Quantification of Yield Gaps and Impact Assessment of Rice Production Technologies

Biswajit Mondal, P Samal, NC Rath, GAK Kumar, SK Mishra, Lipi Das, NN Jambhulkar, PK Guru, MK Bag, SM Prasad, S Roy and K Saikia

1. INTRODUCTION

It is projected that there would be 60% increase in demand for agricultural production by 2050 (FAO, 2012), which is very large, but not unreachable. There is a huge ‘yield gap’ and closing these gaps could improve not only the productivity but also the efficiency of rice production. The term ‘yield gap’ has been commonly used to refer to the difference between the average farmers’ yields and an estimate of a reference yield or potential yield at a specific area in a given time. Maximum attainable yield is the yield of experimental or on-farm plots with no physical, biological and economic constraints and with known management practices at a given time and in a given ecology. Potential yield (van Ittersum and Rabbinge 1997) can be defined and measured in a variety of ways such as using crop growth models, maximum yield trials, and other research experiments, or best yields from farmers’ fields (Lobell et al. 2009). Farm level yield is the average farmers yield in a given area at a given time in a given ecology. Yield gaps exist because the best available production technologies are not adopted in farmers’ fields which could be due to farmers’ personal characteristics (e.g., lack of knowledge and skills, risk bearing ability), farm characteristics (e.g., soil quality, land slope, poor road), and unsuitability of the technology to farmers’ circumstances (e.g., labour-intensive, requirement of high initial investment, poor access to inputs). Yield gap has two components, the first one cannot be narrowed or not exploitable, because it is mainly governed by the factors that are non-transferable such as environmental conditions. The second component is mainly due to difference in management practices or farmer’s inefficiency level, which is manageable and can be bridged. As average crop yields are critical drivers of food prices, cropland expansion, and food security, yield gaps should be better quantified and understood (Lobell et al. 2009). An experimental technique for identifying and quantifying yield constraints in farmers’ fields was developed and validated by Gomez (1977). It measures the potential yield, the actual yield, and the yields corresponding to the addition or removal of test factors over and above the farmer’s levels. In agronomy, there are many crop models that can incorporate location-specific physical conditions to estimate crop growth and potential yields for particular crop types, as well as for combinations of many crops. These crop models are often developed using field and experimental data, thus providing reliable estimates of plant growth and potential yields and very much useful tool when designing agricultural systems for the maximisation of production outputs (de Koeijer et al. 1999; van Ittersum and Rabbinge 1997). However, economic, institutional and social factors are not associated in these models (de Koeijer et al. 1999), thus preventing their usefulness in socio-economic analysis. Hence, a different approach is required that integrates the experiments in farmers field into socio-economic analysis of productive efficiency.

Impacts are the longer-term results produced by a programme or policy implementation or adoption of a technology, which may be intended and unintended, positive and negative, direct and indirect in nature. Impacts do not only refer to what has happened-in some cases, the impact is in terms of preventing negative changes; it also includes the reduction, avoidance or prevention of harm, risk, cost or other negative effects'. An impact evaluation provides evidence about the results that have been produced (or expected to be produced). It has to not only provide credible evidence that changes have occurred but also undertake credible causal inference that these changes have been at least partly due to a project, programme or technology. There are different types of impact evaluation and categorized based on the period of the exercise, like (a) e*x-ante* impact where evaluation undertaken before the programme is initiated or the technology being adopted; (b) e*x-post* impact evaluation which is conducted after a technology has been adopted by farmers in the target areas or a programme being implemented fully; and (c) concurrent impact evaluation, which gathers evidence about whether the programme is on track to deliver intended results (during implementation process). Economic evaluations combine evidence about stream of benefits and costs, through, (a) cost-benefit analysis, which transforms all the benefits (positive impacts) and costs (resources consumed and negative impacts) into monetary terms, taking into account discount factors over time, and produces a single figure of the ratio of benefits to costs, and (b) cost-effectiveness analysis, which calculates a ratio between the costs and a standardised unit of positive impacts of different propositions or choices. For impact evaluation process, the standard challenge is determining what would have happened in the absence of the programme/ technology for which evaluation is being undertaken. To understand the impact of a programme/technology on a given indicator, information would ideally be available from the beneficiaries and those same beneficiaries without the particular programme/ technology. The indicator could then be compared between these two situations to examine if the programme/technology had an impact. However, beneficiary farmers cannot be simultaneously in the project and out of the project making it necessary to search for a substitute group of farmers to act as the counterfactual - that is, what would happen in the absence of the programme/technology. To be a genuine counterfactual, they would need to be exactly like the beneficiaries, or treatment group, except they would have not received the benefit of programme/technology. Thus, any differences in the indicator could be attributed to the particular programme/ technology. Agricultural programme are generally designed to improve production or the returns to agriculture and therefore, impact evaluations of agricultural projects focus on production-based indicators such as gross margins, crop prices, yields, productivity, agricultural investment, spending on agricultural inputs, technology adoption, changes in land use patterns, crop and varietal diversification and food for home production. Collection of this type of information are challenging, beginning with the definition of the sample unit; in fact, while production is often linked to multiple plots and crops, the decision-making process takes place at the household level.

The primary objectives of this chapter are: (a) to briefly discuss the theoretical and empirical issues related to yield gap analysis and impact assessment of modern rice production technologies; (b) to explore the existing knowledge on quantification/ factors of yield gap as well as impact assessment of agricultural technologies; and (c) to identify the gaps in knowledge, suggest research and development needs on yield gap analysis and impact assessment of agricultural technologies.

2. STATUS OF RESEARCH

2.1. Research on rice yield gaps

2.1.1. Approaches to quantify potential yields and yield gaps: The factors that inhibit farmers from getting potential yields with modern varieties may be physical, economic, social, or any combinations of them. Physical conditions on some farms may prevent the farmer from exploiting the full potential of the technology. Sometimes, high yields may be physically possible but economically unprofitable. In some cases, social or institutional problems may also exist. Farmers can't acquire requisite inputs timely due to lack of credit. Further, it is also likely that the technology may not be understood by the farmers or by those directly advising them. The concept of yield gaps in crops originated from different constraint studies carried out by International Rice Research Institute (IRRI) during seventies. To measure the potential yield, the actual yield, and the yields corresponding to the inclusion or withdrawal of test factors over and above the farmer's yield, an experimental technique was developed and validated by Gomez (1977) in plot experiments on sample farms. The relative contribution of each component to the difference between the potential yield and the farmer's yield was then assessed (Fig. 1). De Datta (1981) compared a series of combinations of inputs of increasing intensity (management packages) to establish the yield and profitability of different combinations and to indicate the approximate intensity that is most attractive to farmers.

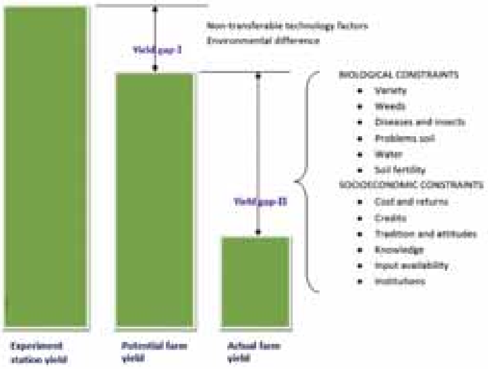

Fig. 1. The concept of yield gaps between an experiment station rice yield, the potential farm yield, and the actual farm yield (Gomez 1977).

There are atleast four distinguished methods to estimate yield gaps at a local level (Lobell et al. 2009): (a) field experiments, (b) yield contests, (c) maximum farmer yields based on surveys, and (d) crop model simulations. The first step associated with each method is to estimate yield ceilings (potential yield: Yp) for a given crop in a given location or region. Yield gap (Yg) is then calculated as the difference between Yp and actual yield (Ya). Although field experiments and yield contests can be used to estimate Yp for a given location and under a specific set of management practices, they require well-managed field studies in which yield-limiting and yield-reducing factors are eliminated (e.g., nutrient deficiencies, and diseases), and they must be replicated over many years to obtain a robust estimate of average Yp and their variation (Cassman et al. 2003). Field experiments and yield contests used as a basis for estimating Yp must use sowing dates and cultivar maturities that are representative of the prevailing cropping systems in the region of interest if they are to serve as benchmarks for these systems.

Surveys among farmers to estimate maximum yields from upper percentiles represent another approach to estimate Yp (Lobell et al. 2009). The best farmers' yields of a given region may give a better idea of what actually can be achieved under the normal edaphic conditions of that region (Lobell et al. 2009). It is also likely that the use of maximum farmers' yields as a proxy for potential yield is most appropriate in intensively managed cropping systems, with high levels of fertilizers and pesticides, where yield limiting factors such as nutrient deficiencies, insect attacks, diseases and competition with weeds are virtually eliminated. However, even then it is still improbable that a farmer reaches the water-limited yield potential, since optimal nutrient and pest management is quite impossible to achieve and in many cases economically not beneficial (Laborte et al. 2012). Moreover, under the conditions of family farms in the tropics, farmers often cannot afford the best available technologies. If crop production resources (including soil properties) and input levels have also been recorded, methods such as the boundary line approach or frontier analysis can be used to identify the highest yields for a given level of resource availability (Tittonell et al. 2008). However, if obstacles prevent all surveyed farmers from realizing Yp, then Yg will be underestimated. Such obstacles must operate at the same scale as the yield gap analysis and could include lack of access to inputs, lack of markets, and lack of knowledge or access to it.

Hoang (2013) has proposed a new analytical framework to examine productive efficiency in crop production systems using the economic, institutional, physical, social and technological factors of farm and the spatial heterogeneity. The novelty of this framework is the incorporation of agronomic knowledge into economic production frontier analysis. The framework has two stages; in the first stage crop growth and economic production models are used to estimate potential and best practice output levels. The framework has been applied to investigate the efficiency of rice production using district-average farm data of eight districts in Sri Lanka (Hoang, 2013). This empirical study yielded several important findings. Firstly, actual yields, on average, achieved only 60% of potential yields, leaving a 40% yield gap. This gap was decomposed into technical inefficiency (approximately 18%) and agro-economic inefficiency (approximately 22%). Theoretically, it is possible to bridge gaps between best practice and potential yields by providing optimal conditions for crop growth. In reality, however, it might not be economically optimal for farms to bridge these gaps because the cost of marginal increments in yield might exceed the marginal gain (i.e. revenues generated from incremental yields). To overcome limitations of the above approaches, crop simulation models can be used to estimate Yp (Laborte et al. 2012). These simulation models are mathematical representations of current understanding of biophysical crop processes (phenology, carbon assimilation, assimilate partitioning) and crop responses to environmental factors. They require site-specific inputs, such as daily weather data, crop management practices (sowing date, cultivar maturity, plant density), soil properties and specification of initial conditions at sowing, such as soil water availability, and a model configuration that ensures nutrients to be non-limiting. Grassini et al. (2015) presented an explicit rationale and methodology for selecting data sources for simulating crop yields and estimating yield gaps at specific locations that can be applied across widely different levels of data availability and quality and it was used to estimate maize yield gaps in the state of Nebraska (USA), and at a national scale for Argentina and Kenya. The aim of the suggested method was to provide a transparent, reproducible, and scientifically robust guideline for estimating yield gaps; guidelines which are also relevant for simulating the impact of climate change and land-use change at local to global spatial scales.

2.1.2. Local studies to global relevance: It is essential to compare and assess different methods of yield gap analysis across spatial scales from the field, to sub-national and national scales, to identify key components that ensure adequate transparency, accuracy, and reproducibility. Yield gap analyses for Southeast Asia helped to explain yield trends in irrigated rice and revealed that nitrogen management had to be improved to increase yields (Kropff et al. 1993). Global studies generally use empirical, statistical approaches or generic crop growth models and a grid-based approach using global datasets on climate, soils and sometimes agricultural land use and general crop calendars. The statistical methods use highest yields within a defined climatic zone (Mueller et al. 2012) or use a stochastic frontier production function (Neumann et al. 2010). They do not verify whether highest yields accurately represent the biophysical potential yield limit as confirmed by either a robust simulation model or field studies. The major limitation of this method is that it does not distinguish between irrigated and rainfed crops; thus, many yield gap estimates for a given climatic zone are based on irrigated crop yields-even in regions where the crop in question is grown almost entirely under rainfed conditions. Global studies using generic crop growth models utilize a single crop model to simulate generic crop yields for the entire globe. Often global studies using generic crop growth models do not have the explicit aim to estimate yield gaps; sometimes they aimed at estimating current yields and sensitivities of these yields to variations in management or climate (Stehfest et al. 2007).

2.1.3. Yield gap estimates in rice: Yield gaps in rice were observed in various countries, especially those of Asia region. Table 1 illustrates the rice yield gaps in India, Nepal, Thailand, etc. as compiled by Mondal (2011). While it was only 3.38% in China and 27.78% in India, yield gap in other countries varied from 17 to 50%. According to a study conducted by BRRI, the yield gap in rice in Bangladesh was about 1.74 t ha^{-1} and it was estimated that at least Tk. 1260 billion could be earned from the additional production annually by bridging the yield gap (BRRI 2011). In India, yield gap varied from 15.50 to 60% with the national average gap of 52.30% in the irrigated ecosystem (Siddiq 2000) and 2560 kg ha^{-1} for rainfed rice (Aggarwal 2008). Nirmala and co-workers (2009) estimated 12.46% yield gap in rice in Raichur district of Karnataka, between potential yield realized at research station and the yield that was reported at the demonstration plot (yield gap I). Yield gap II, which is the difference between potential farm yield (Yd) and the actual yield (Ya) was estimated to be 11.82%. Index of yield gap, which is the ratio of the difference between potential yield (Yp) and actual yield (Ya) to the potential yield (Yp) worked out to be 22.81%. Pushpa and Srivastava (2014) quantified the gap between current and potential yields of major crops namely wheat, rice and sugarcane in eastern region of Uttar Pradesh, and identified the constraints that contribute to this yield gap. In the study area, yield gaps exist in different crops ranging up to 53% and for rice the average gap was estimated to be of 28.26%.

Table 1. Yield levels and yield gaps in rice of several countries of Asia region.

Country	National average yield (t ha^{-1})	Irrigated/better managed yield (t ha^{-1})	Yield gap (t ha^{-1})	Yield gap (%)
India	2.60	3.60	1.00	27.78
Nepal	2.50	4.20	1.70	40.47
Thailand	2.00	4.00	2.00	50.00
Vietnam	3.10	4.30	1.20	27.90
Indonesia	4.40	5.30	0.90	17.00
Philippines	2.80	3.40	0.60	17.65
China	5.70	5.90	0.20	3.38

Source: Mondal (2011)

2.1.4. Factors causing yield gaps: In general, factors causing yield gaps can be classified as (RAP 1999): (a) biological factors: variety, soil fertility, management practices (fertilizer, water, pest management, etc.); (b) socio-economic factors: social and economic status of farmers, family size, farm holding, knowledge and education level of farmers, contact with extension agents; (c) climatic factors: flood, drought, salinity, etc. caused by climatic changes; (d) institutional/government policy related factors: input/ output price, availability of inputs, credit supply, tenancy, etc.; and (e) factors promoting technology transfer: research-extension linkage, training of extension personnel on the new technology, their knowledge and education level about the technology, demonstration of the technology, field visits and monitoring, etc. by extension.

In a case study in Senegal (Ramaswamy and Sanders 1992), the causes of yield gaps at field scale were identified using a basic cross-correlation analysis of yield gaps against indicators of biotic and soil constraints and crop management. In fields with a low water-limited yield potential, poor soil fertility was the main factor explaining the yield gaps, while in fields with a relatively high water-limited yield potential, low soil fertility and weed infestation were the explanatory factors. Both low soil fertility and weed infestation are likely to be directly related to the low purchasing power of farmers and the resulting limited access to fertilisers and herbicides, and to the limited availability of labour on their farms. Studies from other researchers (Perez et al. 1998) in the same region mentioned water runoff as a key factor explaining observed yield gaps. Even with improved access to fertilisers and other external inputs, closing the yield gap in this region would require that farmers combine improved soil fertility and weed management with water saving techniques at field and landscape level in order to reduce production risks induced by rainfall variability, which are expected to increase with crop intensification. Pushpa and Srivastava (2014) identified the causes of yield gaps as: socio-economic, credit institutional/policy related factors, extension services and lack of improved technology. In another case study in Vietnam, Husson et al. (2004) used a similar approach as the one used in the Senegalese case study to identify the main causes of variability of upland rice yields between fields. Here, the major explanatory factors for yield differences were observed to be weed infestation and soil fertility. In central Brazil, a detailed analysis of yield variations was carried out by Affholder et al. (2003), where, the model STICS was used to simulate water- and nitrogen-limited yield for each field. A cross-correlation analysis was performed and observed that aluminium toxicity in soils, weeds and soil waterlogging were the main factors explaining the gap between observed yields and simulated water- and nitrogen limited yields.

2.1.5. Bridging the yield gap: Closing yield gaps to attain potential yields may be a viable option to increase the global crop production. However, traditional methods of agricultural intensification often have negative externalities. So, there is a need to explore location-specific methods of sustainable agricultural intensification. Pradhan et al. (2015) identified regions where the achievement of potential crop calorie production on currently cultivated land will meet the present and future food demand based on scenario analyses considering population growth and changes in dietary habits. By closing yield gaps in the current irrigated and rain-fed cultivated land, about 24% and 80% more crop calories can respectively be produced compared to year 2000. They have also estimated the required fertilizers (N, P_2O_5, and K_2O) to attain the potential yields. Cui et al. (2013) achieved an increase in maize yield of 70% in an on-farm experiment by closing the yield gap and evaluated the trade-off between grain yield, nitrogen (N) fertilizer use, and GHG emissions. Based on two groups of N application experiments in six locations for 16 on-farm site-years, an integrated soil-crop system approach achieved 93% of the yield potential which is 70% higher than existing crop management. Although the N application rate increased by 38%, N_2O emission intensity and the GHG intensity of the integrated system were reduced by 12% and 19%, respectively. Lobell et al. (2009) suggested that yields of 80% of its potential are an approximate of the economic optimum level. Mueller et al. (2012) presented a global-scale assessment of intensification prospects from closing ‘yield gaps’ (differences between observed yields and those attainable in a given region), the spatial patterns of agricultural management practices and yield limitation, and the management changes that may be necessary to achieve increased yields. They found that global yield variability is heavily controlled by fertilizer use, irrigation and climate.

Yield gaps caused by biological, socio-economic, and institutional constraints, which can be effectively addressed through an integrated crop management (1CM) practices. Transfer of the practices through extension agents could effectively help farmers to minimize yield gaps. Timely planting, irrigation, weeding, plant protection, and timely harvesting could account for more than 20% yield increase (Siddiq 2000). However, input/output prices and employment opportunities influence farmers' decision on the level of inputs to be applied.

2.2. Research on impact of rice production technology/training

2.2.1. Impact of rice production technology: Based on a survey conducted in Maharashtra, India, Joshi and Bantilan (1998) observed partial and step-wise adoption of different components of the technology that range between 31% for raised-bed and furrow method of land management to 84% for improved varieties. The technology also contributes in improving the natural resource base, and eases certain women specific agricultural operations. Samal et al. (2009) assessed impact of three modern rice varieties viz. Durga, Gayatri and Sarala in the submergence prone area of Odisha state and indicated that the varieties have spread to 51% of the lowland area within three years. The returns from all the three varieties were found to be attractive in comparison to the traditional varieties in terms of additional return as well as employment generation. Wu et al. (2010) assessed the impact of improved upland rice technology on farmers' well-being using propensity-score matching technique to address the problem of 'self-selection,' because technology adoption is not randomly assigned. It applies this procedure to household survey data collected in Yunnan, China in 2000, 2002 and 2004. The findings indicated that improved upland rice technology has a robust and positive effect on farmers' well-being, as measured by income levels and the incidence of poverty. Gauhan et al. (2012) in a study in stress-prone rainfed area of Nepal indicated that the yield of newer generation modern rice varieties (MVs) is not superior to that of old generation MVs despite their better adaptability in rainfed conditions. They observed through censored regression that favourable land type plays a key role in the adaptation of new generation modern varieties. In Bangladesh, Islam et al. (2012), however, mentioned that the yield of MVs and old generation MVs are not statistically different, which may explain the slow varietal replacement in Bangladesh. Similar observation were made by Behura et al. (2012) in Chattisgarh and Odisha, where the varieties released before 1990 like Swarna, Lalat and Gayatri dominate most of the area. Bagchi and Bool-Emerick (2012) observed in West Bengal that old generation MVs dominates during *aman* season while new generation MVs occupy most rice areas during *boro* season.

2.2.2. Impact of training on rice production technology: Nakano et al. (2014a) investigated impact of training provided by a large-scale private farm on the performance of surrounding small-scale rice farmers in a rain-fed area in Tanzania. They found that the training effectively enhances the adoption of improved rice cultivation practices, and profit from rice cultivation by small-holder farmers. Several other studies have shown that intensive training on rice cultivation can effectively enhance the adoption of new technologies including modern variety, chemical fertilizer and improved agronomic practices, and productivity of rice cultivation increased both in irrigated as well as rain-fed area (Kijima et al. 2012). However, improved rice cultivation technologies are not widely adopted because of weak public extension system (Nakano et al. 2014b).

2.2.3. Impact of investment on rice research: Assessment of economic impact of new technologies delivers helpful information to justify investment efforts in research and development to generate new technologies. Kumar and Rosegrant (1994) estimated total factor productivity (TFP) of rice as 1.03%, which accounted about one-third of output growth during the period of 1971-88. The marginal returns to public investment in rice research in different regions were very high and the internal rate of return (IRR) to public investment was 55%. They have shown that, contrary to popular perception, rice research has paid handsome returns in India, even in the eastern region and demonstrated that research productivity has not declined over time. Jha and Kumar (1998) also propounded that rice research in India has been highly rewarding, generating returns that are close to 30-50% and suggested to accord high priority to three major issues: rice in eastern India, which essentially means rainfed (upland and lowland) rice; sustainable irrigated rice production (in *kharif* as well as *rabi* season); and improved efficiency in rice production. Agricultural research has contributed to breaking the seasonal barrier in rice production in India. During recent periods, area under the highly productive dry-season rice (*boro*) has been growing with the expansion of small-scale groundwater irrigation. Huang et al. (1998) assessed the contribution of research and technological change to the phenomenal growth in rice yield in China raising rice seeds from 2.1 t ha^{-1} during early sixties to 6.1. t ha^{-1} during late nineties.

3. KNOWLEDGE GAPS

Meeting future food demand requires a substantial increase in the yields obtained from existing crop-land. Global analyses done earlier have suggested that these gains could come from closing yield gaps - differences between yields from small-plot research versus those in farmer fields. However, closing this gap requires knowledge of causal factors not yet identified experimentally for different agro-ecological settings. Potential yields vary with the cultivars, ecology as well as the agro-climatic region. Precise knowledge on zone and ecosystem specific potential is a pre-requisite for meaningfully determining the still untapped yield of the currently popular high yielding varieties.

The impact evaluation methods and concepts has been poked with problems both, methodological, such as econometric techniques and data availability, and practical, such as ethical concerns, funding and weak incentives. Along with the sound and robust data collection methods, the impact assessment toolkit has to be evolved, particularly with regard to econometric methods. Because economic evaluation is a predictive tool, it is difficult to determine accurately what a technology’s benefits and costs will be in the future. One useful and simple way of gaining insight into the impact of uncertain outcomes is a sensitivity analysis. Further, the empirical challenge in impact assessment using observational studies is establishing a suitable counterfactual against which the impact can be measured because of self-selection problems. To accurately measure the impact of technology adoption on improving productivity of farm households, the exposure to the technology should be randomly assigned so that the effect of observable and unobservable characteristics between the treatment and comparison groups is the same, and the effect is attributable entirely to the treatment. A coherent method is desirable to identify, quantify and value the social advantages (benefits) and disadvantages (costs) in terms of common monetary units. The benefit stream over time is brought together to a net present value (NPV) by compounding or discounting. Unvalued effects/ impacts (intangibles) are described qualitatively and weighed against valued items. However, integration of this value in benefit stream is scarce or absent in existing literature about impact assessment of agricultural technologies.

4. RESEARCH AND DEVELOPMENT NEEDS

There are two great challenges in regard to the agriculture in India and globally: substantial increases in food demand must be met while decreasing agriculture's global environmental footprint. Closing yield gaps and increasing resource efficiency are necessary strategies towards meeting these challenges, but certainly not through unsustainable expansion of crop-land. The crucial role of nutrient and water management towards sustainable cultivation should be encouraged. Agricultural development programmes and policies must address the factors of yield limitation while emphasizing management practices that maintains trade-offs between higher production and environmental impacts. Changes to agricultural management to close yield gaps should be considered in the context of climate change scenario, which is expected to substantially impact yields and induce management adaptations.

Farmers need adequate amounts of quality inputs at the right time to obtain high yields. It is also important that the fertilizer inputs are integrated with organic manures for balanced use of nutrients. Resource-poor small but productive farmers representing more than 80% of farm population are usually unable to purchase required quantities of the inputs for better yield, therefore, they need to be supported by adequate and timely supply of credit through simplification of lending procedures and revise eligibility criteria. The action may also be taken for the expansion of rural bank branches under public sector. The coordination of research and extension is essential and the researcher should understand farmers' constraints to high productivity and accordingly develop integrated technological package (appropriate variety, timely planting, fertilizer, irrigation, and pest management) for farmers in specific locations to bridge the gaps. The extension service should ensure that the farmers apply correctly and systematically the recommended technological packages through effective training, demonstrations, field visits, monitoring, etc.

Impact evaluation provides information about actual accomplishments in the form needed by the planners/ managers/ policy makers. For evaluation of a technology, all basic data at all stages, i.e. from innovation to adoption by the end user and its' uses are necessary. Hence, proper sampling technique is to be adopted for ensuring representation of the users and the progress at various levels should be monitored. For collection of data, a suitable questionnaire should be adopted and various components such as productive, protective, environmental, etc. should be computed. Evaluation process often seeks to analyze a situation to determine why some thing happened, and suggest what might be done to correct undesirable situation. Evaluation would ideally be a continuous process, starting at appraisal, continuing with mid-term reviews and at termination, followed by an *ex-post* review, and ideally a follow-up review 5, 10 or 15 years after the end of the life of the technology.

Evaluation indicators are designed to provide a standard against which we measure or assess the progress of an activity against stated targets. They provide information and describe the state of the phenomena, that are useful to monitor changes and provide means to compare trends and progress over time. These are used as markers of the progress towards achieving short-term, intermediate term or long term objectives. It must be clear that indicators are not targets because targets are specified results in terms of quantity and/or time. The selection of indicators is of crucial which requires skill and experience. The main challenge in identifying indicators is to select those that are sufficiently representative and at the same time easy to understand and measure. It depends on the nature of the objectives and intended effects and impacts of the technology. Ideal indicators should be of: specific (clearly and unambiguously defined); measurable (either qualitatively or quantitatively); achievable (must be cost effective to monitor; result should be worth the time and money it costs to apply them); relevant (should be in consistency with the objectives and clearly reflect the goals); and time-bound (should be quite sensitive to change in the situation to be documented and sensitive to important changes such as in policy, programmes, and institutions).

Before the mid-sixties, economists gave little consideration to the distributional effects of technological changes. Hence, agricultural technologies tended to recommend or encourage technological changes which were favourable to large-scale farmers at the expense of small-scale farmers and farm labourers. In recent years, in response to the growing number of agricultural critics, agricultural scientists attempted to specifically account for some of the distributional effects of agricultural technology. Although recent attempts to account for the distributional impacts of technological change have significantly strengthened the credibility of economic models, these models still do not take into account all the distributional effects (social, economic or technical) arising from agricultural technology.

5. WAY FORWARD

Bridging yield gaps may not always be desirable or practical in the short term, given marginal returns for additional inputs, regional land-management policies, limits on sustainable water resources and socio-economic constraints (for example, access to capital, infrastructure, institutions and political stability). However, use of precision agriculture techniques, conservation tillage, high-yielding hybrids, increased plant populations and multifunctional landscape management can help to mitigate negative environmental impacts of intensive agriculture. Additionally, use of organic fertilizers is also helpful for improving soil carbon, enhancing soil biota and increasing water-holding capacity. Social triggers of intensification used to differ across regions; because of development interventions by governments or NGOs, market-driven incentives for farmer investment, and land scarcity in regions which are not fully connected to global markets. Hence, to close yield gaps technological solutions must go hand in hand with lifting social and economic constraints through rights to land, critical infrastructure, and links to the world market for food and raw materials.

Impact assessment plays an important role in both identifying and communicating the implications of technology in economic terms starts from the planning process. In the early stages of research planning, preliminary partial budget assessment of the technology would assist planners and researchers in developing feasible management practices as well as to reach a consensus in priority setting of research. Once a consensus has been determined, further economic assessment will help to identify expected impacts and the implications. To be useful to the planning process, the economic implications of the particular technology/management practices must be clearly communicated. The documentation and evaluation of the strategies will generate evidences for prioritizing the technology for future research agenda. To communicate these evidences in a form meaningful for comparison, a matrix summarizing the findings of the assessment can be used. Further, impact evaluation relies on the construction of a counterfactual situation to examine the outcome of a group in two states at the same time, in and out the programme. A technology selected for the impact assessment had to demonstrate that it carefully selected a group of non-participants that were equally needy or deserving of the programme and were the same with regard to most characteristics. Finally, considering the knowledge gaps, issues and needs, the impact assessment of agricultural technologies/programmes should encompasses: establishment of proper evaluation criteria, determining distributional consideration, exact period of analysis based on economic life of the technology, identification of relevant input and output, proper valuation and discounting of inputs (costs) and outputs (benefits), and considering uncertainty and risks through sensitivity analysis.

References

Affholder F, Scopel E, Madeira NJ and Capillon A (2003) Diagnosis of the productivity gap using a crop model - Methodology and case study of small-scale maize production in central Brazil. Agronomie 23: 305–325.

Aggarwal PK, Hebbar KB, Venugopalan MV, Rani S, Bala A, Biswal A and Wani SP (2008) Quantification of yield gaps in rainfed rice, wheat, cotton and mustard in India. Global Theme on Agroecosystems Report No. 43. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Bagchi B and Bool-Emerick M (2012) Patterns of adoption of improved rice varieties and farm-level impacts in stress-prone rainfed areas of West Bengal, India. In: Pandey S, Gauchan D, Malabayabas M, Bool-Emerick M, Hardy B, editors. 2012. Patterns of adoption of improved rice varieties and farm-level impacts in stress-prone rainfed areas in South Asia. Los Baños (Philippines): International Rice Research Institute.

Behura D, Koshta A, Naik D, Samal P and Malabayabas M (2012) Patterns of adoption of improved rice varieties and farm-level impacts in stress-prone rainfed areas of Chhattisgarh and Orissa, India. In: Pandey S, Gauchan D, Malabayabas M, Bool-Emerick M, Hardy B, editors. 2012. Patterns of adoption of improved rice varieties and farm-level impacts in stress-prone rainfed areas in South Asia. Los Baños (Philippines): International Rice Research Institute.

BRRI (2011) Study findings presented in a workshop held in May 2011 on "minimizing rice yield gap" at BRRI, Gazipur.

Cassman KG, Dobermann A, Walters DT and Yang HS (2003) Meeting cereal demand while protecting natural resources and improving environmental quality. Annual Review of Environment and Resources 28: 315–358.

Cui Z, Yue S, Wang G, Meng Q, Wu L, Yang Z, Zhang Q, Li S, Zhang F and Chen X (2013) Closing the yield gap could reduce projected greenhouse gas emissions: a case study of maize production in China. Global Change Biology 19: 2467–2477.

De Datta SK (1981) Principles and practices of rice production. New York (USA): Wiley-Interscience Publications.

de Koeijer TJ, Wossink GAA, van Ittersum MK, Struik PC and Renkema JA (1999) A conceptual model for analysing input-output coefficients in arable farming systems: From diagnosis towards design. Agricultural Systems 61: 33–44.

FAO (2012) World agriculture towards 2030/2050: the 2012 revision. FAO, Rome.

Gauchan D, Panta HK, Gautam S, and Nepali MB (2012) Patterns of adoption of improved rice varieties and farm-level impacts in stress-prone rainfed areas of Nepal. In: Pandey S, Gauchan D, Malabayabas M, Bool-Emerick M, Hardy B, editors. 2012. Patterns of adoption of improved rice varieties and farm-level impacts in stress-prone rainfed areas in South Asia. Los Baños (Philippines): International Rice Research Institute.

Gomez KA (1977) On-farm assessment of yield constraints: methodological problems. In: International Rice Research Institute. Constraints to high yields on Asian rice farms: an interim report. Los Baños, Philippines.

Grassini P, Lenny GJ, van Bussel, Justin Van Wart, Joost Wolf, Lieven C, Yang H, Boogaard H, de Groot H, Martin K van Ittersum and Cassman KG (2015) How good is good enough? Data requirements for reliable crop yield simulations and yield-gap analysis. Field Crops Research 177: 49-63.

Hoang VN (2013) Analysis of productive performance of crop production systems: An integrated analytical framework. Agricultural Systems 116: 16-24.

Huang J, Rozelle S and Lin JY (1998) Impacts of research and technological change on China's rice production. In: Impact of rice research. Proceedings of the International Conference on the Impact of Rice Research, 3-5 Jun 1996, Bangkok, Thailand. Thailand Development Research Institute, Bangkok, Thailand, and International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Husson O, Castella JC, Tuan HD and Naudin K (2004) Diagnostic agronomique des facteurslimitant le rendement du riz pluvial de montagnedans le nord du Vietnam. Cahiers Agricultures 13: 421–428.

Islam MR, Islam MA, Rahman MS, Salam A, Alam S, Harun E and Bool-Emerick M (2012) Patterns of adoption of improved rice varieties and farm-level impacts in stress-prone rainfed areas of Bangladesh. In: Pandey S, Gauchan D, Malabayabas M, Bool-Emerick M, Hardy B, editors. 2012. Patterns of adoption of improved rice varieties and farm-level impacts in stress-prone rainfed areas in South Asia. Los Baños (Philippines): International Rice Research Institute.

Jha D and Kumar P (1998) Rice production and impact of rice research in India. In: Impact of rice research. Proceedings of the International Conference on the Impact of Rice Research, 3-5 Jun 1996, Bangkok, Thailand. Thailand Development Research Institute, Bangkok, Thailand, and International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Joshi PK and Bantilan MCS (1998) Impact assessment of crop and resource management technology: a case of groundnut production technology (In En. Summaries in En, Fr.) Impact Series no.2. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Kijima Y, Ito Y and Otsuka K (2012) Assessing the impact of training on lowland rice productivity in an African setting: Evidence from Uganda. World Dev. 40:1610-1618.

Kropff MJ, Cassman KG, Van Laar HH and Peng S (1993) Nitrogen and yield potential of irrigated rice. Plant and Soil 155(1): 391-394.

Kumar P and Rosegrant MH (1994) Productivity and sources of growth for rice in India. Economic and Political Weekly 29(53): A183-A188.

Laborte AG, De Bie CAJM, Smaling EMA, Moya PF, Boling AA and Van Ittersum MK (2012) Rice yields and yield gaps in Southeast Asia: past trends and future outlook. European Journal of Agronomy 36: 9–20.

Lobell DB, Cassman KG and Field CB (2009) Crop yield gaps: their importance, magnitude, and causes. Annual Review of Environment and Resources 34: 1-26.

Mondal MH (2011) Causes of yield gap and strategies for minimizing the gaps in different crops. Bangladesh Journal of Agricultural Research 36(3): 469-476.

Mueller ND, Gerber JS, Johnston M, Ray DK, Ramankutty N and Foley JA (2012) Closing yield gaps through nutrient and water management. Nature. http://dx.doi.org/10.1038/nature11420.

Nakano Y, Tanaka Y and Otsuka K (2014a) To what extent do improved practices increase productivity of small-scale rice cultivation in a rain-fed area? : Evidence from Tanzania. Tokyo: National Graduate Institute for Policy Studies.

Nakano Y, Kajisa K and Otsuka K (2014b) Credit, access to extension, and irrigation: How can we achieve rice Green Revolution in Tanzania? Tokyo: National Graduate Institute for Policy Studies.

Neumann K, Verburg PH, Stehfest E and Müller C (2010) The yield gap of global grain production: a spatial analysis. Agricultural Systems 103: 316–326.

Nirmala B, Deshimanya J, Muthuraman P, Meera SN and Sain M (2009) Yield gap analysis of rice in Raichur district of Karnataka. Karnataka Journal of Agricultural Sciences 22(1): 238-239.

Perez P, Albergel J, Diatta M, Grouzis M and Sene M (1998) Rehabilitation of a semiarid ecosystem in Senegal, Farm-plot experiments. Agriculture, Ecosystems and Environment 70: 19–29.

Pradhan P, Fischer G, van Velthuizen H, Reusser DE and Kropp JP (2015) Closing yield gaps: How sustainable can we be? PLoS ONE 10(6): e0129487.

Pushpa and Srivastava SK (2014) Yield gap analysis and the determinants of yield gap in major crops in eastern region of Uttar Pradesh. Economic Affairs 59(4): 653-662.

Ramaswamy S and Sanders JH (1992) Population pressure land degradation and sustainable agricultural technologies in the Sahel. Agricultural Systems 40: 361–378.

RAP (Regional Office for Asia and the Pacific) (1999) Report of the expert consultation on bridging rice yield gap in the Asia-Pacific region. FAO.

Samal P, Paris T and Rao KS (2009) Impact of modern rice varieties in submergence prone lowlands: a case study. Oryza 46(1): 61-66.

Siddiq EA (2000) Bridging rice yield gap in India. In: Proceedings of Expert Conference on bridging the rice yield gap in the Asia- Pacific region, RAP, FAO. Status of oil crop production in Bangladesh, 2002. ORC, BARI.

Stehfest E, Heistermann M, Priess JA, Ojima DS and Alcamo J (2007) Simulation of global crop production with the ecosystem model DayCent. Ecological Modelling 209: 203–219.

Tittonell P, Shepherd KD, Vanlauwe B and Giller KE (2008) Unravelling the effects of soil and crop management on maize productivity in smallholder agricultural systems of western Kenya - an application of classification and regression tree analysis. Agriculture, Ecosystems and Environment 123: 137–150.

van Bussel LGJ, Grassini P, Van Wart J, Wolf J, Claessens L, Yang H, Boogaard H, de Groot H, Saito K, Cassman KG, Van Ittersum MK (2015) From field to atlas: upscaling of location-specific yield gap estimates. Field Crops Research 177: 98-108.

van Ittersum MK and Rabbinge R (1997) Concepts in production ecology for analysis and quantification of agricultural input-output combinations. Field Crops Research 52: 197-208.

Wu H, Ding S, Pandey S and Tao D (2010) Assessing the impact of agricultural technology adoption on farmers’ well-being using propensity-score matching analysis in rural China. Asian Economic Journal 24: 141–160.❄