Ex Ante Impact Assessment of a Drought Tolerant Rice Variety in the Presence of Climate Change

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ABSTRACT

Rice productivity and sustainability are continually threatened by abiotic stresses, particularly in the era of global climate change. In severe cases, 100% yield loss can be experienced due solely to abiotic stresses, such as drought. The situation may become worse due to climate change that may multiply the frequency and severity of such abiotic stresses. Hence, there is an urgent need to develop improved varieties that are more resilient to abiotic stresses. This article examines the net economic benefit and potential economic impacts of developing and disseminating a drought tolerant rice variety in South Asia. Drought is one of the most destructive abiotic stresses that not only causes major rice yield losses in South Asia, but also in other parts of Asia and Africa. Using the ORYZA2000 crop simulation model, we demonstrate that the new variety can provide yield gains in South Asia both when there is no change in the climate and also under the different climate scenarios projected by CGCM climate model. Moreover, our economic surplus analysis shows that the economic benefits from the successful development and dissemination of a drought tolerant variety more than outweigh the research investments needed to develop the variety. The partial equilibrium models we used also indicate that rice production is higher and rice prices are lower when a drought tolerant variety is adopted in South Asia (as compared to the case without this new variety). This in turn can lead to more sustainable rice production, improved food security, and better nutritional outcomes for the poor.

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Rice (*Oryza sativa* L.) is associated with the lives of billions of people around the world. It is planted on about 159 million hectares annually in at least 114 countries (Tonini and Cabrera, 2011), and more than 100 million households in Asia and Africa depend on rice cultivation as their primary source of income and employment (FAO, 2004 as cited by Redoña, 2004). Rice is the source of 27% of dietary energy and 20% of dietary protein in the developing world (Redoña, 2004). About 90% of the total rice grown in the world is produced by 200 million small farmers (Tonini and Cabrera, 2011), and rice is the major staple crop of nearly half of the world's population (Zeigler and Barclay, 2008; Khush, 2004). Because of increases in population and income in major rice-consuming countries, demand for rice has been steadily increasing over the years. Mohanty (2009) estimated that the global demand for rice will increase from 465 million ton in 2012 to about 487 million ton in 2020. Therefore, sustainable growth in rice production worldwide is needed to ensure food security, maintain human health, and sustain the livelihoods of millions of small farmers.

One of the most serious long-term challenges to achieve sustainable growth in rice production is climate change (Vaghefi et al., 2011; Wassmann and Dobermann, 2007; Adams et al., 1998; IFPRI, 2010). Rice productivity and sustainability are threatened by biotic and abiotic stresses, and the effects of these stresses can be further aggravated by dramatic changes in global climate. It is widely acknowledged that the climate of the Earth is changing in a manner that was unseen in the past 400,000 years. By 2100, Earth's mean surface temperature is expected to rise by 1.4 to 5.8 °C, precipitation is projected to decrease in the subtropics, and extreme events, such as floods, droughts, and cyclones, are likely to become more frequent (IPCC, 2007). In delta and coastal regions, it is expected that climate change will raise sea levels, and this will increase the risk of flooding and salinity problems in major rice-growing areas (Wassmann et al., 2009).

These predicted changes in climate are likely to further increase the economic vulnerability of poor rice producers in less-favored rainfed environments, where more than 30% of the population is already considered poor (with income less than US$1.25 per day). For example, rice yields may decrease by the increase in temperature due to the atmospheric concentration of carbon dioxide (Peng et al., 2004). Rice yield is found to be more sensitive to nighttime temperature, in which each 1 ^{o}C increase in nighttime temperature leads to a decline of about 10% in rice yield (Peng et al., 2004; Welch et al., 2010). Furthermore, droughts and floods already cause widespread rice yield losses across the globe (e.g., Pandey et al., 2007, IRRI, 2010; IFAD, 2009; Pandey and Bhandari, 2007), and the expected increase in drought and flood occurrence due to climate change would further add to rice production losses in the future. Thus, the major challenge is to mitigate the potential adverse effects of changing climate so that growth in rice production can be sustained and food security can be achieved.

One of the important ways to ensure food security and at the same time provide viable incomes for poor rice farmers in the future is to develop new rice varieties that are more tolerant of the adverse effects of a more volatile climate (Mackill et al., 2010a; Haefele et al., 2010). These newer rice varieties can help minimize production losses from the expected increase in abiotic and biotic stresses due to climate change. However, development and eventual dissemination of these new varieties to farmers entail substantial research investments and costs, such as (1) laboratory research costs for breeding and field trials, and (2) transactions and institutional costs of disseminating the varieties to farmers. Hence, it is important to examine whether the expected economic benefits from the development of new “climate change-tolerant” varieties are higher than the expected research costs needed to develop them. An ex ante economic impact evaluation is necessary to determine the net economic benefit of developing these new varieties that can mitigate the adverse effects of climate change. In particular, the potential impacts of these new “climate change-tolerant” varieties on yields, incomes, consumption, and trade should be investigated (vis-à-vis the research costs) to more fully comprehend the net economic gains from developing these new rice varieties.

The objective of this article is to determine the net economic benefit of developing and disseminating a drought-tolerant rice variety in South Asia. An ex ante impact assessment framework is used because such drought-tolerant variety is not yet in existence. Partial equilibrium economic models, the crop growth simulation model ORYZA2000 (Bouman et al., 2001), and information from rice scientists/breeders are used to accomplish the article objective. Specifically, we use two partial equilibrium models in the ex ante analysis: Alston et al.’s (1998) static economic surplus model for a large open economy and Mohanty et al.’s (2011) global rice model that partially accounts for dynamics and provides trade effects. We also use MODIS (Moderate Resolution Imaging Spectroradiometer) 250m NDVI (Normalized Difference Vegetation Index) data to extract the drought affected areas in South Asia for the 2000-2011 period. Investigating the ex ante economic impact of a new drought tolerant variety is valuable because drought is currently the most prominent abiotic stress that causes large amounts of damage to rice yields and, consequently, to incomes of rice smallholders, especially those in less-favored rainfed areas where poverty is widespread (Pandey et al., 2007; IRRI, 2010). In addition, with climate change expected to increase the frequency of drought in major rice-producing regions, examining the potential benefits of having a new drought tolerant variety is critical to the sustained growth of rice production and to ensuring adequate food supplies in the future.

Description of the Proposed Technology: Breeding for Drought Tolerance

Recent advances in modern plant breeding methodologies, such as molecular genetics, genomics, marker-assisted selection (MAS) (also called marker-assisted breeding, MAB), and transgenic, offer new opportunities to meet the challenge of developing an effective drought tolerant rice variety.[1] In particular, significant progress has been made in developing rice varieties that are tolerant of drought through MAB.[2] Many important genes and/or quantitative trait loci (QTLs) governing a rice plant's tolerance of drought have already been tagged with molecular markers.[3] These scientific developments are key to incorporating abiotic stress tolerance in popular high-yielding rice "mega-varieties" (i.e., IR64 in most of Asia, Swarna in South Asia) that typically are susceptible to abiotic stresses such as drought (Serraj et al., 2009).[4]

Conventional breeding and MAB are the primary strategies used to develop rice varieties with drought tolerance. There has been some recent success in using conventional breeding to develop

[1] Molecular genetics is the field of biology and genetics that studies the structure and function of genes at a molecular level, and how the genes are transferred from generation to generation. Genomics uses intensive efforts to determine the entire DNA sequence of organisms and to fine-scale genetic mapping efforts. MAS is a process whereby a marker (morphological, biochemical, or one based on DNA/RNA variation) is used for indirect selection of a genetic determinant or determinants of a trait of interest. A transgenic is an organism that has had genes from another organism put into its genome through recombinant DNA techniques.

[2] The use of conventional breeding methods to develop varieties that are tolerant of abiotic stresses has had limited success in the past. Thus, scientists have turned primarily to MAS/MAB to allow them to more quickly assess whether a particular variety has the desired tolerance of a specific abiotic stress (or multiple abiotic stresses).

[3] Quantitative trait loci (QTLs) are stretches of DNA containing or linked to the genes that underlie a quantitative trait. A molecular marker/genetic marker is a fragment of DNA sequence that is associated with a part of the genome. These QTLs/markers provide scientists with information about whether genes that control specific traits (i.e., drought or submergence tolerance) are present without having to painstakingly grow the plant out to maturity and expose it to those stresses (as in conventional breeding). In principle, MAB saves time, is more precise in the sense of avoiding inclusion of undesirable traits, and is potentially more cost-effective (Collard and Mackill, 2008; Alpuerto et al., 2009).

[4] The mega-varieties Samba Mahsuri, Swarna, and CR1009 from India, IR64 from the Philippines (IRRI), Thadokkham 1 (TDK1) from Laos, and BR11 from Bangladesh are typically used as recipient parents. These varieties are called "mega-varieties" because they were popular and were planted for many years on a minimum of 1 million hectares.

drought-tolerant varieties, as evidenced by the recent release of drought-tolerant varieties in India, the Philippines, and Nepal (see table 1). These varieties perform well even when there is no drought and they can provide about a 1 t/ha yield advantage under stress (Mackill, 2010a). Most of the popular mega-varieties collapse under these conditions.

Although plant breeders have made significant progress using conventional breeding methods, the past 20 years have seen the use of molecular markers (and MAB) gain prominence in breeding programs. Through these molecular techniques, major progress has been made to identify a QTL (*qtl.12.1*) with larger effects on grain yield under water stress (Bernier et al., 2007; Kumar et al., 2008; Venuprasad et al 2009). Three more QTLs (*qtl3.1, qtl1.1, qtl 9.1*) for drought tolerance have also been identified. These four QTLs are being pyramided with the hope that drought tolerance of rice varieties would increase significantly.[5] Specifically, research is under way to incorporate these drought QTLs within the popular mega-varieties (i.e., IR64) and with the aim of having a yield advantage of more than 1 t/ha under drought (Mackill et al, 2010b; Kumar, 2011).

Donor varieties possessing drought-tolerance QTLs are also being analyzed physiologically to unveil the interaction between these QTLs and facilitate their more effective use in breeding. Moreover, intensive genetic mapping of these QTLs is being undertaken to whether there are specific genetic markers within the drought QTLs that are directly related to drought tolerance.[6] In addition, a wide range of genetic resources, including African rice, *O. glaberrima*, is being

[5] "Pyramiding" is a term that describes a genetic approach to determine and introduce multiple genes that each impart resistance to or tolerance of an independent biotic or abiotic stress.
[6] Breeders have noted that drought tolerance is a complex trait (relative to submergence tolerance, for example) such that there may not be a single gene or marker that directly relates to this trait (Kumar, 2011). It is possible that a QTL (rather than a single gene) is needed for drought tolerance. This is unlike the developed submergence-tolerant varieties that require only one single *SUB1* gene that allows for tolerance of a specific type of flood event (see discussion below).

used for the development of drought-tolerant varieties. Transgenic methods are also being used to further increase the tolerance of drought beyond what has been achieved already. For example, at IRRI, transgenic IR64 lines are under field evaluation to determine their performance under drought stress (Tonini and Cabrera, 2011).

Description of a Dissemination Plan

The development and dissemination of an effective drought tolerant variety can improve farmers' productivity by decreasing expected yield losses when it occurs. Hence, it is more of a "loss-mitigating" (or risk-mitigating) technology rather than a mean yield-increasing technology. For example, ideally the yield advantage would not be present if drought did not occur (i.e., in "normal conditions" the yields of this new variety and existing mega-varieties will be the same). However, with increased water-use efficiency due to the drought-tolerance trait, it is possible that mean yields of the new variety will increase as well. But, we do not take this into account in our analysis.

Based on information from plant breeders at IRRI, an effective drought tolerant variety can feasibly be released to South Asian farmers by 2016 (e.g., Dixit, 2012). A summary of the research pathway for discovery and dissemination of the new variety is presented in table 2. Given the current research progress described in the previous section, IRRI rice breeders indicated that limited field trials for a new drought tolerant variety can begin as early as 2014. Large field trials and selection of suitable lines could occur soon thereafter and dissemination could be reasonably expected by 2016. The discovery and dissemination pathway in table 2 suggest that strong public-sector action may be needed to approve the developed varieties and help in their speedy dissemination in each country.

Economic and Social Value of the Improved Technology

In this article, we first use the economic surplus model of Alston et al. (1998) to estimate economic surplus measures and the rate of returns on the research investments to develop and disseminate the drought tolerant variety.[7]

The critical parameter necessary to compute the economic surplus is the proportionate downward shift in the supply curve for time period *t*, K_t, due to the release of the new variety. This parameter is calculated as follows (see Alston et al., 1998):

(1) $$K_t = \left[\frac{E(Y)}{\varepsilon_A} - \frac{E(C)}{1+E(Y)} \right] \rho A_t \left(1-\delta_t\right),$$

where *E*(*Y*) is the expected proportionate yield change per hectare presuming the new drought tolerant variety is successful and adopted, ε_A is the rice supply elasticity in the large open economy, *E*(*C*) is the proportionate change in input costs per hectare (if any), ρ is the probability that the new variety will fully achieve the yield change *E*(*Y*), A_t is the rate of adoption in year *t*, and δ_t is the rate of annual depreciation of the new variety.

Estimating the Supply Shift: The ORYZA Crop Simulation Model

The key piece of information needed to evaluate the ex ante economic impact of releasing a drought tolerant variety is the estimated supply shift – the *K*-factor – due to the release of this new variety in major rice growing countries in South Asia: Bangladesh, India, Nepal, Pakistan and Sri Lanka. As shown in equation (1) above, the *K*-factor depends on a number of variables and parameters, but one of the most important is the estimated proportionate yield change per

[7] In light of space constraints for this report, we do not provide details of the Alston et al. (1998) model here but we refer interested readers to p. 215 of Alston et al. (1998). Also, the authors can provide the full version of this current article, which includes details of the Alston et al. (1998) model.

hectare presuming the new drought tolerant variety is successful and adopted – $E(Y)$. This term is defined as the $\left[100 \times E(Y)\right]\%$ increase in commercial yields after allowing for the optimization of the input mix when switching from the old variety to the new drought tolerant variety (e.g., if $E(Y) = 0.3$, then $\left[100 \times E(Y)\right]\% = 30\%$).

In this article, we primarily use the ORYZA2000 crop growth simulation model (Bouman et al, 2001) to estimate E(Y). ORYZA2000 is a rice growth simulation model that allows one to simulate the growth of a "virtual rice" under varying environmental conditions. We use data from secondary sources that coincide with the soil, weather, and other environmental conditions in South Asia to parameterize the virtual environment for the analysis. In this ORYZA2000 analysis, current rice area in South Asia was divided into more than 12,500 grid cells with a 5 arc minute resolution. An initial baseline run is first made assuming existing varieties (that do not have traits for drought tolerance) and climate projections based on CGCM3.1/T63 model (The Third Generation Atmospheric Circulation Model) generated and made available by the "Canadian Center for Climate Modeling and Analysis" (CCCMa). The specific climate projections included in the present ORYZA2000 run are A2, A1B and B1 SERS scenarios. These three scenarios differed mainly in the evolution of CO2 concentration. For example, SRES A2 scenario predicted CO2 concentration in the atmosphere by 2100 at 800 ppm, while SRES A1B projected 720 ppm and SRES B1 projected 550 ppm respectively by the end of the year 2100. For the differences in CO2 concentrations predicted by different scenarios, predicted air temperature is also varied among the scenarios. For example, while the air temperature increase is around 3 to 4 °C for SERS A2, the rise will be around 2.3 to 3.4 °C for SERS A1B and 1.4 to 2.2 °C SERS B1. This suggests that the SERS A2 scenario is the "worst-case" scenario with the highest temperature increases, while SERS B1 is the most moderate climate change scenario. We also run the ORYZA2000 crop simulation model for the new drought tolerant variety assuming that there is no change in climate i.e., using a baseline climate scenario. We then run ORYZA2000 crop simulation model for the different climate scenarios assuming that the new drought tolerant variety has been planted. The new drought tolerant virtual variety in this simulation has been developed using the IR72 rice variety as a base. In modeling the virtual variety, we allow the root deepness of the base variety to grow underground from 45 to 50 centimeters and reduce the plant's sensitivity to drought by 20 percent. We also assume that the entire South Asia as rainfed and there is no nitrogen limit. The differences in the maximum rainfed yield outputs from the virtual variety for the baseline run and the run under different climate scenarios would then be used to calculate initial estimates of E(Y). Moreover, ORYZA2000 was run for two periods – from 2015-20 and from 2035-40 and the average E(Y) for the former period is used in the economic surplus analysis from 2011 to 2034 and the average E(Y) for the latter period is used in the economic surplus analysis from 2035 to 2050.

Aside from $E(Y)$, the values for the remaining terms in (1) need to be estimated as well. The values for $E(C)$, ρ, δ_t, and A_t are primarily based on rice scientists' opinions given their experience with the development and dissemination of abiotic stress-tolerant varieties. For $E(C)$, we assume that only harvesting, machinery, and labor costs will increase with the adoption of a new drought tolerant variety and this increase results in a proportional input cost change of 0.01%. The probability (ρ) that the new variety will fully achieve the estimated yield change (i.e., probability of success) is assumed to be 70%. The depreciation rate (δ_t) is assumed to be zero from 2012 to 2035, and from 2035 onward it will linearly reach its maximum in 2050 at 55%. This depreciation rate accounts for the potential reduction in the effectiveness of the new variety over time.

The adoption rate (A_t) used in our analysis follows a logistic-shaped adoption path until it reaches the maximum adoption rate of 25% in 2039 and it will sustain until 2050. A maximum adoption rate of 20 to 25% observed 20 years after release is roughly consistent with the Swarna mega-variety experience in which the observed adoption is 15–20%, 20 years after its release in 1986. The logistic adoption path is also consistent with previous studies that used the Alston et al. (1998) framework. The rice supply elasticity (ε), as well as the demand elasticities to be used in the calculation of producer/consumer surplus, is based on historical estimates (see Mohanty et al. 2011, for example).

Since drought does not occur every year and yield benefits from the new drought tolerant variety primarily occur when drought takes place, an additional multiplicative term (φ_t) is included in equation (1) to reflect the area under drought during the 2000 to 2011 period and the overall probability of drought. Based on the MODIS Normalized Difference Vegetation Index (NDVI) 250m satellite remote sensing time series data, we calculated the area weighted average drought affected area in five countries in South Asia from 2000 to 2011. Table 3 presents the summary of these figures. In calculating the drought affected area, we consider mild to severe drought affected rice areas from 2000 to 2011. Note that under mild drought, yield loss can reach up to 10 percent, and under moderate drought, yield loss can be up to 50 percent. Yield loss can reach 100 percent under severe drought. Table 3 shows that in Bangladesh, the total MODIS rice area is 7.76 million hectares in 2000, of which 16.85 percent of rice area is affected by mild to severe drought from 2000 to 2011 with a probability of 0.34. In India, out of 45.34 million hectares of rice land, nearly 26 percent of this rice area affected by mild to severe drought during the 2000 to 2011 period, with a probability of 0.46. In Nepal, Pakistan, and Sri Lanka the total MODIS rice area are, 1.54 million hectares, 1.96 million hectares, and 0.82 million hectares, respectively, with corresponding drought probabilities of 0.21, 0.36 and 0.36. The probability of drought was calculated by dividing the number of drought years by the total number of sampled years (for details see Pandey et al., 2007). Hence, we use these figures as a conservative estimate of the average drought affected area in South Asia.

Estimating the Economic Surplus Effects: The Partial Equilibrium Models

Once the *K*-factor has been calculated, the surplus measures from Alston et al.'s (1998) static partial equilibrium model can be calculated for all the years in the period of interest. To implement this model, one also needs information on initial 2012 production, consumption, and prices for all sampled countries and the rest of the world (ROW). In addition, estimates of the demand elasticities, supply elasticities, excess demand elasticities, and the fraction of the production consumed locally (S_A) by rice exporting countries, such as India and Pakistan are also needed as well.

The initial production, consumption, and price figures used in the analysis are based on IRRI projections for 2012. Actual (or observed) data for these variables are not yet available, which is why projections are used. Moreover, the production figures we use in the analysis only pertain to the specific areas within the South Asian countries that are affected by drought. It is reasonable to assume that the new drought tolerant variety would only be pertinent to production areas that are affected by drought only. In this analysis, only drought affected areas from MODIS data are assumed to be affected by drought. Hence, the production figures we utilize for the analysis is proportional to these areas affected by drought. Actual production, consumption, and price figures used in the analysis can be seen in table 4. As we assumed our sampled five countries as open economies[8], in calculating the net benefit, we use 5 % broken Thai milled rice price in our estimation process. Table 4 shows that in 2012, the price of 5 % broken Thai milled rice price was USD550.15 per ton. The demand elasticities, supply elasticities, and excess demand elasticities are again based on historical estimates and the actual elasticity values used are summarized in table 4. Other key parameters used in the economic surplus model are presented in table 4 for easy reference.

Using all the data above, the discounted sum of surplus measures can be calculated and compared against the sum of the discounted research costs to calculate rate of return measures (i.e., net present value (NPV), and internal rate of return (IRR) at a 5% discount rate). This gives an estimate of the net benefits of investments in research to develop and release a combined drought- and flood-tolerant variety in South Asia.

Estimating the Market and Trade Effects: The IGRM Model

Since the Alston et al. (1998) economic surplus model is primarily static, we also use the IRRI Global Rice Model (IGRM) to somewhat account for market dynamics and to determine the trade effects of releasing a drought tolerant variety in South Asia. The IGRM model simulates long-run changes in rice production, consumption, trade, and prices in the major rice producing regions of the world. The IGRM is a partial equilibrium structural econometric simulation model that includes 30 major rice producing, consuming, and trading countries. The representative country model includes supply, demand, trade, ending stock, beginning stock and market equilibrium conditions. For major rice producing countries, supply is modeled in a regional

[8] In calculating net benefit, we consider India and Pakistan as a large open economy, and Bangladesh, Nepal and Sri Lanka as small open economies.

framework to capture different mix of crops due to climatic differences and regional heterogeneity in availability of water and other natural resources. Rice production is modeled by estimating separate area harvested and yield equations. Assuming an adaptive price expectations for both rice and competing crops' prices, the area harvested is specified as a function of lagged rice farm price, lagged farm price of competing crops, and lagged area harvested. Yield is determined by fertilizer use and technological change (i.e., the trend).

On the demand side, per capita rice consumption is specified as a function of real per capita GDP and real retail price. Individual country models are then linked through net trade equations to solve Thai FOB (5% broken, Bangkok) to appropriately link individual country to the world rice economy. Structurally, the following identity is satisfied for each country and the rest-of-the-world (ROW): Beginning Stock + Production + Imports = Ending Stock + Consumption + Exports. This identity is satisfied by: (1) solving the prices in most of the net exporting and net importing countries; and (2) modeling domestic price as a function of the world price with a price transmission equation, and set one of the variables as the residual to satisfy the identity. Since rice market is heavily distorted, the model tries to explicitly include policy variables in supply, demand, ending stocks, exports, imports, and price transmission equations.

The IGRM model is used to develop projections of global supply, demand, trade and prices with a set of assumptions about the general economy, agricultural policies, and technology changes in net exporting and net importing countries. In this baseline scenario, the technology assumption is that the existing varieties without drought tolerance are modeled. In the next IGRM runs, the proportionate yield change per hectare $E(Y)$ in the Alston et al. (1998) model is utilized to quantify the yield effects of having the new drought tolerant variety through time. More specifically, we further multiply $E(Y)$ by the adoption rate and probability of drought and the proportion of drought affected area. Then we use the resulting value to adjust the intercept of the yield equations in the IGRM model to account for the effect of the drought tolerant variety. We make these adjustments to specific regions in the IGRM model that are deemed drought prone. The results from the latter IGRM run (with intercept adjustment) are then compared with the baseline run (without any intercept adjustment) to quantify the price, consumption, and trade effects of the new variety under the specific climate change scenarios we examine (base line, A2, A1B and B1 SERS scenarios from the CGCM). Table 5 presents the values of the discounted $E(Y)$ at some specific sample years that we used in IGRM to quantify the price, consumption, and trade effects of the new variety under the specific climate change scenario.

Results: Yield Effects from ORYZA2000 and the Estimated Economic Surplus Measures

The results of the ORYZA2000 runs under different climate change scenarios to calculate the yield advantage of the new drought tolerant variety can be graphically seen in figures 1, 2, 3 for the periods 2015-20 and 4,5 and 6 for the periods 2035-40. The ORYZA2000 crop growth simulation run suggest that the new drought tolerant variety would result in a substantial yield advantage in South Asian countries than the base case had this particular variety been developed and disseminated in South Asia. For example, during 2015-2020, under no climate change scenario, yield gain from the proposed drought tolerant variety in Bangladesh and India would be 1.71 and 6.85 percent, respectively. In Nepal, Pakistan and Sri Lanka would be 7.6, 18.9 and 8.96 percent, respectively, as compared to the existing variety. The ORYZA2000 crop growth simulations also projected yield gain under changing climate scenarios and under the assumption that there is no climate change in the sampled countries during 2035-40. As noted in the previous section, the projected yield gain during 2015-2020 and 2035-2040 corresponds to E (Y) estimates needed in the economic surplus model.

Based on the $E(Y)$ estimates from the ORYZA2000 runs and the parameters discussed in the previous section, we implement the Alston et al. (1998) model to calculate economic surplus measures and obtain the return on research investment measures (e.g., NPV and IRR). The estimated cumulative net benefits of a new drought tolerant variety that is released in 2016 (for the period 2011-50 and discount rate at 5%) are nearly US$344 million for Bangladesh, US$1.5 billion for India, US$26 million for Nepal, US$94 million for Pakistan and US$10 million for Sri Lanka under the assumption of no climate change (table 6). The corresponding rate of return on research investments (i.e., IRR) for developing and releasing the new variety is estimated at 26% for Bangladesh, 43% for India, 54% for Nepal, 46% for Pakistan and 29% for Sri Lanka (table 6). Table 6 also presents return on research investment measures (e.g., NPV and IRR) under the assumption of different climate scenarios. For example, under the assumption of SERS A2 climate scenario, estimated cumulative net benefits are US$ 411 million for Bangladesh, US$1.4 billion for India, nearly US$5 million for Nepal, US$ 67 million for Pakistan and US$ 6 million for Sri Lanka and the corresponding rate of return on research investments (i.e., IRR) are estimated at 59% for Bangladesh, 39% for India, 13% for Nepal, 37% for Pakistan and 23% for Sri Lanka (table 6). These return on investment measures suggest that the returns from the development and dissemination of a drought tolerant variety in South Asia are worth the costs incurred. The economic welfare of producers and consumers in South Asia is improved with the development and release of a combined drought- and flood-tolerant variety.

Importantly, table 6 shows that return on investment from developing and disseminating a drought tolerant variety in South Asia varies among countries under different climate scenarios. For example, for the SERS A2 climate scenario, the IRR for Bangladesh and Sri Lanka were large relative to the other climate scenarios and other South Asian countries. In contrast, India and Nepal had the highest return on investment in the no climate change scenario, and Pakistan has the highest return on investment in the SERS B1 scenario. While, findings in table 6 confirms net gain from investment in developing and disseminating of a drought tolerant variety under differing climate scenarios in all countries, there is significant heterogeneity in the magnitude of the returns on investments. This may suggest that adoption of country specific targeted programmes and policies may influence the magnitude of the returns to investment in drought tolerance rice research.

Sensitivity analysis was also conducted to check the sensitivity of results to changes in some of the parameters. For example, effects of changing the probability of success and the probability of droughts were examined. In general, even with the changes in some of the parameter estimates, the economic surplus analysis suggests that investing US$84 million in the development and dissemination of a drought tolerant variety provides a healthy economic return over the long-run. Detailed results of the sensitivity analysis are available from the authors upon request.

Results: Market and Trade Effects from the IGRM Model

The projected production, consumption, and price effects (in 2035) of developing and disseminating a drought tolerant variety in South Asia are presented in table 7. The baseline scenario results where we assumed that the drought tolerant variety was never developed and without considering any projected climate scenario can be seen in column B. The “new variety” scenario results where we assumed that drought-tolerant variety is developed and disseminated in South Asia are seen in columns C, D, E and F. Note that columns D, E, and F present projected production, consumption, and price effects in 2035 under the SERS A2, SERS A1B and SERS B1 climate scenarios, while at the same time assuming that the drought tolerant varieties are available. For reference, we include 2012 values in column A.

Overall, the IGRM results suggest that in 2035 rice production and consumption in South Asia would be higher if a drought tolerant variety is developed and released in the region (as compared to the case where the variety was not developed and released). Milled rice production in Bangladesh would be nearly one million ton to three million tons higher than the baseline scenario that assumes that the new variety has not been developed. In India, milled rice production would be six to eight million ton higher than the base line scenario. Simulation results also show similar production gains for Nepal, Pakistan and Sri Lanka. Importantly, IGRM result shows that production gain in Pakistan would be substantial if the new drought tolerant variety would be developed and in the hand of the farmers. Overall, total milled production in the world would be six to 12 million tons higher and nominal price of milled rice per ton would be US$200 to US$70 lower in the world under different climate scenarios where the drought tolerant variety has been developed and adopted. It means, production would have been smaller and world rice prices would have been higher had the new drought tolerant variety not been developed and disseminated. The price reduction effect observed here implies that poor rice importing countries in the world would benefit from the release of a drought tolerant variety in South Asia. Lower prices would make rice more affordable to poor people and may lead to improved nutritional outcomes.

The estimated consumption effects in 2035 for the baseline scenario without the drought tolerant variety and for the new drought tolerant variety under different climate scenarios are also presented in table 7. It shows that consumption in Bangladesh, Nepal and Sri Lanka would not change much had the new drought tolerant variety been developed and disseminated compared to the base line scenario. However, overall rice consumption in India and in Pakistan would increase substantially compared to the baseline scenario. This is mainly because of the reduction in domestic retail price for the increase in supply due to the adoption of the new drought tolerant variety.

The estimated trade effects (exports and imports) in 2035 for the baseline scenario without the drought tolerant variety and with the new drought tolerant variety under different climate scenarios are also presented in table 7. These results suggest that South Asian rice exports would be higher and rice imports would be lower when a drought tolerant variety has been released and adopted in the region. For example, Indian rice exports would be four to seven million tons higher in the scenarios when the new drought tolerant variety is made available in the region. In addition, rice imports in Bangladesh, Nepal, and Sri Lanka would be lower with the development and release of the drought tolerant variety under any climate scenario. These trade results can be tied back to the increased domestic rice production in the region due to the new variety. With the higher domestic production, the dependence of Bangladesh, Nepal, and Sri Lanka on rice imports would be drastically reduced.

Summary and Conclusions

This article examines the ex ante economic impact of developing and disseminating a drought tolerant rice variety in South Asia under different climate scenarios. Specifically, we investigate the potential yield, production, consumption, and trade effects of having a new drought tolerant rice variety in South Asia, as well as measure the rate of returns to investing in the development of this new variety.

Our analysis indicate that the economic benefits of a new drought tolerant rice variety more than outweighs the cost of developing this new variety, especially in light of global climate change. The development and release of this new variety in South Asia would provide a net economic benefit of about US$2.0 billion when we do not consider any change in the climate and from to US$ 1.5 to US$ 1.9 billion when we consider change in the climate scenarios for the region alone.

In addition, results from our partial equilibrium market models suggest that production, consumption, and rice exports in South Asia would be higher with the drought tolerant variety (as compared to the case where this new variety is not developed). Reliance on rice imports by Bangladesh, Nepal, and Sri Lanka would be substantially reduced when this new variety is made available and adopted in South Asia. Rice prices in the world are expected to be lower if the drought tolerant variety is developed and released. Hence, rice would be more affordable to poor consumers and would likely improve the nutritional status of the poor in the region.

These results imply that substantial economic benefits can be achieved from the development of an improved rice variety that is tolerant to the abiotic stress, such as drought. This type of technology would allow rice producers to adapt to worsening global climate and make them able to mitigate the adverse effects of climate change in the future. In the long-run, the returns to the investment of developing this particular “climate change tolerant” variety is high. Thus, we strongly encourage policy makers and donors to fund the research, development, and dissemination of new rice varieties that are more tolerant to drought and other abiotic stresses, so that farmers can better cope with the changing global climate in future.

Although this article provides some estimates of the economic benefit in investing in research to develop a drought tolerant variety, it is important to recognize its limitation. One major limitation of the article is that we use the ORYZA2000 crop simulation model to estimate the economic benefits under the assumption of no nitrogen stress. The results might be significantly different if we do not have this assumption. In fact, preliminary simulation runs show that potential nitrogen stress might severely reduce the yield gain from the drought tolerant variety. For example, in the case of nitrogen 40 to 60 kilogram
ha^{-1} and 80 to 70 kilogram ha^{-1}, the ORYZA2000 crop simulation model show substantial decrease in the yield gain even when the new drought tolerant variety is available in South Asian countries. Another limitation of the article is the assumption of homogeneous agronomic conditions in South Asia, which is not true in reality. Given these two limitations, we suggest that any new drought-tolerant variety must be released under a "package program" where clear instructions should be included on how much water and fertilizer (or other inputs) should be applied with the new variety, under differing agronomic environments. Such a "package programme" also may include training of the farmers about specific agronomy that is necessary with the new variety so as to get maximum benefit.

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Table 1. Drought tolerant varieties of rice released during 2009-10.

Variety name	Year released	Countries where released	Special features
IR74371-54-1-1 Sahod Ulan	2009	Philippines	Early, drought tolerant, suitable for both direct seeded and transplanted situation
IR74371-54-1-1 Sukha dhan 2	2010	Nepal	Medium slender grain, drought tolerant
IR80411-49-1-1-B Tarharra1	2009	Nepal	Early, drought tolerant, suitable for both direct seeded and transplanted situation
IR74371-70-1-1 Sahbhagi dhan	2010	India	
IR74371-70-1-1 Sukha dhan 3	2010	Nepal	Early, drought tolerant, suitable for both direct seeded and transplanted situation
IR74371-70-1-1 (pre-released line)	2011	Bangladesh	
IR74371-46-1-1 Sukha dhan 1	2010	Nepal	Early, drought tolerant, suitable for both direct seeded and transplanted situation

Source: Kumar (personal communication) as cited in Tonini and Cabrera (2011).

Table 2. Summary of ex ante impact assessment pathway for discovery of a variety for tolerance to drought and its dissemination.

	Step in pathway	Date	Approximate cost (Million US$)
1	Drought tolerant QTL combined with popular mega varieties	End of 2012	5.0
2	Seed preparation for dry season testing in IRRI	End of 2012	5.0
3	Seed preparation for wet season testing in IRRI	May-13	10.0
4	Seed multiplication	2013	10.0
5	Limited field trial in India in dry season	2014	17.0
6	Large scale field trial in different IRRI stations across India, Bangladesh, Nepal	2014-16	17.0
7	Selection of suitable lines and approval by the national governments, dissemination to the farmers	2014-16	20.0
	Total	5 Yrs	84.0.0

Source: Experts opinion (Kumar, 2011).

Table 3: MODIS 250m NDVI rice farm land in South Asia and the proportion of drought affected area and probability of drought at the regional level.

Country and Region	Rice Area (Million hectares)	% Area affected by drought (area weight average)*	Probability of occurrence of drought**
Bangladesh	7.76	16.85	0.34
Barisal	0.68	12.12	
Chittagong	1.18	12.90	
Dhaka	1.91	20.22	
Khulna	1.03	21.18	
Sylhet	0.69	17.83	
Rajshahi	2.28	17.46	
India	45.34	25.79	0.46
East	20.01	39.25	
North	9.72	19.20	
South	8.0	21.97	
West	7.61	22.75	
Nepal	1.54	12.13	0.21
Central	0.46	18.76	
Eastern	0.48	15.14	
Far western	0.16	7.89	
Mid western	0.15	11.37	
West	0.3	8.42	
Pakistan	1.96	26.92	0.36
Baluchistan	0.10	37.67	
NWFP	0.08	20.57	
Punjab	1.20	27.39	
Sind	0.58	21.51	
Sri Lanka	0.82	8.73	0.36
Central	0.045	5.16	
Eastern	0.14	9.47	
North Central	0.17	9.61	
North West	0.10	8.89	
Northern	0.08	17.3	
Sabaragamuwa	0.04	1.86	
Southern	0.12	5.41	
Uva	0.07	7.32	
Western	0.055	13.58	

* Considered rice area affected by mild, moderate and severe drought during 2000-2011 in wet season only. Calculated area weighted average over sample years. Under mild drought crop damage ranges upto 10%, under moderate drought upto 50% and under severe damage 100%. **Adapted from Pandey et al., (2007)

Table 4. Summary of the key parameters used in economic surplus model.

Parameter	Bangladesh	India	Nepal	Pakista n	Sri Lanka	World
Probability of success of research (α)	0.70	0.70	0.70	0.70	0.70	0.70
Estimated Research costs (million US$)	15.0	60.0	2.0	5.0	2.0	84.0
Milled rice production in 2012 (Million ton)	34.34	100.55	2.91	6.56	2.84	464.93
Rice consumption in 2011 (Million ton)	34.94	94.99	2.97	2.85	2.85	462.20
Retail Price of milled rice in 2012 (US$/ton)	370.92	226.46	187.75	251.43	186.94	550.15
Supply elasticity	0.13	0.13	0.11	0.31	0.16	0.12
Demand elasticity	-0.03	-0.09	-0.001	-0.96	-0.14	-0.098
Excess demand elasticity for the rest of the world	--	30.48	--	48.37	--	--

Sources: IRRI IGRM, December, 2011.

Table 5: Adjusted Yield gain E(Y)* of Adopting new drought and flood tolerant rice variety at the region level in the sample countries used in IGRM to quantify the price, consumption, and trade effects of the new variety under different climate scenario.

Climate scenarios	No Change in climate			A2			A1B			B1		
Year	2016	2025	2035	2016	2025	2035	2016	2025	2035	2016	2025	2035
India												
East	0.022	0.166	0.463	0.036	0.268	0.359	0.132	0.434	0.489	0.014	0.107	0.098
North	0.052	0.391	0.487	0.027	0.200	0.735	0.113	0.370	0.369	0.051	0.383	0.625
South	0.014	0.108	0.151	0.012	0.091	0.172	0.058	0.191	0.177	0.014	0.103	0.150
West	0.022	0.168	0.170	0.019	0.142	0.209	0.053	0.173	0.240	0.019	0.141	0.214
Bangladesh												
Barisal	0.004	0.033	0.173	0.014	0.102	0.056	0.005	0.038	0.112	0.006	0.045	0.057
Chittagong	0.001	0.005	0.083	0.012	0.093	0.089	0.004	0.029	0.082	0.006	0.046	0.088
Dhaka	0.005	0.039	0.359	0.022	0.164	0.130	0.001	0.010	0.186	0.008	0.059	0.123
Khulna	0.008	0.061	1.022	0.015	0.114	0.059	0.002	0.012	0.168	0.007	0.052	0.116
Sylhet	-0.001	-0.005	0.251	0.015	0.112	0.104	0.011	0.081	0.118	0.005	0.039	0.022
Rajshahi	0.002	0.016	0.143	0.012	0.089	0.056	0.007	0.056	0.074	0.004	0.034	0.090
Nepal												
Central	-0.009	-0.067	0.056	0.004	0.031	0.130	0.016	0.120	0.097	0.000	0.002	0.015
Eastern	-0.013	-0.101	0.181	0.000	0.003	0.092	0.016	0.118	0.129	0.000	0.000	0.090
Far western	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mid western	0.010	0.073	0.090	0.030	0.225	0.143	0.007	0.052	0.246	0.041	0.311	0.160
West	-0.002	-0.014	0.002	0.022	0.164	0.072	0.007	0.056	0.129	0.006	0.046	0.074
Pakistan												
Baluchistan	0.028	0.212	2.062	0.047	0.354	1.590	0.116	0.867	0.098	0.210	1.572	3.291
NWFP	0.053	0.397	0.602	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Punjab	0.073	0.545	0.550	0.033	0.247	0.250	0.024	0.181	0.605	0.041	0.309	0.190
Sind	0.073	0.548	1.202	0.137	1.026	1.239	0.087	0.654	0.142	0.145	1.086	0.850
Sri Lanka												
Central	0	0	0	0.000	0.000	0.000	0.001	0.004	0.000	0.000	0.000	0.000
Eastern	-0.007	-0.040	0.030	0.002	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.021
North Central	0.003	0.016	0.043	0.002	0.014	0.000	0.000	0.000	0.001	0.000	0.000	0.015
North West	0.006	0.040	0.052	0.004	0.027	0.016	0.002	0.013	0.012	0.002	0.013	0.029
Northern	0.049	0.297	0.311	0.022	0.164	0.217	0.021	0.157	0.125	0.022	0.164	0.178
Sabaragamuwa	0.001	0.007	0.008	0.000	0.001	0.000	0.000	0.001	0.001	0.000	0.000	0.002
Southern	0.003	0.020	0.019	0.003	0.022	0.020	0.002	0.013	0.010	0.002	0.014	0.022
Uva	-0.001	-0.007	0.042	0.002	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.016
Western	0.000	0.000	0.000	0.002	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.020

* E(Y) is adjusted during 2016-35 using the rate of adoption and 11 year weighted average drought area at the region level.

Table 6. Net economic benefit (in million US$) of the development and dissemination of a new drought tolerant rice variety in South Asia under SERS A2, SERS A1B, SERS B1 and under no climate change scenarios (probability of success = 0.7; weighted average of drought area and constant probability of drought in the sampled countries; discount rate = 5%).

Climate scenarios	No climate change (base scenario)		SERS A2		A1B		B1	
Name of the country	NPV	IRR	NPV	IRR	NPV	IRR	NPV	IRR
Bangladesh	343.85	0.26	411.29	0.59	176.77	0.26	186.01	0.36
India	1543.29	0.43	1471.26	0.39	1551.31	0.43	1242.63	0.39
Nepal	26.48	0.54	4.79	0.13	16.16	0.35	5.83	0.17
Pakistan	94.07	0.46	67.05	0.37	57.76	0.39	118.67	0.57
Sri Lanka	10.53	0.29	6.38	0.23	3.46	0.17	4.65	0.18
South Asia	2018.22	--	1960.77	--	1805.46	--	1557.79	--

Table 7: Global and Regional impacts of introduction of new drought tolerant rice variety in South Asia (production, consumption and trade are in million tons).

Country/Region	Indicators	2012	2035				
			Existing variety	New drought tolerant variety			
				No climate change	A2	A1B	B1
		A	B	C	D	E	F
World	Milled Production	464.93	530.36	542.09	539.59	539.02	536.35
	Nominal price (USD/Ton)*	550.15	1107.5	879.25	1025.21	993.81	1035.44
Bangladesh	Milled Production	34.34	40.40	43.07	40.92	41.31	40.90
	Consumption	34.94	42.74	42.84	42.77	42.79	42.77
	Imports	0.60	2.34	0.17	1.84	1.49	1.88
India	Milled Production	100.55	111.83	119.49	120.10	119.21	116.42
	Consumption	94.99	106.41	113.21	113.54	113.01	110.55
	Exports	4.67	5.30	5.96	6.16	6.11	5.79
Nepal	Milled Production	2.91	3.24	3.32	3.30	3.36	3.30
	Consumption	2.97	3.36	3.36	3.36	3.36	3.36
	Imports	0.06	0.13	0.04	0.06	0	0.06
Pakistan	Milled Production	6.56	8.00	9.69	9.26	8.86	9.36
	Consumption	2.85	4.13	5.51	5.20	4.88	5.36
	Export	3.74	3.87	4.15	4.08	4.01	4.09
Sri Lanka	Milled Production	2.84	3.09	3.12	3.09	3.08	3.10
	Consumption	2.85	3.13	3.17	3.15	3.15	3.14
	Imports	0.01	-0.04	-0.05	-0.05	-0.07	0.04

* Thai 5% broken rice.

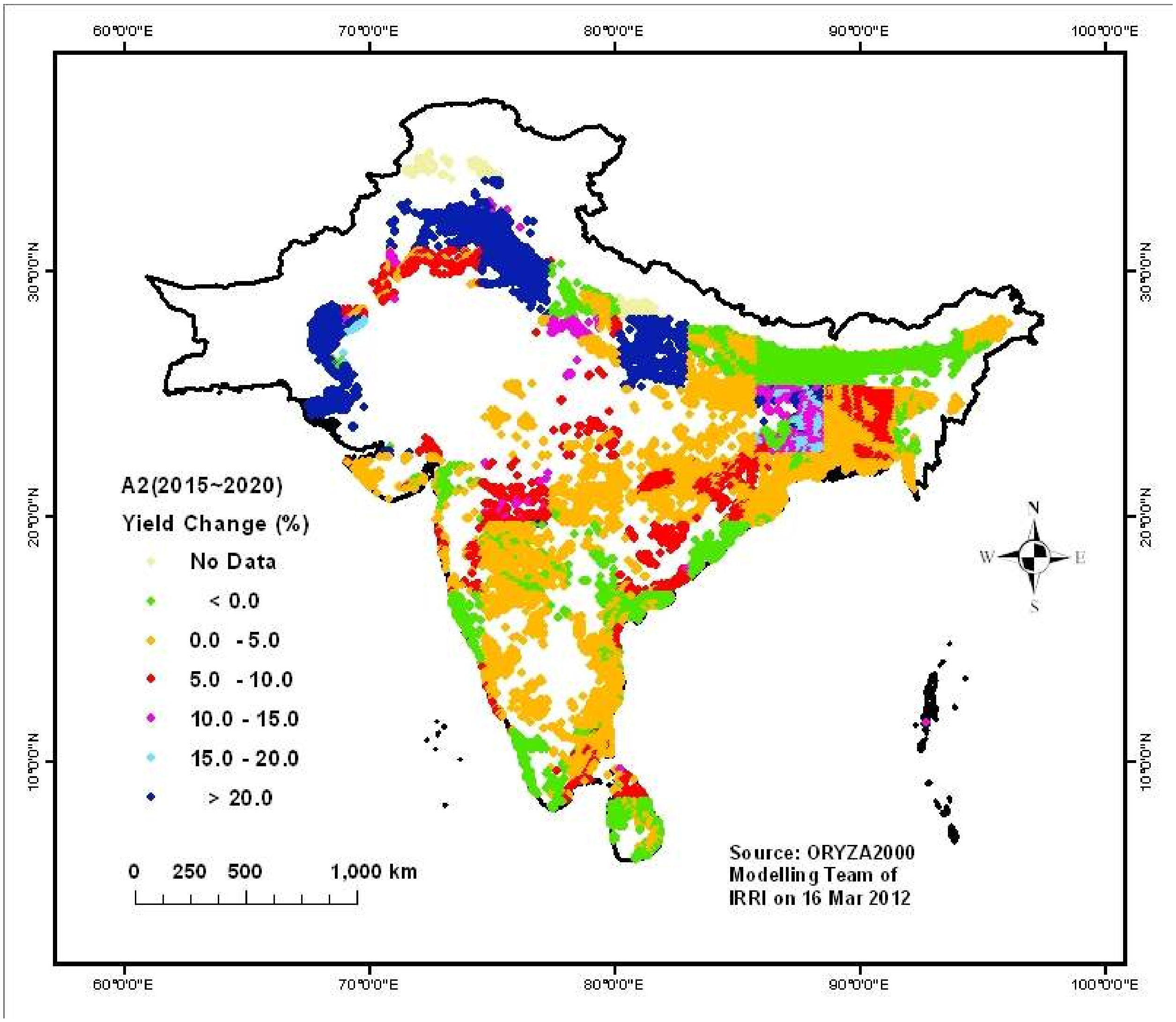

Figure 1. Net yield gain of new drought-tolerant variety over existing variety under A2 climate change scenario (2015-20 average).

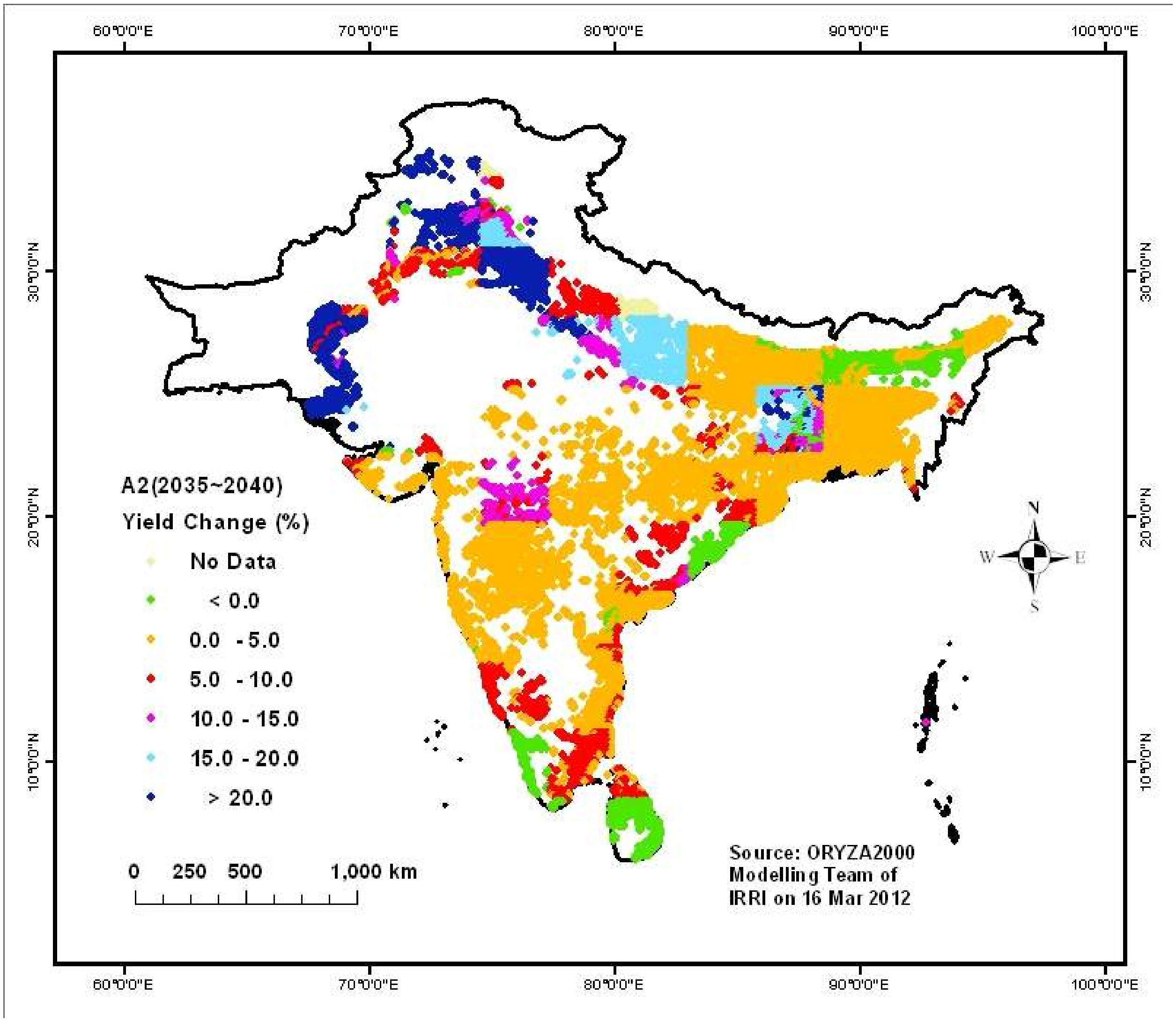

Figure 2. Net yield gain of new drought-tolerant variety over existing variety under A2 climate change scenario (2035-40 average).

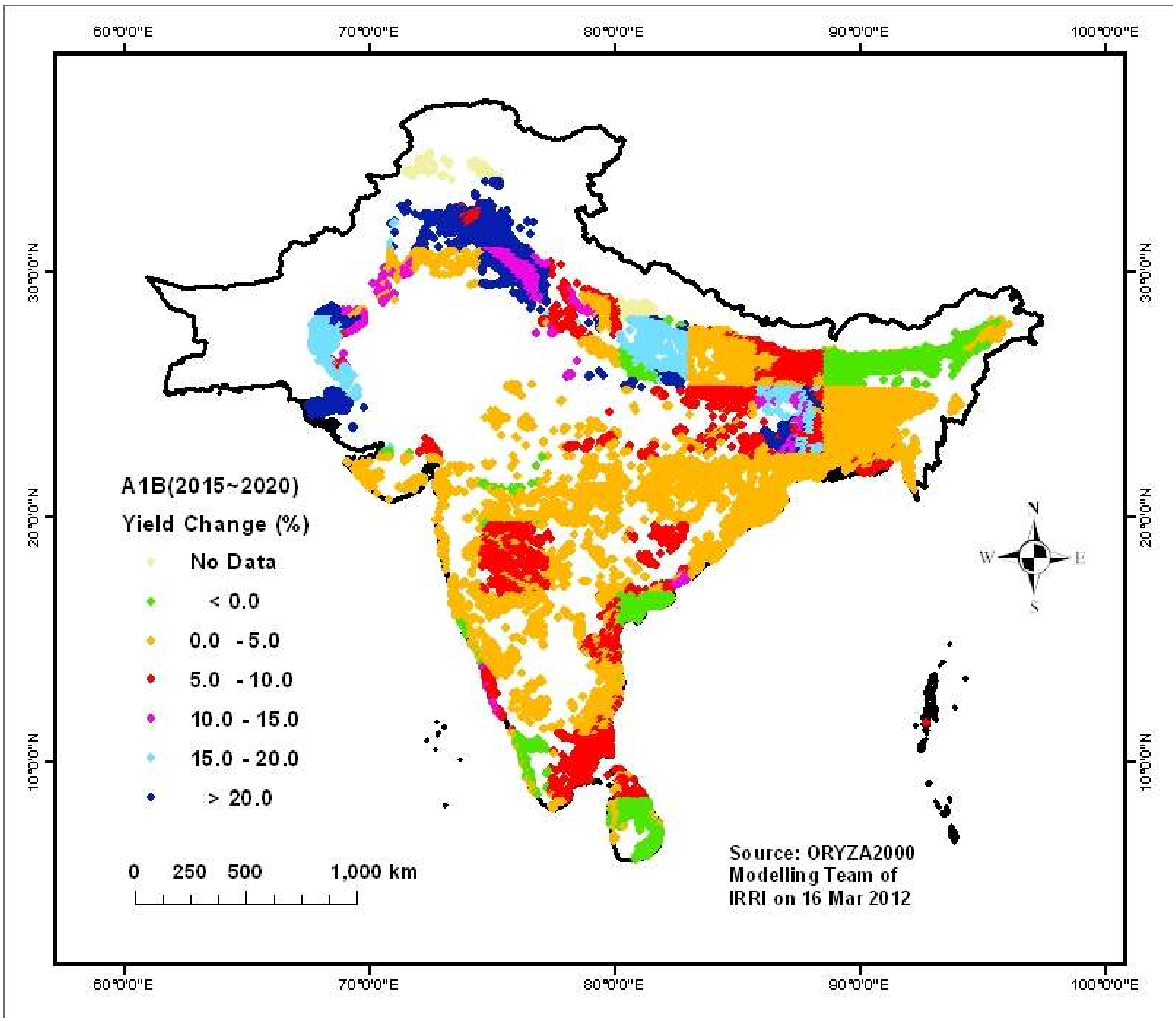

Figure 3. Net yield gain of new drought-tolerant variety over existing variety under A1B climate change scenario (2015-20 average).

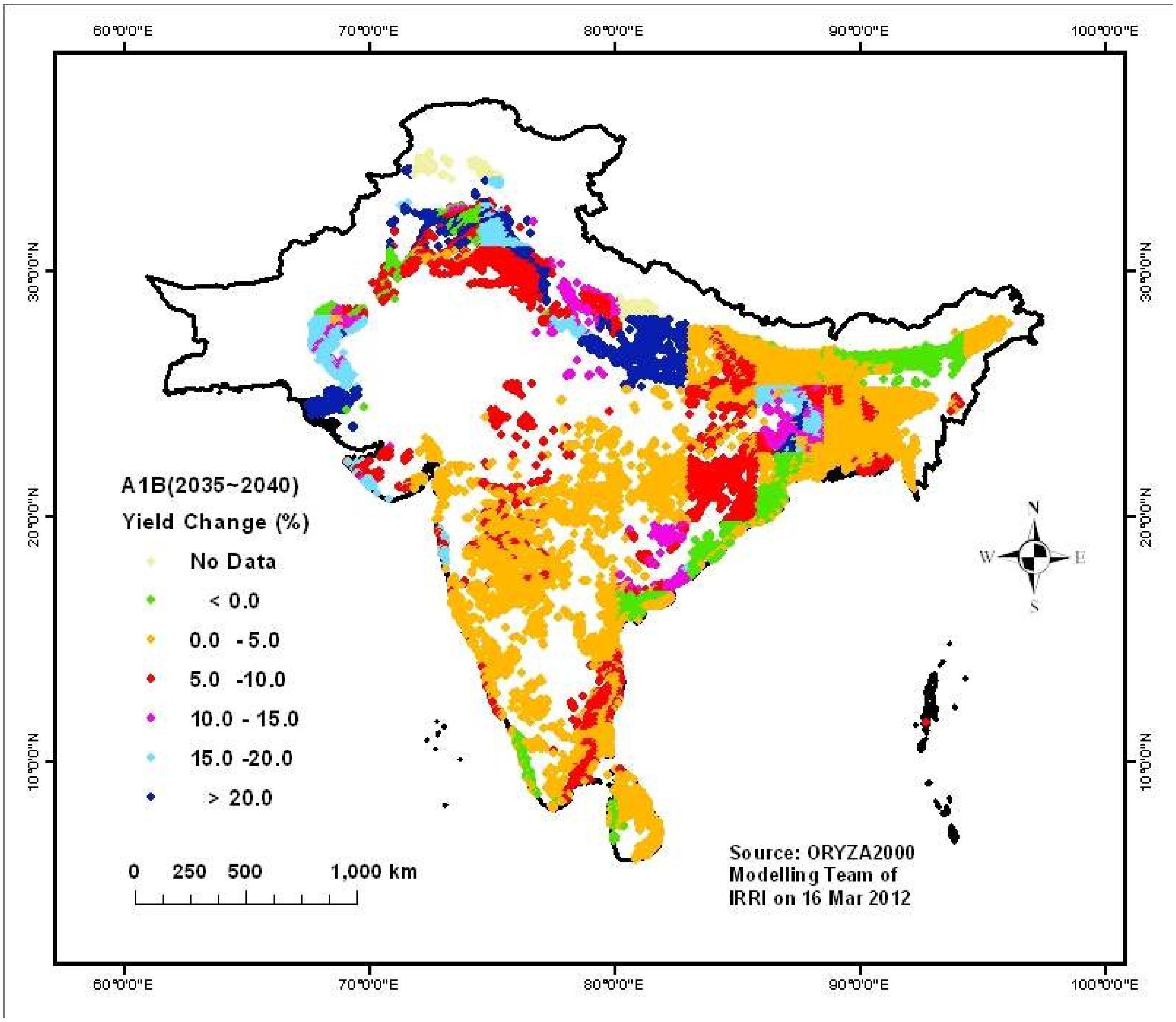

Figure 4. Net yield gain of new drought-tolerant variety over existing variety under A1B climate change scenario (2035-40 average).

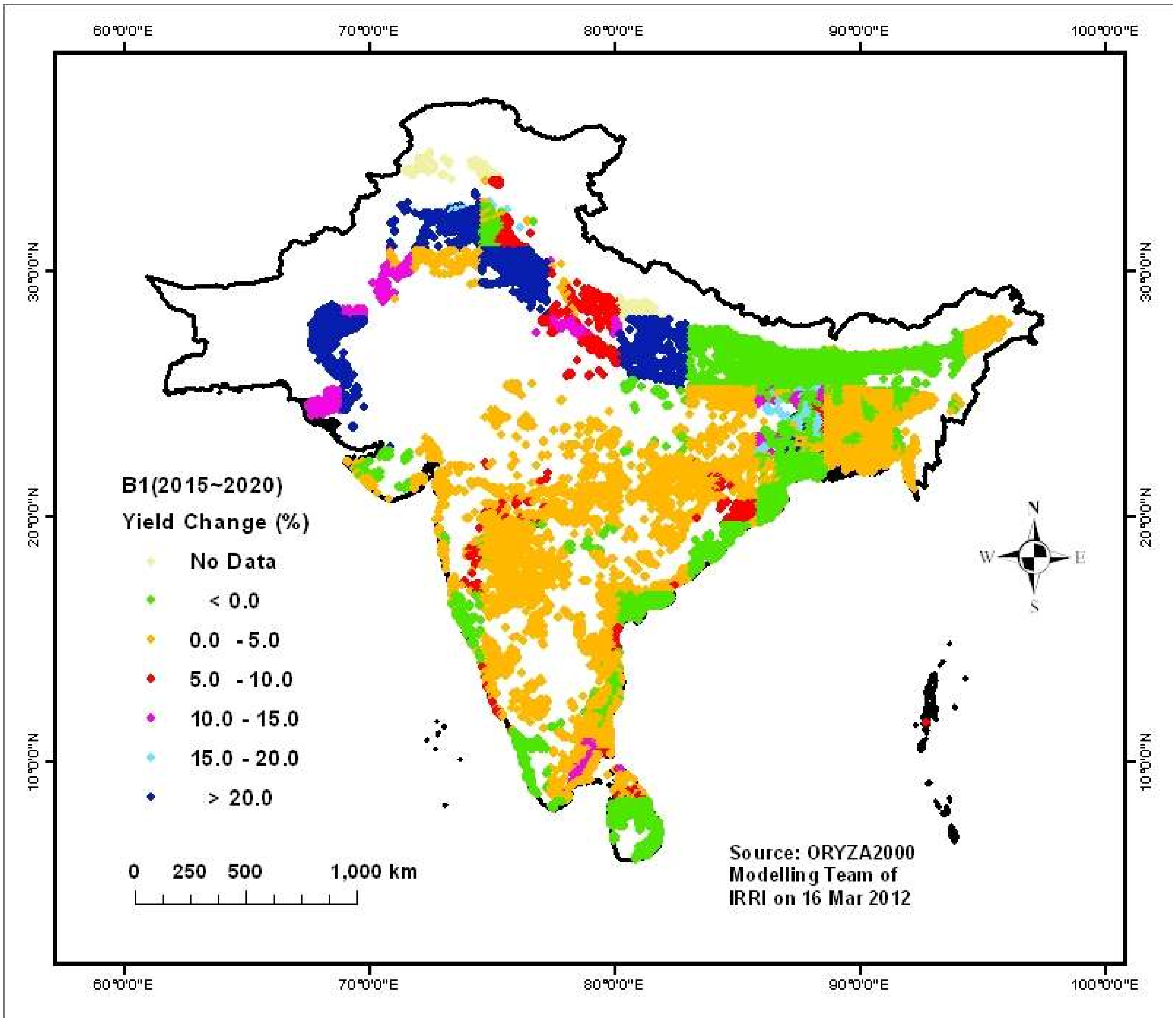

Figure 5. Net yield gain of new drought-tolerant variety over existing variety under B1 climate change scenario (2015-20 average).

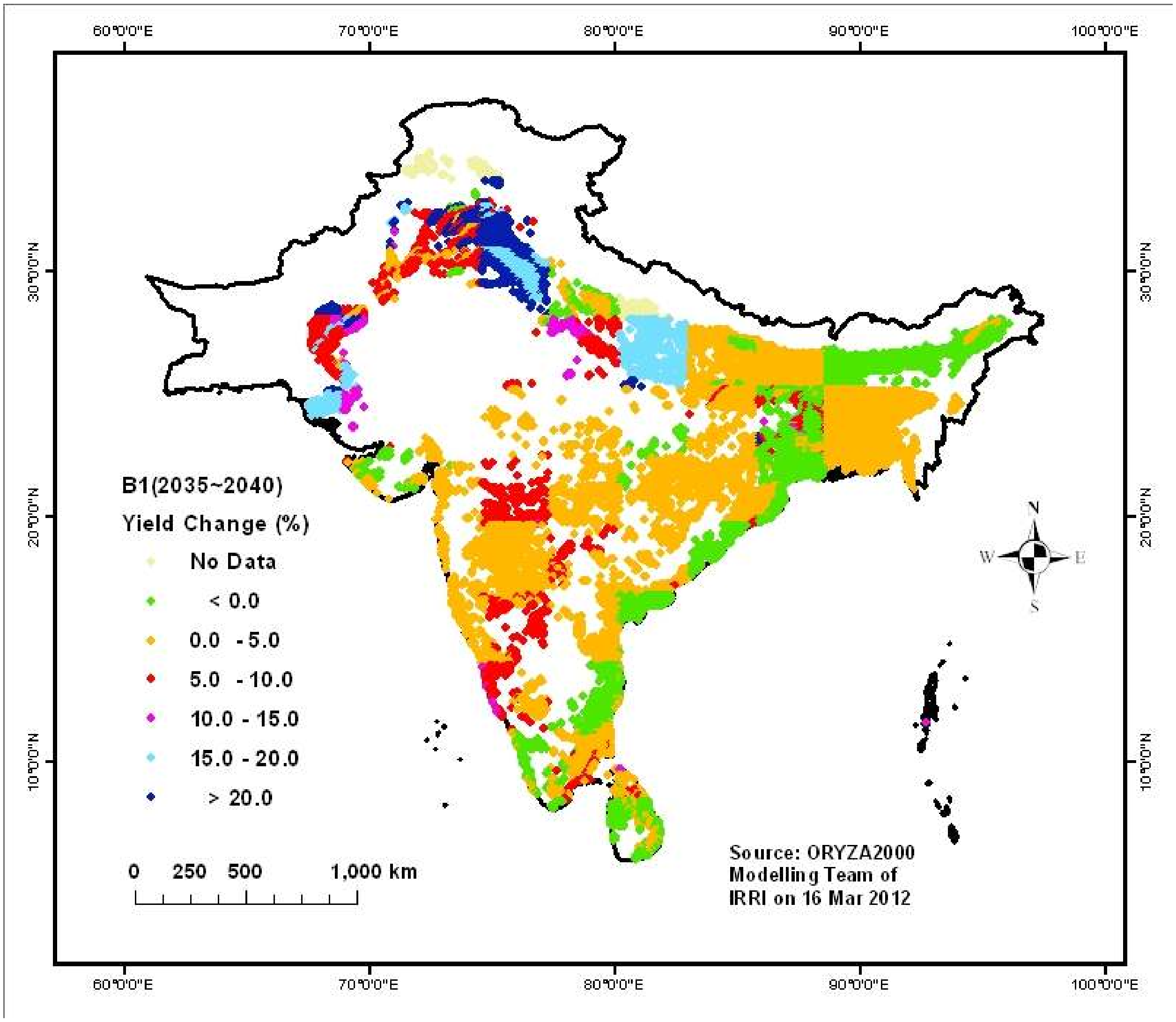

Figure 6. Net yield gain of new drought-tolerant variety over existing variety under B1 climate change scenario (2035-40 average).

Foot notes

[1] Molecular genetics is the field of biology and genetics that studies the structure and function of genes at a molecular level, and how the genes are transferred from generation to generation. Genomics uses intensive efforts to determine the entire DNA sequence of organisms and to fine-scale genetic mapping efforts. MAS is a process whereby a marker (morphological, biochemical, or one based on DNA/RNA variation) is used for indirect selection of a genetic determinant or determinants of a trait of interest. A transgenic is an organism that has had genes from another organism put into its genome through recombinant DNA techniques.

[2] The use of conventional breeding methods to develop varieties that are tolerant of abiotic stresses has had limited success in the past. Thus, scientists have turned primarily to MAS/MAB to allow them to more quickly assess whether a particular variety has the desired tolerance of a specific abiotic stress (or multiple abiotic stresses).

[3] Quantitative trait loci (QTLs) are stretches of DNA containing or linked to the genes that underlie a quantitative trait. A molecular marker/genetic marker is a fragment of DNA sequence that is associated with a part of the genome. These QTLs/markers provide scientists with information about whether genes that control specific traits (i.e., drought or submergence tolerance) are present without having to painstakingly grow the plant out to maturity and expose it to those stresses (as in conventional breeding). In principle, MAB saves time, is more precise in the sense of avoiding inclusion of undesirable traits, and is potentially more cost-effective (Collard and Mackill, 2008; Alpuerto et al., 2009).

[4] The mega-varieties Samba Mahsuri, Swarna, and CR1009 from India, IR64 from the Philippines (IRRI), Thadokkham 1 (TDK1) from Laos, and BR11 from Bangladesh are typically used as recipient parents. These varieties are called “mega-varieties” because they were popular and were planted for many years on a minimum of 1 million hectares.

[5] “Pyramiding” is a term that describes a genetic approach to determine and introduce multiple genes that each impart resistance to or tolerance of an independent biotic or abiotic stress.

[6] Breeders have noted that drought tolerance is a complex trait (relative to submergence tolerance, for example) such that there may not be a single gene or marker that directly relates to this trait (Kumar, 2011). It is possible that a QTL (rather than a single gene) is needed for drought tolerance. This is unlike the developed submergence-tolerant varieties that require only one single SUB1 gene that allows for tolerance of a specific type of flood event (see discussion below).

[7] In light of space constraints for this report, we do not provide details of the Alston et al. (1998) model here but we refer interested readers to p. 215 of Alston et al. (1998). Also, the authors can provide the full version of this current article, which includes details of the Alston et al. (1998) model.

[8] In calculating net benefit, we consider India and Pakistan as a large open economy, and Bangladesh, Nepal and Sri Lanka as small open economies.