss in benefits from salt-tolerant rice for every additional year of delay in the MAB breeding cycle.

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The best family one could ever ask for

Chapter 1: Introduction

1.1 Background of the Study

Abiotic stresses such as salinity and phosphorous (P) deficiency are major yield-limiting factors for rice, particularly on marginal lands. In Asia alone, more than 12 million hectares are currently affected by salinity (Ismail et al. 2004), while about 20 million hectares across Asia, Africa, and Latin America are P-deficient (IRRI 2000).

There are two types of salinity – coastal and inland. Coastal salinity occurs due to tidal intrusion of seawater in rice lands, while inland salinity is caused by the excessive use of irrigation water from river streams or canals where salts have accumulated. In both cases, the salts are carried into the rice plant's root zone and then are left behind after most of the water evaporates. When the salt concentration increases, the osmotic pressure of the soil solution rises slowing down the movement of water from the soil to the roots (Abrol, Yadav, and Massoud 1988). This renders less water available to rice resulting in poor and spotty stands, uneven and stunted growth, and poor yields (Abrol, Yadav, and Massoud 1988). Besides causing extensive yield losses, the International Rice Research Institute (IRRI) reported that salinity leaves millions of hectares in the humid regions of South and Southeast Asia technically suited for rice production uncultivated.

P, one of the macronutrients rice needs, is also one of the most unavailable and inaccessible (Vance et al. 2003). This nutrient plays a vital role in numerous activities such as energy transfer, photosynthesis, nutrient transport, sugar metabolism, and reproduction (http://www.agrium.com). Adequate P results in higher grain production, improved quality, greater stalk strength, increased root growth, and earlier crop maturity (http://pubs.cas.psu.edu/FreePubs/pdfs/uc055.pdf). P deficiency is frequently not due to low soil-P content in absolute terms but due to tight binding of soil-P in forms that are not readily available to the plant (Wissuwa 2005). Many soils in rice-growing areas have high P-fixing capacity (Wissuwa et al 1998), hence only 10-20% of the P supplied in fertilizers is available to plants, while the rest are being bound in the soil mainly to iron and aluminum (Wissuwa et al. 1998). Apparently, this soil binding explains why inorganic fertilizer application can not totally solve the problem.

Several ways to reclaim and manage saline soils include removing the salts that have accumulated on the soil surface by mechanical means (scraping), washing away the surface accumulated salts by flushing water over the surface (flushing), and ponding fresh water on the soil surface and allowing it to infiltrate (leaching) (Abrol, Yadav, and Massoud 1988). However, these management practices are often ineffective and impractical. The scraping method, resorted to by many farmers, has limited success because although this method might temporarily improve crop growth, the ultimate disposal of salts still poses a major problem (Abrol, Yadav, and Massoud 1988). Similarly, because the amount of salts that can be flushed from a soil is rather small, the flushing method does not have much practical significance (Abrol, Yadav, and Massoud 1988).

Applying fertilizer to remedy P deficiency is not very effective. Moreover, farmers are constantly facing financial difficulties with increasing fertilizer costs, especially in developing countries (Wissuwa et al. 1998). The non-renewable nature of inorganic P fertilizers also means that cheap P sources, such as phosphate rocks, will be exhausted within the next 60-90 years (Runge-Metzger 1995). There are also concerns that excess P added to soil can pollute local watercourses, contributing to the process of eutrophication (Withers, Edwards, and Foy 2001).

Since soil amendments are expensive and impractical for poor farmers who often farm in these marginal areas, scientists have devoted their efforts to developing varieties that could thrive in salt-affected soils and varieties capable of using a higher portion of the fixed P already present in soils. However, conventional breeding typically requires 12-15 years from initiation to varietal release. Also, the complexity and polygenic nature of tolerance traits[1] make abiotic stresses difficult problems to solve through conventional breeding because of "linkage drag", i.e. undesirable traits accompany desirable ones during backcrossing. Thus, scientists have turned to marker-assisted backcrossing (MAB) to develop rice varieties with tolerance to saline and P-deficient soil. DNA molecular markers for these traits are now available and molecular rice breeders are in a position to use MAB to selectively incorporate quantitative trait loci (QTL)[2]/genes into existing popular rice varieties in Asia. MAB, enabled by advances in genomics and molecular mapping in recent years, is potentially more precise (reduce linkage drag), time-saving, and cost-effective. Through these modern molecular tools, the genetic basis of tolerance can be unraveled, and tolerance genes can be tagged and traced in the breeding process.

Scientists working on the Generation Challenge Program (GCP) Project 2 entitled "Revitalizing marginal lands: discovery of genes for tolerance to saline and phosphorus deficient soils to enhance and sustain productivity" are currently in the last stages of fine-

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[1] Tolerance for abiotic stresses such as salinity, nutrient deficiency, acidity, aluminum toxicity, submergence, and extreme temperature are quantitative traits. Quantitative traits are controlled by several genes (polygenes or quantitative trait loci). In contrast, resistance to pests and diseases are qualitative and monogenic (controlled by a single gene) traits, and hence straightforward breeding targets (Islam 2004; Shannon 1985; Yeo and Flowers 1986 as cited by Niones 2002).

[2] Quantitative trait loci (QTL) are the regions within genomes that contain genes associated with a particular quantitative trait (Collard et al. 2005).

mapping the location of *Saltol* (gene that confers salinity tolerance), and *Pup1* (gene that improves phosphorus uptake). Therefore, rice varieties with tolerance to saline and P-deficient soils are potential near-term economically useful products that could be subjected to ex-ante analysis.

1.2 Problem Statement

There is growing concern that breeding efforts directed only at favorable areas will not provide sufficient breakthroughs to shift the yield frontier, or to reduce poverty in marginal areas. The yield potential of recently released modern inbred varieties (9-10 tons/ha) is the same as that of IR8, the first high yielding variety in 1965 - a palpable evidence of yield stagnation (Peng et al. 2004). To make matters worse, there is pressing need to expand to unfavorable farm lands amidst growing population and urbanization as arable lands have been on the decline to accommodate increasing demand for housing, commercial, and infrastructure development (Hossain 2002). Until now, the majority of rice R&D programs were primarily concentrated in developing modern varieties and management practices for favorable areas because it was hoped that this would achieve greater impacts even on the poor as product and factor market adjustments might counter balance the negative first round distributional effects (David and Otsuka 1994). Studies have shown however that many of the poorest farmers in fragile environments have not been reached. Given these concerns, it is sensible that revitalization of marginal rice lands has begun to receive considerable attention in recent years. Organizations such as IRRI have devoted roughly twice as many resources to fragile environments as compared to favorable environments in recent years (Hareau et al. 2004). Even in modern agricultural biotechnology, it is foreseen that the development of tolerance to abiotic stresses is where the largest impacts may be expected (Hareau et al. 2004). In other words, gains would be greater from rice biotechnology research if it were directed to addressing abiotic constraints in unfavorable rice growing ecosystems.

There is debate on how to strike a balance between research on favorable and unfavorable environments, and arguments arise in determining the optimal research portfolio in public rice research and development (R&D). One major criterion considered in decision-making is product delivery, and hence an important input to decision making is information on potential returns from investments and impact pathways of rice R&D outputs (CGIAR 1998).

So far, little economic analysis has been undertaken to assess the potential impacts of utilizing MAB, even for a major crop such as rice. If the breeding process can be reduced even by just a few years, the potential gains would be significant, with many of the benefits going to the poorest farmers. Production would increase on unfavorable lands and additional areas might be brought into production. Higher production would translate into larger profits and poverty alleviation. However, molecular breeding also requires resources, and effort spent targeting traits for marginal rice lands may be effort diverted from breeding for favorable rice environments. Clearly, there is opportunity cost involved. Hence, economic impact analysis is needed to assist in designing an optimal breeding portfolio and to determine if the breeding program is worth the investment.

1.3 Objectives

The purpose of this study is to carry out an ex-ante economic impact assessment of developing rice with tolerance to saline and P-deficient soils through MAB. The goal is to project total economic benefits of marker-assisted breeding for:

(1) salinity tolerance in rice for Bangladesh, India, Indonesia, and Philippines; and

(2) rice with tolerance to P-deficient soils in Indonesia.

1.4 Research Hypothesis

The study has two research hypotheses. These are:

1. The economic benefits of using marker-assisted backcrossing to develop rice varieties with tolerance to saline soils in Bangladesh, India, Indonesia, and the Philippines, and P-deficient soils in Indonesia outweigh the costs.
2. The economic benefits of using marker-assisted backcrossing to develop rice varieties with tolerance to saline soils in Bangladesh, India, Indonesia, and the Philippines, and P-deficient soils in Indonesia are higher than those from conventional backcrossing since the former method shortens the breeding cycle that leads to earlier varietal release.

1.5 Overview of methods used

The study employs the economic surplus approach to measure the economic benefits of MAB for salinity tolerance in rice for Bangladesh, India, Indonesia, and Philippines, and for rice with tolerance to P-deficient soils in Indonesia. These are the countries where these abiotic problems are especially severe and where IRRI is undertaking research in collaboration with national research systems. The net present value (NPV) and the internal rate of return (IRR) of the welfare gains are estimated through cost-benefit analysis. The benefits of reduced breeding years and earlier varietal release are determined by comparing the gains of using marker-aided backcrossing versus conventional backcrossing to develop the tolerant varieties. The study also determined the change in net benefits if abandoned rice lands due to severe salinity were brought into production. Sensitivity analysis is performed to determine the change in benefits resulting from uncertainty of critical variables namely adoption rate, percent yield increase, own-price elasticity of supply, rest-of-the-world elasticity of demand, and discount rate.

1.6 Organization of thesis

The technology impact pathway and review of literature is presented in Chapter 2. Chapter 3 discusses the methods and assumptions used in the analysis. The results are reported in Chapter 4. The summary and conclusion, along with the limitations of the study and opportunities for future research, is tackled in Chapter 5.

Chapter 2: Technology Impact Pathway and Literature Review

This chapter discusses the technology impact pathway and potential benefits in order to have more understanding of the varieties being developed, likely timing of commercial release, and intended geographic area of impact. A review of past ex-ante studies on agricultural technologies and a valuation study of shorter breeding for rice are also presented in this chapter.

2.1 Technology impact pathway

The technology impact pathway is constructed based on proposals, annual reports, and publications out of the GCP Project 2 "Revitalizing marginal lands: discovery of genes for tolerance of saline and phosphorous deficient soils to enhance and sustain productivity" were reviewed. The project's main objective is to develop rice varieties that are tolerant to salinity and P-deficiency by: (1) discovering genes associated with *Saltol* and *Pup1* QTL, and (2) developing a marker system to incorporate the QTLs into popular varieties using marker-aided backcrossing (MAB). Figure 1 chronicles how earlier studies, in terms of IRRI's initiative, discovered and fine-mapped the location of *Saltol* and *Pup1*. These past research achievements paved the way for the GCP project. Other contributing factors that ushered the GCP project are the development of DNA markers, and the completion and availability of the full rice genome. The GCP project aims to emulate the success of isolating and breeding the *Sub1* gene into popular varieties. *Sub1* confers submergence tolerance allowing some rice plants to survive completely underwater for up to 2 weeks. In addition, the future activities that are related with the project, such as gene pyramiding and making rice to be salt-tolerant during reproductive stage, are also highlighted (Figure 1).

2.1.1 Identification and Fine-mapping of *Saltol* and *Pup1*

In 1993, IRRI developed IR66946, a cross between two *indica* rice varieties: the salt-tolerant traditional tall variety Pokkali and the elite but salt susceptible IR29 (Figure 1). Since then, traditional rice lines with high levels of salt tolerance have been used in conventional backcrossing programs to develop high-yielding salt-tolerant elite varieties (Ismail et al. forthcoming).

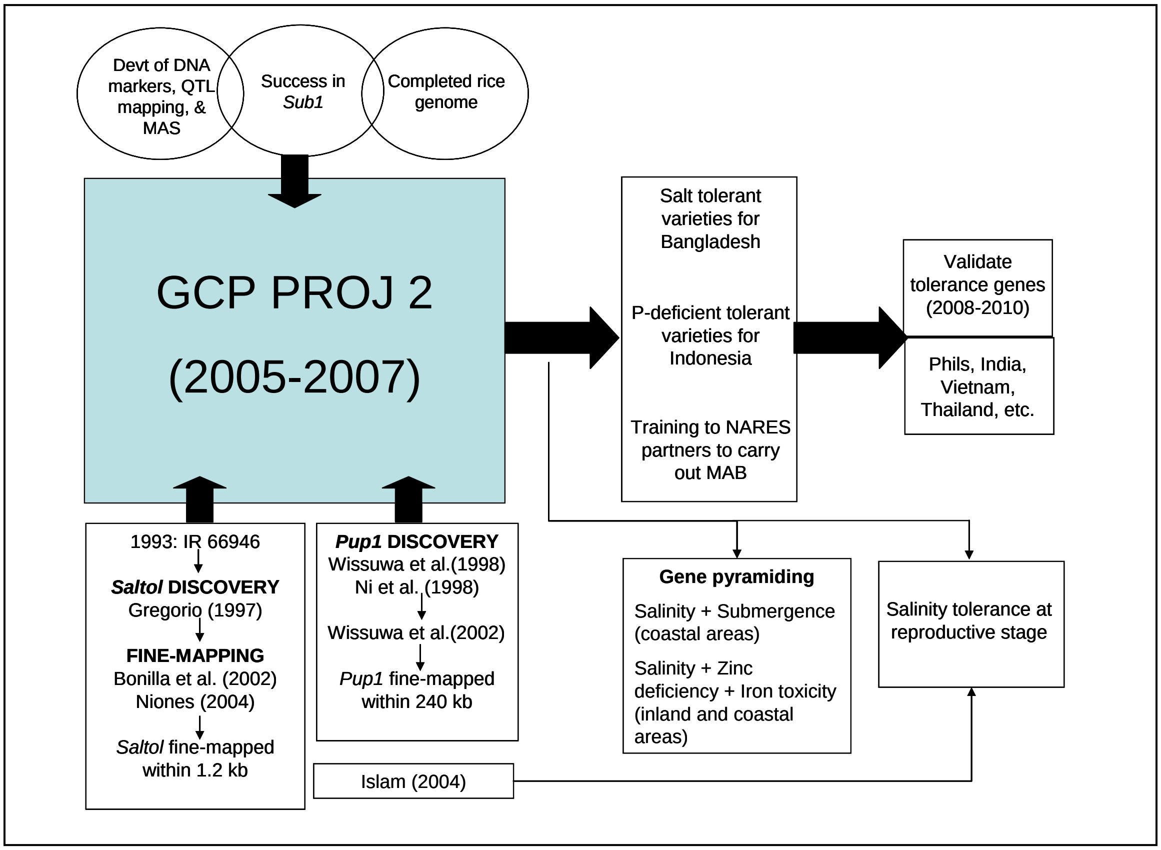

Figure 1. Previous research endeavors and future projects related to GCP Project 2

A drawback with conventional backcrossing is the length of time to develop a new variety. Six to eight backcrosses are typically needed, which translates to approximately 3-4 years (1 generation = 1 season of planting; 1 year = 2 backcross generations) of breeding work. There is no absolute number for how many backcrosses are needed (Collard and Mackill, in press), and sometimes it takes 10-15 years to develop a variety.

Another obstacle is the occurrence of “linkage drag”, wherein undesirable genes included in the chromosomal region where the target gene is located are “dragged” when the target gene is transferred into the popular variety. These unwanted genes from the donor parent might negatively affect the performance of the popular variety. Linkage drag requires many additional backcross generations, and if the undesirable genes are really tightly linked to the target locus, then it may be extremely difficult to eliminate these genes using conventional backcrossing (Collard and Mackill, in press).

The breeding efforts to develop salt-tolerant rice varieties are also seriously limited by the complexity and polygenic nature of the salt tolerance trait (Singh, Gregorio, and Jain 2007). Unlike the *Sub1*, which is a single gene, salinity tolerance is a quantitative trait controlled by many genes. Hence, accurate phenotypic identification of salt-tolerant lines is difficult because it is heavily affected by environmental variation that prevents evident expression of the trait. Indeed, being governed by two or more genes that significantly interact with the environment, the heritability of salt tolerance is a low 19.18% (Islam 2004). Consequently, tolerance of the breeding lines is not as high as that of the traditional donor parents such as Pokkali (Ismail et al. 2007). Thus, selection for salinity-tolerant genotypes of rice based on phenotypic merits alone is less reliable and delays breeding progress (Islam 2004).

Fortunately, advancement in genomics, development of markers, and molecular mapping in recent years have provided new tools for molecular dissection of complex traits such as salinity tolerance (Singh, Gregorio, and Jain 2007) (Figure 1). Moreover, after the completion of the sequencing of the rice genome with more than 99% accuracy, 18,838 new class I SSR markers were reported on its physical map, which has opened the flood gates to enormous avenues for the rice QTL/gene mapping (IRGSP 2005). These developments have led to understanding of stress perception/responses, enabled rapid discovery of genes/QTLs specifically involved in tolerance to salinity and P deficiency, and will permit molecular designing of crops that can withstand saline and P-deficient soils (Singh et al. forthcoming). Molecular markers are used for linkage mapping of stress-tolerant genes/QTLs, and then in transferring or even pyramiding these genes/QTLs into already proven, popular varieties (Singh, Gregorio, and Jain 2007). Moreover, these developments gave rise to marker-aided backcrossing, which allows efficient selection and effective breeding leading to quicker variety release and higher farmer adoption.

The mapping program for salinity tolerance at IRRI was initiated by Gregorio (1997). He was able to map a common quantitative locus for salinity tolerance at chromosome 1, which is now known as *Saltol*. *Saltol* confers tolerance at the seedling stage, which is important for good crop establishment in coastal areas, where river water is brackish early in the wet season before the rains weigh in (Fredenburg 2006). Gregorio’s research prompted many other studies, including Bonilla et al. (2002) and

Niones (2004), to fine map the *Saltol* QTL and identify the precise location of the *Saltol* gene on chromosome 1. These later studies successfully reduced the length of the *Saltol* linkage map. It is very important to reduce the size of the donor chromosome segment containing the target locus to avoid the "linkage drag". The shorter the chromosomal region, the less occurrence of linkage drag.

For phosphorus deficiency, Wissuwa et al. (1998) and Ni et al. (1998) detected the major QTL *Pup1* in chromosome 12, which improves the plant's uptake and capability to extract higher proportion of fixed P in the soils. Physiological studies suggest that the *Pup1* gene is expressed in root tissue where it either leads to higher root growth per unit P (higher internal efficiency) or improves P uptake per unit root size (external efficiency) (Wissuwa 2003). Wissuwa et al. (2002) mapped *Pup1* with higher precision and certainty and by the start of the GCP project, the length of the *Pup1* linkage map is manageable.

In summary, the GCP project benefited from the excellent progress made in understanding the physiology of salinity and P deficiency tolerance, and in the earlier efforts of fine-mapping *Saltol* and *Pup1*. By reducing the length of the QTL regions, the focus is limited to fewer genes in the regions, thereby accelerating the process of gene discovery. Likewise, the purpose of fine-mapping the QTL loci is to reduce linkage drag, that is, to reduce the chances that the new lines will have unfavorable traits from the donor variety. The finer the mapping they do, the greater the certainty that they have the gene, and therefore, the smaller part of the chromosome they have to take.

2.1.2 Success in mapping and introgressing *Sub1A* gene that confers submergence tolerance to rice

Prior to the salinity and P-deficiency research, a MAB project on submergence tolerance gene *Sub1* was completed. The single gene that controls for the submergence trait was located and was successfully introgressed to popular varieties by BC_3F_2, allowing some to survive under water for 2 weeks. This is the first successful case of molecular breeding for abiotic stress. GCP Project 2 is along the way toward repeating this success with *Saltol* and *Pup1*.

2.1.3 GCP Project 2

The project primarily aims to breed *Saltol* into at least one aman (wet) season variety boro (dry) season variety already popular with farmers in Bangladesh (Fredenburg 2007). Another major goal is to transfer *Pup1* to at least two popular upland varieties in Indonesia.

Aside from gene discovery, the project aims to develop a marker system to incorporate QTLs/genes into popular varieties through MAB. This is primarily because varieties are specific to each country and it would be a colossal task for the project to develop varieties for every country. By developing markers which are optimized for specific varieties and tested for compatibility with recurrent parents, and transferring the marker system to partners in national agricultural research and extension systems (NARES), local scientists would be able to carry out the MAB themselves, and incorporate the tolerance traits to whichever variety they would like. Hence, at the conclusion of the GCP project, the MAB package, which includes the markers (foreground, flanking, and background) and the donor parents (i.e. IR64*Saltol*), will be transferred to NARES in target countries such as the Philippines, Bangladesh, India, and Indonesia. The markers are already optimized and tested for compatibility for specific popular local varieties (recurrent parent) enabling these local institutions to save resources. The breeding work will be shortened since scientists don't need to develop a new saline variety from scratch. Moreover, they ensure that the original popular variety is maintained so that there would be higher rate of farmer adoption. Another component of the GCP project is to train and strengthen the capacity of scientists through degree and non-degree training so that they will successfully incorporate the tolerant genes into their local varieties.

A major requirement before approval and release in farmer's fields is testing the varieties via experiment stations and on-farm trials. In fact, a new project proposal is to test and validate BR28 with NARES and to bring the variety to farmers' fields in Bangladesh. The project is expected to run for 3 years (2008-2010). This endeavor is also expected to serve as example and motivation for the development and release of the improved varieties in India, Philippines, and other rice growing countries.

2.1.4 Future activities related with GCP Project 2

While the above activities are going on, the project continues with further fine mapping to emulate the success with submergence tolerance. Once they are able to identify a single gene (or small set of 2-5 genes) controlling the salinity and P-deficiency tolerance, they can look for other favorable traits such as submergence tolerance, zinc deficiency, and iron toxicity to combine with it. This combining of genes is known as gene pyramiding, which would be a future endeavor (Figure 1). It is important to combine the two traits because large areas of lowland rice have short term submergence and even favorable areas have short-term flooding problems in some years (Mackill ppt). The implication is that when the tide comes in coastal areas, rice is submerged until the tide recedes (Dr. Randy Barker, personal communication).

It was mentioned earlier that the focus of the studies before GCP 2 and of GCP 2 itself, is to develop the salt tolerance during seedling stage, rice's most sensitive stage under salt stress. However, salinity tolerance at seedling and reproductive stages is only weakly associated (Moradi et al. 2003). Simply said, if rice becomes tolerant at seedling stage, it will not automatically be tolerant at reproductive stage, or vice-versa. Hence, discovering and combining tolerance traits at both stages are essential for developing resilient varieties (Ismail et al. 2007). Islam (2004) is one of the studies that delved into salinity tolerance at reproductive stage. A possible offshoot of GCP 2 in the future is a project to develop varieties tolerant at reproductive stage, and possibly at both stages by means of MAB.

2.2 Potential benefits from GCP Project 2

Collard and Mackill (2008) pointed out that one of the most important barriers for marker-aided selection and marker assisted backcrossing is the prohibitive cost. The costs of equipment and consumables required to establish and maintain a marker lab are considerable, and there is a large initial cost in the development of markers as well (Collard and Mackill 2008). According to them, for marker assisted backcrossing, the initial cost of using markers would be more expensive compared to conventional breeding in the short term however time savings could lead to an accelerated variety release which could translate into greater profits in the medium to long term. As soon as the system, including the genetic materials and equipments, are established, the breeding program would be more efficient and effective, saving time and resources for breeders and institutions. The direct and indirect benefits of GCP 2 are elaborated below.

2.2.1 Direct Benefits

The direct benefits include (1) quicker variety release, (2) higher adoption rates (3) yield increase, (4) additional lands can possibly be brought into production, and (5) cost savings. Factors that contribute to quicker variety release are shorter breeding cycle to develop tolerant varieties, and the possibility of reducing the years required to test and validate the lines in NARES stations and in farmers' fields. The earlier the varieties are released, the better. A longer breeding cycle entails economic cost as farmers lose opportunities to grow better varieties earlier (Pandey and Rajatasereekul 1999).

- ***Shorter breeding cycle to develop tolerant varieties***. The precise identification of *Saltol* and *Pup1* location, and the development of the marker system to incorporate these genes/QTLs make it possible for scientists to use MAB and be more efficient in developing the tolerant varieties. MAB develops the varieties 4-6 years more quickly than conventional backcrossing. And since the project aims to transfer the MAB package, which includes the markers and the donor variety, to NARES located in rice-growing countries, local scientists would also be able to develop their local salt-tolerant varieties at a faster rate. Once the location of the QTL/gene is precisely identified, it can be transferred to any variety. The markers can be used as a replacement for phenotyping, which allows selection in off-season nurseries making it more cost effective to grow more generations per year or to reduce the number of breeding lines that need to be tested by the elimination of undesirable lines at early generations (Ribaut and Hoisington 1998). The markers also make sure scientists would not lose the QTL/gene when it is transferred to the recurrent parent, and at the same time make sure that they get rid of the negative traits that come along with the QTL from the donor parent (Dr. Thomson, personal communication). When the QTL/gene is identified, it can be transferred to any variety. And with the marker system in place, local scientists don't need to start from scratch in introgressing the QTL/gene and breeding salt-tolerant variety, which would be the case with conventional breeding.

- ***Reduced years required to test and validate the lines in NARES stations and in farmers' fields***. The product of a backcrossing program is a breeding line that is almost identical to the original elite variety except that the new line is now superior. Because these are popular varieties already being planted by farmers for quite some time, scientists said that it is possible to reduce the years of testing and validating the lines. However, the amount of years required for testing and validating still depends on the country's government. Some will still require numerous years, others relatively few years.

- ***Higher adoption rates*** are expected since the tolerance traits are introgressed into popular varieties that farmers already prefer. Some of the these so-called mega-varieties that can be can be improved for salinity tolerance through the GCP project include IR64 (All Asia), BR11 (Bangladesh), Mahsuri and Samba Mahsuri (India), and Swarna (Bangladesh and India. Farmers generally tend to be risk-averse, and hence would be apprehensive to adopt a completely new variety. They won't have major concerns with the improved popular varieties for which they have already determined the optimum crop management (sowing rates and date, fertilizer application rates, number and timing of irrigations). Because the improved varieties are inbred, farmers could also keep the seeds and plant them in subsequent seasons unlike hybrid and transgenic rice.

- ***Increase in yield***. The breeding effort aims to develop varieties that would be able to provide a reasonably good yield under conditions of moderate to high salinity in which salt accounts for 0.4 – 0.5% of the soil (Fredenburg 2007). Scientists estimate that planting salt-tolerant varieties would lead to a yield increase of 1 ton/ha. Aside from a yield increase, it is possible that lands that are presently abandoned because of high salinity can be brought into production. With a salt-tolerant variety, it may now be possible for farmers to plant during the dry season when the salinity problem is worse, thereby opening the possibility of increasing crop intensity. Similarly, it is expected that rice varieties with *Pup1* will increase farmer's yield in areas P deficient uplands. It was observed in experiments that rice with *Pup1* extract up to 3 times as much naturally occurring soil phosphorus, tripling the grain yield and dry weight[3] (Fredenburg 2006).

- ***Additional lands brought into production and cost savings***. With varieties that can now withstand saline and P-deficient soils, it is possible for farmers to grow rice in lands left uncultivated due to these abiotic stresses. Cost savings are

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[3] Grain yield and dry weight are standard measures of plant bulk.

possible too as the efficiency of MAB leading to quicker release saves breeding institutions financial resources and time.

2.2.2 Indirect Benefits

Scientists pointed out that there are also indirect benefits from GCP 2. These are (1) knowledge which could be used for further improvement in MAS/MAB, and (2) make screening, breeding, etc. less tedious to scientists, both of which also translate to savings in terms of resources and time.

2.3 Salinity

Salinity is a pressing global concern. There are 2 kinds of salinity: (1) coastal, which is caused by natural salt accumulation cycles, and (2) inland, which is human-induced. Of the natural cycles, marine cycle due to the accumulation of marine salts in areas lying near the sea or saline lakes, is considered to be the main natural cause of salinization (http://www.fao.org/ag/agl/agll/spush/topic2.htm). On the other hand, the human-induced or anthropogenic cycles are caused by irrigation mismanagement (including insufficient water application, irrigation at low efficiency, seepage from canals and water losses on the farm, and irrigation with saline water or marginal quality water without soils and water management, and agronomic practices), poor land leveling, dry season fallow practices in the presence of shallow watertable, misuse of heavy machinery and soil compaction, excessive leaching with insufficient drainage, and use of improper cropping patterns and rotations.

Salinity is accompanied by related soil problems such as alkalinity and sodicity. Soil sodicity and salinity are often confused as one and the same, but they actually differ. In layman's term, soil salinity is caused by the presence of sodium and chlorine (that forms salt) in soils in excess of the threshold 4 dSm^{-1} (http://www.science.org.au/nova/032/032key.htm). In sodic soils, much of the chlorine has been washed away, leaving behind sodium ions attached to tiny clay particles in the soil (http://www.science.org.au/nova/032/032key.htm).

FAO estimates that the total area of saline and sodic soils is 397 million ha and 434 million ha, respectively. The FAO/Unesco Soil Map of the World provides the distribution salt-affected soils in member countries[4] (http://www.fao.org/ag/agl/agll/spush/table3.htm). It should be noted that the areas represent all salt-affected land and not necessarily arable. FAO reported that there are around 57.9 million ha of saline agricultural lands.

2.3.1 Rice production in saline-affected areas in Bangladesh, India, Indonesia, and Philippines

This thesis evaluates the benefits of growing salt-tolerant rice in four Asian countries namely Bangladesh, India, Indonesia, and Philippines. Aside from FAO, there are many studies that estimate the extent of salinity in these countries. In India for instance, salt-affected soils range from 7 to 12 million ha (Singh et al. 2005). Again, these numbers don't necessarily reflect the rice areas affected but all the salt-affected lands. It is estimated that 1.5 million ha out of the 8.6 million ha of salt-affected lands are rice saline areas (Mahabub Hossain, personal communication).

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[4] Countries that are members of the Global Network on Integrated Soil Management for Sustainable Use of Salt-affected Soils.

Bangladesh is another country where salinity is a major problem particularly in the coastal region of the country. Saline-affected areas in the coastal district have increased from 0.83 million ha in 1966-75 to about 3.05 million ha in 1995 (Karim, Hossain, and Ahmed 1990). However, accurate assessment of the said areas is difficult because the level of salinity varies according to season and year (Rahman et al. 2003). The 0.83 million ha is more or less the amount of salt-affected rice lands because Dr. Hossain estimated the area to be around 0.8 million ha. The common trend in Bangladesh is an increase in salinity from November-December to March-April until the onset of the monsoon rains (http://www.fao.org/ag/agl/agll/spush/topic2.htm). And usually, July-August is the period of minimum salinity, January-February of intermediate salinity and March-April of maximum salinity corresponding with the peak dry season (http://www.fao.org/ag/agl/agll/spush/topic2.htm). In general, salinity in coastal areas is often high during the dry season but decreases with the onset of rains (Ismail et al. 2007). In some instances, severe salinity and lack of irrigation can leave lands uncultivated during dry season. Scientists anticipate that these fallow lands can be brought into production once the saline-tolerant varieties are made available to farmers.

In the Philippines, it is estimated that there are around 400,000 to 500,000 ha of salt-affected lands (http://www.fao.org/ag/agl/agll/spush/topic2.htm) and 200,000 ha (Hossain, personal communication) of these represent the saline rice lands. According to FAO, 13 million ha of lands in Indonesia are affected with salinity and around 500,000 ha of these are rice areas (Hossain, personal communication).

2.4 Upland rice production and P deficiency

Phosphorus is one of the six essential (N, P, K, Ca, Mg, and S) macronutrients required by plants (Hammond et al. 2004). Research on farms in Thailand, Laos, and the Philippines confirmed that the lack of phosphorus in upland rice farms limits yields (IRRI 1996). P deficiency is associated upland with soils that are highly weathered, acidic, and inherently low in P. Upland soils which have high capacity to fix P in forms not easily available to crops, and hence are inherently low in P (IRRI 1996; Lafitte, Ismail and Benett; Wissuwa 2003).

Upland rice is grown on small, subsistence farms using little or no purchased inputs (Sacks et al. 1999). Traditional upland rice farms, usually being one component within a cropping system that includes several crops grown after or with rice, are more diversified than lowland farms. In Indonesia, the common crops mixed with upland rice are maize, cassava, and legume.

Upland rice covers about 20 million hectares across Asia, Africa, and Latin America (IRRI 2000). The largest areas of upland rice in Asia are found in India, Indonesia, Bangladesh, China, and the Philippines (De Datta 1975). In Indonesia for instance, the topography is generally upland, comprising about 65.79% of total agricultural land in 2003 (Table 1). Of the total upland in Indonesia, 1 million hectares are grown with rice, accounting for less than 10% of the total rice area of Indonesia (Syaukat and Pandey 2005).

Table 1. Total area of agricultural land in Indonesia by islands, 2003 (excluding Maluku and Papua)

Island	Total area (ha)			
	Irrigated	Rainfed	Upland	Total
Sumatera	1,691,544	710,997	7,097,329	9,499,870
Java	4,663,175	879,417	2,792,861	8,335,453
Bali and Nusa Tenggara	708,886	89,283	1,471,482	2,269,651
Kalimantan	321,534	413,829	6,687,296	7,422,659
Sulawesi	1,116,706	327,196	2,953,964	4,397,866
Total	8,501,845	2,420,722	21,002,932	31,925,499
% of Indonesia	26.63%	7.58%	65.79%	100.00%

Source: BPS (2003)

adapted from Table 1 of Syaukat and Pandey (2005)

IRRI presented data on input costs for upland rice production, but pointed out that most upland rice farmers maintain few records of inputs used and outputs produced, and published data on the economics of upland rice are scanty. It can be roughly assumed that the lower the costs, the lower the input costs since the costs are obtained by multiplying quantity of input use by the unit price. For instance, labor (family, hired, and exchange) is a major input in upland rice production in most of tropical Asia and Africa, and is substituted for capital. Among the activities for upland rice production in the Philippines, harvesting requires the most labor (385 to 439 hours/ha), followed by weeding (186 to 244 hours/ha) (Table 2). Labor (hired and unpaid) in all the farms constitutes 54% of the total costs in upland rice production (Table 3).

Many small and subsistence farmers who grow upland rice do not usually apply fertilizer because of high fertilizer costs and unavailability of local P sources (De Datta and Ross). Unlike fertilizer use for lowland rice that increased considerably in the period of 1960-1990, fertilizers remain underused on upland crops FAO). In addition, the poor infrastructure and lack of markets in fragile environments like the uplands do not offer much incentive for farmers to purchase fertilizers (George et al. 2001). Fertilizer costs constitute only around 7% of the total costs (Table 3). And in the circumstance that inputs are purchased, they are generally applied to nonstaple crops and not to upland rice because of lack of proven benefit, i.e. yield increase, since much of the applied P would be fixed and rendered unavailable to rice grown in P-fixing soils (George et al. 2001).

Table 2. Labor utilization for upland rice production, Cale, Batangas, Philippines, 1975-1977

Farm operation	Labor (hours/ha)	
	1975-1976	1976-1977
Plowing	61	58
Harrowing	12	9
Furrowing	15	14
Planting	6	4
Harrowing to cover seeds	7	7
Weeding	186	244
Harrowing for cultivation	16	16
Lithao for weed control	28	34
Fertilizer application	5	6
Harvesting	385	439
Threshing	137	130
Total	858	961

Adapted from Table 2 in Chapter 12 of "Upland rice: the global perspective", (http://www.knowledgebank.irri.org/Rice/Ricedefault.htm)

Upland rice, characterized by low levels of modern input use and plagued with abiotic (drought, nutrient availability, acidity, erosion) and biotic (weeds, blast, nematodes) stresses, has generally low yields. Seen in Table 3, the yield ranges only from 0.47 tons/ha to 2.09 tons/ha. Yet, harvesting 2.09 tons/ha is already considered high yield for upland rice production. The IRRI program report for 2000 indicated that the average yield is 1 ton/ha in upland rice areas of Asia, Africa, Latin America. De Datta (1975) and Sacks et al. (1999) estimated that mean yield ranges from 0.5 to 1 ton/ha in Asia. An

IRRI-led collaborative multiyear experiment initiated at 13 sites in 6 countries reported that the average yield of the breeder check variety in Indonesia (B6144) is 2 tons/ha.

Table 3. Costs and returns (in thousand US $) of producing upland rice in the Philippines by yield group, 1981

Item	Low yield	Medium yield	High yield	All farms
Number of farms	93	212	95	400
Average area (ha)	2	1	1	1
Average yield/ha (tons/ha)	0.47	1.01	2.09	1.01
Variable costs	84	158	240	144
Cash costs	29	62	119	60
Hired labor	18	38	73	36
Food for laborers	2	5	5	4
Fertilizers	4	10	27	11
Chemicals	1	2	6	2
Transport cost	0.10	0.4	0.9	0.35
Seeds	5	6	6	6
Noncash costs	54	96	121	84
Landlord share	5	12	31	13
Harvester share	7	15	20	13
Seeds	1	5	10	4
Unpaid labor	41	63	59	54
Fixed costs	16	27	38	25
Depreciation	2	4	9	4
Interest on capital	9	17	25	15
Interest on crop loan	2	2	0	2
Land tax	2	3	3	3
Others	0.20	0.60	1	0.60
Total costs	100	185	278	168
Total returns	60	145	297	139
Returns above cash costs	30	30	83	178
Returns above total variable costs	(24)	(13)	57	(4)
Net returns	(41)	(40)	19	(29)
Return-cost ratio	0.59	0.78	1.07	0.83

Adapted from Table 8 in Chapter 12 of "Upland rice: the global perspective", (http://www.knowledgebank.irri.org/Rice/Ricedefault.htm)

Study sites include upland rice areas in southern Tagalog, Bicol, and central, western and southern Mindanao

US$1 = Php 8.20

Low yield = 0.700 t/ha and below; medium yield = 0.701 to 1.500 t/ha; high yield = 1.501 t/ha and above

Values in parentheses are negative profits

Return cost ratio = gross returns / total costs

Nonetheless, it should be emphasized that the mere absence of a yield response to a small addition of P may not automatically indicate that upland rice would not respond to P. In fact, high yields under upland conditions are possible (de Datta 1975). Under ideal conditions on experiment stations, yields of 7 tons/ha have been recorded in the Philippines (de Datta and Beachell 1972), 7.2 tons/ha in Peru (Kawano et al. 1972), and 5.4 tons/ha in Nigeria (Abifarin et al. 1972).

Although it may seem that contribution of upland rice to the national rice production is relatively low, it has an important role in supporting the livelihood of upland farmers (Syaukat and Pandey 2005), who are among the poorest in many parts of Asia, Africa, and Latin America (IRRI 1997). In contrast to wetland farmers who grow rice to obtain profits by selling to the market, upland farmers are subsistent. They primarily grow rice to meet their family's food requirements and only sell if there is surplus of production over consumption (Syaukat and Pandey 2005). Table 12 confirms that the total costs are greater than the gross returns. The low and medium yield categories, and even for all the farms ("all farms" category with n = 400 observations) have negative profits and return-cost ratios below 1. Only the high yield category has returns above the total costs. Clearly, there is a need for technological improvements such as improved varieties to allow upland farmers to sell more rice and earn profits. Studies confirm that farmers who planted modern upland varieties in Bangladesh and the Philippines have obtained higher net profits than those who grew local varieties (Table 4 and Table 5). Notice that even if the costs are higher for the improved varieties, the increase in yields compensates this, hence the higher net returns.

Table 4. Estimated gross margin for 6 upland rice production systems, Zamboanga del Sur, Philippines, 1983

Item	Participants		Nonparticipants			
	Improved variety		Improved variety		Local variety	
	Owner n=38	Tenant n=38	Owner n=25	Tenant n=18	Owner n=36	Tenant n=18
Gross benefits ($)	336	267	311	227	170	130
Variable costs ($)	178	190	182	149	100	95
Nonlabor inputs	109	116	115	77	40	41
Labor inputs	69	74	67	71	61	54
Gross margin ($/ha)	158	78	129	78	69	35

Adapted from Table 9 in Chapter 12 of "Upland rice: the global perspective",
(http://www.knowledgebank.irri.org/Rice/Ricedefault.htm)
US$1 = Php 11.00
Participants refer to farmers who joined the government's multiple cropping production program
Nonparticipants refer to farmers who did not join the program but grew improved varieties
Nonparticipants refer to farmers who did not join the program and grew local varieties

Table 5. Productivity and costs and returns analysis of farmers' direct seeded upland rice at Alimganj cropping system research site, Rajshashi district, Bangladesh, 1980

Item	Local variety		Modern variety		
	Hashikalmi	Dharial	BR3	BR9	Purbachi
Average grain yield (ton/ha)	2.3	2.2	2.8	3.2	2.2
Average production cost($/ha)	146	155	234	218	187
Average net return ($/ha)	313	256	348	435	268
Benefit cost ratio	3.14	2.65	2.48	2.99	2.44

Adapted from Table 11 in Chapter 12 of "Upland rice: the global perspective",
(http://www.knowledgebank.irri.org/Rice/Ricedefault.htm)

2.5 Literature Review

Using cost-benefit analysis, Pandey and Rajatasereekul (1999) determined the economic benefit from a reduction in the length of the breeding cycle for rice in Northeast Thailand. A longer breeding cycle, according to them, entails economic cost as farmers lose opportunities to grow better varieties earlier. They reported that completing the breeding cycle 2 years earlier would lead to $18 million dollars of benefit. Their sensitivity analyses indicated that the benefits are sensitive to the discount rate, the number of years required for full adoption, the yield increase over current varieties, and the maximum area under improved varieties.

The ex-ante benefits of transgenic drought tolerance research for maize, rice, and wheat in eight countries (Bangladesh, India, Philippines, Indonesia, Kenya, Nigeria, Ethiopia, and South Africa), including the potential magnitude of private sector profits, are examined by Kostandini et al. (2007). They employed country-specific agroecological-drought risk zones and considers not only yield increases but also the yield variance reductions when estimating producer and consumer benefits from research. This study is different from other reseach that focused exclusively on benefits generated by expected mean yield increases, because it accounted the benefits of yield variance reductions as measured by risk reduction to producers and consumers through changes in the variances of incomes and prices, respectively. They calculated for each country the changes in producer income (designated as Pr.Y), changes in consumer income (Cs.Y), profits to the private sector (Π), as well as risk benefits to producers (Ps.RB) and consumers (Cs.RB) from yield variance reductions. A total gain of $418 million for producers and $339 million for consumers are estimated. In aggregate, the potential gains from mean yield increases are larger than gains from yield variance reductions. The private sector also stands to earn estimated profits of $93 million from transgenic drought tolerance research of the three crops across all countries.

Islam and Norton (2007) assessed the potential economic impacts of transgenic salinity and drought resistant (SDR) rice in Bangladesh. The ex-ante analysis projects that planting of SDR rice over 10 years has a total economic surplus (TS) amounting to $302.8 million if no international trade is assumed, of which $184.1 million is producer surplus (PS) and $119.7 million is consumer surplus (CS). Less the research costs, the net present value (NPV) of benefits is $215.7 million and the internal rate of return (IRR) is 33.8%.

Bayer (2007) evaluated the economic impact of the regulatory process on four transgenic crops in the Philippines: *Bacillus thuringiensis* (*Bt*) rice, ringspot virus resistant (PRSV) papaya, *Bt* eggplant, and multiple virus resistant (MVR) tomato. With *Bt* eggplant and MVR tomato, the Philippines is modeled as a small-closed economy while when dealing with *Bt* rice and PRSV-resistant papaya, the country is considered small-open economy. The net benefits (total surplus less total costs) are substantial: $20.5 for *Bt* eggplant, $33.5 for MVR tomato, $257.2 for *Bt* rice, and $240.2 for PRSV papaya. Sensitivity analysis is carried out where the base costs of regulation are increased and decreased by 25%, and increased by 200% and 400%, holding other base model assumptions constant. The results reveal that changing the regulatory costs has very minimal effect to the net benefits. On the other hand, varying the regulatory time, and hence the commercial release date has substantial impacts on the benefits of the technologies.

The poverty-reducing impact of research on Rosette virus-resistant peanut varieties in Uganda are determined by Moyo et al. (2007). Uganda is modeled both as small-open and closed economy. Economic surplus analysis is combined with household-level data analysis to allocate income changes to individual households. Then, they estimated a probit model to determine farmers' probability of adopting new technology. The associated changes in poverty resulting from adoption are computed using the Foster-Greer-Thorbecke (FGT) poverty indices. Lastly, they aggregated the predicted income changes at the household level to the market level and reconciled with calculations of economic surplus changes. The benefits to adopting peanut producers in the open economy model are estimated to be from $35.6 to $62.0 million over fifteen years, while poverty rates for the headcount index declined about 5%. For the closed economy case in which price declines, the research benefits are lower, ranging from $34.0 to $58.3 million. And since the benefits are spread between producers and consumers, the decline in poverty is also lower (0.5%). They also reported that the severity index declined from 0.1896 to 0.1642 and in the open economy and from 0.1896 to 0.1833 for the closed economy.

Mishra (2003) projected that the welfare benefits of adopting *Bt* eggplant in India, Bangladesh, and the Philippines is $411 million, $37 million, and $28 million, respectively. Mishra (2003) reported that consumers gain about 57% of the total surplus, while producers gained 43%.

According to Mamaril (2002), the total welfare gains from adopting *Bt* rice in the Philippines and Vietnam are $618.8 million ($269.6 million for the Philippines, $329.1 million for Vietnam, and $20.1 million for ROW). Mamaril (2002) reported that producers in both countries will capture 66.5% of the total welfare effect, 25.9% will go to consumers, 3% to the ROW, while the loss in Philippine government revenue is around 4.6% of the total welfare effect.

Hareau et al. (2005) conducted an ex-ante evaluation of the economic impact of herbicide resistant transgenic rice in Uruguay, accounting for multinational market power. They came up with a $1.82 million mean net present value for producers while $0.55 million will go to the multinational firm. They mentioned that the relatively small multinational firm benefits suggest that unless a firm has established strategic partnerships with local institutions or access to wider regional markets, it will not undertake significant effort to develop transgenic varieties adapted to Uruguay.

Chapter 3: Conceptual Framework and Assumptions

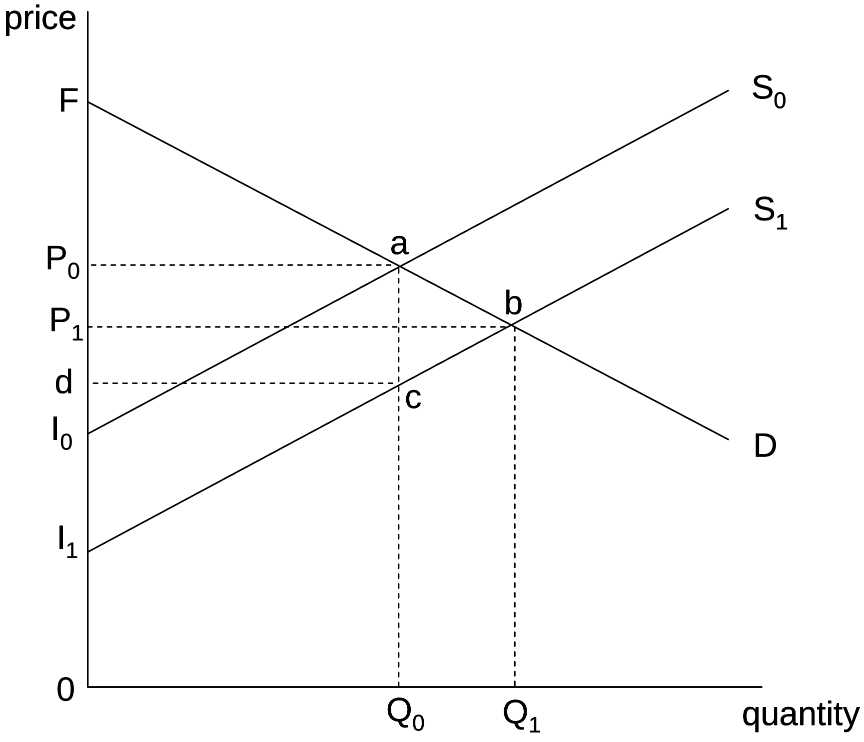
This chapter explains the basics of the economic surplus model. Two specific models used in the study, namely small open (importer) and large open (exporter) economy, are discussed. A framework for assessing the value of shorter breeding cycle, as well as the incremental benefits of bringing abandoned saline rice lands into production are presented. This section also explains the key assumptions used in the analysis. Lastly, details of the timeline of developing the improved varieties and the R&D costs are provided.

3.1 Economic Surplus Model

The economic surplus model has been widely used to estimate the welfare effects of new agricultural technologies and research projects in a partial-equilibrium framework (Kostandini et al. 2007; Islam and Norton 2007; Bayer 2007; Moyo et al. 2007; Hareau et al. 2005 Mishra 2003; and Mamaril 2002). Basically, the model measures the research-induced supply shift, and evaluates the net welfare effects through the resulting changes in producer and consumer surplus. In order for these standard surplus measures to be used as measures of welfare change, the three postulates presented by Harberger (1971) are invoked. These are: (1) that the competitive demand price for a given unit measures the value of that unit to the demander; (2) that the competitive supply price for a given unit measures the value of that unit to the supplier; and (3) that when evaluating the net benefits or costs of a given action (project, program, or policy, the costs and benefits accruing to each member of the relevant group (i.e. country) should be added without regard to the individual(s) to whom they accrue (Alston, et al. 1995). When these assumptions hold, Alston et al. (1995) discussed that consumer benefits from consumption may be measured as the area beneath the ordinary demand curve (Figure 7), net changes in consumer welfare (area beneath the demand curve less the cost of consumption) may be measured using the Marshallian surplus (FaP_0), and the area beneath the supply curve is a measure of total costs of production, so changes in the net welfare of producers (total revenue less total costs of production) may be measured using producer surplus (P_0aI_0).

Aside from the three postulates, there are other are important simplifying assumptions that are retained throughout the economic surplus analysis in this thesis. These are that: (1) supply-and-demand curves are assumed to be linear and to shift in parallel as a result of research-induced technical changes; (2) a static model is used and dynamic issues are put aside; and (3) competitive market clearing is imposed.

The technological change increases yield and/or lowers production costs, which shift the supply curve downward to S_1 (Figure 1). The equilibrium price is reduced to P_1, while Q_1 is the new equilibrium quantity. Consumers gain because they can buy more goods at a lower price. Producers, on the other hand, gain from the lower cost if they are able to sell enough additional quantity to offset the lower price. The change in consumer surplus is represented by the area P_0abP_1, and the change in producer surplus is denoted by the area P_1bI_1 less P_0aI_0. The total net surplus, which is the sum of the changes in consumer and producer surplus, is the area I_0abI_1. As described by Alston et al. (1995) this area can be viewed as the sum of two parts: (a) the cost saving on the original quantity (the area between the two supply curves to the left of Q_0, i.e. area I_0acI_1); and (b) the economic surplus due to the increment to production and consumption (the triangular area *abc*, the total value of the increment to consumption, i.e. area Q_0abQ_1 less the total cost of the increment to production, i.e. area Q_0cbQ_1).



Source: Figure 2.4 of Alston et al. (1995)

Figure 1. Producer and consumer surplus
Adapted from Alston et al. (1995)

3.1.1 Small open economy

The main assumption in a small importing country is that it is “too small” in world market trade to influence the international price significantly. Bangladesh, Indonesia, and the Philippines are examples of small open economies in the world rice market. The world price remains constant and all the benefits of the supply shift accrue to producers. This is illustrated in Figure 2. The initial equilibrium is defined at the following: consumption at C_0; production at Q_0; at the world market price, P_w; and net imports, (difference between consumption and production) equal to QT_0. Production increases as the supply curve shifts from S_0 to S_1. This leads to a decrease in imports to QT_1. And since the country does not affect P_w, the economic surplus change equal to area I_0abI_1 is all producer surplus. The CS, PS, and total net surplus change are algebraically defined as follows (Alston et al. 1995):

$$\Delta CS = 0 \tag{1}$$

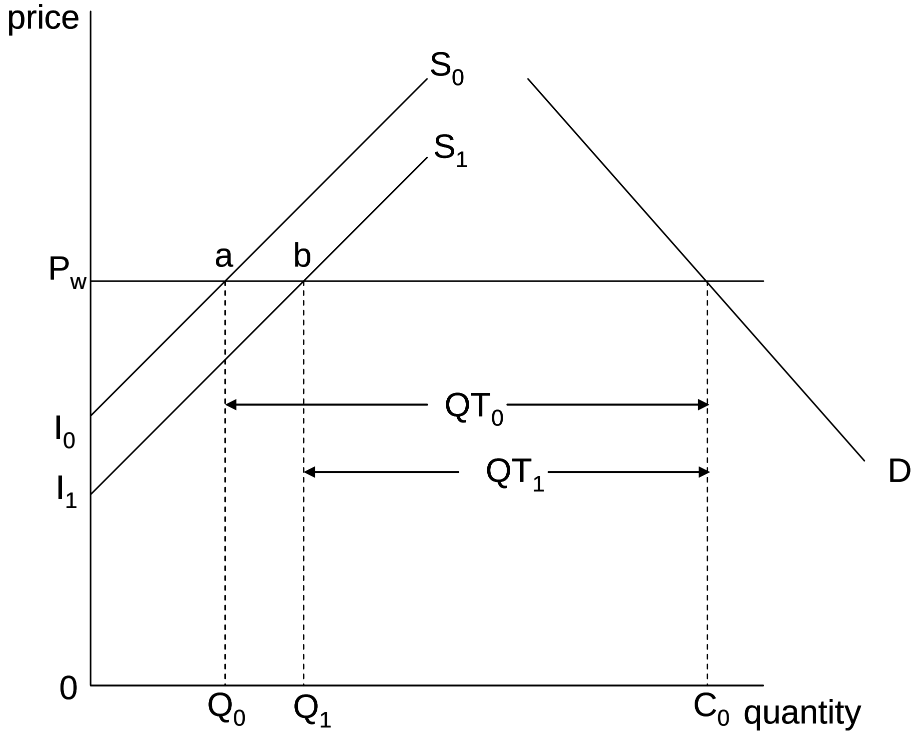
$$\begin{aligned} \Delta PS = \Delta TS &= P_w Q_0 K(1+0.5K\varepsilon) \\ &= P_0 Q_0 K(1+0.5\ K\varepsilon) \end{aligned} \tag{2}$$

P: world price
Q_0: pre-research quantity
K: technical change; vertical shift of the supply function expressed as a proportion of the initial price
ε: supply elasticity

K is calculated using the following formula:

$$K = \left(\frac{E(Y)}{\varepsilon}\right) - \left(\frac{E(C)}{1+E(Y)}\right) p\ A_t\ (1\text{-}d_t) \tag{3}$$

E(Y): expected yield increase per hectare after adoption of the new technology
E(C): expected proportionate in variable input costs per hectare
ε: supply elasticity
p: probability of success of achieving the expected yield change from adoption
A_t: adoption rate of technology in time *t*
d_t: depreciation rate of the new technology



Source: Figure 4.5 of Alston et al. (1995)

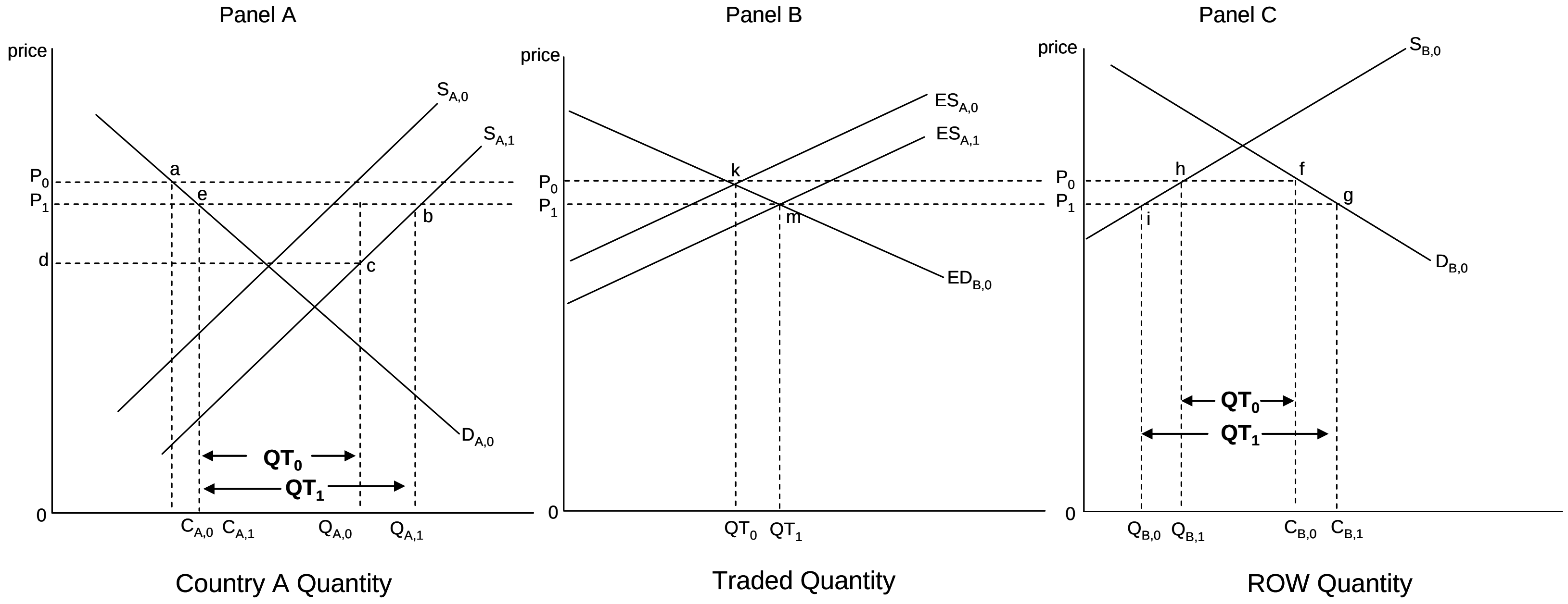
Figure 2. Small open economy economic surplus model

(Adapted from Alston et al., 1995)

3.1.2 Large open economy

When the innovating country is a "large country" in trade for a product such as the case with rice in India, it can influence the international price of the commodity. Hence, price spillovers occur because the technical change in the large exporting country affects other countries (i.e. rest-of-world or ROW) through the effects on the prices of goods traded between the countries (Alston et al. 1995). The research-induced price spillover is analyzed in an excess-supply, excess-demand framework. Excess supply is the difference between domestic demand and supply, while the excess demand in the difference between the ROW demand and supply. The worldwide market is modeled in terms of trade between the home country (country A) and ROW so that market clearing is enforced by equating excess supply and excess demand. The supply and demand in country A is represented in panel a, and panel c illustrates the aggregated supply and demand in the ROW, i.e. region B (Figure 3). The assumption that supply and demand curves are linear is maintained in this model.

The following description of panel b is derived heavily from Alston et al. (1995), (p.214-216). $ES_{A,0}$ is the excess (export) supply in country A, which is the horizontal difference between the domestic supply (initially $S_{A,0}$) and demand (initially $D_{A,0}$). The initial excess (or import) demand from ROW is shown as $ED_{B,0}$ and is given by horizontal difference between the ROW demand (initially $D_{B,0}$) and supply (initially $S_{B,0}$). International market equilibrium is established by the intersection of excess supply and demand at a price P_0. The corresponding domestic quantities are shown as consumption ($C_{A,0}$), production ($Q_{A,0}$), and exports (QT_0). The ROW consumption, production, and imports are represented as $C_{B,0}$, $Q_{B,0}$, and $Q_{T,0}$, respectively. With the adoption of technology in the home country, domestic supply shifts from $S_{A,0}$ to $S_{A,1}$, and consequently, the excess supply shifts from $ES_{A,0}$ to $ES_{A,1}$. P_1 then becomes the new equilibrium price, and the new corresponding domestic quantities are $C_{A,1}$ for consumption, $Q_{A,1}$ for production, and $Q_{T,1}$ for exports. The ROW quantities, on the other hand, are shown as consumption, $C_{B,1}$, production, $Q_{B,1}$, and imports, QT_1.



Adapted from Figure 4.2 of Alston et al. (1995)

Figure 3. Large open economy economic surplus model

The reduction in P_w, caused by the research-induced supply shift, helps consumers in both countries and producers in country A, but affects ROW producers negatively. In panel a, the area P_0aeP_1 behind the demand curve and area P_1bcd behind the supply curve represents the domestic consumer and producer benefits, respectively. From the standpoint of domestic producers, the relevant measure of surplus is unaffected by whether the consumers are domestic or overseas. The determinants of producer benefits in both cases are (a) the size of the research-induced supply shift, (b) the resulting decline in price, and (c) the initial output. Meanwhile, consumer benefits are given by the area P_0fgP_1 in the ROW and producer losses are shown by the area P_0hiP_1.

For this study, only the effects on the home country are considered (i.e. only panel a). Since both consumers and producers gain, the national research benefits are unambiguously positive in the home country. Mathematically, the CS, PS, and TS in country A are as follows:

(4) $\Delta CS_A = P_0 C_{A,0} Z(1 + 0.5Z\eta_A)$

(5) $\Delta PS_A = P_0 Q_{A,0}(K - Z)(1 + 0.5Z\varepsilon_A)$

(6) $\Delta TS_A = \Delta CS_A + \Delta PS_A$

P_0: pre-research equilibrium world price
$C_{A,0}$: pre-research consumption in country A
$Q_{A,0}$: pre-research production in country A
η_A: absolute value of the domestic demand elasticity
ε_A: domestic supply elasticity
Z: relative reduction in price
K: technical change; vertical shift of the supply function expressed as a proportion of the initial price

Z is calculated using the following formula:

(7) $Z = \varepsilon_A K / [\varepsilon_A + s_A\, \eta_A + (1 - s_A)\, \eta_{row}]$

ε_A: domestic supply elasticity

K: technical change; vertical shift of the supply function expressed as a proportion of the initial price
s_A fraction of production consumed domestically
η_A absolute value of the domestic demand elasticity
$\eta_{row}{}^{E}_{B}$ absolute value of the elasticity of export demand (i.e. the ROW excess demand)

K is calculated using the following formula:

$$\text{(8)} \qquad K = \left(\frac{E(Y)}{\varepsilon}\right) - \left(\frac{E(C)}{1+E(Y)}\right) p\ A_t\ (1-d_t)$$

E(Y): expected yield increase per hectare after adoption of the new technology
E(C): expected proportionate in variable input costs per hectare
ε: supply elasticity
p: probability of success of achieving the expected yield change from adoption
A_t: adoption rate of technology in time *t*
d_t: depreciation rate of the new technology

3.2 Evaluating the stream of benefits and costs

To evaluate the stream of benefits and costs of the rice research program, the net present value (NPV) and internal rate of return (IRR) are calculated. NPV calculation discounts the future gains on a common base present year. It is the sum of the stream of future benefits, B_{t+k}, less the costs C_{t+k}, associated with the program, and discounted at an appropriate *r*:

$$\text{(9)} \qquad NPV_t = \sum_{k=0}^{\infty} \frac{B_{t+k} - C_{t+k}}{(1+r)^t}$$

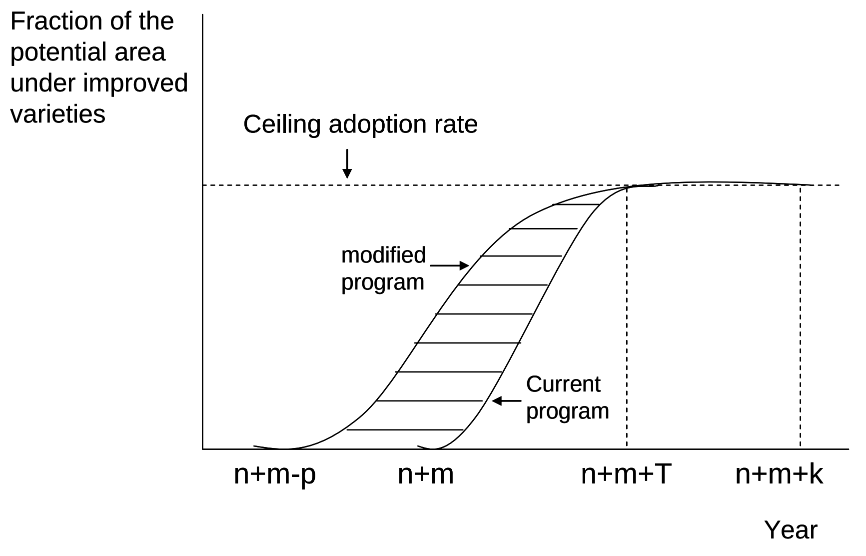
For the base model, a 5% discount rate is used, and 10% for the sensitivity analysis to verify the importance of discounting.

IRR is an indicator used to decide whether it is worth investing on a project. It indicates the efficiency of an investment, as opposed to net present value (NPV), which indicates value or magnitude (www.wikipedia.org). If the IRR of a project is greater than the opportunity cost of capital, then the project is said to be viable (Hidalgo 2001). In contrast, the investor cannot expect to recover his or her capital investment when the IRR is below this rate. In this study, IRR indicates the likely profitability of the breeding program for salt- and P deficient-tolerant varieties . It is calculated as the discount rate at which the NPV is exactly equal to zero (Alston et al. 1995):

$$(10) \qquad 0 = \sum_{k=0}^{\infty} \frac{B_{t+k} - C_{t+k}}{(1+IRR)^{t}}$$

3.3 Assessing the value of shorter breeding cycle

The model developed by Pandey and Rajatasereekul (1999) for assessing the economic gains from modifications or improvement that result in earlier completion of breeding and varietal release is adopted in this study. The shaded area in Figure 4 represents the potential incremental benefits when scientists use the modified program instead of the current program to develop the varieties. The incremental benefits are calculated as the difference between the benefits when IRRI employed MAB versus CB to develop salt- and P-deficiency tolerant varieties.



Source: Adapted from Figure 2 of Pandey and Rajatasereekul (1999)

Figure 4. Varietal adoption paths for current and modified/improved breeding program

where

n: number of years needed for completing the breeding program
m: number of years needed for the completion of the release process, i.e. years needed for national field trials, seed increase, etc.
p: number of breeding years saved, i.e. breeding cycle is completed “p” years earlier
T: number of years for full adoption
k: useful life of the variety developed

3.4 Assessing the benefits if abandoned rice lands due to severe salinity are brought into production

IRRI[5] reported that millions of hectares in the humid regions of South and Southeast Asia are technically suited for rice production but are left uncultivated or are grown with very low yields because of salinity and problem soils. This study tries to determine the additional benefits in the event that the salt-tolerant varieties can be grown

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[5] http://www.knowledgebank.irri.org/ricebreedingcourse/Breeding_for_salt_tolerance.htm

in abandoned rice lands. However, no reliable data were found on the acreage of the affected lands. The total surplus is also very sensitive to own-price supply elasticity and using the above mentioned methods may lead to overestimation especially if reliable data on supply elasticity for the countries are unavailable. The available data are on the extent of total saline agricultural land provided by FAO. Hence for this study, it is assumed that a certain percentage (e.g. 1-5%) of the total saline agricultural land represents the new lands, where the minimum yield in rice saline lands (i.e. 1.5 mt/ha) is also assumed to be harvested. The incremental production is the product of the yield and additional areas, which is added to the original average national production to come up with a new level of national production used in the surplus simulation.

3.5 Assumptions

Key assumptions included (a) area planted to rice that is currently affected by salinity and P-deficiency, projected changes in area under cultivation, and rice production, (b) the nature of the markets (small vs. large economy; open vs. closed economy), (c) projected yield and cost changes, (d) estimated time for discovery, development, and deployment of the DNA marker technologies and associated germplasm, (e) estimated time required to breed, test and disseminate superior rice varieties, including rates of adoption by farmers, and (f) the discount rate for benefits and costs that occur over time. Key variables and parameters such as prices, consumption, rice trade, and elasticities are also discussed in this chapter.

3.5.1 Nature of markets

The large open economy model is used to project the economic benefits of adopting the saline-tolerant varieties in India. India is the second largest rice net exporter, comprising 21% of the world market (FAPRI 2007).

On the other hand, Bangladesh, Indonesia, and the Philippines are small rice importing countries covering 3%, 5%, and 6% of the world market, respectively (FAPRI 2007). These countries are modeled as small open economies. The parallel shift of the supply curve will not affect the world price of rice and all benefits would be reflected by an increase in producer surplus.

3.5.2 Adoption rate

Varietal releases per se are not necessarily a good measure of the success of a research endeavor. A better measure is adoption of varieties in farmers' fields. Adoption rates are crucial for the analysis because, all else equal, they are a main determinant of the magnitude of the change in total economic surplus (Hareau 2002).

The main advantage of MAB technology is allowing the introgression of tolerance traits into varieties that are already popular among farmers. Hence, farmers tend to be less risk averse and a more rapid diffusion of the technology and higher adoption rates are expected.

The benefits from adopting the varieties are calculated over a 15-year period for each country. The adoption rate in this study is represented by the percent of total rice saline and P-deficient areas that will be planted to the improved varieties. Similar to

Mamaril (2001), the diffusion of the tolerant varieties is patterned after the adoption profile of the popular modern varieties released in the past as documented below.

An in-house descriptive adoption study carried out by PhilRice reported that modern varieties released in the previous 5 to 7 years are planted at any given time to around 30% to 50% of the rice area. On the other hand, 3-year old varieties occupy 10% to 20% of the total area, whereas one-year old varieties occupy and 0-2%. The study reported that in general the varieties in farmers' fields are replaced every 8 to 11 years. The study also found that there are varieties first released in the 1980s that are still being planted by farmers to date. One of these "enduring varieties" is IR64. In fact in the 2002 dry season, 17 years after its first release, IR64 was still being planted on 16% of the study sites' area.

Based on this PhilRice study, a base adoption scenario is assumed wherein the adoption profile for the area affected by salinity and P deficiency is approximated by a logistic-shaped initial adoption phase of 5 years starting from 5% in year 1, a plateau phase of 5 years at 50%, and a decline phase after that as new and superior varieties will be introduced (Figure 5). These adoption rates are also applied to Bangladesh, India, and Indonesia. Sensitivity analysis involving conservative and progressive adoption rate scenarios are carried out to account for uncertainty (Table 6). In fact, the high adoption rate scenario looks appropriate given the fact these are popular varieties.

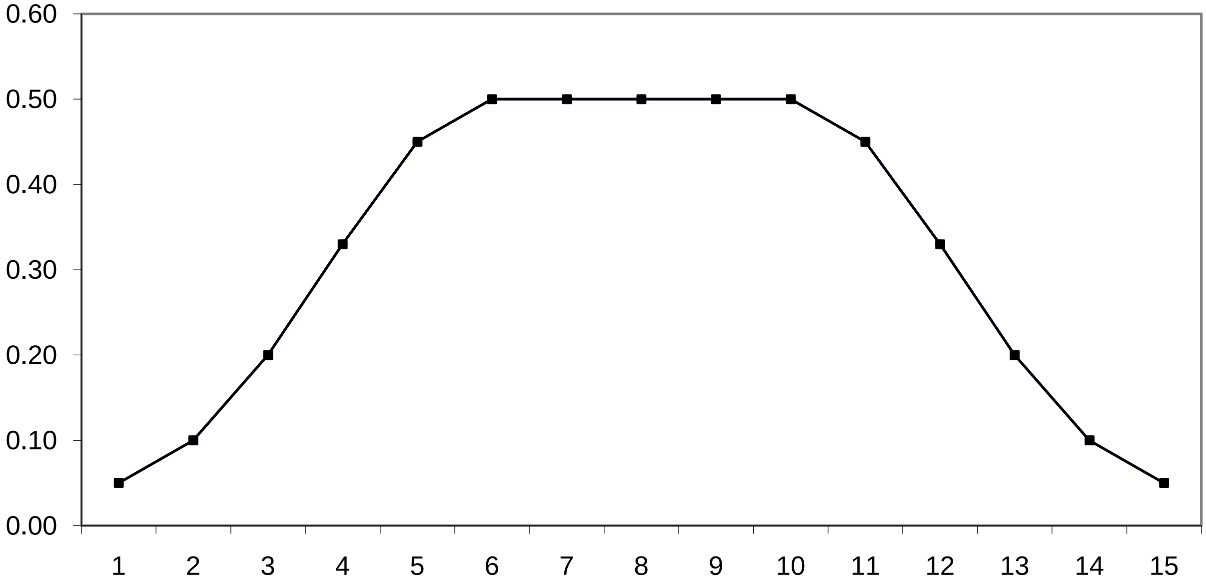

Figure 5. Base adoption rate

Table 6. Adoption rate scenarios

Year	Adoption rate		
	Base	Conservative	Progressive
1	0.05	0.02	0.10
2	0.10	0.06	0.25
3	0.20	0.12	0.40
4	0.33	0.19	0.55
5	0.45	0.25	0.65
6	0.50	0.30	0.70
7	0.50	0.30	0.70
8	0.50	0.30	0.70
9	0.50	0.30	0.70
10	0.50	0.30	0.70
11	0.45	0.25	0.65
12	0.33	0.19	0.55
13	0.20	0.12	0.40
14	0.10	0.06	0.25
15	0.05	0.02	0.10

3.5.3 Percent change in yield

Salinity

Rice with tolerance to salinity is expected to increase yield in affected areas by 0.5 to 1 ton/ha (Mahabub Hossain, IRRI, personal communication). To compute the percent yield change, the current average yield in salt-affected rice areas of the countries is determined. FAO reported that in severe cases of salinity in the Philippines, farmers harvest 30 to 50 cavans/ha. If 1 cavan is equivalent to 50 kg, this yield range translates to 1.5 to 2.5 tons/ha, for an average of 2 tons/ha (Table 7). In the case of Bangladesh and India, the yields in affected districts and states were derived from published studies. Islam and Norton (2007) reported yields in 3 salt-affected districts in Bangladesh: Noakhali (1 to 1.5 tons/ha), Khulna (1.2 to 1.6 tons/ha), and Barisal (fluctuated around 1 ton/ha in earlier years; fixed at 1.4 tons/ha in recent years). For India, average yield of 2.10 tons/ha was determined from the values reported by Siddiq (2000). No data were found for Indonesia, hence the yield of 2 tons/ha is assumed. In the base scenario, 1 ton/ha increase is assumed, hence there would be 50%, 60%, 48%, and 40% change in yield for Philippines, Bangladesh, India, and Indonesia, respectively (Table 7). Sensitivity analysis is done where a relatively low (0.5 ton/ha) and high (1.5 ton/ha) yield increase are used (Table 8).

Table 7. Average yield in saline-affected areas and percent yield change in the base scenario

Country/Division/State	Average Yield (tons/ha)	Base % yield change	Source
PHILIPPINES	**2.00**	50%	FAO
BANGLADESH	**1.35**		
Barisal	1.40	74%	Islam and Norton (2007)
Khulna	1.40		
Noakhali	1.25		
INDIA	**2.10**		
Eastern UP	1.80	48%	Siddiq (2000)
Maharashtra	2.54		
Orissa	1.98		
INDONESIA	**2.00**	50%	assumption

Table 8. Sensitivity analysis: low and high percent yield change in saline-affected rice areas

Country/Division/State	Low % yield change	High % yield change
Philippines	0.25	0.75
Bangladesh	0.37	1.11
India	0.24	0.71
Indonesia	0.25	0.75

P deficiency

Upland rice, plagued with abiotic (drought, nutrient availability, acidity, erosion) and biotic (weeds, blast, nematodes), has generally low yields. Several studies provide yield estimates for upland rice. The IRRI program report for 2000 indicated that the average yield is 1 ton/ha in upland rice areas of Asia, Africa, and Latin America. De Datta (1975) estimated that mean yield ranges from 0.5 to 1 ton/ha in Asia. An IRRI-led collaborative multiyear experiment initiated at 13 sites in 6 countries reported that the average yield of the breeder check variety in Indonesia (B6144) is 2 tons/ha (IRRI 1997).

Derived from these numbers, the average yield of upland rice in Indonesia is assumed to be 2 tons/ha. As with the assumption with salinity, the expected yield increase from planting rice with tolerance to P deficient soils is 1 ton/ha, thereby translating to a 50% yield increase. This relatively significant yield effect is assumed because experiments show that rice with Pup1 extract up to 3 times as much naturally occurring soil phosphorus, tripling the grain yield and dry weight[6] (Wissuwa, Opposites attract attention). For sensitivity analysis, a 0.5 ton/ha and 1.5 ton/ha increase are simulated leading to a 25% and 75% yield change, respectively.

3.5.4 Areas affected

Salinity

The extent of salinity affected areas where rice is grown is found in Table 9. Saline rice fields occupy 5%, 7%, 3%, and 4% of total rice area in Philippines, Bangladesh, India, and Indonesia, respectively. Though relatively low percentages, the yield increase in these areas could improve subsistence farmer's livelihood, as well as contribute to national production.

There are no available and reliable data found in the literature on the magnitude of rice lands left uncultivated because of severe salinity. For this study, it is assumed that abandoned rice lands occupy 5%, 10%, and 15% of the total saline agricultural lands (Table 10). These figures are used in the simulation to assess the incremental benefits gained if salt-tolerant varieties are grown in these lands.

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[6] Grain yield and dry weight are standard measures of plant bulk.

Table 9. Extent of salinity affected areas where rice is or might be grown (1000 ha)

Country	Rice saline area *	Total saline land **	% rice saline of total saline land	Total rice area (2000-2005)***	% rice saline of total rice area
Philippines	200	500	40%	4,047	5%
Bangladesh	800	1,500	53%	10,738	7%
India	1,500	8,500	18%	43,135	3%
Indonesia	500	13,000	4%	11,669	4%

* Source: personal communication with IRRI scientists

** Source: FAO

*** Source: IRRI WRS

Table 10. Extent of uncultivated rice lands due to severe salinity assumed at different percentages of total saline agricultural lands (1000 ha)

Country	total saline agricultural land (1000 ha)	area brought to production (1000 ha)
5%		
Philippines	500	25
Bangladesh	2400	120
Indonesia	1000	50
10%		
Philippines	500	50
Bangladesh	2400	240
Indonesia	1000	100
15%		
Philippines	500	75
Bangladesh	2400	360
Indonesia	1000	150

P deficiency

The total upland rice area in Indonesia is 1 million ha (Syaukat and Pandey 2005), accounting for around 9% of the total rice area of Indonesia. In general, upland soils are characterized as being acidic and low in P supply (Buresh, Smithson, and Hellums 1997; Fairhurst et al. 1999; and Kirk et al. 1998). Traditional upland rice is adapted to soil acidity (Garrity, Mamaril, and Soepardi 1990; Wade et al. 1988) and improvement in upland rice adaptation to soil acidity can be brought about by breeding (Zeigler et al., 1995; Kirk et al., 1998). Given that upland rice is inherently tolerant to soil acidity and that improved acid soil adaptation can be incorporated into superior germplasm, P becomes a major nutrient limitation to upland rice yield (George et al. 2001). Using this information, it is assumed that all of the 1 million ha upland rice area suffers from P deficiency.

3.5.5 Change in input costs

Another important component in the economic surplus analysis is the input cost change per ha that results from the adoption of the varieties. It is computed by summing up the product of the expected percent change of each input and its input cost share.

Salinity

For the saline-tolerant variety, it is assumed that there is no increase in seed costs because the varieties are being developed by the public research sector. Moreover, the varieties are inbred allowing farmers to save and reuse the seeds, unlike the seeds of hybrid rice and genetically modified crops that they need to purchase every planting season.

It is assumed that farmers’ would incur additional costs in fertilizer (5%), pesticides (5%), machinery (5%), and labor (10%) with the adoption of the variety. The contention is that rational farmers would opt to invest more inputs as they presume there is lower production risk involved in planting the improved varieties. Likewise, with higher production there would be additional labor and machine requirements particularly for harvesting rice. On the other hand, there would be no change in cost of irrigation and other inputs. Usually, the saline areas in Philippines and India are non-irrigated and only planted during the wet season, having no/minimal need for irrigation. Although Islam and Norton (2007) reported that Bangladeshi farmers also produce rice in the affected areas during the Aus (dry) season, the assumption of zero change in irrigation cost is maintained.

The input cost share data for the Philippines, Bangladesh, and India is derived from the PhilRice-BAS Rice Statistics, Islam and Norton (2007), and IRRI-ICAR-NDUAT Collaborative Research Project, respectively. The data and input cost computations for each country are presented in Appendix A-C. The Philippine data were used for Indonesia since no information was found for the latter. The input cost shares are shown in Table 11, while the magnitude of change and gross proportional cost change/ha estimates are provided in Table 12.

The cost changes, ranging from 5% to 7%, seem relatively small but are still considered reasonable for this study because the improved varieties are inbred. Unlike hybrid rice and transgenic rice, seeds of inbred varieties have much lower price. Moreover, being popular varieties, farmers are not required to perform drastic changes in management practices if they chose to adopt.

In the scenario where fallow lands are brought into production, it is expected that farmers will incur higher costs. A 50% gross proportional input cost change per ha is assumed for the analysis.

Table 11. Input cost share for saline-tolerant rice

Input	Cost share			
	Philippines	Bangladesh	India	Indonesia
Seed	0.014	0.072	0.042	0.014
Fertilizer	0.093	0.137	0.206	0.093
Pesticide	0.049	0.030	0.008	0.049
Labor	0.419	0.527	0.508	0.419
Machine/tools/animal	0.006	0.125	0.168	0.006
Irrigation	0.000	0.108	0.067	0.000
Other	0.486	0.000	0.000	0.486

Table 12. Magnitude of change and the gross proportional input cost change per ha for saline-tolerant rice

Input	Magnitude of change	Gross proportional input cost change per ha			
		Philippines	Bangladesh	India	Indonesia
Seed	0.00	0.000	0.000	0.000	0.000
Fertilizer	0.05	0.005	0.007	0.010	0.005
Pesticide	0.05	0.002	0.002	0.000	0.002
Labor	0.10	0.042	0.053	0.051	0.042
Machine/tools/animal	0.05	0.000	0.006	0.008	0.000
Irrigation	0.00	0.000	0.000	0.000	0.000
Other	0.00	0.000	0.000	0.000	0.000
Total		0.049	0.067	0.070	0.049

P deficiency

For the varieties that could withstand P-deficient uplands, it is also assumed that there is no increase in seed costs because again, these are inbred. Since the literature review reveals that upland rice production is characterized by low levels of modern input use particularly fertilizer for a number of reasons (high fertilizer costs, unavailability of local P sources, fertilizers applied to nonstaple crops instead of rice, etc.), it reasonable to assume that even with the introduction of the improved varieties, we don’t expect subsistence farmers to change the amounts of their fertilizer use. Moreover, the research experiments showed that the *Pup1* enables the plants to increase P uptake by 3- to 4-fold primarily because it conferred strong and high root growth rates despite P deficiency in soils (Ismail et al. 2007). Hence, it can be expected that farmers would experience yield increase with the adoption of the varieties despite not increasing fertilizer application – a huge advantage for subsistence farmers given that fertilizers are very expensive.

Additional costs are expected to be incurred from machinery (5%) and labor (10%) because higher production entails more labor and machine use to harvest rice. Similar to the assumption for saline-tolerant rice, there would be no change in cost of irrigation and other inputs. Since input cost data for upland rice production in Indonesia are not available, the costs and returns data from Philippines for the medium yield category reported in Table 3 is used. The overall computed gross proportional input cost change per ha for Indonesia that is used in the analysis for the P-deficient tolerant varieties is 0.06 (Table 13).

Table 13. Magnitude of change and the gross proportional input cost change per ha for the P-deficient tolerant rice varieties in Indonesia

Input	Magnitude of change	Gross proportional input cost change per ha
Seed	0.00	0.000
Fertilizer	0.00	0.000
Pesticide	0.00	0.000
Labor	0.10	0.057
Machine/tools/animal	0.05	0.005
Irrigation	0.00	0.000
Other	0.00	0.000
Total		**0.062**

3.5.7 Elasticities

<u>Rice own-price supply and demand elasticities</u>

Several studies provide a range of estimates for own-price supply and demand elasticities (Table 14 and Table 15). The figures under the base scenario are the mean calculated from these studies (Table 16). The own price supply elasticity is an important variable in the economic surplus analysis that could significantly affect the net benefits. Hence sensitivity analysis using low and high supply elasticities found in Table 17 is carried out.

Table 14. Rice own-price supply elasticities in each country from various sources

Country	Supply elasticity	Source
Philippines	0.30 to 0.50	Mangahas et al. (1974)
	0.40	Kostandini et al. (2006)
	0.30	Hossain (1998)
Bangladesh	0.10	Kostandini et al. (2006)
	0.13	Islam and Norton (forthcoming)
India	0.10	Rosegrant et al. (2002) Kostandini et al. (2006)
Indonesia	0.186 to 0.434	Warr (2005)
	0.32	Kostandini et al. (2006)

Table 15. Rice own-price demand elasticities in each country from various sources

Country	Demand elasticity	Source
Philippines	-0.23 to -0.47	Nasol (1971)
	-0.35	Kostandini et al. (2006)
	-0.93	Hossain (1998)
Bangladesh	-0.29	Kostandini et al. (2006)
	-0.20	Islam and Norton (forthcoming)
India	-0.29	Kumar and Kumar (2003)
Indonesia	-0.48	Friedman and Levinsohn (2001) Kostandini et al. (2006)

Table 16. Rice own-price demand and supply elasticities: Base scenario

Country	Supply	Demand
Philippines	0.40	-0.58
Bangladesh	0.13	-0.29
India	0.10	-0.25
Indonesia	0.32	-0.48

Table 17. Sensitivity analysis: base, low, and high values for rice own-price supply elasticities

Country	Base supply elasticity	Low supply elasticity	High supply elasticity
Philippines	0.40	0.30	0.50
Bangladesh	0.13	0.10	0.20
India	0.10	0.05	0.20
Indonesia	0.32	0.19	0.43

Elasticity of export demand

The absolute value of elasticity of export demand for Indian rice exports, also known as the ROW excess demand, is computed by adapting the formula used by Mamaril (2001):

$$\eta_{In}^{E} = \eta_{Th}^{E} * \frac{s_{Th}}{s_{In}}$$

where η_{In}^{E} is the elasticity of demand for Indian rice exports, while η_{Th}^{E} is the elasticity of demand for Thai rice exports assumed to be 4.0 similar to Mamaril (2001). s_{Th} is Thailand's export share of the world long grain *Indica* rice exports and is calculated to be 33%. s_{In} is India's export share and is around 21%. The computation shows that η_{In}^{E} is around 6.22. A sensitivity analysis is performed wherein the world price elasticity of demand for Indian exports is assigned to be 3.11 and 9.33.

3.5.8 Base production, consumption, and price

The prices for 2002-2005 are used in the study and gathered from the FAO database. The mean price of paddy rice in the Philippines, Bangladesh, and Indonesia is \$173, \$126, and \$165, respectively (Table 18). In India, the wholesale prices of milled rice (rupee/ton) reported by IRRI World Rice Statistics for the period 1999-2001 is used (Table 19). The prices in rupee are converted to US \$ using the annual average exchange rate for years of interest. The average price for milled rice in India is \$206. The prices for the countries are held constant for the 15-year adoption period during the analysis.

The average production of paddy rice in the Philippines, Bangladesh, and Indonesia provided in Table 20. Similar to prices, these production levels are assumed constant throughout the useful life of the varieties. The data on milled production and consumption of rice in India are derived and projected using the ERS-USDA rice supply use and demand projection (Table 21).

Table 18. Average price of paddy rice (in thousand US \$) in the Philippines, Bangladesh, and Indonesia

	Price of paddy rice (US\$/ton)		
Year	Philippines	Bangladesh	Indonesia
2002	171	114	134
2003	163	103	140
2004	169	143	176
2005	189	144	210
mean	173	126	165

Source: FAO core production data (http://faostat.fao.org)

Table 19. Wholesale price of milled rice (US $/ton) in India

Year	Rupee/ton*	Exchange rate rupee to $US**	US$/ton
1999	9,705	43.12	225
2000	8,904	45.00	198
2001	9,207	47.23	195
mean	9,272	45.12	206

* Source: http://www.irri.org/science/ricestat/index.asp

** Source: India/US Foreign Exchange Rate (http://www.economagic.com/em-cgi/data.exe/fedstl/exinus+2)

Table 20. Average production (1000 tons) of paddy rice in the Philippines, Bangladesh, and Indonesia

Year	Philippines	Bangladesh	Indonesia
2002	13,271	37,593	51,850
2003	13,500	38,361	52,138
2004	14,497	36,236	54,088
2005	14,603	39,796	53,985
mean	13,968	37,997	53,015

Source: FAO core production data (http://faostat.fao.org)

Table 21. Projected milled rice production and consumption in India

Year	Area harvested (000 ha)	Yield (mt/ha)	Milled production (000 mt)	Rice consumption (000 mt)	Exports(000 mt)
2005	43,400	2.10	91,040	85,224	3,800
2006	44,000	2.07	91,000	87,517	4,300
2007	44,180	2.10	92,836	88,756	4,580
2008	44,326	2.13	94,266	89,365	4,606
2009	44,585	2.16	96,244	91,629	4,729
2010	44,641	2.18	97,412	92,383	4,898
2011	44,770	2.21	98,972	93,947	5,080
2012	44,879	2.24	100,603	95,220	5,266
2013	44,992	2.28	102,367	96,828	5,400
2014	45,076	2.31	104,004	98,321	5,600
2015	45,140	2.34	105,609	99,727	5,801
2016	45,221	2.37	107,309	101,208	6,000
2017	45,391	2.40	108,926	102,804	6,257
2018	45,561	2.43	110,568	104,425	6,525
2019	45,732	2.45	112,234	106,072	6,805
2020	45,903	2.48	113,925	107,745	7,096
2021	46,075	2.51	115,642	109,444	7,400
2022	46,248	2.54	117,385	111,170	7,717
2023	46,421	2.57	119,154	112,923	8,048
2024	46,596	2.60	120,950	114,704	8,393
2025	46,770	2.63	122,772	116,513	8,752
2026	46,946	2.65	124,622	118,350	9,127
2027	47,122	2.68	126,500	120,216	9,518
2028	47,298	2.72	128,407	122,112	9,926
2029	47,476	2.75	130,342	124,038	10,351
2030	47,654	2.78	132,306	125,994	10,794
2031	47,833	2.81	134,300	127,981	11,257

Source: ERS rice supply and use projection

Notes:

2005-2017 data are from USDA ERS rice supply and use projection; projection for 2017-onwards assumes the average annual growth rate calculated from 2016-2017 and are as follows:

area harvested = 0.00375
yield = 0.01129
milled production = 0.01507
food consumption = 0.01577
exports = 0.04284

3.6 Timeline and R&D costs for varietal development

There are five sets of timeline discussed in this section. The first one (Timeline 1) shows the length of time it will take for the GCP project 2 to develop varieties with tolerance to salinity for Bangladesh and India, and varieties with tolerance to P-deficient soils for Indonesia. The second (Timeline 2) describes the period for national rice research institutes in the Philippines and Indonesia to introgress the *Saltol* gene into local popular varieties upon receiving the MAB package/technology from GCP project 2. Timeline 3 explains how long it will take IRRI to produce varieties that could withstand P-deficient uplands by means of conventional backcrossing. The fourth and fifth timelines (Timeline 4 and Timeline 5) represent the number of years and activities involved when NARES in the Philippines and Indonesia develop salt-tolerant varieties in the absence of MAB technology, and thus use conventional backcrossing instead.

The probability of success of developing the improved varieties under both methods is assumed to 0.90. It can be argued that the probability of CB should be lower than MAB because the latter is said to be the more efficient and precise breeding method. Then again, it can be contended that CB has been the standard and “proven” method to develop varieties, hence should have a higher probability of success. To be conservative, the study assumed equal probability of success.

This section also presents the corresponding costs for each timeline. A caveat is that the activities and costs outlined represent just one of the several breeding “styles” under each method that scientists could choose from. The study acknowledges that the set of activities outlined in this study is just one of the several approaches that can be carried out by breeders. It is likely that a different MAB or CB scheme can be performed contingent upon the breeders' preference and/or institutes' protocol, hence the costs and length of breeding cycles may be different from those presented in this study.

3.6.1 Activities and costs for Timeline 1 (T1)

According to the Generation Challenge Program 2008-2010 Medium Term Plan, the genes associated with salinity and P-deficiency tolerance are precisely identified and stable tolerant lines will have been developed by 2009. The costs for 2005-2009 were taken from the GCP 2 midyear reports and are portioned into two – the first half is assigned to Indonesia, and the other half is further divided between Bangladesh and India (Table 22). This is because the project primarily aims to develop varieties that could withstand salinity in Bangladesh and India, and P deficient soils in Indonesia. Cost data for 2008-2009 are not available, and hence an annual cost of $500,000 is assumed, which again is partitioned among Indonesia (1/2), Bangladesh (1/4), and India (1/4).

The next step is for national agricultural research and extension systems (NARES) to test and validate the tolerance genes on experiment stations and farmers' fields. Hence, a commissioned project is underway from 2008-2010 where the *Saltol* gene is validated by the Bangladesh Rice Research Institute (BRRI) and Dhaka University. Similarly, it is expected that *Pup1* gene will undergo validation in P-deficient uplands soils in Indonesia through the partnership of IRRI and Indonesian Center for Agricultural Biotechnology and Genetic Resources Research and Development (ICABGRRD). This endeavor is assumed to incur an annual cost of $50,000. These annual costs are also adopted in India and Indonesia for 2008-2010.

Table 22. Timeline and the R&D costs of developing salt-tolerant and P-deficient tolerant varieties in target countries (US $)

Year	Molecular-aided backrossing						Conventional backcrossing		
	Timeline 1				Timeline 2		Timeline 3	Timeline 4	Timeline 5
	GCP 2	P-deficiency tolerant	Saline-tolerant		Saline-tolerant		P-deficiency tolerant	Saline-tolerant	
		Indonesia	Bangladesh	India	Philippines	Indonesia	IRRI	NARES	
2005	528,300	264,150	132,075	132,075			86,187	27,856	
2006	570,244	285,122	142,561	142,561			86,267	28,408	
2007	441,956	220,978	160,489	110,489			86,257	28,401	
2008	500,000	300,000	175,000	175,000			89,168	29,622	
2009	500,000	300,000	175,000	135,000			89,168	29,638	
2010		50,000	50,000	50,000	35,390	35,390	89,168	29,720	27,856
2011		10,000	10,000	10,000	42,452	42,452	87,837	32,912	28,408
2012		10,000	10,000	10,000	37,847	37,847	89,496	39,694	28,401
2013		10,000	10,000	10,000	37,398	37,398	91,031	31,719	29,622
2014		10,000	10,000	10,000	45,757	45,757	91,031	31,719	29,638
2015				10,000	47,608	47,608	87,387	28,169	29,720
2016					37,683	37,683	86,517	28,042	32,912
2017					33,099	33,099			39,694
2018									31,719
2019									31,719
2020									28,169
2021									28,042

Assumptions:

Costs for 2008-2009 =	$500,000.00
Costs assumed for commissioned project =	$50,000.00
Costs assumed for release and scale up =	$10,000.00

After that is the release and scaling up of the seeds, which last from 3 to 4 years. The figure ($10,000 per year) indicated for 2011-2014 for Indonesia and Bangladesh and 2011-2015 (India) is the assumed yearly costs of this activity.

All in all, the ideal process takes 9 to 10 years. It is assumed that, since salinity programs in Indian research institutes are also very active and developing salt-tolerant lines for India is part of the GCP 2 project, this timeline applies to India as well. The study used the optimistic scenario of 3 years for the process of release and scale up for Bangladesh and Indonesia, and extended it to another year for India. It is expected, then, that salt-tolerant varieties will be available in Bangladesh by 2015 and by 2016 in India, while P-deficient tolerant varieties for uplands in Indonesia will be released by 2015 (Table 22).

3.6.2 Activities and costs for Timeline 2 (T2)

The second timeline refers to development of saline-tolerant varieties by NARES in the Philippines and Indonesia once they receive the MAB package, which includes the markers (foreground, flanking, and background) already optimized and tested for compatibility for specific popular local varieties, and the donor parents (i.e. IR64*Saltol*). The timeline is patterned after what breeders from the Philippine Rice Research Institute (PhilRice) expect to do when they receive the *Saltol* materials (i.e. donor parent, markers) from the GCP project, which will likely be in 2010. It is comparable with the protocol they have prepared for introgressing the submergence tolerance trait upon receiving the donor parent IR64*Sub1* and the corresponding markers from IRRI recently.

The ideal breeding scenario is assumed wherein the scientists successfully introgressed the salinity tolerance to popular varieties by BC_3F_2[7]. After line development, general yield trials (GYTs) and participatory varietal selection[8] (PVS) are simultaneously conducted for 2 seasons[9]. GYTs are done in both PhilRice fields (research managed), and on site fields where the saline problem is very serious (i.e. Bicol and Cagayan, Philippines) and managed by researchers and farmers alike. The PVS, on the other hand, is carried out in a minimum of 4 sites each in Bicol and Cagayan regions for 2 seasons. The national cooperative trials (NCT) then follow and require 3 seasons. After a year (which involves pre-release in farmers' fields and seed increase activities), the improved variety will be released commercially to farmers. The process takes approximately 8 years. The timeline is adopted for the salt-tolerant varietal development by the Indonesian NARES. Hence, the Philippines and Indonesia almost simultaneously release the varieties by 2018.

The expenses for timeline 2 will start in 2010 as soon as PhilRice receives the materials. In this case, the GCP costs are treated as sunk costs. The costs of introgressing the salinity tolerance trait to Philippine local varieties were determined from interviews with scientists at PhilRice. They estimated the costs treating the endeavor as a completely independent project because the breeding program for salinity was de-emphasized by PhilRice's management indefinitely. For this reason, the costs are relatively higher than the institute's budget allocation for the salinity program. Still, the costs are considered

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[7] Ideal scenario is patterned to the success in introgressing *Sub1A* by BC_3F_2.

[8] Participatory varietal selection (PVS) is the selection of fixed line(s) by farmers in target environment using their own criteria. In PVS, access and selection of breeding lines are decentralized, with farmers' participation. Source: (Gregorio et al. 2004)

[9] In the Philippine setting, there are 2 seasons in 1 year.

within acceptable limits because more often than not, scientists are able to get external funding from organizations such as FAO and USAID.

The scientists indicated that PhilRice has the human resources (technical expertise) and most of the equipment needed to perform MAB. The PhilRice Plant Breeding and Biotechnology Division is equipped with a PCR machine, electrophoresis tanks, gel documentation system, and spectrophotometer, all of which were acquired in 2007. Other machines were ordered as well, namely a liophylizer, geno grinder, and ultra-low ultra-high speed centrifuge, which are expected to arrive in 2008 just before the project begins. Ideally, a screenhouse would be built for the project since current ones are already crowded. It is necessary to have the screenhouse to prevent the contamination of the plants by pollens, pests, and other contaminants. Another PCR machine for the project should be purchased as well according to the scientists. The costs expended for the equipment bought before 2010 are also considered sunk, while those for a screenhouse and PCR machine were divided equally throughout the years in such a way that a 10% salvage value is left during the last year.

The annual salaries of the researchers from start to end of the project are also incorporated in the computations. The costs from the first year until half of the fifth year are to be expended for developing and genotyping the salt-tolerant lines (i.e. costs in laboratory, screenhouse, experimental field, etc). The cost estimated by Collard and Mackill per data point for marker genotyping during molecular aided selection equal to $0.30 is used. This is the cost estimate when marker genotyping is performed by a research technician as compared to $1.00 per data point when performed by postdoctoral research follow. For this study, marker genotyping is assumed to be done by a research technician. Since salary is already included in the computed genotyping expenses, it is appropriate to deduct the salary of one research technician from the total annual salary for the years when marker genotyping is performed. The expenses for the following years are those coming from generalized yield trials, participatory varietal selection, national cooperative testing, pre-release and seed increase. To convert the costs from Philippine peso to US dollar, the exchange rate of $1 = Php 40.95387 is used (calculated exchange rate from January to March 2008). The costs may seem to be relatively larger than expected because the Philippine peso appreciated against the dollar in the past few months. As seen in Table 22, the estimates for the Philippines are adopted for Indonesian NARES.

3.6.3 Activities and costs for Timeline 3 (T3)

Timeline 3 describes the activities and the length of time involved when IRRI normally breeds improved varieties through conventional backcrossing, in the absence of new methods such as MAB. Conventional backcrossing is one of the most indispensable tools of breeders in creating and maintaining superior varieties. CB at IRRI has been and is expected to go on continuously, with or without the existence of projects such as GCP Project 2. For instance, IRRI has active upland rice ecosystem research programs, as well as strong partnership with NARES in countries including Indonesia. This proves to be advantageous especially since local rice research institutions in developing nations tend to discontinue programs for unfavorable environments because of lack of resources. Hence, timeline 3 specifically refers to the length of time for IRRI to release varieties for P-deficient uplands via CB.

The downside with CB is the relatively longer time it requires to develop the varieties. For instance, it will take CB until BC_6F_2 to have the lines, which is equivalent to 6 ½ years of breeding work. Similar with MAB, the activities carried out after achieving stable lines include limited and national field trials, pre-release, and seed increase. A difference is that the number of seasons for RYT and NCT under CB is longer by 1 season compared to MAB, which is the standard number in the former method. This analysis takes into account the higher breeding efficiency and precision of MAB, hence the fewer seasons for its trials. It is assumed that with the aid of markers, scientists and evaluators can be sure that the lines contain the *Saltol* QTL/gene. With CB it is still possible that some of the lines do not contain it and scientists would only be able to verify this with more trials. It is estimated that breeding cycle under CB takes 12 years and the saline-tolerant and P-deficient tolerant varieties are available by 2017. The estimated costs incurred at IRRI when breeders go on with their usual business of doing CB to develop varieties such as P-deficient tolerant upland rice for Indonesia are derived from interviews with junior breeders at the institute.

3.6.4 Activities and costs for Timeline 4 (T4) and Timeline 5 (T5)

Timeline 4 describes the likely activities and length of time for the Central Soil Salinity Research Institute (CSSRI) in India and the Bangladesh Rice Research Institute (BRRI) in Bangladesh, which are NARES with active salinity breeding programs, to breed salt-tolerant varieties if GCP Project 2 does not exist. It follows IRRI's ideal 12-year conventional backcrossing scheme outlined in Timeline 3 and varietal release takes place by 2017.

When a MAB package/technology is non-existent and NARES in the Philippines and Indonesia do not receive the MAB package in 2010, Timeline 5 discusses the option for these institutes to proceed with breeding salt-tolerant rice using the alterative method. Similar with Timeline 4, this timeline follows IRRI's protocol for conventional breeding. Hence, the breeding process also lasts 12 years and the varieties are released by 2022.

The costs for both these timelines are again determined by interviewing PhilRice scientists and converted using the exchange rate of $1 = Php 40.95387. Although the costs are the same, NARES incurred them at different time frames. For timeline 5, the GCP costs are considered sunk and expenses start not until 2010. On the other hand, expenses for Timeline 4 start in 2005, the same year the GCP Project 2 started.

Chapter 4: Results and Discussion

In this chapter, the welfare gains of employing MAB for each country in the base scenario are presented, as well as the NPVs under different scenarios of adoption rates, percent yield change, own-price supply elasticity, world price elasticity of demand for Indian rice exports, and discount rate. The additional gains when new saline lands are brought into production are shown in this chapter. This section illustrates the incremental benefits gained from reduced breeding years when scientists employ MAB instead of CB.

4.1 Base scenario

The benefits of adopting the improved varieties are substantial considering that the saline lands range only from 3% to 7% of the total rice area in the countries of interest (Table 23). The benefits over 15 years of planting salt-tolerant varieties amount to $226.9 million in the Philippines, $3.666 billion in Bangladesh, $6.848 billion in India, and $895.7 million in Indonesia. The gains from growing varieties that can withstand P deficient soils in Indonesia amount to $2.070 billion. The benefits of the improved varieties clearly outweigh the costs of development. The internal rate of returns (IRRs), ranging from 88% to 147%, are higher than the discount rate (r) (5% and 10%), confirm that investing on the development of these varieties is worthwhile. When the discount rate is increased to 10% instead from 5%, the net benefits in all countries decrease by more than 55% (Table 23). This substantiates that the higher the opportunity cost of capital, the lower are the returns from investment.

The distribution of total surplus in India between producer and consumer surplus using a 5% discount rate is shown in Figure 6. Producer surplus comprises 86% of the total surplus, suggesting that producers are the main beneficiaries of the yield increase of salt-tolerant varieties. When the 10% discount rate is used, the distribution basically remains the same (86% for PS and 14% for CS).

Table 23. Results of the base scenario using 5% and 10% discount rate

Country	Years of MAB breeding cycle	NPV (in thousand US $) r = 5%	r = 10%	IRR
Saline-tolerant				
Philippines	8	226,886	88,137	112%
Bangladesh	10	3,666,383	1,638,150	109%
India	11	6,847,857	2,901,809	107%
Indonesia	8	895,749	348,125	147%
P deficiency-tolerant				
Indonesia	10	2,069,667	924,405	88%

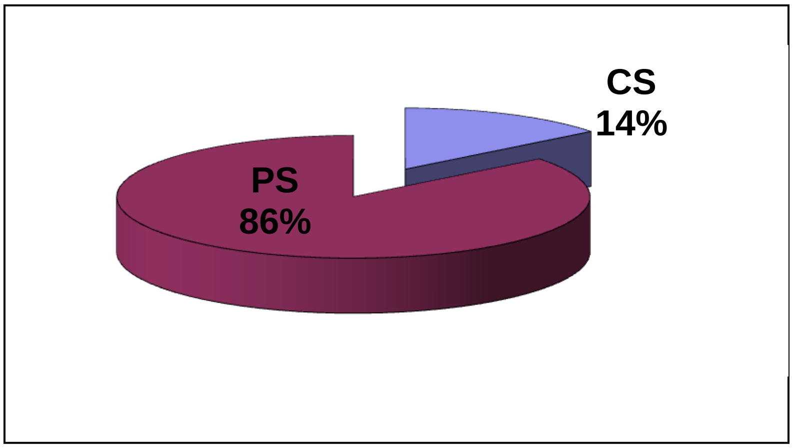


Figure 6. Distribution of total surplus in India in the base scenario

4.2 Sensitivity analysis

4.2.1 Sensitivity analysis: Adoption rate

Table 24 verifies the extent to which higher levels of adoption over the 15-year period result in larger benefits. Benefits for saline and P-deficient tolerant varieties in the base adoption scenario are higher than those in the low adoption by around 42% in all countries. Likewise, the high adoption situation generates about 56% more welfare gains compared to base adoption. The changes in total, producer, and consumer surplus distribution in the three adoption scenarios for saline-tolerant rice in India are shown in Table 25. The figures indicate that all three (TS, CS, and PS) follow the same trend (i.e. 42% lower benefits in base than low adoption, 56% higher benefits in high than base adoption). The share of consumer and producer surplus remains at 14% and 86%, respectively, for both adoption rate simulations. The relatively large benefits that result when adoption rates are high emphasize the importance for the national government and agriculture ministries/departments implementing programs and policies to ensure nationwide promotion of the varieties and farmers’ access. Failure to capitalize on the potential maximum adoption rates would undoubtedly result in millions of dollars in losses.

Table 24. Results of the base, conservative, and progressive adoption rate scenarios (in thousand US $)

Country	NPV (in thousand US $)		
	Base	Conservative	Progressive
Saline-tolerant			
Philippines	226,886	132,135	354,228
Bangladesh	3,666,383	2,131,378	5,736,292
India	6,847,857	3,997,468	10,659,347
Indonesia	895,749	522,041	1,397,833
P deficiency-tolerant			
Indonesia	2,069,667	1,203,988	3,235,365

Base: 5%-10%-20%-33%-45%-50%-50%-50%50%-50%-45%-33%-20%-10%-5% over the 15-year period
Conservative: 2%-6%-12%-19%-25%-30%-30%-30%30%-30%-25%-19%-12%-6%-2% over the 15-year period
Progressive: 10%-25%-40%-55%-65%-70%-70%-70%70%-70%-65%-55%-40%-25%-10% over the 15-year period

Table 25. Total, producer, and consumer surplus of saline-tolerant rice in India for base, conservative, and progressive adoption rate scenarios (in thousand US $)

	in thousand US $		
	Base	Conservative	Progressive
TS	6,848,527	3,998,138	10,660,017
CS	986,472	575,789	1,535,391
PS	5,862,054	3,422,348	9,124,626

Base: 5%-10%-20%-33%-45%-50%-50%-50%50%-50%-45%-33%-20%-10%-5% over the 15-year period
Conservative: 2%-6%-12%-19%-25%-30%-30%-30%30%-30%-25%-19%-12%-6%-2% over the 15-year period

4.2.2 Sensitivity analysis: Percent yield change

As expected, the analysis reveals that there are more gains the higher the percent yield change derived from cultivating the tolerant varieties. The gains are around 50% higher than those in the base scenario if the assumed increase in yield is 1.5 ton/ha (Table 26). Similarly, the welfare benefits are halved when 0.5 ton/ha yield increase is instead assumed.

For India, total, consumer, and producer surplus are larger by 49% if the high percent yield change is used; while all three are smaller by 51% if the scenario is low percent yield change (Table 27). Meanwhile, the distribution of consumer (14%) and producer surplus (86%) remains constant in low, base, and high percent yield change scenarios.

Table 26. Results of the base, low, and high percent yield change scenarios

Country	NPV (in thousand US $)		
	Base % yield change	Low % yield change	High % yield change
Saline-tolerant			
Philippines	226,886	108,796	345,167
Bangladesh	3,666,383	1,806,107	5,550,663
India	6,847,857	3,347,830	10,235,990
Indonesia	895,749	433,424	1,358,814
P deficiency-tolerant			
Indonesia	2,069,667	990,905	3,153,770

Base: Philippines - 50%, Bangladesh - 74%, India - 48%, Indonesia - 50%
Low: Philippines - 40%, Bangladesh - 61%, India - 40%, Indonesia - 40%
High: Philippines - 67%, Bangladesh - 94%, India - 67%, Indonesia - 67%

Table 27. Total, producer, and consumer surplus of saline-tolerant rice in India for base, low, and high percent yield change scenarios (in thousand US $)

	in thousand US $		
	Base % yield change	Low % yield change	High % yield change
TS	6,848,527	3,348,500	10,236,660
CS	986,472	482,176	1,474,939
PS	5,862,054	2,866,324	8,761,721

Base: 48%, Low: 40%, High: 67%

4.2.3 Sensitivity analysis: Own-price supply elasticity

The own price supply elasticity (ε) is a very important factor in the ex-ante analysis because it is used to convert a proportionate yield change to a per unit cost change (*K*). The welfare gains are very responsive to changes in the supply elasticities, hence sensitivity analysis is warranted. As expected, the more elastic the supply curve, the lower the gains derived from the tolerant varieties and vice versa (Table 28). This is because a high supply elasticity directly reduces the size of *K* and vice versa (see equation 3 and 8 in Chapter 3).

The magnitude of change in producer and consumer surplus, as well as the change in total surplus as a result of salt-tolerant rice adoption in India are compared for the ε simulations. With a larger elasticity, the amount of total surplus is lessened by 34%, while, the value of producer and consumer surplus diminished by 38% and 7%, respectively (Table 29). The PS share decreased to 80%, while the CS share increased from 14% to 20% (Figure 7). These results adhere to economic intuition because a relatively elastic supply curve suggests that farmers will supply less rice in the market when the price of rice decreases. The opposite situation happens if low supply elasticity is used in the analysis.

Table 28. Results of the base, low, and high supply elasticity scenarios (in thousand US $)

Country	NPV (in thousand US $)		
	Base supply elasticity	Low supply elasticity	High supply elasticity
Saline-tolerant			
Philippines	226,886	304,635	180,236
Bangladesh	3,666,383	4,774,121	2,974,047
India	6,847,857	13,811,668	4,528,760
Indonesia	895,749	1,555,145	655,330
P deficiency-tolerant			
Indonesia	2,069,667	3,602,398	1,510,827

Base: Philippines - 0.40, Bangladesh - 0.13, India - 0.10, Indonesia - 0.32

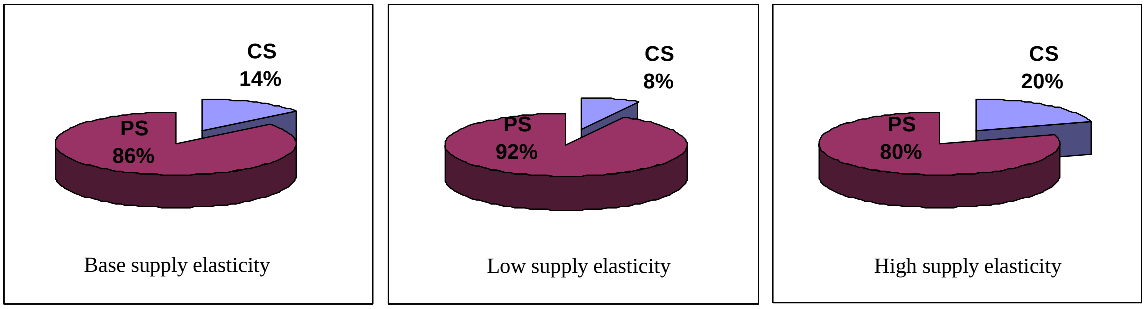
Low: Philippines - 0.30, Bangladesh - 0.10, India - 0.05, Indonesia - 0.19

High: Philippines - 0.50, Bangladesh - 0.20, India - 0.20, Indonesia - 0.434

Table 29. Total, producer, and consumer surplus of saline-tolerant rice in India for base and high supply elasticity scenarios (in thousand US $)

	in thousand US $		
	Base supply elasticity	Low supply elasticity	High supply elasticity
TS	6,848,527	13,812,338	4,529,430
CS	986,472	1,072,324	912,675
PS	5,862,054	12,740,015	3,616,754

Base: 0.10, Low: 0.05, High: 0.20



Base supply elasticity Low supply elasticity High supply elasticity

Figure 7. Comparison of producer and consumer surplus share of saline-tolerant rice in India for base, low, and high supply elasticities

4.2.4 Sensitivity Analysis: World price elasticity of demand for Indian rice exports

Variations in the world price elasticity of demand for Indian rice exports (η_{row}) have minimal effects on both the NPV and total surplus derived from planting salt-tolerant rice compared to the magnitude of impact of changing the other key variables (Table 30). However, the value and share of consumer and producer surplus are affected by variations in η_{row} (Figure 8). A relatively inelastic η_{row} (3.11) increases CS value by 25%, while a relatively elastic η_{row} (9.33) decreases consumer benefits by the same magnitude (i.e. decrease by 25%). Consumers' portion of the total surplus becomes 19% and 12% for low and high η_{row}, respectively. On the other hand, the value of PS is affected in the opposite direction – it goes down by 6% with a relatively inelastic η_{row}

(3.11) and rises by 3% with high η_{row} (9.33). In a similar fashion, producer's benefits account for 81% of total surplus with low η_{row} and becomes 88% with high η_{row}.

Table 30. Results of changing ROW elasticity of demand for Indian rice exports (in thousand US $)

Scenario	NPV (in thousand US $)
Base world price elasticity of export demand (6.22)	6,847,857
Low world price elasticity of export demand (3.11)	6,831,569
High world price elasticity of export demand (9.33)	6,857,777

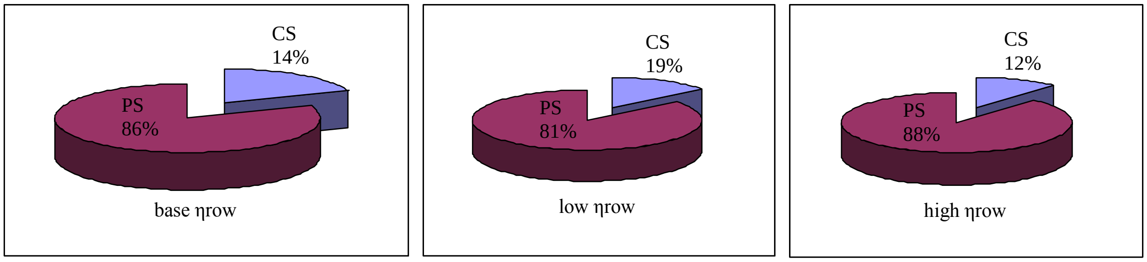


Figure 8. Comparison of producer and consumer surplus share of saline-tolerant rice in India for base, low, and high ηrow

4.3 Assessing the benefits if additional saline rice lands are brought into production

This study opted for a conservative way to estimate the benefits of planting saline-tolerant varieties in lands rendered fallow by severe salinity. The amount of new lands for each country corresponding to the simulated 5%, 10% and 15% portion of the total saline agricultural land, as well as the corresponding new levels of national production if a 1.5 tons/ha yield is assumed are summarized in Table 31. It can be observed that the ranges of percent increase in national production for the countries are very low. In India, milled production is simulated to increase by around the same range - 0.5%, 0.75%, and 1.25% as soon as adoption of the varieties start. As expected, the change in NPVs ranging from 0.14% to 1.42%, are relatively low as well (Table 32).

In India, it can be noticed that the amount of CS decreases as the percent change in milled production increases, i.e. decreases by as much as 11.20% when a 1.25% increase in milled production is assumed. The amount and distribution of CS and PS in India remained relatively the same in the three scenarios (around 14% and 86%, respectively) (Table 33). If the average yield in these new lands is going to be higher than 1.5 tons/ha, then the incremental benefits will increase.

Table 31. The extent of additional areas planted with saline-tolerant varieties and the corresponding increase in national production

Country	total saline agricultural land ('000 ha)	area brought to production ('000 ha)	production in new lands ('000 mt)	existing national production ('000 mt)	new national production ('000 mt)	% increase in national production
5%						
Philippines	500	25	37.5	13,968	14,005	0.27%
Bangladesh	2400	120	180	37,997	38,177	0.47%
Indonesia	1000	50	75	53,015	53,090	0.14%
10%						
Philippines	500	50	75	13,968	14,043	0.54%
Bangladesh	2400	240	360	37,997	38,357	0.95%
Indonesia	1000	100	150	53,015	53,165	0.28%
15%						
Philippines	500	75	112.5	13,968	14,080	0.81%
Bangladesh	2400	360	540	37,997	38,537	1.42%
Indonesia	1000	150	225	53,015	53,240	0.42%

Table 32. Net present values when additional saline lands are brought into production (in thousand US $)

Country	Base adoption	NPV (in thousand US $)		
		5% additional lands	10% additional	15% additional
Saline-tolerant				
Philippines	226,886	227,495	228,105	228,715
Bangladesh	3,666,383	3,683,755	3,701,128	3,718,500
Indonesia	895,749	897,016	898,284	899,551

Table 33. NPV, TS, CS, and PS when additional saline lands are brought into production in India (in thousand US $)

India	Base adoption	NPV (in thousand US $)		
		0.5% increase	0.75% increase	1.25% increase
NPV	6,847,857	6,879,415	6,895,275	6,943,137
TS	6,848,527	6,880,085	6,895,945	6,943,807
CS	986,472	946,274	927,517	875,943
PS	5,862,054	5,933,812	5,968,429	6,067,865

4.6 Assessing the value of shorter breeding cycle to develop salt-tolerant rice in the Philippines

The incremental benefits of reduced breeding years are determined by comparing the NPVs under MAB (T1, T2), which materialized because of GCP Project 2, versus the gains when the MAB technology/package is not available and CB is used instead to develop the improved varieties (T3, T4, T5). The ideal breeding cycle for each of the five timelines is assumed for both methods: 10 years, starting at 2005, to produce saline-tolerant varieties in Bangladesh and P-deficient tolerant varieties in Indonesia using MAB (T1); 11 years, starting at 2005, to produce saline-tolerant varieties in India (T1); 8 years, starting at 2010, to produce saline-tolerant varieties in the Philippines and Indonesia using MAB technology/package (T2); 12 years, starting at 2005, for IRRI to produce P-deficient tolerant varieties for uplands in Indonesia using CB (T3); 12 years, starting at 2005, to produce saline-tolerant varieties in Bangladesh and India using CB (T4); and 12 years, starting at 2010, to produce saline-tolerant varieties in the Philippines and Indonesia by means of CB (T5). The reduced time with MAB is brought about by the precise identification of *Saltol* and its efficient introgression to varieties with the use of marker system. More years are saved when additional backcrosses need to be made under CB (i.e. 13, 14, 15, or 16 years), while maintaining the ideal breeding years under MAB.

On the other hand, fewer years are saved if MAB entails more BC generations (i.e. obtain tolerant lines by BC_4F_2, BC_5F_2, or so on instead of BC_3F_2), while the CB breeding cycle is pegged at 12 years. In general, the longer the breeding years, the higher will be the cost incurred (Pandey and Rakatasereekul 1999). In Timeline 1, a delay in validating the *Saltol* and *Pup1* genes is assumed to cost $50,000 per year. Every additional year needed for further backcrosses costs $37,398 under MAB in Timeline 2, $89,168 under CB in Timeline 3, and $29,720 under CB both in Timeline 4 and 5 (Table 22). In addition, the forgone opportunities to grow improved varieties earlier entail economic loss (Pandey and Rakatasereekul 1999).

At the 5% discount rate, the NPVs of salt-tolerant rice in Bangladesh and India, and P-deficient tolerant rice in Indonesia for different breeding years via MAB and CB are shown in Table 34. In Bangladesh and Indonesia, the gains are reduced by 5% when the MAB breeding cycle is delayed from 2014 to 2015, whereas a 1 year extension in India results in a 3% decrease in gains. If it takes 2 more years to develop the varieties, there is a 9% loss in Bangladesh and Indonesia, and 7% in India. In Bangladesh and Indonesia, there would be 14% and around 18% less gains when MAB is delayed to 13 and 14 years, respectively. In India, 14- and 15-year breeding processes reduce the benefits by 10% and 13%. The benefits of CB are also reduced by the same percentages every time the 12-year breeding cycle is extended by 1 year. Evidently, the benefits are lower under CB because of the longer time needed for varietal development.

The incremental benefits from completing the salt-tolerant and P-deficient tolerant breeding cycles 2 years earlier are $340.5 million in Bangladesh and $192.1 in Indonesia, respectively (Table 35). For India, $227.0 million is gained even if MAB develops salt-tolerant varieties just a year earlier (Table 49). The simulation results confirm that shorter breeding cycles, and hence higher number of years saved, translate to substantial economic gains. If it takes MAB the same number of years as CB to develop the improved varieties, i.e. “0 number of years saved (MAB 12 years)” scenario, the former completely loses its value as incremental benefits become negative (Table 35 and Table 36). Years are also saved and additional gains are made when CB encounters delays (i.e. CB = 13…., or 15 years) while MAB produces the varieties in the ideal scenario, i.e. 10 years for Bangladesh and Indonesia, and 11 years for India.

Table 34. Net present value of developing salt-tolerant rice in Bangladesh and India, and P-deficient tolerant rice in Indonesia through MAB and CB (in thousand US $)

Year cycle ends / No. of years	Saline tolerant	P-deficient tolerant	Year cycle ends / No. of years	Saline-tolerant
	Bangladesh	Indonesia		India
MAB	Timeline 1	Timeline 1	Timeline 1	
2015 / 10 years	3,666,383	2,069,667	2016 / 11 years	6,847,857
2016 / 11 years	3,491,724	1,971,018	2017 / 12 years	6,620,386
2017 / 12 years	3,325,382	1,877,066	2018 / 13 years	6,400,474
2018 / 13 years	3,166,961	1,787,588	2019 / 14 years	6,187,871
2019 / 14 years	3,016,084	1,680,779	2020 / 15 years	5,982,332
CB	Timeline 4	Timeline 3	Timeline 4	
2017 / 12 years	3,325,919	1,877,598	2017 / 12 years	6,620,821
2018 / 13 years	3,167,514	1,788,104	2018 / 13 years	6,400,927
2019 / 14 years	3,016,651	1,702,872	2019 / 14 years	6,188,339
2020 / 15 years	2,872,973	1,621,698	2020 / 15 years	5,982,816
2021 / 16 years	2,736,137	1,544,390	2021 / 16 years	5,784,123

* values are in thousand US $

Table 35. Incremental benefits of reducing the breeding cycle of salt-tolerant rice in Bangladesh and P-deficient tolerant rice in Indonesia (in thousand US $)

Number of years saved	Saline tolerant Bangladesh	P-deficient tolerant Indonesia
	CB = 12 years	
2 (MAB 10 years)	340,464	192,069
1 (MAB 11 years)	165,805	93,419
0 (MAB 12 years)	-537	-532
	CB = 13years	
3 (MAB 10 years)	498,870	281,563
2 (MAB 11 years)	324,211	182,913
1 (MAB 12 years)	157,869	88,962
0 (MAB 13 years)	-552	-516
	CB = 14years	
4 (MAB 10 years)	649,732	366,795
3 (MAB 11 years)	475,073	268,146
2 (MAB 12 years)	308,731	174,194
1 (MAB 13 years)	150,310	84,716
0 (MAB 14 years)	-567	-22,093
	CB = 15years	
5 (MAB 10 years)	793,410	447,969
4 (MAB 11 years)	618,751	349,319
3 (MAB 12 years)	452,409	255,368
2 (MAB 13 years)	293,988	165,890
1 (MAB 14 years)	143,111	59,080
	CB = 16years	
6 (MAB 10 years)	930,246	525,277
5 (MAB 11 years)	755,587	426,628
4 (MAB 12 years)	589,245	332,676
3 (MAB 13 years)	430,824	243,198
2 (MAB 14 years)	279,947	136,389

* values are in thousand US $

Table 36. Incremental benefits of reducing the breeding cycle of salt-tolerant rice in India (in thousand US $)

Number of years saved	Saline-tolerant rice
	India
	CB = 12 years
1 (MAB 11 years)	227,036
0 (MAB 12 years)	-435
	CB = 13years
2 (MAB 11 years)	446,930
1 (MAB 12 years)	219,459
0 (MAB 13 years)	-452
	CB = 14years
3 (MAB 11 years)	659,517
2 (MAB 12 years)	432,047
1 (MAB 13 years)	212,135
0 (MAB 14 years)	-468
	CB = 15years
4 (MAB 11 years)	865,040
3 (MAB 12 years)	637,570
2 (MAB 13 years)	417,658
1 (MAB 14 years)	205,055
0 (MAB 15 years)	-484
	CB = 16years
5 (MAB 11 years)	1,063,734
4 (MAB 12 years)	836,263
3 (MAB 13 years)	616,352
2 (MAB 14 years)	403,748
1 (MAB 15 years)	198,210

* values are in thousand US $

The NPVs of salt-tolerant varieties developed by NARES in the Philippines and Indonesia using MAB and CB are illustrated in Table 37. Again, the gains are reduced by 5% when varietal release under MAB breeding cycle is extended to 2018, 9% if 2019, 14% if 2020, and 18% if 2021 for both countries. Likewise, every time the 12-year CB breeding cycle is extended by 1 year, the benefits of CB are reduced by these same percentages. Again, it is seen that the benefits are lower under CB because of the longer time needed for varietal development.

The incremental benefits from completing the salt-tolerant rice breeding cycle 4 years earlier are $40.3 million in the Philippines and $158.9 in Indonesia (Table 38). As expected, more years are saved and higher incremental benefits are gained when CB encounters delays (i.e. CB = 13…., or 15 years) while MAB produces the varieties in 8 years. On the other hand, if MAB, like CB, takes 12 years to develop the varieties, zero years are saved and losses are incurred.

Table 37. Net present value of developing salt-tolerant rice in the Philippines and Indonesia through MAB and CB (in thousand US $)

Year cycle ends / No. of years	Saline tolerant rice	
	Philippines	Indonesia
MAB	Timeline 2	Timeline 2
2018 / 8 years	226,886	895,749
2019 / 9 years	216,053	853,066
2020 / 10 years	205,737	812,416
2021 / 11 years	195,912	773,701
2022 / 12 years	186,583	736,830
CB	Timeline 5	Timeline 5
2022 / 12 years	186,614	736,889
2023 / 13 years	177,705	701,777
2024 / 14 years	169,221	668,337
2025 / 15 years	161,141	636,490
2026 / 16 years	153,446	606,159

* values are in thousand US $

Table 38. Incremental benefits of reducing the breeding cycle of salt-tolerant rice in the Philippines and Indonesia (in thousand US)

Number of years saved	Saline-tolerant rice	
	Philippines	Indonesia
	CB = 12 years	
4 (MAB 8 years)	40,272	158,860
3 (MAB 9 years)	29,440	116,177
2 (MAB 10 years)	19,123	75,527
1 (MAB 11 years)	9,298	36,812
0 (MAB 12 years)	-31	-59
	CB = 13years	
5 (MAB 8 years)	49,180	193,972
4 (MAB 9 years)	38,348	151,289
3 (MAB 10 years)	28,032	110,639
2 (MAB 11 years)	18,207	71,924
1 (MAB 12 years)	8,878	35,053
	CB = 14years	
6 (MAB 8 years)	57,664	227,412
5 (MAB 9 years)	46,832	184,729
4 (MAB 10 years)	36,516	144,079
3 (MAB 11 years)	26,691	105,364
2 (MAB 12 years)	17,362	68,493
	CB = 15years	
7 (MAB 8 years)	65,744	259,259
6 (MAB 9 years)	54,912	216,576
5 (MAB 10 years)	44,596	175,926
4 (MAB 11 years)	34,771	137,212
3 (MAB 12 years)	25,442	100,341
	CB = 16years	
8 (MAB 8 years)	73,440	289,590
7 (MAB 9 years)	62,608	246,907
6 (MAB 10 years)	52,292	206,257
5 (MAB 11 years)	42,466	167,543
4 (MAB 12 years)	33,137	130,672

* values are in thousand US $

Chapter 5: Summary and Conclusion

This study employed the economic surplus approach to measure the economic benefits of MAB for salinity tolerance in rice for Bangladesh, India, Indonesia, and Philippines, and for rice with tolerance to P-deficient soils in Indonesia. At a 5% discount rate, the benefits over 15 years of planting salt-tolerant varieties amount to $226.9 million in the Philippines, $3.666 billion in Bangladesh, $4.848 billion in India, and $895.7 million in Indonesia. The gains from growing varieties that can withstand P deficient soils in Indonesia amount to $2.070 billion. The benefits of the improved varieties clearly outweigh the costs of development. The IRRs, ranging from 88% to 147%, confirm that investing on the development of these varieties is worthwhile. The incremental benefits if abandoned rice lands due to severe salinity were brought into production are calculated. The changes in NPVs, ranging from 0.14% to 1.42% depending on the country, are relatively low. If the average yield in these new lands is going to be higher than 1.5 tons/ha, then the incremental benefits will increase. The benefits of reduced breeding years and earlier varietal release are determined by comparing the gains of using marker-aided backcrossing versus conventional backcrossing to develop the tolerant varieties. The incremental benefits from completing the salt-tolerant and P-deficient tolerant breeding cycles 2 years earlier are $340.5 million in Bangladesh and $192.1 in Indonesia, respectively. In India, $227.0 million is gained even if MAB develops salt-tolerant varieties just a year earlier. The additional gains from completing the salt-tolerant rice breeding cycle 4 years earlier are $40.3 million in the Philippines and $158.9 in Indonesia. The simulation results confirm that shorter breeding cycles, and hence higher number of years saved, translate to substantial economic gains. In general, the gains from saline- (Bangladesh, Indonesia, Philippines) and P-deficient (Indonesia) tolerant rice are reduced by 5%, 9%, 14%, and 18% when MAB breeding cycle is delayed by one, two, three, and four years, respectively. In India, there is 3%, 7%, 10%, and 13% loss in benefits from salt-tolerant rice for every additional year of delay in the MAB breeding cycle. Finally, sensitivity analysis is performed to determine the change in benefits resulting from uncertainty of critical variables namely adoption rate, percent yield increase, own-price elasticity of supply, rest-of-the-world elasticity of demand, and discount rate. As expected, relatively higher percent yield change and adoption rates increase benefits significantly, whereas higher supply elasticities lower them.

Limitations of the study and further research

One major limitation of the study is the unavailability of detailed cost data for the following: (1) GCP activities from 2008-2009, (2) validation of the *Saltol* and *Pup1* in experiment stations and farmers' fields from 2008-2010, (3) release and scale up costs from 2010-2015, and (4) country-specific R&D costs of employing MAB and CB to develop the tolerant varieties. Hence, rough costs estimations and assumptions were made in the study. More accurate figures will result if the necessary costs data are made available and collected for each NARES.

As mentioned in Chapter 3, a caveat is that the activities and costs outlined in the different timelines are based on a particular breeding "style" out of the several ways scientists could choose from under each method. The study acknowledges it is likely that a different MAB or CB scheme can be performed contingent upon the breeders' preference and/or institutes' protocol, hence the costs, length of breeding cycles, and eventually the benefits calculated may vary from those presented in this study.

Another consequence of data limitation is the assumptions of constant yield increase and extent of areas affected by salinity and P-deficiency. For instance, the literature reveals that soil salinity levels vary widely with farm location and season over the years even within a district; hence the varieties may perform differently. Though numerous studies provide the magnitude of affected rice areas in the countries, the figures are not in agreement. Moreover, though studies claim that substantial areas are left uncultivated due to severe salinity, no reliable data are found, hence this study is forced to make simplistic assumptions. Future studies can integrate spatial and temporal data analysis using Geographic Information System (GIS), a tool that is becoming handy to economists these days, to more accurately determine the extent of the problem and benefits of the technology. This study also made crude assumptions (i.e. assumed an average yield and no change in input costs) in calculating the benefits of bringing abandoned lands into production once salt-tolerant varieties are planted. Subsequent evaluation studies should consider these issues once data become available.

There is also the issue that salinity never occurs in isolation and is often accompanied by nutrient deficiencies such as P, one of the macronutrients rice need but also one of the most unavailable and inaccessible (Vance et al. 2003 as mentioned in Hammond et al. 2004). In fact, salinity even exacerbates P-deficiency because saline or alkaline-sodic soil conditions promote P-fixation that convert P into forms that the roots of the crops could not easily absorb (Ismail et al. 2004). Hence, it is also possible that some of the P-deficient uplands suffer from salinity problem. This study did not take this into consideration and estimated the benefits treating salinity and P-deficiency as independent problems because of insufficient data and information (amount of yield loss, amount of area affected, etc) about the combined (salinity + P-deficiency) effects. Once the data are available, future studies can factor these considerations in the analysis.

The results of this study lend evidence to the hypotheses presented in section 1.4. However, the validity of the hypotheses and the assumptions made in the study can only be tested once the improved varieties are released. Hence, an ex-post evaluation needs to be carried out. In addition, poverty analysis can be done to verify if the improved varieties reduced poverty among the subsistence farmers who are usually the ones growing rice in marginal areas.

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Appendix

Appendix A. Input cost share data for the Philippines

Input	Costs (pesos/ha)							Cost share
	2000	2001	2002	2003	2004	2005	Average	
Seed	219	212	193	207	224	244	217	0.014
Fertilizer	762	908	1,143	1,482	2,006	2,496	1,466	0.093
Pesticide	332	395	866	998	990	1,064	774	0.049
Labor	7,918	8,080	5,093	5,872	6,121	6,438	6,587	0.419
Hired	4,005	4,087	2,646	2,694	2,808	2,954	3,199	
Imputed (family/operator labor)	3,913	3,993	2,447	3,178	3,313	3,484	3,388	
Machine/tools/animal	116	118	88	91	95	100	101	0.006
Irrigation	-	-	-	-	-	-	-	0.000
Others	7,918	8,080	5,093	5,872	6,121	6,438	6,587	0.419
Total costs	17,265	17,793	12,476	14,522	15,557	16,780	15,732	1.000

Source: PhilRice-BAS Rice Statistics, non-irrigated areas, 2000-2005

Labor costs = hired labor costs + imputed costs of family/operator labor

Others include fuel and oil, food expense, land rental, interest on loan, non-cash costs, and imputed costs

Appendix B. Input cost share data for Bangladesh

Input	Costs (US $/ha)			Cost share
	Noakhali	Sathkhira	Average	
Seed	25.95	15.65	20.80	0.07
Fertilizer	49.04	29.48	39.26	0.14
Pesticide	6.36	10.97	8.67	0.03
Labor	149.90	152.50	151.20	0.53
Machine/tools/animal	33.28	38.77	36.03	0.13
Irrigation	13.47	48.78	31.13	0.11
Total costs	278.00	296.15	287.08	1.00

Source: Islam and Norton (2007)

Appendix C. Input cost share data for India

Input	Costs (Rps/ha)				Cost share
	Unnao	Faizabad/Sultanpur	Jagatsinghpur	Average	
Seed	289	348	642	426	0.04
Fertilizer	3,599	2,319	346	2,088	0.21
Pesticide	182	-	60	81	0.01
Labor	5,043	5,334	5,035	5,137	0.51
Machine/tools/animal	3,228	1,559	325	1,704	0.17
Irrigation	1,496	539	-	678	0.07
Total costs	13,837	10,099	6,408	10,115	1.00

Source: Paris et al. (in press)

Appendix D. A sample of small open economy economic surplus spreadsheet: rice with tolerance to saline soils in Bangladesh developed through MAB (base scenario)

Year	Supply elasticity	Demand elasticity	Yield change	Gross prop. cost change	Gross prop. input cost change per ha	Prop. input cost change per ton	Net change	Prob of Success	Adoption rate	K	Price (US$/ton)	Quantity (mt)	CTS	Costs (US$)	Benefits (US$)	NPV	IRR
	e	n															
2005	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.000	0.000	125.97	37,996,505.00	-	132,075.00	(132,075.00)	3,666,383,220	1.09
2006	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.000	0.000	125.97	37,996,505.00	-	142,561.00	(142,561.00)		
2007	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.000	0.000	125.97	37,996,505.00	-	160,489.00	(160,489.00)		
2008	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.000	0.000	125.97	37,996,505.00	-	175,000.00	(175,000.00)		
2009	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.000	0.000	125.97	37,996,505.00	-	175,000.00	(175,000.00)		
2010	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.000	0.000	125.97	37,996,505.00	-	50,000.00	(50,000.00)		
2011	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.000	0.000	125.97	37,996,505.00	-	10,000.00	(10,000.00)		
2012	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.000	0.000	125.97	37,996,505.00	-	10,000.00	(10,000.00)		
2013	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.000	0.000	125.97	37,996,505.00	-	10,000.00	(10,000.00)		
2014	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.000	0.000	125.97	37,996,505.00	-	10,000.00	(10,000.00)		
2015	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.004	0.019	125.97	37,996,505.00	90,836,624.56		90,836,624.56		
2016	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.007	0.038	125.97	37,996,505.00	181,896,800.03		181,896,800.03		
2017	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.015	0.076	125.97	37,996,505.00	364,687,803.74	-	364,687,803.74		
2018	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.025	0.125	125.97	37,996,505.00	603,652,943.07	-	603,652,943.07		
2019	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.034	0.171	125.97	37,996,505.00	825,577,454.13	-	825,577,454.13		
2020	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.037	0.190	125.97	37,996,505.00	918,426,036.96	-	918,426,036.96		
2021	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.037	0.190	125.97	37,996,505.00	918,426,036.96	-	918,426,036.96		
2022	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.037	0.190	125.97	37,996,505.00	918,426,036.96	-	918,426,036.96		
2023	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.037	0.190	125.97	37,996,505.00	918,426,036.96	-	918,426,036.96		
2024	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.037	0.190	125.97	37,996,505.00	918,426,036.96	-	918,426,036.96		
2025	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.034	0.171	125.97	37,996,505.00	825,577,454.13	-	825,577,454.13		
2026	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.025	0.125	125.97	37,996,505.00	603,652,943.07	-	603,652,943.07		
2027	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.015	0.076	125.97	37,996,505.00	364,687,803.74		364,687,803.74		
2028	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.007	0.038	125.97	37,996,505.00	181,896,800.03		181,896,800.03		
2029	0.13	0.29	0.74	5.69	0.0673	0.04	5.65	0.90	0.004	0.019	125.97	37,996,505.00	90,836,624.56		90,836,624.56		

Appendix E. A sample of small open economy economic surplus spreadsheet: rice with tolerance to P-deficient soils in Indonesia developed through MAB (base scenario)

Year	Supply elasticity	Demand elasticity	Yield change	Gross prop. cost change	Gross prop. input cost change per ha	Prop. input cost change per ton	Net change	Prob of Success	Adoption rate	K	Price (US$/ton)	Quantity (mt)	CTS	Costs (US$)	Benefits (US$)	NPV	IRR
	e	n															
2005	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.00	0.000	165.13	53,015,090	-	264,150.00	(264,150.00)	2,069,666,947	0.88
2006	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.00	0.000	165.13	53,015,090	-	285,122.00	(285,122.00)		
2007	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.00	0.000	165.13	53,015,090	-	220,978.00	(220,978.00)		
2008	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.00	0.000	165.13	53,015,090	-	300,000.00	(300,000.00)		
2009	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.00	0.000	165.13	53,015,090	-	300,000.00	(300,000.00)		
2010	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.00	0.000	165.13	53,015,090	-	50,000.00	(50,000.00)		
2011	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.00	0.000	165.13	53,015,090	-	10,000.00	(10,000.00)		
2012	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.00	0.000	165.13	53,015,090	-	10,000.00	(10,000.00)		
2013	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.00	0.000	165.13	53,015,090	-	10,000.00	(10,000.00)		
2014	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.00	0.000	165.13	53,015,090	-	10,000.00	(10,000.00)		
2015	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.004	0.006	165.13	53,015,090	51,406,230.77		51,406,230.77		
2016	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.009	0.012	165.13	53,015,090	102,908,874.30		102,908,874.30		
2017	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.017	0.023	165.13	53,015,090	206,203,399.65		206,203,399.65		
2018	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.028	0.039	165.13	53,015,090	341,062,830.95		341,062,830.95		
2019	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.039	0.053	165.13	53,015,090	466,126,936.42		466,126,936.42		
2020	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.043	0.059	165.13	53,015,090	518,400,882.07		518,400,882.07		
2021	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.043	0.059	165.13	53,015,090	518,400,882.07		518,400,882.07		
2022	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.043	0.059	165.13	53,015,090	518,400,882.07		518,400,882.07		
2023	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.043	0.059	165.13	53,015,090	518,400,882.07		518,400,882.07		
2024	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.043	0.059	165.13	53,015,090	518,400,882.07		518,400,882.07		
2025	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.039	0.053	165.13	53,015,090	466,126,936.42		466,126,936.42		
2026	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.028	0.039	165.13	53,015,090	341,062,830.95		341,062,830.95		
2027	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.017	0.023	165.13	53,015,090	206,203,399.65		206,203,399.65		
2028	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.009	0.012	165.13	53,015,090	102,908,874.30		102,908,874.30		
2029	0.32	0.48	0.50	1.56	0.0619	0.04	1.52	0.90	0.004	0.006	165.13	53,015,090	51,406,230.77		51,406,230.77		

Appendix F. A sample of large open economy economic surplus spreadsheet: rice with tolerance to saline soils in India developed through MAB (base scenario)

year	e	n	yield change	gross prop cost change	gross prop input cost change per ha	prop. input cost change per ton	net change	prob of success	adoption rate	K	milled production (mt)		domestic consumption (mt)		fraction consumed	elasticity of export demand	Z (book)	price (US$/ton)	CS	PS	TS	Costs	Benefits	NPV	IRR
2005	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0000	0.00	91040	91040000	85224	85224000	0.94	6.22	0.0000	206	0	0	0	132075	($132,075.00)	$6,847,856,617.43	1.07
2006	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0000	0.00	91000	91000000	87517	87517000	0.96	6.22	0.0000	206	0	0	0	142561	($142,561.00)		
2007	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0000	0.00	92836	92836000	88756	88756000	0.96	6.22	0.0000	206	0	0	0	110489	($110,489.00)		
2008	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0000	0.00	94266	94266000	89365	89365000	0.95	6.22	0.0000	206	0	0	0	175000	($175,000.00)		
2009	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0000	0.00	96244	96244000	91629	91629000	0.95	6.22	0.0000	206	0	0	0	135000	($135,000.00)		
2010	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0000	0.00	97412	97412000	92383	92383000	0.95	6.22	0.0000	206	0	0	0	50000	($50,000.00)		
2011	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0000	0.00	98972	98972000	93947	93947000	0.95	6.22	0.0000	206	0	0	0	10000	($10,000.00)		
2012	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0000	0.00	100603	100603000	95220	95220000	0.95	6.22	0.0000	206	0	0	0	10000	($10,000.00)		
2013	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0000	0.00	102367	102367000	96828	96828000	0.95	6.22	0.0000	206	0	0	0	10000	($10,000.00)		
2014	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0000	0.00	104004	104004000	98321	98321000	0.95	6.22	0.0000	206	0	0	0	10000	($10,000.00)		
2015	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0000	0.00	105609	105609000	99727	99727000	0.94	6.22	0.0000	206	0	0	0	10000	($10,000.00)		
2016	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0017	0.01	107309	107309000	101208	101208000	0.94	6.22	0.0011	206	22442146	140234671	162676817	0	$162,676,816.61		
2017	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0035	0.01	108926	108926459	102804	102803693	0.94	6.22	0.0022	206	45854043	284441295	330295338	0	$330,295,338.23		
2018	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0070	0.03	110568	110568297	104425	104424544	0.94	6.22	0.0044	206	93705720	576963700	670669420	0	$670,669,419.94		
2019	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0115	0.05	112235	112234882	106071	106070951	0.95	6.22	0.0072	206	158001452	965534165	1123535617	0	$1,123,535,617.06		
2020	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0156	0.07	113927	113926588	107743	107743315	0.95	6.22	0.0099	206	220179141	1335339747	1555518888	0	$1,555,518,887.61		
2021	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0174	0.07	115644	115643793	109442	109442047	0.95	6.22	0.0111	206	249967474	1504652073	1754619548	0	$1,754,619,547.62		
2022	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0174	0.07	117387	117386881	111168	111167562	0.95	6.22	0.0112	206	255381636	1525784444	1781166080	0	$1,781,166,079.74		
2023	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0174	0.07	119156	119156243	112920	112920282	0.95	6.22	0.0112	206	260922888	1547192616	1808115504	0	$1,808,115,504.22		
2024	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0174	0.07	120952	120952274	114701	114700637	0.95	6.22	0.0113	206	266594534	1568879444	1835473979	0	$1,835,473,978.59		
2025	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0174	0.07	122775	122775376	116509	116509061	0.95	6.22	0.0114	206	272399975	1590847781	1863247756	0	$1,863,247,756.14		
2026	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0156	0.07	124626	124625958	118346	118345998	0.95	6.22	0.0103	206	250472707	1451707520	1702180227	0	$1,702,180,227.46		
2027	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0115	0.05	126504	126504433	120212	120211896	0.95	6.22	0.0076	206	187629804	1079311786	1266941590	0	$1,266,941,590.04		
2028	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0070	0.03	128411	128411223	122107	122107214	0.95	6.22	0.0046	206	116161139	663158080	779319219	0	$779,319,219.09		
2029	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0035	0.01	130347	130346753	124032	124032413	0.95	6.22	0.0023	206	59337235	336162179	395499414	0	$395,499,414.14		
2030	0.10	0.25	0.48	4.80	0.0699	0.05	4.75	0.90	0.0017	0.01	132311	132311457	125988	125987967	0.95	6.22	0.0012	206	30316115	170411390	200727505	0	$200,727,505.00		