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Synergies at the interface of farmer–scientist partnerships: agricultural innovation through participatory research and plant breeding in Honduras

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Abstract

Background: The article describes the institutionalization of farmer participatory research and plant breeding that has occurred in Honduras over the past 22 years and demonstrates how this approach can offer a positive response to climate change and sustainable agricultural development. In Honduras, participatory plant breeding (PPB) involves the collaboration of farmer researchers organized in local agricultural research committees (CIALs), plant breeders, and non-governmental organizations (NGOs). While earlier debates often questioned the role of farmers in agricultural research, particularly the synergistic effect of this role with regard to scientific research, little empirical evidence was provided to settle this debate. Nor was the contextualization of farmer research adequately addressed. The article responds to calls for studies that detail what actually happens in development practice.

Results: The article provides detailed cases of farmer–NGO–scientist collaboration in the development of new bean varieties in Honduras. The documented cases of PPB-generated bean varieties demonstrate how and why this collaboration has produced synergies for scientific research and positive benefits for poor farmers in the Honduras context. Very high adoption rates of PPB varieties compared to unimproved local and conventional scientist-developed varieties show the importance of this approach for regions of the world where agro-biodiversity is high and agricultural research budgets are inadequate to address this diversity.

Conclusions: PPB provides a means to improving food security in poor and agro-biodiverse countries, such as Honduras. Nevertheless, to incentivize farmers to engage in PPB research over the long term, seed regulatory systems must allow for the development of small seed enterprise. Research support must also be long term. PPB in Honduras has been successful because donor support to both scientists and NGOs for farmer participatory research has been sustained allowing for trusting partnerships to evolve between the different players.

Keywords: Farmer participatory research, Participatory plant breeding, Climate change, Sustainable agriculture

Background

Discussion of sustainability, which has long been a prominent theme in international development, particularly in the area of agricultural development [1–5], is today commonly pursued under the mantle of climate change priorities. These priorities, along with global concerns around food security following the spike in food prices in 2007/8, have helped to imbue sustainable agricultural development with a new urgency that has propelled it to the forefront of scientific research agendas [6, 7]. Since 2008, renewed interest in funding international agricultural research has the scientific community keenly focused on the development of new technologies to

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help communities both mitigate, and adapt to, climate-related changes, as well as respond to diverse development dilemmas. However, as researchers have previously noted, sustainable solutions generally involve *processes* that are adaptable to moving targets, rather than to specific ends or fixes, such as new technologies or policies [1, 2, 7]. And almost inevitably, this involves innovation on a continuing basis.

Involving farmers as protagonists of their own agricultural research agendas is one means of permitting continual innovation, allowing the moving target of sustainability to be kept continually in the "crosshairs" of local people. Farmer research is particularly important in the Global South where strained research budgets are liable to exclude poor and marginalized rural populations due to the heterogeneity of the physical and sociocultural landscapes they frequently inhabit [8–10].[1]

This article revisits some of the earlier, as well as more recent debates on farmer participatory research, and contributes extensive empirical research on participatory research gathered over many years. Our goal in this article is to throw light on a topic that is often debated but seldom well documented. We provide detailed case study material from Honduras where more than 20 years of institutional support for research conducted by hillside farmers has served, it will be argued, to effectively position local farmers, non-governmental, and scientific institutions, at the forefront of innovation for climate change adaptation. By documenting the experiences of hillside farmers in research, the article also responds to calls for studies that detail what actually happens in development practice [12], particularly in the field of participatory development where past claims of success have been much greater than the evidence to support them [13].

Looking back at farmer participatory research

Biggs' personal reflections on the history of participatory technology development (PTD) show just how culturally and methodologically diverse approaches to participatory research have been since the seventies [14]. But most importantly, he shows how technology development is always rooted in specific historical and socioeconomic contexts and replication outside a given context may be neither easy, nor appropriate. In particular, he focuses on negative fallout in the nineties from intense rivalry amongst "mainstream PTD advocates" (p. 495–7) as they attempted to establish the superiority of one approach over another. This, he argues, stifled learning from participatory technology development and amounted to a lost decade in advancing knowledge of different approaches. Also missing from the nineties' analysis was the employment of social science skills to contextualize the different environments in which these approaches were being employed. Instead, adherents to the cause of participatory technology development, or farmer participatory research, were more focused on frameworks and management tools that could be "scaled out and scaled up" (p. 499).

Competition was notable between those who favored a farming systems research (FSR) approach and those who called for farmers to be accorded greater agency in research planning that went beyond what those in FSR considered appropriate. Adherents to FSR argued that farmers' research was best understood to serve the role of complementing the work of scientists rather than adding extra benefits to science. Sumberg and Okali, who put forward this position, questioned the scientific validity of much of the farmer participatory research literature, which, they argued, was largely unreviewed and tended to be self-referencing in nature (p. 164) [15]. While acknowledging that farmers engage widely in research of a tinkering, or adaptive nature, these authors rejected claims of "significant extra benefits" or synergies, either for farmers or for scientists, through the development of a collegial research relationship, and concluded "that training farmers in the techniques of formal experimentation should not be seen as either essential or desirable" (p. 158). Rather, they supported a model of "agricultural research with farmer participation". This was a model reflective of the more consultative relationship between farmers and scientists in which farmers adapt new technology to their own needs and provide feedback to the formal scientific sector. They regarded this as a particular form of agricultural extension, which was, in essence, development—rather than research—focused. Their particular concern was that efforts to exaggerate farmers' impact on research were diverting funding for scientific research to development ends, thus mixing the agendas for empowerment and self-reliance with agricultural research to the detriment of the latter (p. 27).

Amongst those who envisioned a collegial relationship between farmers and scientists were social scientists working at some of centers of the Consultative Group on International Agricultural Research (CGIAR). Having witnessed firsthand the disregard that agricultural scientists often paid to the needs of poor farmers, they were determined to find ways to put farmers "in the driving seat" so that the farmers themselves could actively participate in the planning and development of their own

[1] A Comment in Nature [11] argues that this approach should also be implemented in the rich northern countries where the engagement of farmers in small-scale innovation in situ is critical for equipping farmers to tackle climate change uncertainties. However, to date, it has been in the Global South where farmer participatory research has been almost exclusively focused through various efforts of international development programming.

technologies [16, 17]. And this meant teaching farmers a basic understanding of the scientific method so that scientists in the CGIAR could respect their research and collegiality might be genuinely pursued between the parties. The CIAL methodology (the acronym derived from the Spanish, comités de investigación agrícola local) developed by Ashby and her team at the International Centre for Tropical Agriculture (CIAT) in 1990 did precisely that: farmers organized in research teams were given the tools to plan and carry out randomized block design trials and replications, and to evaluate and analyze the results in a manner that was statistically verifiable and thus readily available to scientists within the CGIAR and other institutions [17, 18]. These tools were considered an important means for empowering farmers and allowing for a collegial relationship to be established between farmers and scientists.

Other social scientists within the CGIAR (e.g., International Potato Centre) leaned more towards the farmer field school (FFS) approach supported by the Food and Agriculture Organization. While the CIAL methodology was by nature deductive, involving farmers in testing and evaluating alternative technologies against a control or customary technology, the FFS approach was inductive. By observing differences between a customary plot, or "control", typically treated with agrochemicals, and the "treatment plot", managed according to agro-ecological principles, farmers in the field schools learned about agro-ecological processes and the logic behind the application of an integrated pest management approach [19]. Over time, this approach has been adapted to deal with more complex issues including "learning fields" and associated experiments [20]. Like the CIALs, the field school concept supported the development of analytical skills applicable to research execution, and these, in turn, were expected to foster shared decision making between farmers and scientists, including farmer involvement in the early stages of research development [21].

Both the FFS and CIAL platforms were intended to be replicable in different contexts, or "scaled up and out". But, as Biggs points out, little attention was paid to context and explaining how this affected different outcomes [14]. Those supporters of farmer participatory research who have been most concerned with context have generally been social scientists working outside the CGIAR and other large development institutions. This group, involving social scientists from a range of academic disciplines, has often questioned the appropriateness of teaching farmers the scientific method. This is particularly true of those who are guided by precepts of cultural relativism, as many anthropologists are, and argue that farmers' experiments have their own value, which it is incumbent upon outsiders to try to understand. To do otherwise is to devalue local knowledge and increase existing differentials in power relations between farmers and researchers [22–24]. Stolzenbach, one of those who favored learning from farmers' research, argued that it is hard to separate farmer experiments from daily farming practice, but it is the continuous performance of those practices that explains the "innovative element of the craft of farming" (p. 155) [25, 26]; Richards referred to such practices as agricultural "adaptive performances" [27]; Bentley called them folk experiments [28]. In research conducted in the Andes, Bentley et al. describe how farmers, who were organized in CIALs, turned the topics learned through formal experiments with scientists into their own creative folk experiments that better met their needs [29]. Forcing farmers to mold their experiments to the demands of science, this group of researchers argues, runs the risk of stifling cultural performance, serving to undermine farmers' creativity and the value of farmers' research for science.

While the examples provided by Bentley et al. demonstrate that CIALs may successfully foster folk experiments [29], it is less clear that FFS have this effect. The meta-analysis of literature on the FFS conducted by Waddington, et al. shows that experimentation is not a prominent feature of the FFS approach [30]. None of 92 impact studies included by Waddington et al. in their meta-evaluation of FFS provided information on experimentation. However, sustainability was a consideration in 11 of the studies. These studies drew attention to the need for follow-up after the field schools ended to "support farmers in the continuing development of local practices" and that "good leadership, collective goals and a supportive group environment might be important in maintaining FFS groups and providing impetus for further farmer-led initiatives" (p. 138). The bulk of these studies also showed that "little if any" diffusion of FFS knowledge and learning beyond the group was noted (p. 139). In other words, the documentation included in the meta-analysis of FFS did not point to farmer research or to the spread of new ideas beyond the schools as a sustainable element of this approach. However, as Van den Berg and Jiggins stress in their earlier review of the FFS literature, most impact studies of the FFS approach have sought statistical rigor and generally been narrow in scope, while the focus on immediate impacts has excluded longer term effects, such as experimentation and diffusion [31]. They argue that intermediate- and long-term impacts do include experimentation, as well as farmer organization, which were widespread in the 182 sub-districts in Indonesia where the FFS had taken place [31]. Nevertheless, they recognize that such impacts are sparsely described and without convincing evidence of attribution, while diffusion is limited by the complexity of integrated pest management, necessitating experiential learning for effective up-scaling.

As demonstrated, the documentation dealing with farmer participatory research generally fails to provide convincing empirical evidence of sustainable farmer innovation and systematic integration with the formal research sector. Long-term studies capable of illuminating the intricacies of farmer innovation are rarely conducted because most development projects are short term and impact assessments are focused on immediate outputs and outcomes. It is the short-term nature of most development funding that prevents the kind of deep learning that longitudinal research can provide.

In Honduras, by contrast, long-term donor support for farmer participatory research offers a unique learning opportunity. Below we provide an analysis of the context for the emergence of this initiative, discussion of the development of a program of farmer research teams and the institutional partners that support them, case studies describing individual bean breeding initiatives conducted between farmers and scientists over a 15-year period, quantitative analysis of bean varietal adoption, and a discussion of the dynamics behind the involvement of farmers in the breeding process that has generated synergies between farmers and scientists in research.

Contextualizing farmer participatory research in Honduras

In Honduras, the context of participatory research is well described through the lens of political ecology [32]. Public sector debt in the late eighties led to a series of structural adjustments to the economy, including agriculture, and resulted in the disappearance of agricultural extension from government-supported services (p. 185) [33]. While agricultural research continued, it has been severely restricted by limited funding to the country's public university system, and to the government department in charge of agricultural research, Dirección de Ciencia y Tecnología Agropecuaria, (DICTA). This has left the private-, and not-for-profit sectors,[2] to play a leading role in the country's agricultural research and to deliver specialized, fee-based extension services, while public sector research has been mainly confined to experiment stations with limited application for farmers who make a living off subsistence crops of maize and beans on the country's mountains and hillsides. These make up approximately 80 % of the landmass [34] and provide a home to most of the rural population [35];[3] the latter comprises just under half of the country's total population. According to the World Bank, 6 out of 10 rural Hondurans live in extreme poverty,[4] a statistic that encompasses nearly all of the country's hillside farmers [35]. It is within this context, comprising high agro-biodiversity associated with a mountainous landscape, extremely limited public sector agricultural research capacity, the absence of public extension services, and impoverished hillside farmers, that farmer participatory research finds its particular niche. Here, a system of research that involves farmers as experimenters at diverse locations becomes a sine qua non of the country's research apparatus. Such a system requires strong partnerships between scientists, non-governmental and farmer research organizations capable of supporting highly decentralized and innovative research.

It is this decentralization requirement, and the system that has grown up to support it, which underpins our argument that farmer participatory research contributes synergistically with science in the Honduran context. We cannot make the claim that such synergy is necessarily a given in every context. Nor do we claim that farmers should be involved in every stage of the planning process. This is simply not practical. However, we do make an argument for the necessity of a flexible and open system of research that is receptive to the "demand-pull" of farmers' ideas and incorporates these into research design and planning. Such a flexible and open system allows for constant innovation to occur in response to pressures from climate change.

Additionally, there are multiple development benefits that come from farmer participatory research in the form of farmer skill acquisition and learning, and the associated income and empowerment effects derived from these. These other development impacts have been detailed in separate articles and book chapters [36–38]. This article focuses on the creation of an environment that has been conducive to farmer and scientist co-learning for research and innovation.

The CIAL experience in Honduras

Local Agricultural Research Committees (CIALs) have been operating in Honduras since 1993 [39, 40]. Initially introduced as a pilot project by the International Centre for Tropical Agriculture (CIAT), the CIAL methodology

[2] Fundación Hondureña de Investigación Agricola (FHIA) is an example of a non-profit private research foundation. It focuses mainly on export crops (especially cacao, plantain and bananas) and charges fees for its services. It carries on banana research started in 1958 by the United Fruit Company.

[3] According to Hansen, et al. 60 % of the total population is rural with most living on hillsides [35]. Since that time the percentage of the population that is considered rural has declined to 46 % [54].

[4] According to USAID, two-thirds of Hondurans live in poverty and 40 % live in extreme poverty [55]. Honduras has the most extreme inequality at 57.4, as measured by the Gini Coefficient, of any country in Latin America (p. 24).

has become the central organizing framework for two local non-governmental organizations, the Foundation for Participatory Research with Honduran Farmers (Spanish acronym FIPAH, formerly IPCA) and the Program for Rural Reconstruction (PRR). For more than 20 years, these two organizations have been supported by Canadian donors, specifically the International Development Research Centre (IDRC), and most importantly, World Accord and USC Canada, the latter with backing from the Canadian International Development Agency (CIDA).[5] More recently, FIPAH has been involved in training other organizations to support CIALs in the south of the country. Today these organizations facilitate research with 139 CIALs, with a further 23 planned over the next 5 years, that conduct research into a wide array of topics across a variety of agricultural zones but mostly focus on the principal food crops, maize and beans.

Uptake of the CIAL methodology in Honduras has been shown to shift significantly over the duration of the project [39, 40]. Teaching extremely poor, semi-literate farmers in Honduras to conduct research according to the logic of the scientific method was slower than Jacqueline Ashby and her co-workers at CIAT had anticipated when they originally designed and tested the methodology in 1990 in Colombia [17]. At the outset, when the Honduran program was perceived in the light of previous development projects, it was subject to elite capture and the exclusion of women [36, 39], limiting broader dissemination. However, once local people began to grasp the meaning of research and to understand the essence of the program, especially expectations around work and the long-term nature of the commitment, the elites departed and women found a space for themselves as part of an organization that offered them both camaraderie and opportunities to take on new roles outside of the household. An evaluation undertaken in 2004 found social and economic improvements occurring amongst CIAL members to be significantly associated with the CIAL program [36, 37].

Over time, regular support to the CIALs passed from agronomists to local farmer facilitators. While PRR has long had a cadre of farmer facilitators to support local farmers, FIPAH evolved as an organization specifically around the CIAL approach. Farmer facilitators who came to work with FIPAH were those farmers who were quick to grasp the logic of formal experimentation and were good at explaining the process to other farmers; and most importantly, they were people who were trusted, and respected, by other farmers [41]. Thus, much of the spread of the CIALs into ever more remote mountainous areas grew with the training and recruitment of farmer facilitators, who also lived in these remote zones and could visit neighboring CIALs on their motor bikes and provide them with the necessary research support. Working as part-time NGO employees, alongside the management of their land and research within their own CIAL, these facilitators linked the farmer researchers to an agronomist at one of the regional NGO offices. The CIAL approach, like FFS, requires facilitation. However, unlike most FFS, which assemble only for the purpose of field school training, the CIALs are permanent organizations that become close-knit teams over time and typically do more than research, such as rotating savings and loans, group income generation activities, and leadership on community development projects. Some of the oldest CIALs have been in existence for 15–20 years, usually with most of the same members. This CIAL network structure, which over time has reached into ever more remote areas, provides the basis for decentralized research covering a wide range of agro-ecological zones. There are 5 research networks organized as Associations of CIALs (ASOCIALs) located in different regions of Honduras. Farmer facilitators oversee the planning of research with individual CIALs and help with the collection of data that gets fed into a broader set of trial data managed by agronomists working at FIPAH and PRR, and subsequently shared with scientists at the Escuela Agrícola Panamericana, El Zamorano (EAP-Zamorano).

EAP-Zamorano has worked with both FIPAH and PRR since the mid-nineties. While it is a private institution, it receives public funding for pro-poor bean research through the Bean Research Program (Spanish acronym, PIF), which focuses on improving red and black beans used by the region's small farm families and by public and private sector organizations [42]. In the early years of the CIAL program, EAP-Zamorano provided FIPAH and PRR with conventional varieties of maize and beans for the CIALs to test out against their own local materials, usually landraces. After nearly 5 years of testing, it became clear that the formal sector materials were not well adapted to the conditions faced by most of the CIAL members, particularly those located above 1000 m.a.s.l. In multiple trials conducted by CIALs supported by FIPAH at upper altitude locations in the early years of the program, farmers' varieties out-yielded conventional,

[5] La Fundación para la Investigación Participativa en Centroamérica (FIPAH) was incorporated as a research foundation in 2003. Before that it was known as Investigación Participativa en Centroamérica (IPCA), a project started by CIAT in 1993 and subsequently funded by the International Development Research Centre (IDRC) in Ottawa (1995–2000) through the University of Guelph. In 2000, USC Canada began funding it with support from the Canadian International Development Agency (CIDA). CIDA was absorbed by the Department of Foreign Affairs, Trade and Development (DFATD) in 2013. DFATD continues to fund FIPAH through USC Canada up to the present. Funding was recently extended for another 5-year period (2015–2020). It includes scaling out the program across Honduras, as well as extending it through supporting local NGOs to Nicaragua and Guatemala.

formal sector varieties approximately four out of six times in the case of beans and approximately five out of six times in the case of maize [43]. Since 2000, the focus of support to the CIALs by EAP-Zamorano, FIPAH, and PRR has been directed towards participatory plant breeding to better adapt cultivars to the local conditions of CIAL members. This initiative was initially given an impetus by the CGIAR's Participatory Research and Gender Analysis program,[6] and longer term by the Development Fund of Norway through the Mesoamerican Collaborative Participatory Plant Breeding Program. The latter includes NGOs, farmer associations and cooperatives, universities and governments from across the region and has helped to generate a strong regional interest in PPB and been instrumental in bringing together different players from each country.

Participatory plant breeding through the CIALs

Food insecurity occurs so regularly in the mountains of Honduras that it is simply known as 'los junios' after the calendar month when grain scarcities generally set in. The precariousness of farmer livelihoods is further affected by climate-change-related stressors. While climate extremes, including hurricanes and drought, are not uncommon, heavy rain and extended periods of drought now occur with greater frequency than in the past affecting the regions' farmers in multiple ways. Indeed, Honduras was recognized as the world's most climate-change-vulnerable country over the 20-year period between 1993 and 2012 [44]. It is frequently acknowledged that climate-smart agricultural technologies are needed to help farmers everywhere combat climate perturbations, including a wider spectrum of disease-resistant crops and treatments, as well as greater crop and varietal diversity, better soil management practices, and other measures [45].

While CIALs engage in a variety of soil and crop management activities that respond proactively to the changing climate, it is PPB that most clearly positions the CIALs as vehicles to effectively adapt to, and mitigate, climate change. Varietal diversity that includes crops that are disease resistant, tolerant of drought and moisture extremes, and adaptable on an ongoing basis to the locales where farmers live and work, provide a level of resilience for local communities to withstand climate change risk. PPB is a special case of farmer participatory research and farmers trained in formal research methods can fairly easily be trained as breeders. However, it is important to recognize that not all CIALs have the same research capabilities and that those with strong research skills, as well as those who are highly motivated with long-term horizons, are much better equipped for PPB than some others. It is also important to recognize that farmers without formal skills are capable of creating new varieties through plant selection, as they have done throughout history. However, institutionalization of participatory plant breeding involving farmers and scientists necessitates some level of formalization. In this article, following Almekinders et al. and Rosas, PPB is the term used to include both participatory plant breeding and participatory varietal selection [42, 46].[7]

Bean research has been a principal focus of the PPB program in Honduras from the start, because beans, along with maize, were identified by CIALs as research priorities. As the primary source of protein in the diets of most poor Hondurans, beans are critical to nutritional security. At the same time, EAP-Zamorano was in a position to provide institutional support to FIPAH and PRR for CIAL research due to funding from the PIF program. After 2000, PIF began incorporating a focus on participatory breeding into its bean research agenda with a shift in focus towards hillside farmers living in environments characterized by a high degree of agro-biodiversity [42].[8] Between 2004 and the present, the partnership between EAP-Zamorano, FIPAH, PRR and the CIALs has led to the development of 23 new bean varieties, most of which have been released at the municipal level; one has been released at the national level. While EAP-Zamorano has been less actively involved in maize research with its partners, nevertheless, the CIALs have generated 9 new maize varieties, four of which have been released at the national level. In this case, the International Maize and Wheat Improvement Centre (CIMMYT) worked closely with FIPAH and the CIALs to develop new maize varieties in conjunction with the government's agricultural research unit, DICTA.[9]

[6] The Participatory Research and Gender Analysis program (PRGA) of the CGIAR funded Zamorano between 2000 and 2004 to support farmer participatory research with the CIALs. The Development Fund of Norway supported the larger PPB network program.

[7] Following from the work of Vernooy [56], Almekinders, et al. state that "PPB refers to approaches that involve close collaboration between researchers and farmers, and potentially other stakeholders, to bring about plant genetic improvements within crops" (p. 7) [46]. This includes both participatory plant breeding as well as participatory varietal selection.

[8] The Bean Research Program (PIF) was initiated in 1988 with the Panamerican Agricultural School, El Zamorano, in collaboration with regional national programs, NGOs, CIAT, and the Bean/Cowpea and Dry Grain Pulses CRSPs. It is supported primarily by USAID in partnership with US universities. The Collaborative Program for Participatory Plant Breeding in the Region of Central America is supported by funding from the Development Fund, Norway with counterpart funding from the Norwegian government.

[9] These included a variety with high lysine content as well as varieties with drought and low-nutrient tolerance. During the process of testing CIMMYT materials, FIPAH discovered a line of maize resistant to fungal Tar Spot disease (*Phyllachora maydis),* a disease that was previously little known in the region but has proliferated with prolonged heavy rainfall associated with climate change. The new variety, DICTA96, is scheduled for release in 2015.

Seed regulation

Seed regulation in Honduras is governed by the public sector under a 1980 seed law, which is still in effect. Nevertheless, in 1985, under structural adjustment, an action plan was introduced to move seed production and commercialization into the private sector. The plan did "not try to contribute to the seed needs of small subsistence farmers, since they [were] … outside the economic flow on which the strategy was founded" (p. 5) [47]. Seed regulations in Honduras require national release of a registered variety before it can be promoted as "commercial seed".[10] And commercial seed must be registered and certified, which includes a field inspection and laboratory test to ensure seed quality. In the case of decentralized seed production carried out by producers at remote locations, this is clearly impossible, especially given budget restrictions affecting the public sector. In other words, the seed regulatory framework militates against small-scale seed growers and decentralization. As a consequence, most PPB seed produced by local CIAL members is sold officially as "grain", although it is recognized locally as "seed" and differentiated from grain by a higher price. To ensure high quality "seed", local seed growers buy foundation, or registered seed from EAP-Zamorano and produce what in essence boils down to "commercial seed equivalent" for local sale.[11] Recent discussions regarding changes in national seed regulations have raised the possibility of legally recognized production of a new seed category called "apt seed". Apt seed, if it were produced by registered, small seed enterprises, would only require commercial inspection prior to sale, foregoing the additional requirement of a field inspection. And this would help to open up the opportunity for the development of a sustainable, decentralized commercial seed system fully supported by locally generated PPB seed. Local seed production and profitable sales are essential to making PPB a sustainable undertaking, as will be discussed.

Methods

Research for the case studies in this article is drawn from a number of sources. These include long-term agronomic field notes provided by the Foundation for Participatory Research with Honduran Farmers (FIPAH); research data generated by plant breeders at the Panamerican Agricultural School, El Zamorano (EAP-Zamorano); as well as qualitative research conducted by graduate students and faculty at the University of Guelph, Canada in accordance with Canadian Tri-Council protocols. This data have been generated over a 22-year period between 1993 and 2015.

Of particular importance for this article is a quantitative assessment of PPB, involving a randomized sample of 189[12] famers in 30 participating CIAL communities in the municipalities of Yorito, Sulaco and Victoria in north-central Honduras. This study was conducted in 2013 by a University of Guelph graduate student [51] with the support of local farmer facilitators. The sample included both CIAL members and non-members who had planted beans in the previous (spring and fall 2012) cycle. All non-members were located in CIAL communities.[13] CIAL members were divided into two groups of older members (5 or more years in a CIAL) and newer members (4 or fewer years in a CIAL). This division was predicated upon the observation by FIPAH that many of the changes associated with CIAL membership were not immediate and generally took about 4 years to become apparent. Varieties planted by farmers in the two seasons in 2012 were divided into three categories: PPB (and PVS varieties), traditional (farmers' or landrace varieties) and conventional (formal sector varieties). Descriptive varietal adoption data from this assessment are presented following the case studies.

Results and discussion

Learning from case studies: much more than a hill of beans

Case studies of PPB are employed below to illustrate the varied ways that farmers have been involved with formal sector scientists in the generation of new bean varieties. All but one of the cases are drawn from the municipalities of Yorito, Sulaco and Victoria, the region with the largest number of CIALs (32) and the one that has been the most extensively documented by researchers seeking

[10] Honduras is not a member of the International Union for the Protection of New Varieties of Plants (UPOV) but is one of 17 countries/states that has initiated procedures for acceding to the UPOV convention. The Honduran seed law demands that seed be registered and certified before it can be commercialized. Honduras follows the terminology of the Association of Official Seed Certifying Agencies (AOSCA) which categorizes seed as: breeders', foundation, registered and certified.

[11] Seed growers may also be provided with foundation seed by EAP-Zamorano through PIF project funding, rather than through purchase.

[12] The goal was to include approximately 200 farmers from the region reported on here, namely Yorito–Sulaco–Victoria. CIAL member names were provided by FIPAH. For non-CIAL members, records provided by the local health authorities were used. Where there were no records, local farmer facilitators were contracted to generate local lists of inhabitants. Numbers were assigned to the names from the three combined lists using a random number generator (StatTrek). For CIAL members, a rule of thumb was that 60 % of members were selected. 8 of the respondents in the sample did not appear on the randomly generated list of names but were included when the principal researcher was not present at the interviews. Those names were kept in the study to maintain the number of observations at an acceptable level for purposes of analysis.

[13] At the outset, it had been planned to draw the non-members from non-CIAL communities to better provide a counterfactual. However, in communities where people were not exposed to the CIALs, there was a reluctance to answer questions. Moreover, most communities have CIALs, making selection of non-CIAL communities difficult and presenting other biases since non-CIAL communities are different to CIAL communities by virtue of not wanting a CIAL.

to measure the impact of the CIALs on poverty reduction and gender empowerment [36, 37]. It is also amongst the poorest regions in the country, listed earlier as being at the lowest level of human development, under 400 on the Human Development Index [48], although it does not appear on the more recent government list of the 40 poorest municipalities [49].

Starting off

The first two PPB beans developed by members of the Association of CIALs of Yorito, Sulaco, Victoria were Macuzalito and Cedron. The two narratives illustrate the early history of PPB development amongst FIPAH-supported CIALs.

Macuzalito

Macuzalito was the first PPB bean released in Honduras. Developed in the upland area around Yorito from one of the most widely used trailing landraces, Concha Rosada, the improved offspring has gained broad acceptance amongst both CIAL and non-CIAL members. In 2000, prior to initiating the PPB process, CIAL members (17 women and 20 men) identified their ideal bean traits through a focus group.

- (non-trailing) Bush beans, 35–40 cm in height.
- Yields of 25–40 pods/plant.
- Little disease.
- Even ripening.
- Thick stem.
- Resistant to heavy rain and drought.
- Thickish pod to prevent the beans from sprouting during wet weather.
- 7–8 beans/pod.
- Longish, thick, heavy bean.
- Dark reddish color, shiny.
- Easy to shell.
- Firm bean skin to prevent pest infestation in storage.
- Produces a thick soup in the cooking process and doesn't need lard.
- 'Yields' or expands in the pot.
- Soft, good tasting bean.
- Cooks quickly without much fire [43].

- At Zamorano, scientists selected 5 elite lines[14] for crossing with Concha Rosada seeking to improve disease resistance, yield, and architecture while retaining the desirable traits of the landrace. Amongst these was early maturity. Early maturing varieties are valued by poor farmers because they shorten "los junios", the hungry period, and provide food at an earlier date than later maturing materials. Earliness, farmers tell you, allows the variety to "escape poor weather", such as drought or heavy rains, depending on the growing season. However, farmers recognize that this benefit is offset by lower yields than those provided by later maturing varieties and farmers typically include both early and late maturing varieties amongst their planting materials.

- The development of Macuzalito involved 53 members (30 men and 23 women) from 4 CIALs over 4 years. Originally, the process was conceived by EAP-Zamorano as being centralized in one upland community; however, the 4 participating CIALs decided to decentralize it, selecting materials amongst (F3) lines from 120 families for planting in their own communities (ranging from 1350 to 1650 m.a.s.l.) to ensure adaptation to local conditions. The 10 best bets from the individual community trials were subsequently put into replicate trials (F6) in the four communities, along with 5 materials selected on-station by EAP-Zamorano, plus the local check. At that stage, farmers selected 4 lines for multiplication (F7), followed by verification trials from which they selected one line, Macuzalito, for local varietal release. None of the lines selected by EAP-Zamorano was amongst those identified by farmers, reflecting the very different environmental conditions of the two participant groups, as well as differences in preference criteria used by farmers compared to those typically employed by the scientific community. Macuzalito, named after the highest point in the municipality, had the best traits on average of the finalist materials: good yields (but not the highest); moderate maturity; medium disease tolerance; good commercial value, amongst others. It was released in the municipal seat of Yorito in 2004 [43].

- Cedron
  Cedron was the product of a multiline-cross using scientist-generated materials[15] and technically constitutes participatory varietal selection (PVS), rather than PPB. The process of farmer

[14] According to unpublished FIPAH documents, the improved breeder materials used for crossing with Concha Rosada, the maternal parent, were SRC 1-1-18, SRC1-2-12 and UPR 9609-2-2.

[15] A FIPAH brochure notes that the improved materials used in the multiline cross that led to Cedron were MD23-24/MD30-37//UPR9177-214-1/Tío Canela 75.

learning and selection began in 1999. What came to be called Cedron was selected by CIAL Chaguitio from 16 advanced lines (F6) that were part of a regional adaptive trial [Ensayo Centroamericano de Adaptación y Rendimiento (ECAR)] provided to FIPAH by EAP-Zamorano. Line EAP 9508-93 was chosen by CIAL members for its high yield, high tolerance to disease and drought, its upright bush architecture, and its adaptation to high-altitude zones (1000–1400 m.a.s.l.). The members named it Cedron after the mountainside where local farmers cultivate beans and where the research had taken place. However, the dark red color of the bean reduced its commercial value. EAP-Zamorano subsequently improved this, increasing its marketability and broadening its appeal. Cedron was released at the municipal level in 2007 and since then has been used widely both locally and regionally. A local FAO representative reports that it is broadly disseminated in the western departments of Intibuca and Lempira (Personal communication, Edgardo Navarro).

La Esperanza, where hopefulness resides

Four of the PPB varieties developed by different members of the ASOCIAL of Yorito, Sulaco, Victoria region have come from one CIAL, La Esperanza (Spanish meaning hope). This CIAL, comprising 14 members, has 8 seed growers amongst them—more than three-quarters of the most active members of the local seed committee.[16] And since the commercial application of PPB, as "seed", is a driver for the development of new varieties, this helps to explain the enthusiasm of CIAL La Esperanza for PPB. However, the environment where the CIAL is located is also a factor influencing its active role in plant breeding. The community of La Esperanza is perched atop a mountain, surrounded by 360° views across valleys to other mountain ranges, in an environment that is considered excellent for growing beans: moderate humidity, even while surrounding areas may be undergoing periodic drought, permits fairly reliable production of rain-fed crops, especially of beans, which are grown twice yearly without irrigation. But at 1350 m.a.s.l., the community is relatively isolated, linked by a muddy, and sometimes impassable, dirt road to a few other communities and to the municipal seat of Yorito over the mountain range in the valley below. Electricity was only installed at the end of 2014, a project brought in largely by the efforts of CIAL members who, as in other communities, have become de facto local leaders [36, 37]. It was mostly bean production that helped households in La Esperanza pay the necessary quota (one-third of the total cost of US $50,000) to be hooked up to the grid. Thus, the whole community has benefited from the work of the CIALs and the provision of well-adapted local bean seed.

Estica Mejorada

Estica Mejorada (Improved Estica) comes from a trailing landrace bean, Estica, that is widely used in the uplands of Yorito and Sulaco. Estica has long been the preferred traditional variety for farmers across a range of high-altitude locations due to its high yield and commercial value (color, shape of bean), as well as its taste. Because trailing beans are typically grown in association with other crops, particularly with maize, their long climbing stature contributes to high yields, while intercropping with other species supports disease resistance. But local farmers dislike trailing materials because they ripen unevenly, making the harvest very time-consuming. Additionally, Estica is affected by angular leaf spot and anthracnose, and more recently, by powdery mildew, a fungal disease that farmers associate with climate change. Thus, at the request of CIAL La Esperanza members, Estica was sent to EAP-Zamorano to be crossed with disease-resistant materials. In 2009, farmers received 16 segregating (F3) lines for selection. CIAL members in La Esperanza prefer to receive materials at early generations as this gives them a wider selection of lines to test for adaptation to local conditions. However, it took the CIAL 6 years of repeated selections to find a bush bean that was capable of out-yielding the trailing landrace. Some members of the CIAL were ready to "throw in the towel" but other members insisted on persevering, particularly the 8 members of the local seed committee. This group could see the commercial seed potential from an improved version of the landrace and managed to keep the CIAL focused on the goal ahead. Estica Mejorada eventually emerged from this protracted process. Zamorano is currently testing different lines from Estica in regional adaptive trials.

Amilcar and Esperanceño

Amilcar and Esperanceño beans are derived from conventional breeding techniques. Both originated from a

[16] There are 40 seed growers in the ASOCIAL of Yorito, Sulaco and Victoria but most are only occasional seed producers. Ten of these seed growers are women. Eleven growers regularly produce seed twice a year; 8 of these come from La Esperanza. The survey conducted in 2013 showed that at least one of the CIAL members in La Esperanza had higher than average land holdings (7 hectares), although other surveyed CIAL members in the community owned or accessed much smaller amounts—between 1 and 3 has. Certainly access to land is an important factor in seed production, although none of the growers can be considered a large landowner. The isolation of the community, however, has likely meant that pressure on the land is lower than in communities where road access is better.

set of 58 materials contained in a regional adaptive trial (Vivero de Adaptación Centroamericano) known as VIDAC. Between 2006 and 2008, CIAL La Esperanza members engaged in successive rounds of selection from the VIDAC trial, selecting 4 materials in the fifth round: two lines for early maturity, and two lines for lateness. CIAL members subsequently selected a variety from each of these two groups: one from the early maturing group that was named Esperanceño after the community; one from the late maturing group that was called Amilcar after a local CIAL member.

What became known as Amilcar seed had been identified earlier in the trial by the wife of Amilcar. At the different stages of a trial, extra seed is typically shared out amongst members and is either eaten and/or planted in farmers' fields. Amilcar's wife identified the excellent culinary properties of this late maturing line and made sure that her husband got some of it in a fifth round of testing to plant on their land. Amilcar selected seed from the line over a few cycles, improving the seed quality. During this period, the CIAL and farmer facilitator typically monitor seed distributed to individual farmers, comparing how the different lines progress. In 2010, Amilcar's seed was selected over the other late maturing line. Subsequently, a new bean, Amilcar 58, a golden mosaic virus-resistant selection derived from Amilcar, was identified using molecular markers at Zamorano and returned to the CIAL for seed multiplication and dissemination. The virus-resistant variety will allow for the dissemination of Amilcar in the lowlands of southern Honduras, where the original variety has been adopted by many farmers but has presented susceptibility to this disease.

Demand for Amilcar seed is very strong in both upland and lowland areas because of its commercial value and also because of its excellent culinary qualities. Since all families eat beans on a daily basis, culinary properties are highly valued alongside commercial ones. While women tend to rank culinary properties at the top of their list of preferred traits, men generally put commercial value at the top of theirs. However, these criteria are not rigidly gender-specific and men will rate culinary properties very highly if the beans are for home consumption, while women are likely to put commercial traits at the top of their ranked list if sales are their priority.

Chepe

Chepe came from a set of 16 beans, developed through the CGIAR's AgroSalud program, selected by EAP-Zamorano for Central America. The AgroSalud program aims to develop bio-fortified crops for Latin America, in this case beans dense in iron and zinc to combat deficiencies, such as anemia, a problem endemic in the region [50]. In trials conducted at the FIPAH office in Yorito, CIAL members selected 8 lines. These 8 lines were subsequently distributed to 200 CIAL members in ¼-lb bags at the 2007 biannual regional research meeting, the "encuentro regional". Chepe, a member of CIAL La Esperanza, received one of these bags and selected seed from it over two seasons. Farmer facilitators, who monitored the recipients of the seed, evaluated Chepe's seeds as being superior to those received by other CIAL members. This seed was subsequently increased by CIAL members in La Esperanza and released under the name of Chepe at the municipal level in 2012, just 4 years after it was first introduced into the region. It has not been released beyond the local region because it is susceptible to bean golden mosaic virus, although this virus is not a problem at high altitudes where a large percentage of the country's poorest farmers resides.

Going national

The bean variety, Don Rey, is named after an individual farmer and CIAL member, as in the cases of Amilcar and Chepe beans. Unlike the other bean case studies provided here, the CIAL in this instance is located in the central department of Francisco Morazán, about an hour and a half's drive from the capital, Tegucigalpa. To date, it is the only bean generated through farmer–scientist collaboration that has been released at the national level.

Don Rey

The bean, which farmers call Don Rey, originated from a cross (backcross-self-fertilizing process) between a landrace, Paraísito, from the department of El Paraíso, and a conventional material, Carrizalito,[17] which was initiated by EAP-Zamorano in 2003. In 2006, lines from this cross were placed in a VIDAC trial containing 93 materials. Eighteen of these trials were distributed to national bean programs across the 6 Central American and Caribbean countries; in Honduras, they were also distributed to FIPAH and PRR for use with the CIALs. Different CIAL groups selected different materials: CIAL Trinidad de las Quebradas in the municipality of Vallecillo, Francisco Morazán, selected line IBC307-7, which they released in 2008 at the municipal level as

[17] Carrizalito was generated from a simple cross between Tio Canela 75 and DICTA 105, conducted in Zamorano in 1995 and released in Honduras in 2003 [42] (p. 2).

Quebradeño; neighboring CIAL San Jose de La Mora selected the line X0-233-174-1, released in the municipality in 2011 as San Jose; in Zacapa, Sta. Barbara, PRR-supported CIALs selected MDSX14797-6-1 released locally in 2013 as Don Kike; CIAL San Isidro in Vallecillo selected 30 materials but failed to come up with a single candidate for local release. In 2008, however, CIAL San Isidro was given 4 materials from the original VIDAC trial for testing as part of a farmers' trial for drought tolerance and low fertility. One of the CIAL members, also the local farmer facilitator, Reinaldo Fuñez, or Don Rey as he is known, identified the line IBC302-29 based on a number of characteristics including its architecture, taste, long "pot life" (unrefrigerated), quick cooking time, good commercial color, earliness, and red pods. The latter is a trait appreciated by local farmers as it makes it easy to identify beans at harvest time. As a consequence, Don Rey started cultivating the line, noting yield levels and commercial acceptability, and producing seed in response to strong demand from his neighbors, as well as from farmers in surrounding communities. As per established practice, this information was passed back to EAP-Zamorano where it fed into Zamorano's ongoing research. In December 2014, IBC302-29 was released at the national level under the name Paraísito Mejorado 2 (PM2-Don Rey), after the original landrace and Don Rey, whose input had helped to seal its destiny, as noted in a government press release.

By popular demand

The final case details the development of a new variety, which, at the time of writing, is still being improved.

Rosado

No one is quite sure where the bean, locally named Rosado, came from. It is thought to have arrived in the Yorito, Sulaco, Victoria region back in 2008. Some people felt it came from Nicaragua, others believed it may have arrived through the Honduran Government's "Bono Tecnologico" program, a package that provided seeds and inputs to farmers. Once it started to circulate in the area; however, CIAL seed growers, especially those in La Esperanza, were beset with demand for the new seed, both from local farmers who wanted to grow it, and from local bean buyers who wanted to sell it based on the commercial value of the variety, namely its particular grain size, form and color. However, it is susceptible to anthracnose, which is a serious problem in the region. So members of the CIAL seed committee are reluctant to produce seed, notwithstanding strong local demand. The response of the farmer breeders/seed growers has been to pass Rosado onto EAP-Zamorano for crossing to introduce resistance to this disease. It will be passed back to the CIALs for selection in early generations.

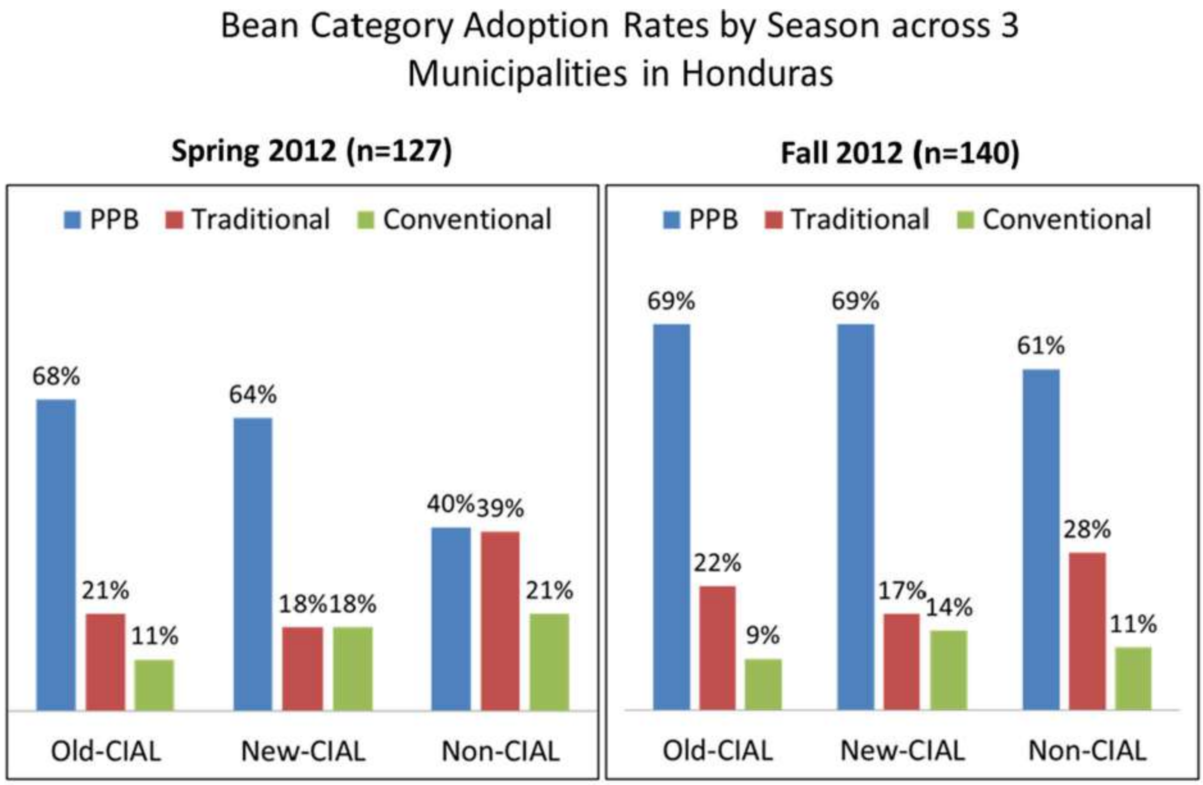
Understanding the system dynamics

The case studies demonstrate the dynamic process that comprises PPB varietal development in Honduras. At the centre of the system is the responsive partnership between CIAL members and plant breeders connected through FIPAH, which allows for an outward flow of materials from EAP-Zamorano to the farmers for further research and selection, and an inward flow of farmers' materials to EAP-Zamorano for crossing and improvement. This two-way system has led to the generation of multiple new varieties that are widely disseminated in the CIAL regions across the country (FIPAH reports, Zamorano field notes). Additionally, as can be discerned from the case studies, the role of local demand and the responsiveness to this by farmer breeders, as seed suppliers, are the principal system drivers. Evidence of the demand for PPB-generated seed and the incentives for its supply, along with discussion of the partnership between farmers and scientists, are detailed below.

(a) Demand for PPB varieties

As outlined in the Methodology section, in 2013, a quantitative study was conducted to evaluate adoption of different bean varieties in 30 participating CIAL communities in the Yorito–Sulaco–Victoria region in the previous planting cycle (spring and fall 2012) [51]. The study sought to describe the demand for PPB-generated varieties relative to others.

As can be gauged from the nature of varietal adoption shown in Fig. 1, there is a strong demand for PPB-generated materials in the municipalities of Yorito, Sulaco and Victoria. PPB varietal adoption is not only extremely high amongst CIAL members, both old and new (between 64 and 69 %), but also amongst non-members (40–61 %). Diffusion of program benefits has moved beyond direct beneficiaries, i.e., CIAL members, to non-participants. By contrast, adoption of formal sector (conventional) materials is much lower over the two cycles (9–21 %) amongst the three groups; use of traditional materials generally falls in the middle range (17–28 %). Clearly PPB and associated local seed production is welcomed broadly by local communities [51]. The most widely



Old-CIAL=Members with 5 or more years in CIAL	PPB=PPB and PVS varieties
New-CIAL=Members with 4 or fewer years in CIAL	Traditional=Landrace, farmers', local varieties
Non-CIAL= Non-CIAL farmers in CIAL communities	Conventional=Formal sector-generated varieties

Fig. 1 Bean adoption rates by category. Adapted from Kindsvater SD. Participatory plant breeding in Honduras: an economic impact assessment. M.Sc. Thesis, University of Guelph, 2014

planted varieties were Cedron, Chepe and Macuzalito, presented as case studies above.[18]

(b) Supply of PPB seed

Strong local demand, as evidenced by the evaluation, for PPB-generated varieties by the region's farmers helps to drive the PPB research process, and the supply of seed. Farmer breeders derive social capital from the provision of seed that benefits family, friends and neighbors; it boosts their standing in their communities and their leadership credentials. And while individual CIAL members, such as Amilcar, Chepe and Don Rey, may have selected individual varieties, the process is a collective undertaking that involves monitoring by the CIAL and the support of FIPAH. Individual actions that lead to seed generation are motivated by collective values that come from being part of a CIAL and the social capital inherent in CIAL membership. But innovation is also motivated by the opportunity for personal economic improvement. It is a "both-and" proposition [52].

One of the reasons why CIAL La Esperanza has been so actively involved in PPB research is because La Esperanza CIAL members make up the bulk of active seed growers within the ASOCIAL seed committee and committee members stand to profit personally once their research has been turned into seed. Thus, notwithstanding the personal satisfaction that comes from sharing seed with family and friends, there is also an individual economic incentive built into the process through seed sales that helps to make the process sustainable. Even so, variability in the price of local seed means that seed growers must have access to savings or credit to prevent forced sales into a weak market. Making a profit from seed production is far from guaranteed.

[18] Cedron was the most consistently popular variety (with up to 25 % overall adoption) over the two cycles, followed by Chepe, and then Macuzalito.

Product differentiation, leading to higher prices for high-quality beans at the point of sale, provides farmers with a strong incentive to regularly purchase fresh seed to maintain bean quality. The introduction of interest-free loans for seed kits, repayable after the harvest, allows farmers who may not have access to savings prior to planting, to regularly purchase seed.[19] In general, farmers are more likely to buy fresh seed for the spring planting but to save seed from the latter to replant in the fall. However, sale prices in local markets are also affected by factors other than grain quality, such as price fluctuations associated with the seasonality of the bean market, increasing unpredictability of weather patterns, especially of drought, and monopsony power of intermediaries due to the isolation of communities. And these risks in turn affect the demand for seed. According to the 2013 impact study, older CIAL members received higher average prices for their beans compared to new and non-members in both cycles in 2012 [51].[20] While this may reflect sales of higher quality beans, it may also reflect the tendency amongst older CIALs to sell their beans collectively, as individual CIALs. The longevity of their association, resulting in higher levels of trust and collective savings, puts members in a stronger bargaining position to obtain the best prices for their products. In general, however, sales of CIAL members' beans are still a patchwork of arrangements and higher prices overall are limited by this. To date, there have been insufficient funds within the local CIAL Association to buy all members' beans to market them collectively. Nevertheless, this remains the stated goal and a means to increase sale prices by entering the value chain at a higher level. Collective sales require bean quality standardization. And regular seed renewal through the purchase of fresh seed supply is one way to help ensure this and to also add stability to the local seed market.

At present, seed sales are mostly confined to the local market. Since seed growers are technically selling grain, they are not getting a fair market price for their seed. Seed production incurs costs associated with the purchase of foundation or registered seed,[21] rogueing, controls for humidity and germination. Typically there is 100 % price differential between commercial seed and grain sold in Honduras that serves to cover these, and additional marketing costs. As mentioned, commercial seed production requires prior national release of a registered variety. Most of the varieties produced by PPB have not been released at the national level as the case studies demonstrate. While PPB seeds are adapted to the locality for which they were bred/selected, they may not meet the broad-spectrum requirements necessary for national release. However, unpublished results from a study led by the CGIAR and local organizations (including Zamorano, FIPAH and PRR) in 49 communities in 4 regions of Honduras based on the method known as Participatory Mass Evaluation found that 6 PPB varieties[22] outperformed the formal sector check on the majority of criteria; neither altitude nor zone explained any differences, except on the criterion "vigor". The results, which show that varieties selected by farmers generally did better than the formal sector check developed specifically for broad adaptation, suggest that farmers' criteria for selection may be much more robust than has traditionally been believed and that they may not in fact inhibit broad-spectrum adaptation. This finding opens the door to much greater involvement of farmers in the national release of crop varieties and lends strong support to the argument that restrictions on farmers that prevent the sale of PPB varieties as commercial seed, unnecessarily limit farmers' access to broader markets, and hence the profits of artisanal seed growers. In the long run, this could act as a disincentive for CIAL members to invest in uncertain, long-term research. The introduction of a different seed category, such as "apt seed",[23] which would allow legally regis-

[19] Individual loans covering one manzana (0.7 of a hectare) were provided to credit-worthy farmers in fall 2014 in the form of interest-free seed kits, repayable after the harvest. At that time, the ASOCIAL was able to fund bean production on 112 hectares (160 manzanas) in the hillsides of Yorito–Sulaco–Victoria. Shortages resulting from drought throughout the country in the previous cycle, pushed bean prices above seasonal levels and resulted in gross earnings for ASOCIAL loan recipients of $165,000. Considering that the average size of property holding in the region is less than 3 hectares (Kindsvater, unpublished summary statistics), this represents substantial earnings to local bean growers. The provision of non-interest-bearing 'seed kits' provides a way around farmers' traditional reluctance to pay for seed over simply replanting their own grain [53]. Of course, there has to be an incentive in the form of a premium on basis of quality to make it worth farmers' investment.

[20] The evaluation by Kindsvater showed that old CIAL members sold at an average price of 5.267 Lempiras compared to 4.618 L for new CIAL members and 4.672 L for non-members in spring 2012 [51]. Fall 2014, old members sold at 5.468 L, compared to 4.77 L and 4.69 L for new CIAL and non-CIAL groups, respectively.

[21] If EAP-Zamorano is unable to supply sufficient foundation or registered seed, CIAL seed growers use carefully selected "second generation" foundation seed. This occurred in spring 2015 when 14 manzanas (around 10 ha.) of seed were planned but EAP-Zamorano could only supply around 20 % of the seed required.

[22] The six PPB varieties were Cedron, Macuzalito, Chepe (FIPAH-supported CIALs) and Victoria, Campechano, Don Kike (PRR-supported CIALs). The formal sector check was Amadeus 77.

[23] Similar rules that prevent sale of uncertified seed are common throughout the region (GRAIN, 2015). If a category of "apt seed" is permitted in Honduras, it would mark an important step in recognizing "farmers' right" to produce and sell seed.

tered groups of seed growers to sell certified farmers' seed, is one of the changes to the regulatory framework that should be put into effect to make small-scale commercial seed production, and associated research, a more sustainable undertaking for the long term.

(c) Seed supply and climate change risk

Climate change is another system driver of PPB. While farmers still use a substantial number of landraces as part of their portfolio to diversify risk,[24] increasingly these are becoming less viable as new diseases, especially diseases associated with high humidity, as well as prolonged drought, become more prevalent as the climate changes. This makes the crossing of landraces with disease-resistant, drought-tolerant materials imperative. And local farmers will need to have access to improved, locally adapted seed as they become available. What is important is that local farmer researchers and seed growers have the capacity to identify and select seed for their region as well as the institutional arrangements with the formal scientific sector to bring these seeds to local, as well as to national level markets. There is an inherent nimbleness within the system that government bureaucracies cannot replicate. Moreover, given the extent of agro-biodiversity in Honduras, and the requirement of broad adaptation for the authorization of national release, many of the varieties that local farmers have selected will likely never receive national recognition. However, this does not prevent them from being widely adopted at the local level if they meet local farmers' needs, as the above impact evaluation clearly demonstrates they do [51]. As Mog has pointed out, sustainability is a process; it is not a policy, or a particular technology [1]. The flexibility of the process described here, particularly farmers' role in driving change and the system's responsiveness to farmers' requirements, puts it at the cutting edge of climate change adaptation.

(d) The power of partnerships

The case studies underline the critical importance of the linkage between the formal sector, specifically EAP-Zamorano, and farmer breeders/seed growers, in a relationship that is mediated by NGO partners, FIPAH and PRR. This relationship underpins the nimbleness of the research process and its responsiveness to local demand and climate change adaptation. It is a relationship marked by trust. The bean breeder at EAP-Zamorano refers to FIPAH and to PRR, as "partners", a sentiment that is reciprocated by the two NGOs. More recently, as CIAL members have come to identify as farmer breeders and seed growers, they too have turned their attention to the important role played by EAP-Zamorano. It was not always so. In a study conducted in 2006, CIAL members in Yorito were generally unaware of the importance of the role played by EAP-Zamorano in PPB [37]. Their partnership was with FIPAH and did not extend much beyond that. While FIPAH still occupies the key boundary-spanning role between farmers and scientists, such as delivering genetic materials in both directions, backstopping the work of farmer facilitators, problem-solving as issues arise, evaluating results, amongst other activities, farmer breeders clearly understand the important role played by EAP-Zamorano. Field visits by Zamorano's bean breeder and his request to receive promising, farmer-identified materials for improvement, as well as the obvious importance he places on farmers' selection criteria, leave them in little doubt as to his sincerity regarding the importance of their role in PPB. Similarly, his decision to place CIAL selected/generated materials into regional adaptive trials illustrates the potential for broader adaptation of farmers' materials, as well as highlighting CIAL members' capacity to identify/select such varieties.

The value of the relationship between farmers and EAP-Zamorano was clearly expressed by the breeder at the biannual farmers' research meeting in September 2014. At this event, in response to a question from the floor about his perspective on farmer participatory research, the breeder stressed the importance of the social organization and institutional capacity embedded in the CIALs and in their support organizations, FIPAH and PRR, that have provided the *context for long-term research alliances* with his institution and the necessary research capability for engaging in participatory plant breeding. He contrasted this to short-term research relationships, more typical of farmer field schools in Honduras, which have not yielded such outcomes. Such comments underline *the importance of long-term partnerships for collaborative research in the Honduran context.*

These comments are reflective of the fact that in the Honduran context participatory research/breeding is not simply adaptive research where farmers tinker with the breeder's materials as the supporters of farming research systems have tended to portray farmer participatory research [15]. Rather there is a *synergy in the system comprising farmers, NGOs, and scientists that provides added value to the breeding process*. The institutionalization of "demand-pull" by organized and skilled farmer researchers on the formal scientific sector marks a fundamental shift away from the supply-driven model of conventional plant

[24] 28 traditional varieties were reported as being planted by farmers in the 2013 evaluation.

breeding, as typically pursued in the past, to one in which farmers help to shape the research agenda.

Compared to EAP-Zamorano, government agricultural researchers in DICTA have been much slower to recognize the value of farmer participation in research. However, as the national government has begun to question the effectiveness of its agricultural research office, in part due to the low rate of release and diffusion of formal sector-developed varieties, members of this office have come to value the strategic importance of aligning themselves with farmer researchers and their NGO partners. This was made evident at the above-mentioned biannual farmer research meeting, which, for the first time in 22 years, was hosted by the Ministry of Agriculture and Livestock. In his closing speech, the deputy director of DICTA stated that the agency would, he hoped, soon include an office of participatory research, making it clear that linking government researchers to farmers and their NGO partners was to be a priority for his office. Ten months later, in June 2015, at a ceremony attended by the Canadian donors, DICTA and FIPAH signed an agreement that includes the provision of training in participatory research, along with mutual collaboration in research, as practiced between EAP-Zamorano and FIPAH for more than 20 years and discussed above. At this event, the Honduran government recognized the importance of agro-biodiversity, and hence the necessity of decentralized research, as a driver of this accord between the parties. Thus, PPB has been accepted as an integral part of the Honduran government's agricultural policy agenda. Only time will tell how this change will affect seed regulations as these relate to small farmer seed enterprise and sales.

Conclusions

As Robert Tripp discusses, the emergence of institutions for seed system development cannot be imposed externally through aid programs; rather "they must emerge from the experience, negotiation and compromise of the actors themselves" (p. 26) [53]. As the case studies and subsequent discussion demonstrate, the institutions governing the development of the seed system in Honduras have emerged over a prolonged period of time. We have argued that the context for this can be linked to the low funding envelope allocated to public agricultural research associated with structural adjustment and the resulting termination of public extension services after 1990, in conjunction with the high degree of agro-biodiversity characteristic of the Honduran landscape. Given the constraints on public research, farmers, NGO partners and scientists in Honduras have taken the opportunity to join forces over the past 20-year period to create an innovative agricultural research system—a system that produces recognized synergies for scientific research and that demonstrably serves the needs of the country's poorest farmers. This opportunity has been enabled by the formal research skills of CIAL members, and the generation of research results that are respected by the scientific community. It has also been enabled by the benefits—both social and economic—that accrue to CIAL members, and in particular to those farmer breeders who generate seed and whose ambitions help to drive the system. Recently, agricultural researchers in the Honduran government have elected to align themselves to this research system. While some may argue that farmers are providing private services that should be covered by the public or corporate sectors, the financial returns to some of the farmers through "seed" sales have made research provision sufficiently attractive up to now to sustain their inputs. Nevertheless, changes to the seed regulatory structure are important to ensure farmer participation in plant breeding over the long term. At the same time, foreign donors have underpinned the services provided by the two NGOs and EAP-Zamorano. It is this combination of long-term donor funds both from the public, as well as from the charitable sector, alongside the private investments of hundreds of individual Honduran farmers that sustains this innovative research system.

A commentary in nature recognizes the value of involving farmers in their own research as a means to adapt to, and mitigate, climate change [11]. Until now, most farmers in the North have not had much cause to invest their time and energy in the way that farmers in Honduras have found it both necessary and advantageous to do so. But climate change has brought new uncertainties, turning sustainability ever more into a moving target. Climate-smart technologies alone will not solve the problems that lie ahead. In situ research with skilled farmers permits flexible responses to climate-associated changes to local environments. Moreover, public demand in the North for locally produced food, and a growing appreciation of terroir, means that in situ knowledge and appreciation for the value of agro-biodiversity is likely to take on more significance in plant breeding. But, as we have seen, research adapted to conditions of agro-biodiversity requires the added ingredient of local investment in research to deliver the required research outcomes. It is unlikely that the public and/or corporate sectors will be in a position to deliver what local farmers and increasingly savvy, and environmentally conscious, consumers demand. Participatory research that links farmers to the formal research sector is one way to keep farmers at the forefront of sustainable agriculture and a means to meet the growing demand for local specialty food. The Honduran experience provides a credible model worthy of emulation.

Abbreviations
ASOCIAL: Association of CIALs; CGIAR: Consultative Group on International Agricultural Research; CIAL: Local agricultural research committees (comités de investigación agrícola local); CIAT: International Centre for Tropical Agriculture; CIDA: Canadian International Development Agency; CIMMYT: International Maize and Wheat Improvement Centre; DICTA: Dirección de Ciencia y Tecnología Agropecuaria; EAP-Zamorano: Panamerican Agricultural School, El Zamorano; ECAR: Ensayo Centroamericano de Adaptación y Rendimiento; FFS: Farmer field school; FIPAH: Fundación para la Investigación Participativa con Agricultores de Honduras, formerly known as IPCA; FSR: Farming systems research; IDRC: International Development Research Centre; IPCA: Investigación Participativa en Centro America, now known as FIPAH; NGO: Non-governmental organizations; PIF: Bean Research Program (Spanish acronym); PPB: Participatory plant breeding; PRR: Program for rural reconstruction; PTD: Participatory technology development; PVS: Participatory varietal selection; UPOV: International Union for the Protection of New Varieties of Plants; VIDAC: Vivero de Adaptación Centroamericano.

Authors' contributions
SH was responsible for drafting the article. She has worked as a social science researcher with IPCA/FIPAH since 1993 initially through her position at the International Centre for Tropical Agriculture and afterwards as a faculty member at the University of Guelph. JCR has supported experiments with the CIALs in Honduras since 1993 through his position as bean breeder at the Escuela Agricola Panamericana and director of the Bean Research Program in Central America and the Caribbean. He also contributed to the draft. MG, JJ, OG, FS, CA, MB are all agronomists with FIPAH who support farmers in participatory plant breeding and helped to institutionalize the PPB process in collaboration with the Escuela Agricola Panamericana. They are responsible for generating data for the article through their research with farmers. All authors read and approved the final manuscript.

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Marvin Gomez, Jose Jimenez, Omar Gallardo, Fredy Sierra, Carlos Avila, Merida Barahona are all Honduran agronomists, graduates of the agricultural school of the National Autonomous University of Honduras who work with FIPAH. Jose Jimenez, director of FIPAH, helped to initiate the CIAL program with Sally Humphries in 1993. He was previously director of bean research with the Honduran government.

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Competing interests
The authors declare that they have no competing interests.

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