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Adoption and impacts of international rice research technologies

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ABSTRACT

To meet rising demand for rice, it is estimated that the global rice production needs to increase by 116 million tons by 2035. Much of the increase has to come from smallholder rice farmers in developing countries. In this article, we review 25 evaluation studies on new rice technologies and practices that have been tried and used by smallholder rice farmers in developing countries. Stress-tolerant rice varieties are found among promising new rice varieties. African farmers benefit from New Rice for Africa (NERICA) varieties. Some natural resource management (NRM) practices have been evaluated in farmer trials and found beneficial. However, the NRM evaluation studies faced with difficulties in defining NRM "technology" and "adoption", and the difficulties remain as future challenges for evaluation studies.

1. Introduction

Rice is a staple for nearly half of the world population of more than seven billion people and it is cultivated in more than 100 countries, with a total harvested area of 161 million hectares, producing more than 700 million tons of paddy rice in 2013/14 (United States Department of Agriculture (USDA), 2005). Among the various rice-growing regions, Asia accounts for nearly 90% of total rice production and consumption, with the remaining 10% divided between Africa and Latin America. However, rice is gaining importance in both Africa and Latin America, with a 40% increase in annual per capita consumption in Africa in the past two decades, from 16.7 kg in 1990 to 23.3 kg in 2011, and a 46% increase in annual per capita consumption in Latin America during the same period, from 7.1 kg in 1990 to 10.4 kg in 2011 (FAOSTAT). According to Seck et al. (2012), global rice production will need to increase by 116 million tons (26%) by 2035, from the 2010 production level, to meet the rising demand.

Because the majority of the 144 million rice farmers are small, the bulk of the production increase has to be achieved by smallholder rice farmers. To meet this challenge, rice genetic improvement and natural resource management (NRM) research are relentlessly pursued at international agricultural research centers. Previous studies on agricultural research show evidence that crop genetic improvement research, in general, generated large impacts, citing the Green Revolution as an example (Evenson and Gollin, 2003; Renkow and Byerlee, 2010; Maredia and Raitzer, 2012). There are growing concerns, however, about declining and low returns from international agricultural research in recent years. The yields of major cereals, including rice, have not increased at the pace recorded from the 1950s to the 1990s (Khush, 1999). For NRM research, only modest impacts have been quantified (Renkow and Byerlee, 2010). Promising benefits from advanced biotechnology, including genetically modified crops, have yet to be fully realized (Conway and Toenniessen, 1999; Araus et al., 2008).

The objective of this article is therefore to present evidence on the impacts of the most recent international agricultural research on rice by reviewing 25 recent studies in the last 10 years, from 2006 to 2015. The scope of this review is limited to new rice technologies that are developed at international agricultural research centers. It is also limited to technologies that are already used by farmers and consumers in developing countries. We do not review technologies that are (1) in the process of research and development at international research centers, such as Golden Rice, (2) mainly developed by the private sector, such as hybrid rice, or (3) developed and promoted outside of international research centers, such as the System of Rice Intensification (SRI). In recent years, there have been numerous methodological developments in impact assessments at the micro-level (de Janvry et al., 2011). However, as we show in this review, only a small number of studies have applied advanced methods to evaluate new rice technologies. Impact assessment studies on NRM practices are especially limited in number and area coverage. By reviewing a

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wide range of adoption and impact assessment studies on rice technologies and practices, we also aim to guide future studies.

The next section describes the scope of this review, including the types of studies and broad analytical methods used. Section 3 focuses on the aggregate contributions of improved germplasm. Section 4 discusses adoption and impact studies on specific improved varieties. Finally, Section 5 reviews improved crop management practices and NRM studies.

2. Scope of the review

As mentioned earlier, we review new rice technologies that have been developed by international agricultural research centers in collaboration with their partners. We choose technologies that are already used by the farmers in countries where they were taken up as part of their rice programs. To assess the actual impact of new technologies and improved practices of rice research, we limit our review to adoption and ex post impact evaluation studies published in peer-reviewed journals between 2005 and 2015 and include the most recent technical and project reports as needed. de Janvry et al. (2011) provide a comprehensive review of impact assessment methods that have been used to evaluate new agricultural technologies, including rice. After comparing different evaluation methods, they noted the rigorous evaluation methods that have been developed but that have not been used widely or appropriately in impact assessment research on recent agricultural technology. As will be discussed below, the same holds true for impact assessment of rice technologies.

Table 1 presents the number of studies included in this review, separately for improved germplasm and natural resource management technologies. A total number of 25 studies are reviewed in this article. Among them, 18 studies are on adoption and impact assessment of specific technologies, which are almost equally split between improved germplasm (10 out of 18) and NRM technologies (8 out of 18). Instead of evaluating individual technologies, five studies estimated the total benefits from improved germplasm research at the International Rice Research Institute. Regarding analytical methods (Tables 1 and 2), economic surplus and benefit-cost analysis (BCA) are used by the five studies that evaluated the overall benefits from agricultural research programs. Descriptive statistical analyses are used by six studies on farm trials, adoption studies, and simple impact assessment. In farm trials, new technologies were tested under the close supervision of project researchers. This starts with selecting farmer-participants (who agree to allocate a parcel of their farms and implement the technology trial by adhering to the instructions set by the researchers) and "control" or nonparticipating farmers (whose demographic characteristics are comparable with those of the participating farmers). Simple comparisons were used to identify the differences in the targeted outcome variables between the farmer-participants and control farmers. Farm trials are heavily used to demonstrate and evaluate NRM technologies and practices probably because farmer-participants need technical assistance to properly implement them.

However, as new technologies are increasingly adopted by farmers, the need to understand the process of adoption and identify adoption constraints increases. Simple regression analyses are often used to identify the determinants of adoption. In this review, we find eight studies that use regression analyses. However, at this stage, identifying the impact of a technology becomes murky. A given technology is likely adopted in areas where the technology is agro-physically most suitable and by the more progressive or innovative farmers, which survey sampling must consider or else the impact results will be tainted with "self-selection" bias. Simple regression analyses can be used to identify the factors that are associated with the adoption of the technology. However, such regression analyses fail to identify the causal impacts of the new technology on outcomes because the adoption of a technology could be influenced by unobserved factors, such as farmers' ability, social networks, or plot characteristics. To overcome this estimation problem, more appropriate evaluation techniques are used by five studies reviewed in this article.

The propensity score matching (PSM) approach is one of such impact evaluation methods used by two studies reviewed in this article. The method identifies a pseudo-counterfactual group by estimating a propensity score of adopting a given technology for each user or nonuser. Next, every user is matched with a group of nonusers, provided that such a group exists, based on the estimated propensity scores. The average impact of adopting the technology is estimated by comparing the means of the outcome of the users and the matched nonusers. The basic assumption is that the propensity score, which is estimated by observed variables, identifies a counterfactual group of nonusers for a given user. This assumption fails, however, if important factors are omitted in the propensity score estimation. As a result, PSM matches users and nonusers even when the users and nonusers have different unobserved characteristics. For this limitation, the PSM approach based on cross-section data is often criticized (Smith and Todd, 2005; de Janvry et al., 2011).

One way to eliminate unobserved characteristics from estimation models is to use panel data, which consist of repeated observations on the same cross-section data of samples, such as farmers and individuals, over time. By using panel data, researchers can calculate a difference-in-differences (DD) estimator. The DD estimator is calculated by taking a difference in average changes of an outcome variable between users and nonusers of a technology. Because the DD method is based on average changes over time, time-invariant factors, such as farmers' ability and soil characteristics, are removed from differenced variables. It also eliminates the average trend, which is measured in the change in the outcome variable among nonusers. Because of its simplicity, the DD estimation is often used in evaluation studies. However, the DD method assumes that outcomes should be evolving similarly for all samples (i.e., users and nonusers) regardless of their technology use status. This assumption is nontrivial (de Janvry et al., 2011). For instance, if the outcome variable of technology users in between surveys were evolving differently from that of nonusers, then the DD estimation could lead to biased estimators.

To improve the comparisons in panel data, the PSM approach can be combined with the DD approach. Instead of simply

Table 1
Number of reviewed studies on improved Germplasm and NRM.

	All (A)	Improved germplasm (B)	Natural resource management (NRM) (C)
	Number (%)	Number (%)	Number (%)
Study purpose			
Agricultural research impact	5 (20.0)	5 (33.3)	–
Adoption and impact assessment	18 (72.0)	10 (66.7)	8 (80.0)
Farm trials	2 (8.0)	0 (0)	2 (20.0)
Analytical method			
Economic surplus/ BCA	5 (20.0)	5 (33.3)	–
Descriptive	6 (24.0)	3 (20.0)	3 (30.0)
Regression analysis	9 (36.0)	6 (40.0)	3 (30.0)
Impact evaluation estimations	5 (20.0)	1 (6.7)	4 (40.0)
Total	25 (100)	15 (100)	10 (100)

Table 2
List of reviewed studies (2006–2015).

Analytical method	Improved germplasm (A)	Natural resource management (NRM) (B)
Economic surplus analysis	*MV*: Renkow and Byerlee (2010), Brennan and Malabayabas (2011), Maredia and Raitzer (2012), Raitzer et al. (2015) and Labarta et al. (2015a)	
Descriptive	*MV*: Tsusaka et al. (2015) *STRV*: Malabayabas et al. (2015) and Yamano et al. (2015)	*AWD*: Lampayan et al. (2015) *SSNM*: Pampolino et al. (2007) *IPM-FFS*: van den Berg and Jiggins (2007)
Regression analysis	*NERICA*: Diagne (2006), Diagne and Demont (2007), Kijima et al. (2008, 2011), Diagne et al. (2015), Dontsop-Nguezat et al. (2013)	*AWD*: Mushtaq et al. (2009), *DSR*: Malabayabas et al. (2012, 2014)
Impact evaluation estimations	*STRV*: Dar et al. (2013)	*AWD*: Rejesus et al. (2011) *DSR*: Ali et al. (2014), *SSNM*: Rodriguez and Nga (2012) *IPM-FFS*: Yamazaki and Resosudarmo (2008)

Note: Modern Variety (*MV*), New Rice for Africa (*NERICA*), Stress-Tolerant Rice Variety (*STRV*), Alternate Wetting and Drying Water Management (*AWD*), Direct-Seeded Rice (*DSR*), Site-Specific Nutrient Management (*SSNM*), Integrated Pest Management-Farmer Field School (*IPM-FFS*)

calculating the DD estimator, the PSM–DD estimator calculates the difference in the average changes after matching farmers with different technology use status based on the propensity score of adopting the technology. Because the DD estimator is free from the influence of unobserved time-invariant factors, the PSM–DD estimator is considered to be more reliable than the PSM estimator.

Nevertheless, the estimation methods listed above and other estimation methods appear to be too technical to people who are not familiar with regression analyses. Moreover, building panel data requires resource commitments at the beginning of a project even before impacts are yet to be confirmed. Identifying relevant impact questions in a baseline survey also requires careful planning. As a result, in many research projects, baseline data are not collected or end up unusable when ex post impact assessments are called for. These limitations and challenges may explain why it is still rare to find ex post impact assessment studies with panel data (as we find in this review), and they may also explain why randomized control trials (RCTs) have become popular in recent years.

Under RCTs, sample farmers are randomly selected and assigned into two groups: treatment and control. Farmers in the treatment group receive a new technology, whereas farmers in the control group do not. After one cropping season, outcome variables of the two groups are compared to identify the impact of adopting the new technology. The main assumption is that, because farmers in both groups are selected randomly, the two groups are comparable on average. Because of the simple setup of the RCT, this method has become popular in social sciences in recent years (Deaton, 2010).

However, there are some concerns about RCT studies, aside from ethical issues (Barret and Carter, 2010). One of the main concerns involves distorting (or simplifying) research questions to apply RCTs, instead of choosing appropriate estimation methods for relevant research questions. As a result, results from some RCT studies are obvious and not insightful to policymakers. In addition, RCT studies are often implemented at a small scale and are specific to study areas and fail to provide results that can be generalized for larger areas (Deaton, 2010). Nonetheless, given the limitations of other estimation methods, RCT studies are expected to be used more in impact assessments for agricultural technologies. One study reviewed in this article, Dar et al. (2013), has successfully employed this method.

3. Aggregate economic returns on improved germplasm research

Investments in the research and development (R&D) of rice technologies and improved practices in international agricultural research centers are substantial and, inevitably, call for evidence of impacts in terms of returns to investment. Many previous studies already document the pro-poor impacts of international agricultural R&D (Thirtle et al., 2003). For instance, Renkow and Byerlee (2010) reviewed recent evidence on the impacts of CGIAR research as a whole and report that genetic improvement research had the most profound documented positive impacts.[1] Indeed, in Southeast Asia, Maredia and Raitzer (2012) estimated the net present value (NPV) of the total monetary gains from agricultural research at about USD 19.8 billion on varietal improvement (excluding quality) and USD 13.7 billion on quality improvement.

More recently, Brennan and Malabayabas (2011) estimated the impact of IRRI's research on rice production in three Southeast Asian countries from 1985 to 2009. The authors measured IRRI's contribution to the development of modern rice varieties by examining the pedigree of each variety and employing the "last cross pedigree" rule, providing 100% weight to varieties that were either bred by IRRI (regardless of the source of materials) or bred by national agricultural research centers (NARC) but were of IRRI parents and grandparents. IRRI receives partial credit for varieties developed by NARC with some materials from IRRI. The results indicate that, between 1985 and 2009, the estimated NPV during the 25-year period was about USD 9.9 billion in Indonesia, USD 4.3 billion in the Philippines, and USD 9.8 billion in Vietnam (Table 3). Note that all USD values presented in Table 3 are in 2005 USD. Furthermore, the authors calculated a benefit-cost ratio (BCR) of 21.7. Because modern varieties (MVs) were effective and mostly adopted in irrigated areas, the benefits were largely realized in irrigated areas.

The modern varieties we find planted in the world today are crosses of older varieties and were developed by breeders from both international and national breeding institutions worldwide. Precisely allocating the contributions of different research institutions to the development of a modern variety is difficult. An accepted approach in previous studies is based on the "last cross rule" and "geometric rule" (Pardey et al., 2002) as applied by previous studies in estimating the economic benefits of Green Revolution or modern varieties attributed to IRRI. Taking attribution seriously puts such a rule into question whether it is giving fair credit to the alternative breeder and supplier of breeding

[1] The main pathway by which modern varieties reduced poverty in both countries was the lowered consumer rice price, which resulted from the increased rice supply. This is consistent with the earlier findings for Southeast Asia as reported by David and Otsuka (1994).

Table 3
Estimated benefits from IRRI's research on rice genetic improvement.
Sources: Brennan and Malabayabas (2011) and Raitzer et al. (2015)

	Brennan and Malabayabas (2011) (A)	Raitzer et al. (2015) (B)
Study period	1985–2009 (25 years)	1990–2010 (21 years)
Counterfactual & attribution	Last cross-pedigree rule	Breeder-pedigree rule 1990 IRRI shutdown
Source of benefits	Yield gain	Yield and HPR[a] gains
Discount rate	5%	5%
Country	NPV in 2005 USD million[b]	NPV in 2005 USD million[b]
Indonesia	9912	2392
Philippines	4267	273
Vietnam	9849	n.a.
Bangladesh	n.a.	296

[a] Host-plant resistance (HPR).
[b] The figures are converted to 2005 USD by using GDP deflator and PPP values from the World Bank Economic indicators.

materials—the NARC.

A most recent study by Raitzer et al. (2015) modified the "rules" to squarely and fairly address the issue of attribution. Weights of 50–50 are assigned for the breeder and source of materials. The last cross rule picks up a 50% weight instead of 100%. The geometric rule picks up the remaining 50%. Under this new attribution rule, the only time IRRI would have 100% credit for the benefits generated would be when the adopted variety under study was developed by IRRI and was of 100% IRRI pedigree. Partial credit is given when a variety was bred by IRRI and was of mixed parent and grandparent materials. The new breeder-pedigree rule with more conservative weights regarding IRRI's contribution toward the development of post-1989 MVs gave conservative results. A second major departure from the benefit measurement methodology in previous studies was the way the counterfactual was dealt with wherein IRRI shut down in 1990. The results, which have countries comparable with those of the Brennan–Malabayabas study, are presented in Table 3. IRRI's contributions are still substantial but are now made smaller. Obviously, the main reasons for this are the assumptions about the counterfactual scenario and the new breeder-pedigree weights for attributing IRRI's contributions to varietal development. Nonetheless, these studies provide lower and upper estimates, which will guide future studies and provide useful information for planning research investment at IRRI.

In China and India, two of the world's largest rice producers, Fan et al. (2005) found that, because of IRRI's research on MVs, more than 6.8 million Chinese people were moved out of poverty from 1981 to 1999 and 14 million Indian people were moved out of poverty from 1991 to 1999. However, the bulk of the poverty reduction in India and China occurred because of early-generation MVs. Although this raises questions about the recent contributions of rice research, no study has quantified the contributions of international rice research to varietal improvements and economic impact in the way measured in the two studies discussed above.

In South Asia, a recent study by Tsusaka et al. (2015) finds that farmers cultivate mostly modern rice varieties. However, the modern varieties that they cultivate are old, developed more than a few decades ago. Given the large sum of investments devoted to varietal improvement in South Asia, there is a strong need to conduct impact evaluation studies in South Asia.

In Latin America, data collected in seven countries (Peru, Bolivia, Ecuador, Costa Rica, Nicaragua, Panama, and Venezuela) suggest that 63.4% of the total rice area is estimated to be grown using varieties released with International Center for Tropical Agriculture (CIAT) participation. An economic surplus analysis conducted with the data from these seven countries estimates that the economic returns attributable to CIAT's rice genetic improvement program from 1995 to 2012 are around USD 314.4 million (Labarta et al., 2015a).

4. Adoption and impact of improved Germplasm

The successful development of modern varieties, such as IR8, led to subsequent modern varieties with added improvements (Khush, 1995; Evenson and Gollin, 2003). Along with the development and distribution of the modern varieties, a large number of studies have been written about the adoption and impact of modern varieties (Estudillo and Otsuka, 2013; Stevenson et al., 2013). A lower growth rate in rice yield during the late 1990s and the early 2000s raised questions about the effectiveness of rice-breeding programs.

In South Asia, farmers continuously use old modern rice varieties that were released more than several decades ago (Pandey et al., 2015). For example, Swarna, which was released in 1979, is planted on 4.3 million ha or more than 30% of the total rice area in the three eastern Indian states of West Bengal, Odisha, and Chhattisgarh. In Bangladesh, two varieties dominate the Boro season: BRRI dhan28 (released in 1994, accounting for 19% of rice area) and BRRI dhan29 (released in 1994, planted on 14% of rice area). During the main rice season, Aman, BR11 (released in 1980) occupied 14% and Swarna occupied 6%. The popularity of these old varieties is despite the release of newer modern rice varieties that are supposedly superior in terms of yield, resistance to pests, or tolerance of abiotic stresses.

4.1. *Stress-tolerant rice varieties*

Stress-tolerant rice varieties are tolerant of abiotic stresses such as submergence, drought, and salinity. In the past decade, several stress-tolerant varieties have been developed and disseminated in South and Southeast Asia. The important submergence-tolerant rice varieties include Swarna-Sub1, Samba Mahsuri-Sub1, and IR64-Sub1 in India; BBRI dhan52 (BR11-Sub1) and BRRI dhan51 (Swarna-Sub1) in Bangladesh; and Samba Mahsuri-Sub1 and Swarna-Sub1 in Nepal.[2] Similarly, drought-tolerant variety Sahbaghi dhan was also released recently in India, Bangladesh (with the name of BRRI dhan56), and Nepal.

The distribution of stress-tolerant rice varieties in South Asia started in 2008 under the project Stress-Tolerant Rice for Africa and South Asia (STRASA). It coordinates seed multiplication with local counterparts and distributes stress-tolerant rice variety seeds through NGOs and government agencies through mini-kits and demonstrations. Seed distribution expanded exponentially in India after the National Food Security Mission (NFSM) of India picked up distributing stress-tolerant rice variety seeds in 2010. To track the distribution of Swarna-Sub1 in South Asia, a large-scale household survey of about 9000 households was conducted in 2014 (Yamano et al., 2015; Malabayabas et al., 2015). According to the survey, the total area under stress-tolerant rice varieties was estimated to be 0.6 million ha (or 3% of the total rice area) with 1.4 million farmers in 2013 in Bangladesh and four states in eastern India.

To measure the farm-level impact of adopting stress-tolerant

[2] In the 1990s, rice scientists found that the submergence tolerance in certain rice varieties is controlled by a single major quantitative trait locus (QLT), which is named SUB1 (Xu and Mackill, 1996). In the early 2000s, rice scientists successfully introgressed the SUB1 QTL into popular rice varieties through marker-assisted crossing (Neeraja et al., 2007; Septiningsih et al., 2009).

rice varieties, a randomized control trial was conducted and the results are summarized in Dar et al. (2013), which indicated that the average yield of Swarna-Sub1 was 45% higher than that of Swarna, one of the parental varieties, under submergence for 10 days. They found no difference in the yields of the two varieties under normal conditions. The results indicated that, because farmers who belong to disadvantaged castes, such as scheduled caste (SC) and tribe (ST), tend to occupy low-lying lands that are prone to submergence, they tend to benefit more than farmers who belong to other caste groups and have less submergence-prone land. More specifically, the estimated probability of short-duration flooding (1–7 days) on September 18, 2011, was about 40% in villages where a large share of the population is relatively better-off castes, although the same probability was higher by 15 percentage points in SC villages (Dar et al., 2013).

4.2. New rice for Africa (NERICA)

New Rice for Africa (NERICA) is a set of high-yielding rice varieties suited to the African environment (Diagne et al., 2015). NERICA varieties were developed by crossing rice varieties of Asia origin from the species *Oryza sativa* with varieties of African origin from the species *Oryza glaberrima*. After interspecific crosses of these varieties became a viable option in the early 1990s, rice scientists at AfricaRice successfully developed NERICA varieties. Although the first generation of NERICA varieties was targeted for uplands, NERICA varieties suited for irrigated and lowland areas have been developed and released since 2005.

By using data from AfricaRice's Rice Statistics Survey in 2009, Diagne et al. (2015) found that NERICA varieties as a group occupied about 8% of the rice cultivated area of 6.8 million ha across 13 rice-growing countries in sub-Saharan Africa. Thus, the total area under NERICA varieties was about 0.5 million ha in 2009. Uganda had the highest share under NERICA varieties at 40.3%, although the total rice area in the country was small at 0.12 million ha. Among large rice-producing countries, NERICA varieties occupied about 5% of the total rice area of 1.2 million ha in Nigeria. According to earlier studies, the NERICA adoption rate in Côte d'Ivoire was 4% in the study area, but the authors speculated that the adoption rate could have been 28% in 2000 if the whole population were exposed to and had access to its seed in 2000 or before (Diagne, 2006; Diagne and Demont, 2007). However, it is unclear how much of the potential will be realized in the presence of the constraints that farmers face.

In Uganda, Kijima et al. (2011) found that more than 50% of the farmers who cultivated NERICA varieties in 2004 discontinued using them by 2006. This was disappointing because an earlier study by the same authors found NERICA varieties to be promising in reducing poverty (Kijima et al., 2008). Kijima et al. (2011) found that the profitability of NERICAs depended largely on rainfall in Uganda, where rice was cultivated in upland. Where and when rainfall failed, NERICA profitability was low relative to alternative crops, and farmers discontinued using NERICAs. This suggests that the use of NERICAs will be limited to areas where farmers have access to surface water, such as rivers or ponds.

5. Adoption and impact of improved management practices

5.1. Alternate Wetting and Drying (AWD) water management

In many rice-growing areas, water scarcity is becoming a critical issue. AWD water management can potentially enable farmers to reduce water use. Under AWD, the field is not continuously flooded. Instead, the soil is allowed to dry out for one to several days after the disappearance of pond water before it is flooded again. After careful testing, the method was modified to be called "Safe AWD" (Bouman et al., 2007). Safe AWD consists of three key elements: (1) shallow flooding for the first two weeks after transplanting (this helps rice plants recover from transplanting shock and suppresses weeds); (2) shallow ponds from heading to the end of flowering as this is a critical stage when the rice crop is very sensitive to water-deficit stress, and a time when the crop has a high growth rate and water requirement; and (3) keeping irrigation water applied whenever the perched water table falls to about 15 cm below the soil surface during all other periods.

Lampayan et al. (2015) reviewed studies in Bangladesh, the Philippines, and Vietnam and compared yields and economic returns by using a "with and without" analysis between AWD users and nonusers and a "before and after" analysis among AWD adopters. The results from all case studies showed higher net returns for the use of AWD without yield penalties. The main results are presented in Table 4. By using the PSM approach discussed in Section 2, Rejesus et al. (2011) estimated the impact of Safe AWD adoption at one of the project sites in Tarlac Province in the Philippines. Data were collected for the 2005 dry season from 146 farmers: 30 AWD adopters and 116 nonadopters. The results indicate that Safe AWD reduced the hours of irrigation use by about 38% without a significant reduction in yield and profit. The economic benefits of AWD reviewed in the study are average benefits. Arguably, the economic rationale behind farmer adoption of AWD depends primarily on the private marginal cost of using water. Farmers who belong to irrigation groups, for instance, pay a fixed rate per season and therefore have little incentive to apply AWD. On the other hand, farmers who use privately owned pumps and pay for fuel may consider applying AWD to reduce additional costs. To this date, however, this remains as a topic for further examination. Furthermore, on the adoption rates of AWD, no study has attempted to estimate the adoption rates of AWD on a wide scale.

In Zhanghe Irrigation District (ZID) in Hubei Province, China, Mushtaq et al. (2009) examined AWD adoption by using data from 100 farmers who lived near ponds. They found that only 8% of the farmers applied AWD on a full scale. Many of the farmers used simplified versions of AWD. This study raises an important question about how to define "adoption". An improved management practice such as AWD needs to be modified as farmers in different

Table 4
Impact of Alternate Wetting and Drying (AWD) on yield and net income.
Source: Lampayan et al. (2015)

Country	Study year and season	Yield (t/ha)	Net income (USD/ha)	Yield (t/ha)	Net income (USD/ha)
Before and after		*Before*		*After*	
Philippines (Bohol)					
Upstream	DS: 2005, 2010	3.1	150	3.2	208
Downstream	DS: 2005, 2010	2.5	92	3.2	214
Vietnam					
An Giang	2009, 2011	7.1	876	7.8	1105
With and without		*AWD*		*Control*	
Philippines					
Tarlac site A	2002 DS	5.4	577	5.4	530
Tarlac site B	2005 DS	4.8	397	4.9	301
Vietnam					
An Giang province	2011	7.9	1155	7.9	984
Bangladesh					
Kushtia district	2009 Boro	5.6	579	5.2	418

Note: DS: dry season.

places find it fit. However, this makes it difficult to identify the impact of the technology. This issue emerges repeatedly as we review articles on improved management practices. We will return to this issue later.

5.2. Direct-seeded rice

The dominant method of rice establishment is transplanting in many Asian countries. However, labor costs for establishing a nursery, preparing fields, and transplanting have increased significantly in many developing countries and are expected to further increase in the future. Direct seeding of rice (DSR) is a method of establishing a rice crop by sowing seeds in the field rather than by transplanting seedlings grown in the nursery (Farooq et al., 2011). Hand-broadcasting is a common practice among farmers in Asia, although line-seeding with the aid of seed drums and tractor-drawn seeders has been tested and promoted by numerous projects. Because of the potential importance of this technology in the future, international research centers have intensified their research on it in recent years (Kumar and Ladha, 2011). The research activities include identifying better weed management practices, improving rice varieties suitable for direct seeding, and disseminating the technology to farmers.

Several studies evaluated the technology among farmers. Malabayabas et al. (2012) surveyed 40 DSR users, 40 farmers with both DSR and transplanting, and 20 farmers with both in eastern Uttar Pradesh and Bihar, India. Results based on simple mean comparisons indicated that average net income was higher for DSR than for transplanting, mainly because of the lower labor costs for DSR. In Bangladesh, Malabayabas et al. (2014) used data from 179 farmers in northern Bangladesh. They examined the combined impact of DSR and early-maturing rice varieties (EMV) by including three dummy variables: a DSR dummy, an EMV dummy, and an interaction term between the two dummy variables. The results indicated that the combination of DSR and EMV increased annual crop income (by USD 625 per ha) of farmers in Bangladesh. The main reasons for the increase in income were a higher rice yield and a reduction in costs because of less labor required in crop establishment.

The above two studies did not control for self-selection of the DSR adoption among farmers. Thus, the results could be biased. Ali et al. (2014) employed the propensity score matching (PSM) method to control for self-selection among 238 farmers in the rice-wheat area of Pakistan Punjab. The sampling was stratified by the adoption of DSR technology. The results indicated higher average rice yield under DSR by 0.9 t per ha than with the traditional method, although no explanations were given in the paper about the high average yield under DSR. The total cost of production was lower and profits higher under DSR. The results also indicated that the PSM method reduced potential estimation biases.

In general, the three studies indicate that DSR technology decreases labor costs. The impact of DSR on yield is mixed. Weed control is a major challenge for DSR adopters. Few studies have examined the adoption of DSR technology since its dissemination is still low in the study areas. More studies are required to evaluate the impact of this technology among farmers.

5.3. Site-specific nutrient management

Site-specific nutrient management (SSNM) is a low-tech, plant-need-based approach for optimally applying fertilizers such as nitrogen (N), phosphorus (P), and potassium (K) to rice (Pampolino et al., 2007). The key features include (1) dynamic adjustments in fertilizer management to accommodate field- and season-specific conditions; (2) effective use of indigenous nutrients; (3) efficient fertilizer N management through the use of the leaf color chart (LCC); (4) use of the omission plot technique to determine the requirements for P and K fertilizer; and (5) managing fertilizer P and K to both overcome P and K deficiencies and avoid mining of these nutrients from the soil (Pampolino et al., 2007). Dobermann et al. (2002) conducted on-farm experiments from 1997 to 1999 to develop and test an SSNM approach for eight key irrigated rice production domains of Asia located in six countries. They found that SSNM led to significant increases in nitrogen-use efficiency, thus increasing profits for farmers who applied SSNM. Pampolino et al. (2007) also examined the economic benefits of SSNM in irrigated systems in Asia, particularly in the Philippines, southern India, and southern Vietnam. They also found that the use of SSNM led to higher efficiency of nitrogen use: the reduction in fertilizer use with SSNM averaged about 10% in the Philippines and 14% in Vietnam.

These studies, however, are typically based on controlled field experiments and focus group discussions. They conducted simple "with and without" comparisons without controlling for self-selection. Rodriguez and Nga (2012) controlled for farmers' self-selection of adopting the SSNM technology by using the instrumental variables approach. Their study found that SSNM improved paddy yield by 0.6 t per ha and profit by USD 150 per ha, although it found no impacts on the amount of pesticide and nitrogen use. The evidence on the impact of SSNM is limited, and the need for more rigorous evaluation studies is high.

5.4. Integrated pest management and farmer field schools

The introduction of modern agricultural technologies in the 1960s and 1970s dramatically increased the use of chemical inputs, including pesticide, without adequate knowledge about health and environmental side effects. Integrated pest management (IPM) was developed and has been promoted in the major rice-producing regions in Asia, especially in Southeast Asia. In the Mekong Delta of Vietnam, a media campaign was started in 1994 to motivate farmers to reduce pesticide spraying in the first 40 days after sowing. This campaign was based on an earlier finding that early spraying was unnecessary as any damage from leaf-feeding insects (the prime cause of early spraying) seldom affected yield (Heong et al., 1994).

Meanwhile, a total of 107,250 farmers (or about 4.3% of the 2.3 million farm households in the Mekong Delta) attended a Farmer Field School (FFS) in a 5-year period between 1992 and 1997. Huan et al. (1999) reported a significant decline in insecticide spray applications, from 3.4 times to 1.0 time per season, by using two separate cross-sectional data on 685 farmers in 1992 and 2598 farmers in 1997 in the Mekong Delta.

As the Vietnamese government nationalized rice production campaigns, farmers started overusing inputs in the belief that "more is better". Thus, Huan et al. (2005) conducted a farmer participatory study of 951 farmers and observed little difference in rice yields between experimental plots (with reduced pesticide sprays, seed rates, and nitrogen fertilizer) and control plots. Because of the reduced input costs, the authors found higher incomes on the experimental plots. Provincial government officials quickly responded to the results and engaged in a massive media campaign and extension efforts to reduce inputs under a catchy program named "Three Reductions, Three Gains (3R3G)". Huelgas and Templeton (2010) studied the impacts of this program through a survey of three provinces in 2005–06 and reported farm-level income benefits through reduced costs.

In Indonesia, IPM was integrated to form a holistic approach to rice production as taught in FFSs in 1998. The FFS then became a popular farmer extension program among donors (Kenmore, 1991). IPM-FFS activities involve season-long field training and intensive discussions with farmers about pesticide use and other rice crop management topics. Since then, FFS-type extension formats have evolved beyond IPM materials or agriculture and beyond Asia (Davis et al., 2012; Larsen and Lilleor, 2014).

Although IPM-FFS programs have been adopted in many developing countries and earlier studies found encouraging results, their impact is a matter of heated debate. The debate was sparked by an article by Feder et al. (2004), which criticized earlier FFS evaluation studies on methodologies for not considering the potential bias of nonrandom program placement and self-selection of participants. van den Berg and Jiggins (2007) joined the debate by reviewing 25 impact evaluation studies. The major difference between the early evaluation studies reviewed in van den Berg and Jiggins (2007) and Feder et al. (2004) was the timing of the evaluations. Whereas most of the studies reviewed by van den Berg and Jiggins (2007) examined the immediate impacts of FFS programs on outcomes, Feder et al. (2004) examined changes in outcomes over 8 years, from 1991 to 1999, by using a panel data set. Although the use of the panel data helped Feder et al. (2004) to control for program placement and self-selection of participants, they examined the long-term impacts, not the immediate impacts. Thus, it is not clear whether the immediate impacts estimated by earlier studies did not exist (i.e., the positive estimators were biased) or the immediate impacts existed but disappeared over time. By using panel data from Indonesia, Yamazaki and Resosudarmo (2008) examined this question and found immediate positive impacts of IPM-FFS programs in the short run but not long-run impacts. The debate over the effectiveness of the FFSs has led the discussion about what should be measured as the outcomes of the program. Agricultural productivity and input use are main outcome variables in many studies but FFS programs can improve knowledge among farmers and lead to empowerment (Davis et al., 2012).

6. Conclusions

In this study, we have reviewed studies that examined the adoption and estimated impacts of new rice technologies and practices developed and deployed either directly to farmers by international research centers or indirectly through national agricultural systems. Many of the impact assessment studies used cross-sectional data with descriptive analyses. Only a small number of impact assessment studies reviewed in this article used advanced evaluation techniques that controlled for program placement and farmer self-selection. Although rigorous estimation techniques are not called for in all projects, more studies should employ these techniques.

The reviewed studies on stress-tolerant rice varieties have indicated that these varieties have been quickly disseminated among many farmers in South Asia. However, because these varieties are still in the initial diffusion stage, their diffusion and impacts should be monitored and documented. One caveat needs to be mentioned: since the stress-tolerant rice varieties were new to farmers, the varieties might be wrongly identified by farmers and therefore erroneously recorded and reported by government statistics or farmer surveys. In order to correct for such identification errors, DNA fingerprinting should be used in future studies (Labarta et al., 2015b).

Although the economic returns to recently improved germplasm have been well studied and documented, the number of studies on economic returns to natural resource management is still limited. Moreover, most of the studies on NRM practices were conducted in areas where the NRM practices were promoted. It is therefore difficult to obtain overall adoption rates of NRM practices and evaluate the benefits of the NRM practices outside of project sites. These limitations are understandable to some extent because of the inherent difficulties in assessing NRM research. First, NRM research involves practices that are often modified by farmers to fit their needs. Thus, defining a "technology" or "improved practice" as observed on the ground versus its original form can be problematic and affect impact estimations. Second, much NRM research involves agricultural production systems rather than crops. Estimating impacts on systems is far more complicated than estimating impacts of improved germplasm. Third, quantifying NRM research impacts on the environment has methodological difficulties. Lastly, compared to MV impact studies that rely mostly on secondary data, the cost of an NRM evaluation study is rather high just considering the cost of collecting primary data let alone creating a panel rather than just being satisfied with a cross section. Aside from that, MVs characteristically enhance yield directly, which is easier to measure. Management technologies, on the other hand, are usually not yield increasing but either damage abating or cost reducing and therefore harder to measure and harder to establish counterfactuals for. MV seeds are easier to multiply, distribute, be appreciated by farmers, and be adopted. They are even easier to analyze using binary variables in regressions. Management technologies, being knowledge-based, are much harder to put together in a holistic context, harder to communicate to farmers, and involve a lot of coordination and extension resources; thus, in attempting to come up with evidence of impacts, it is more difficult to address attribution and establish counterfactuals.

Despite these difficulties, the demand for impact assessment of NRM research is high because of the large share of resources devoted to NRM. More evaluation studies, especially large-scale ones, should be in place to assess the technologies.

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References

Ali, A., Erenstein, O., Rahut, D.B., 2014. Impact of direct-sowing technology on rice producers' earnings: empirical evidence from Pakistan. Dev. Stud. Res. 1 (1), 244–254. http://dx.doi.org/10.1080/21665095.2014.943777.
Araus, J.L., Slafer, G.A., Royo, C., Serret, M.D., 2008. Breeding for yield potential and stress adaptation in cereals. Curr. Rev. Plant Sci. 27, 377–412.
Barret, C.B., Carter, M.R., 2010. The power and pitfalls of experiments in development economics: some non-random reflections. Appl. Econ. Perspect. Pol. 32 (4), 515–548. http://dx.doi.org/10.1093/aepp/ppq023.
Bouman, B.A.M., Lampayan, R.M., Tuong, T.P., 2007. Water management in irrigated rice: coping with water scarcity. International Rice Research Institute, Los Baños, Philippines 54 pp.
Brennan, J.P., Malabayabas, A., 2011. International Rice Research Institute's contribution to rice varietal yield improvement in South-East Asia. Australian Centre for International Agricultural Research, Canberra 111 pp.
Conway, G., Toenniessen, G., 1999. Feeding the world in the twenty-first century. Nature 402, C55–C58.
Dar, M.H., de Janvry, A., Emerick, K., Raitzer, D., Sadhoulet, E., 2013. Flood-tolerant rice reduces yield variability and raises expected yield, differentially benefiting socially disadvantaged groups. Sci. Rep. 3 (3315), 1–8.
David, C.C., Otsuka, K., 1994. Modern Rice Technology and Income Distribution in Asia. Lynne Rienner, Boulder 475 pp.
Davis, K., Nkonya, E., Kato, E., Mekonnen, D.A., Odendo, M., Miiro, R., Nkuba, J., 2012. Impact of Farmer Field Schools on agricultural productivity and poverty in East Africa. World Dev. 40 (2), 402–413. http://dx.doi.org/10.1016/j.worlddev.2011.05.019.
Deaton, A., 2010. Instruments, randomization, and learning about development. J. Econ. Lit. 48, 424–455.
de Janvry, A., Dustan, A., Sadoulet, E., 2011. Recent Advances in Impact Analysis Methods for Ex-post Impact Assessments of Agricultural Technology: Options for the CGIAR, Report prepared for the workshop: Increasing the rigor of ex-post impact assessment of agricultural research: a discussion on estimating

treatment effects, organized by the CGIAR Standing Panel on Impact Assessment (SPIA), 2 October 2010, Berkeley, California, USA, Independent Science and Partnership Council Secretariat (ISPC), Rome, Italy.
Diagne, A., 2006. The diffusion and adoption of NERICA rice varieties in Côte d'Ivoire. Dev. Econ. 44 (2), 208–231.
Diagne, A., Kinkingninhoun-Medagbe, F.M., Amobing-Assagba, E., Tebila, N., Sanni, K., Toure, A., 2015. Evaluating the key aspects of the performance of genetic improvement in priority food crops and countries in Sub-Saharan Africa: the case of rice. In: Walker, T., Alwang, J. (Eds.), Crop Improvement, Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa. CABI, United States.
Diagne, A., Demont, M., 2007. Taking a new look at empirical models of adoption: average treatment effect estimation of adoption rates and their determinants. Agric. Econ. 37, 201–210.
Dobermann, A., Witt, C., Dawe, D., 2002. Nutrient management in intensive rice cropping systems of Asia. Better Crop. Int. 16 (1), 25–30.
Dontsop Nguezet, P.M., Diagne, A., Okoruwa, O.V., Ojehomon, V., Manyong, V., 2013. Estimating the actual and potential adoption rates and determinants of NERICA rice varieties in Nigeria. J. Crop Improv. 27 (5), 561–585.
Estudillo, J.P., Otsuka, K., 2013. Lessons from the Asian Green Revolution. In: Otsuka, K., Larson, D. (Eds.), An African Green Revolution: Finding Ways to Boost Productivity on Small Farms. Springer, New York, pp. 17–42, Ch. 2.
Evenson, R.E., Gollin, D., 2003. Assessing the impact of the Green Revolution, 1960 to 2000. Science 300, 758–762. http://dx.doi.org/10.1126/science.1078710.
Fan, S., Chank-Kang, C., Qian, K., Krishnaiah, K., 2005. National and international agricultural research and rural poverty: the case of rice research in India and China. Agric. Econ. 33 (Supp), S369–S379.
Farooq, M., Siddique, K.H.M., Rehman, H., Aziz, T., Lee, D.J., Wahid, A., 2011. Rice direct seeding: experiences, challenges, opportunities. Soil Tillage Res. 111 (2), 87–98.
Feder, G., Murgai, R., Quizon, J., 2004. Sending farmers back to school: the impact of Farmer Field Schools in Indonesia. Rev. Agric. Econ. 26 (1), 45–62.
Heong, K.L., Escalada, M.M., Mai, V., 1994. An analysis of insecticide use in rice: case studies in the Philippines and Vietnam. Int. Pest Manag. 40, 173–178.
Huan, N.H., Mai, V., Escalada, M.M., Heong, K.L., 1999. Changes in rice farmers' pest management in the Mekong Delta, Vietnam. Crop Prot. 18, 557–563.
Huan, N.H., Thiet, L.V., Chien, H.V., Heong, K.L., 2005. Farmers' participatory evaluation of reducing pesticides, fertilizers and seed rates in rice farming in the Mekong Delta, Vietnam. Crop Prot. 24, 457–464.
Huelgas, Z.M., Templeton, D.J., 2010. Adoption of crop management technology and cost-efficiency impacts: the case of three reductions, three gains in the Mekong River Delta of Vietnam. In: Palis, F.G., Singleton, G.R., Casimero, M.C., Hardy, B. (Eds.), Research to Impact: Case Studies for Natural Resource Management for Irrigated Rice in Asia. International Rice Research Institute, Los Baños (Philippines).
Kenmore, P., 1991. Indonesia's Integrated Pest Management: A Model for Asia. FAO Inter-country IPC Rice Program, Manila, Philippines.
Kijima, Y., Otsuka, K., Sserunkuuma, D., 2008. Assessing the impact of NERICA on income and poverty in central and western Uganda. Agric. Econ. 38, 327–337.
Kijima, Y., Otsuka, K., Sserunkuuma, D., 2011. An inquiry into constraints on a Green Revolution in sub-Saharan Africa: the case of NERICA rice in Uganda. World Dev. 39 (1), 77–86.
Kumar, V., Ladha, J.K., 2011. Direct seeding of rice: recent developments and future research needs. Adv. Agron. 111, 297–413.
Khush, G.S., 1995. Modern varieties – their real contribution to food supply and equity. GeoJournal 35 (3), 275–284.
Khush, G.S., 1999. Green Revolution: preparing for the 21st century. Genome 42, 646–655.
Labarta, R.A., Buritica, A., Lopera, D., del Rio, M., Perez, S., Gonzalez, C., Andrade, R. 2015a. Contribución del CIAT al mejoramiento genético de arroz en 8 países de América Latina. Paper submitted to Agronomía Mesoamericana (under review).
Labarta, R., Martinez, J.M., Lopera, D., Gonzalez, C., Quintero, C., Gallego, G., Viruez, J., Taboada, R. 2015b. Assessing impacts of the adoption of modern rice varieties using DNA fingerprinting to identify varieties in farmer fields: a case study in Bolivia. Paper accepted for presentation in the Triennial meeting of the International Association of Agricultural Economics (IAAE), Milan.
Lampayan, R.M., Rejesus, R.M., Singleton, G.R., Bouman, B.A.M., 2015. Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. Field Crop. Res. 170 (1), 95–108.
Larsen, A.F., Lilleor, H.B., 2014. Beyond the field: the impact of Farmer Field Schools on food security and poverty alleviation. World Dev. 64, 843–859.
Malabayabas, A.J., Templeton, D., Singh, P., 2012. Ex-ante impact of direct seeding of rice as an alternative to transplanting rice in the Indo-Gangetic Plain. Asian J. Agric. Dev. 9 (2), 13–29.
Malabayabas, A.J.B., Kajisa, K., Mazid, M.A., Palis, F.G., Johnson, D.E., 2014. Impacts of direct-seeded and early-maturing varieties of rice on mitigating seasonal hunger for farming communities in northwest Bangladesh. Int. J. Agric. Sustain. 12 (4), 459–470.
Malabayabas, M., Yamano, T., Panda, A., Gupta, I. 2015. Rice monitoring survey 2014 in Bangladesh. In mimeo, IRRI.
Maredia, M.K., Raitzer, D.A., 2012. Review and analysis of documented patterns of agricultural research impacts in Southeast Asia. Agric. Syst. 106 (2012), 46–58.
Mushtaq, S., Khan, S., Hafeez, N., Hanjra, M.A., 2009. Does reliability of water resources matter in the adoption of water-saving irrigation practices? A case study in the Zhanghe irrigation system, China. Water Policy 11, 661–679. http://dx.doi.org/10.2166/wp.2009.033.
Neeraja, C.N., Maghirang-Rodriguez, R., Pamplona, A., Heuer, S., Collard, B.C.Y., Septiningsih, E.M., Vergara, G., Sanchez, D., Xu, K., Ismail, A.M., Mackill, D.J., 2007. A marker-assisted backcross approach for developing submergence-tolerant rice cultivars. Theor. Appl. Genet. 115 (6), 767–776.
Pampolino, M.F., Manguiat, I.J., Ramanathan, S., Gines, H.C., Tan, P.S., Chi, T.T.N., Rejendran, R., Buresh, R.J., 2007. Environmental impact and economic benefits of site-specific nutrient management (SSNM) in irrigated rice systems. Agric. Syst. 93, 1–24.
Pandey, S., Velasco, M.L., Yamano, T., 2015. Scientific strength in rice improvement programs, varietal outputs, and adoption of improved varieties in South Asia. In: Walker, T., Alwang, J. (Eds.), Crop Improvement, Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa. CABI, United States.
Pardey, P.G., Alston, J.M., Chan-Kang, C., Magalhaes, E.C., Vosti, S.A., 2002. Assessing and Attributing the Benefits from Varietal Improvement Research: Evidence from Embrapa, Brazil. EPTD Discussion Paper No. 95. International Food Policy Research Institute, Washington, DC, USA.
Raitzer, D.A., Sparks, A.H., Huelgas, Z.M., Maligalig, R., Balangue, Z., Launio, C., Daradjat, A., Ahmed, H.U., 2015. Is Rice Improvement Still Making a Difference? Assessing the Economic, Poverty, And Food Security Impacts of Rice Varieties Released from 1989 to 2010 in Bangladesh, Indonesia, and the Philippines. A report submitted to the Standing Panel on Impact Assessment (SPIA). CGIAR Independent Science and Partnership Council (ISPC), Rome, Italy.
Rejesus, R.M., Palis, F.G., Rodriguez, D.G.P., Lampayan, R.M., Bouman, B.A.M., 2011. Impact of the alternate wetting and drying (AWD) water-saving irrigation technique: evidence from rice producers in the Philippines. Food Policy 36 (2), 280–288.
Renkow, M., Byerlee, D., 2010. The impacts of CGIAR research: a review of recent evidence. Food Policy 35 (5), 391–402.
Rodriguez, D.G.P., Nga, N.T.D., 2012. Impacts of site-specific nutrient management in irrigated rice farms in the Red River Delta, Northern Vietnam. Selected paper for poster presentation at the International Association of Agricultural Economics (IAAE) Triennial Conference, Foz de Iguaçu, Brazil, 18–24 August 2012, 39 p.
Seck, P.A., Diagne, A., Mohanty, S., Wopereis, M.C.S., 2012. Crop that feeds the world: rice. Food Secur. 4, 7–24.
Septiningsih, E.M., Pamplona, A.M., Sanchez, D.L., Neeraja, C.N., Vergara, G.V., Heuer, S., Ismail, A.M., Mackill, D.J., 2009. Development of submergence-tolerant rice cultivars: the Sub1 locus and beyond. Ann. Bot. 103 (2), 151–160.
Smith, J.A., Todd, P.E., 2005. Does matching overcome LaLonde's critique of non-experimental estimators? J. Econom. 125, 305–353.
Stevenson, J.R., Villoria, N., Byerlee, D., Kelley, T., Maredia, M., 2013. Green revolution research saved an estimated 15 to 27 million hectares from being brought into agricultural production. Proc. Natl. Acad. Sci. USA 110 (21), 8363–8368. http://dx.doi.org/10.1073/pnas.1208065110.
Thirtle, C., Lin, L., Piesse, J., 2003. The impact of research led agricultural productivity growth on poverty reduction in Africa, Asia, and Latin America. World Dev. 31 (12), 1959–1975. http://dx.doi.org/10.1016/j.worlddev.2003.07.001.
Tsusaka, T., Velasco, M.L., Yamano, T., Pandey, S., 2015. Expert elicitation for assessing agricultural technology adoption: the case of improved rice varieties in South Asian countries. Asian J. Agric. Dev. 12 (2), 19–34.
United States Department of Agriculture (USDA), 2005. Production, Supply and Distribution Database Online.
van den Berg, H., Jiggins, J., 2007. Investing in farmers: the impacts of Farmer Field Schools in relation to integrated pest management. World Dev. 35 (4), 663–686.
Xu, K., Mackill, D.J., 1996. A major locus for submergence tolerance mapped on rice chromosome 9. Mol. Breed. 2, 219–224.
Yamano, T., Panda, A., Gupta, I., Mehar, M., 2015. Rice monitoring survey 2014 in India. In mimeo, IRRI.
Yamazaki, S., Resosudarmo, B., 2008. Does sending farmers back to school have an impact? Revisiting the issue. Dev. Econ. 46 (2), 135–150.