Global Food Security 20 (2019) 101–104

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Farmer adoption of plot- and farm-level natural resource management practices: Between rhetoric and reality

James Stevenson[a,*], Bernard Vanlauwe[b], Karen Macours[c,h], Nancy Johnson[a], Lakshmi Krishnan[a], Frank Place[d], David Spielman[e], Karl Hughes[f], Paul Vlek[g]

[a] CGIAR Standing Panel on Impact Assessment (SPIA) secretariat/FAO, Italy
[b] International Institute for Tropical Agriculture (IITA), Kenya
[c] Paris School of Economics, France
[d] CGIAR Research Program on Policies, Institutions and Markets, IFPRI, USA
[e] International Food Policy Research Institute (IFPRI), USA
[f] World Agroforestry Center (ICRAF), Kenya
[g] Independent consultant, USA
[h] Institut National de la Recherche Agronomique (INRA), France

ABSTRACT

There is a significant gap between the rhetoric of claims about adoption of farm-level natural resource management practices and the reality. New empirical evidence of low adoption from several developing countries suggests that on-farm natural resource management practices face significant constraints to adoption, and that they deliver heterogeneous private and public benefits. Five recommendations are given to the research community related to: targeting; scaling-up; the proper role of research; trajectories of diffusion; and measurement of environmental impacts.

The intensification of agriculture—increasing yields from the same area of land while mitigating negative environmental impacts and increasing the provision of environmental services—is increasingly viewed as an important policy priority, particularly for developing countries (Tilman et al., 2002; Rockström et al., 2017). Results from agronomic trials suggest that scaling up plot- and farm-level natural resource management (NRM) practices can be a key element of sustainable intensification, particularly because of their potential to reconcile trade-offs between agricultural profits (for the farmer) and environmental benefits (for society at large).

A seminal paper by Pretty et al. (2006) did much to raise expectations around the potential for scaling NRM practices in developing countries. Through a review of 286 agricultural sustainability projects in 57 countries—all of which incorporate NRM practices—they document an aggregate 79% increase in yields attributable to the projects. However, further analysis raised questions about both the validity and representativity of the results (Phalan et al., 2007), and there is little evidence in the literature suggesting that the findings could be replicated at scale. Yet, Pretty et al. (2006) continue to be widely cited, possibly reflecting the broad appeal of its win-win message.

A recent set of nine studies (reported in Stevenson and Vlek, 2018) documents adoption of several plot and farm-level NRM practices drawing on cases from 10 countries, chosen based on claims by CGIAR centers that the uptake of such practices was significant, similar to Pretty et al. (2006).[1] The studies – that focused on conservation agriculture, fertilizer trees, alternate wetting and drying (AWD) in rice, integrated soil fertility management (ISFM), and micro-dosing of fertilizer—systematically found low adoption rates in the focus countries. Observed rates for full adoption of a package of practices ranged from less than 1% (conservation agriculture in Malawi and Zambia) to 29% (ISFM in Kenya). Partial adoption rates (adoption of some but not all components of a recommended package), where applicable, fell within the range of 3–18% (Stevenson and Vlek, 2018).

There are many candidate theories explaining such low adoption rates of potentially beneficial practices. Many smallholder farmers are constrained in their ability to invest the necessary resources in improving their farms (i.e. those that are "hanging in" rather than "stepping up" or "stepping out", to use the DFID conceptual framework on agriculture (Department for International Development, UK, 2015)). For many practices, there is a long time-lag between uptake and the expected effects—particularly for complex multi-component "package" technologies (Brown et al., 2017). Furthermore, the enabling

* Corresponding author.
E-mail address: james.stevenson@fao.org (J. Stevenson).

[1] Stevenson and Vlek (2018) define success as having been the subject of a claim of widespread adoption sometime in the preceding decade in one or more of the annual reports of the CGIAR centers.

https://doi.org/10.1016/j.gfs.2019.01.003

conditions, such as property rights over land and the ability to access the requisite inputs, for the uptake of NRM practices simply may not exist.

Even when there is a significant push from researchers, the government, and/or civil society organizations to lift such constraints, adoption outcomes on farmers' fields may not match expectations. This is illustrated by the large-scale, long-term effort to achieve a better balance between agricultural production and ecological performance across China (reported in Cui et al., 2018). First, the authors and a "core network of 1152 researchers with numerous extension agents and agribusiness personnel" conducted 13,123 field trials between 2005 and 2015 across China's major agroecological zones. This research tested the performance of a decision-support integrated soil-crop system management (ISSM) program. ISSM-based management recommendations were then provided to farmers in each locality, using modelling simulations and local trial conditions to identify practices that would increase average yields by approximately 11% and decrease nitrogen application by 15–18%. However, a massive survey of 8.6 million farmers in counties reached by this program shows that a majority of interviewed farmers (61%) reported yields that were between 10% and 50% below these locally-determined optima, "while their nitrogen rates were comparable to or higher than [the recommended] ISSM-based rates." It is likely even more true for Sub Sahara Africa, given the agroecological and socioeconomic heterogeneity of smallholder farms and farmers, that specific NRM practices are unlikely to be universally beneficial – there will be farmers for whom adoption does not reap the expected private benefits.[2]

Hence, while they are potentially very beneficial, on-farm NRM practices face significant constraints to adoption and they deliver heterogeneous private and public benefits. To take stock of what this means for research, for agricultural development programs and for impact assessment, a group of 40 social and natural scientists from around the world who work on sustainable agricultural development gathered to discuss implications and identify priorities. The discussions resulted in five specific recommendations.

1. Accurately identify and target farmers based on their idiosyncratic needs and circumstances.
   This applies both to research and to the development of interventions and could potentially improve adoption and the ensuing expected private and public benefits. Auctions are one mechanism for bottom-up targeting, but CGIAR has traditionally focused on top-down targeting. Current research and development processes are rarely designed to test and inform targeting strategies of NARES and other development partners, in spite of the vast body of literature describing heterogeneity among smallholder households, and the implications of heterogeneity for agricultural practices, natural resource management, and livelihood strategies (e.g., Tittonell et al., 2010; Suri, 2011). This suggests opportunities to design innovative targeting mechanisms that encourage participatory approaches, dynamic and sequential learning processes, and rigorous evaluation of which innovations and combinations of innovations works, for whom, and under what circumstances (Box 1).
   Such a shift requires better analysis of the full range of benefits of promising innovations. This becomes possible when researchers work with larger numbers of farmers (Vanlauwe, Coe and Giller, 2016; Coe, Sinclair and Barrios, 2014; Nelson, Coe and Haussmann, 2016), when collaboration between biophysical researchers and impact assessment specialists help improve design of trials (Lajaaj et al., 2018; de Roo et al., 2017) and when farmer preferences are explicitly considered (Jack, 2013; Jack et al., 2015). Better quantification of public (environmental) benefits, and more effort in incorporating a good understanding of both private and public benefits into the design of institutional infrastructure and policies to support dissemination are also needed. For instance, if adoption involves upfront costs or involves negative utility for farmers but also results in significant public benefits, farmer compensation in the form of payments of ecosystem services (a conditional subsidy) could be appropriate during the transition period or even in perpetuity.
2. Explore better scaling-up strategies.
   The research to impact pathway for NRM is non-linear and scaling-up strategies will need to take this into account. Strategic alliances between research and development organizations could help build research into development projects that invest in enabling conditions for uptake of NRM practices. Existing examples of such collaborations are often in the context of pilot programs, but pilots are often implemented in artificial contexts, where there may be more investment in promotion of interventions than is feasible at large scale. Therefore, moving towards collaboration in large-scale programs, especially those implemented by governments – as in the China example cited earlier – would be desirable to get a more representative picture. Incorporating lessons from economics (Gars and Ward, 2016; Bell, Zhang, and Nou, 2016; Magruder, 2018) about the factors that influence uptake in such large-scale initiatives could offer important insights. Embedded experimental impact studies could then focus on specific parts of the causal chain, from the development and testing to the diffusion stages, thus complementing adoption studies and long-term impact assessments. Opportunities for learning about mechanisms and heterogeneous effects across experiments could also be created – but this requires advance coordination and planning to set up the right portfolio of impact studies and to collect comparable data. In practice, scaling up is very complex and it can be hard to untangle the constituent elements – a fact that is not unique to NRM interventions but may be more difficult if one considers multiple scales.
3. Play the role of information provider / knowledge broker.
   International agricultural research institutions are increasingly seen by their development partners as a source of highly specific information about NRM innovations, practices and principles, rather than as NRM inventors, developers, or suppliers per se. This role as an information-provider implies different types of research outputs which will have different pathways to impact than a traditional, linear technology development and dissemination model. National extension systems, private sector, farmer-based organizations, and civil society organizations will still be critical interfaces between agricultural research and the ultimate clients – the farmers. However, the way that international research institutes collaborate with these diverse entities, and the capacities needed on both sides for this collaboration to work, are likely to be different than traditionally has been the case. The shift from a "technology pushing" paradigm to one of promoting principles and participatory experimentation is long underway but still incomplete. Much more learning needs to take place with partners in specific geographies, requiring different skill sets among national researchers and local development partners. This also implies that projects from development organizations need to integrate an explicit research component (just as many large CGIAR projects are integrating development components).
4. Carefully consider the expected long-term trajectories for diffusion of NRM practices. Given that uptake of certain practices may need to precede others, this is all the more important. The designs of impact assessments for NRM practices need to account for dynamic adoption processes because documenting sustained adoption and/or dis-adoption is key to understanding potential long-term impacts. This calls for high-quality panel datasets and long-term follow-up surveys, as well as deployment of innovative tools, such as the use of remotely-sensed imagery collected over long time periods. The challenges inherent in measuring adoption of principles as opposed

[2] This is the case for most investments, not just NRM practices.

Box 1
Complementarities, complexities, and targeting: the case of Integrated Soil Fertility Management.

The International Institute for Tropical Agriculture (IITA) led a research project (COMPRO I) in Kenya, Nigeria, and Ethiopia that analyzed the cost effectiveness of 100 commercial inputs, through lab-analysis of input content, research station trials, and on-farm trials. Of these inputs, only a small proportion had sufficiently high benefit-cost ratios to warrant adoption by smallholders. Because returns to inputs vary by socioeconomic and agroecological conditions, there may be significant risks and costs to farmers experimentation that explain low adoption rates. Clearly, NRM research needs to carefully consider upfront the full range of potential benefits (and costs/risks) for better targeting.

Following COMPRO I, Laajaj and Macours (2016) focused on potential constraints to learning through a Randomized Control Trial (RCT) in Western Kenya. Smallholders were invited, prior to randomization, to participate in the trial (a test of different combinations of maize/soya seed and fertilizer packages) on one of their plots over three seasons. While learning was slow, farmers were able to identify which inputs worked best over several seasons, extended it to other plots, and this learning increased their willingness to purchase those inputs. Other studies have illustrated the progression curve, in adoption of NRM practices, from awareness to trials to experimentation and partial use to full use (or, of course, disuse) (Vanlauwe, 2017).

to practices highlight the need to re-think what can be measured and how. For example, can we make better use of information on dissemination from program M&E systems, to measure exposure to innovations (a *sine qua non* for understanding dynamic adoption and impact at scale)?

5. Measure and report the impacts of on-farm NRM practices on environmental outcomes. This is rarely done, and even when such outcomes are measured, the focus is often on one or two outcomes and ignores interactions. Yield and productivity-related goals have dominated what is measured, in part because they are assumed to be what farmers most care about and what policy makers prioritize. Efforts are underway to better define and measure the social and environmental outcomes that are part of sustainable intensification (Box 2).

1. Discussion

Agronomic research has focused on specific management practices and the conditions under which their adoption by farmers can lead to certain desirable outcomes being realized. There may well be opportunities for socially, economically, and environmentally desirable outcomes from the adoption of plot- and farm-level on-farm NRM practices, but rigorous assessments suggest they do not always exist, nor do they automatically materialize. Farmers rarely follow strictly codified recommendations devised by scientists: rather, they often adapt agronomic principles to their practices. When trying to evaluate the effectiveness of scientists' recommendations, a focus on principles over practices does, however, present measurement challenges as the broad application of principles may vary substantially among farmers (see Stevenson et al., 2014 for a discussion in the context of conservation agriculture) or may be unobservable to the investigator. To measure the influence of principles conveyed during a given extension approach, a strong theory needs to be defined prior to data collection regarding what we would expect to see at the farm and/or landscape level if those principles are taken up. Testing the theory might entail: pre-analysis plans, a multi-dimensional measurement effort and, importantly, addressing the issue of farmer intent by asking about their perceptions of the functional role of certain practices. Furthermore, such a shift in emphasis implies that in order to appropriately assess the impact of agricultural research we must take into account influence on development actors (public and private).

Large-scale NGOs and social enterprises are aiming to influence farmer management through their programs, and these efforts are potentially useful in reaching large numbers of farmers. To assure a focus on principles rather than practices, agricultural researchers then may need to build closer research ties with providers of extension, advisory, and information services across the continuum (i.e. in the public sector, private sector, and civil society). The impacts of such efforts need to be assessed rigorously, and research with service providers can help us understand which extension provision strategies, approaches, and

Box 2
Going beyond practices: the case of Alternate Wetting and Drying.

AWD is an irrigation management approach that farmers can apply to save water and reduce costs associated with irrigation without rice yield penalties (Lampayan et al., 2015). AWD could help increase production since farmers can expand acreage under cultivation, and may reduce methane emissions from rice fields, which are a significant source of greenhouse gas emissions globally (Smith et al., 2007). The International Rice Research Institute (IRRI) and its national agricultural research and extension systems (NARES) partners studied and developed AWD in 1990s-2000s (Lampayan and Bouman, 2005), including a low-cost tool (perforated water tubes) that can be installed in farmers' fields to enable water depth monitoring. This is essential to "safe" AWD use, which requires careful management of both irrigation and drainage.

In an RCT designed to quantify these multi-dimensional impacts of AWD in an area of Philippines where it had not been formally introduced to farmers, Rejesus et al. (2017) found no significant differences in yields, gross income, or water use between farmers in treatment and control areas. A likely explanation is that the conventional practice of control farmers in the control group was actually similar to those in the treatment group who used AWD, i.e., farmers in both groups intermittently irrigated their rice fields and did not rely on continuous flooding. This raises questions about how AWD "adoption" is defined and measured, and whether practices among farmers in the control group also constitute a form of sustainable intensification with many of the same private and social benefits.

Furthermore, new insights on the full accounting for the greenhouse gas emissions from a switch to intermittent flooding (Kritee et al., 2018) have reiterated the importance of context. Nitrous oxide emissions from intermittently flooded fields can be 30–40 times higher (Kritee et al., 2018), which could offset the decline achieved in methane emissions. Thus, both for reasons of properly understanding farmer behavior and accounting for the full range of possible impacts, it is appropriate to shift the focus of NRM research design and its assessment to broader principles and guidelines, including interactions and not limit the goal to having farmers adopting a narrow set of practices.

methods (such as the use of community- and ICT-based channels) can be most effective to disseminate NRM principles.

The recommendations outlined in this article point to a considerable research agenda which should be based on science, including science that is driven by needs for solutions to problems identified by farming communities and the development partners engaging directly with farming communities. Some have referred to this kind of approach as "research in development" (Coe et al., 2014). The challenge is how to implement such an approach and draw lessons that have relevance beyond specific study sites. Possible candidates for the latter relate to the lessons learned about the effectiveness of extension models and a deeper understanding of heterogeneity across farmers and agro-ecologies.

Conflicts of interest

None.

Acknowledgements

This paper is a result of the SPIA-organized workshop 'Assessing the Impact of Research on Managing Natural Resources for Sustainable Production' hosted by IFPRI and funded by the CGIAR Independent Science and Partnership Council (ISPC) and the CGIAR Research Program on Policies, Institutions and Markets (PIM), which is carried out with support from the CGIAR Fund (https://www.cgiar.org/funders). We would like to thank the workshop participants for engaging in discussions around NRM research in CGIAR, including the key messages presented in this manuscript.

References

Bell, A.R., Zhang, W., Nou, K., 2016. Pesticide use and cooperative management of natural enemy habitat in a framed field experiment. Agric. Syst. 143, 1–13. https://doi.org/10.1016/j.agsy.2015.11.012.

Brown, B., Nuberg, I., Llewellyn, R., 2017. Stepwise frameworks for understanding the utilization of conservation agriculture in Africa. Agric. Syst. 153, 11–22. https://doi.org/10.1016/j.agsy.2017.01.012.

Coe, R., Sinclair, F., Barrios, E., 2014. Scaling up agroforestry requires research 'in' rather than 'for' development. Curr. Opin. Environ. Sustain. 6, 73–77. https://doi.org/10.1016/j.cosust.2013.10.013.

Cui, Z., Zhang, H., Chen, X., Zhang, C., Ma, W., Huang, C., Zhang, W., Mi, G., Miao, Y., Li, X., Gao, Q., Yang, J., Wang, Z., Ye, Y., Guo, S., Lu, J., Huang, J., Lv, S., Sun, Y., Liu, Y., Peng, X., Ren, J., Li, S., Deng, X., Shi, X., Zhang, Q., Yang, Z., Tang, L., Wei, C., Jia, L., Zhang, J., He, M., Tong, Y., Tang, Q., Zhong, X., Liu, Z., Cao, N., Kou, C., Ying, H., Yin, Y., Jiao, X., Zhang, Q., Fan, M., Jiang, R., Zhang, F., Dou, Z., 2018. Pursuing sustainable productivity with millions of smallholder farmers. Nature 555, 363–366. https://doi.org/10.1038/nature25785.

de Roo, N., Andersson, J.A., Krupnik, T.J., 2017. On-farm trials for development impact? The organization of research and the scaling of agricultural technologies. Exp. Agric. 1–22. https://doi.org/10.1017/S0014479717000382.

Department for International Development, UK, 2015. DFID's conceptual framework on agriculture. ⟨https://www.gov.uk/government/publications/dfids-conceptual-framework-on-agriculture⟩ (Accessed 6 December 2018).

Gars, J., Ward, P.S., 2016. The role of learning in technology adoption: Evidence on hybrid rice adoption in Bihar, India. IFPRI Discussion Paper 01591. Washington.

Jack, B.K., 2013. Private information and the allocation of land use subsidies in Malawi. Am. Econ. J.: Appl. Econ. 5 (3), 113. https://doi.org/10.1257/app.5.3.113.

Jack, B.K., Oliva, P., Severen, C., Walker, E., Bell, S., 2015. Technology adoption under uncertainty: Take-up and subsequent investment in Zambia (No. w21414). Natl. Bur. Econ. Res. https://doi.org/10.3386/w21414.

Kritee, K., Nair, D., Zavala-Araiza, D., Proville, J., Rudek, J., Adhya, T.K., Loecke, T., Esteves, T., Balireddygari, S., Dava, O., Ram, K., Abhilash S.R., Madasamy, M., Dokka, R.V., Anandaraj, D., Athiyaman, D., Reddy, M., Ahuja, R., Hamburg, S.P., 2018. High nitrous oxide fluxes from rice indicate the need to manage water for both long- and short-term climate impacts. Proceedings of the National Academy of Sciences (PNAS). 115(3):9720–9725. https://doi.org/10.1073/pnas.1809276115.

Laajaj, R., Macours, K., 2016. Learning-by-doing and learning-from-others: evidence from agronomical trials in Kenya. In: de Janvry, A., Macours, K., Sadoulet, E. (Eds.), Learning for Adopting: Technology Adoption in Developing Country Agriculture. FERDI, Claremont Ferrand.

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 Crops Res. 170, 95–108. https://doi.org/10.1016/j.fcr.2014.10.013.

Lampayan, R.M., Bouman, B.A.M., 2005. Management strategies for saving water and increase its productivity in lowland rice-based ecosystems. Paper present at First Asia-Europe Workshop on Sustainable Resource Management and Policy Options for Rice Ecosystems (SUMAPOL 2005), 11–14 May 2005, Hangzhou, China.

Magruder, J., 2018. An assessment of experimental evidence on agricultural technology adoption in developing countries. Annu. Rev. Resour. Econ. 10, 299–316. https://doi.org/10.1146/annurev-resource-100517-023202.

Nelson, R., Coe, R., Haussmann, B.I.G., 2016. Farmer research networks as a strategy for matching diverse options and contexts in smallholder agriculture. Exp. Agric. 1–20. https://doi.org/10.1017/S0014479716000454.

Phalan, B., Rodrigues, A.S., Balmford, A., Green, R.E., Ewers, R.M., 2007. Comment on "resource-conserving agriculture increases yields in developing countries". Environ. Sci. Technol. 41 (3), 1054–1055. https://doi.org/10.1021/es062097g.

Pretty, J.N., Noble, A.D., Bossio, D., Dixon, J., Hine, R.E., Penning de Vries, F.W.T., Morison, J.I.L., 2006. Resource-conserving agriculture increases yields in developing countries. Environ. Sci. Technol. 40 (4), 1114–1119. https://doi.org/10.1021/es051670d.

Rejesus, R.M., Yorobe Jr., J.M., Lampayan, R.M., Sibayan, E.B., Ole Sander, B., Mendoza, M.L., Flor, B., R.J, Malabayabas, B., A.J, Singleton, G.R., Mohanty, S., San Valentin, M.R., 2017. Adoption and Impact of Alternate Wetting and Drying (AWD) Water Management for Irrigated Rice Production in the Philippines. Unpublished report submitted to the Standing Panel on Impact Assessment of the ISPC: Rome, Italy.

Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., Wetterstrand, H., DeClerck, F., Shah, M., Steduto, P., de Fraiture, C., 2017. Sustainable intensification of agriculture for human prosperity and global sustainability. Ambio 46 (1), 4–17. https://doi.org/10.1007/s13280-016-0793-6.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., 2007. Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Stevenson, J.R., Serraj, R., Cassman, K.G., 2014. Evaluating conservation agriculture for small-scale farmers in Sub-Saharan Africa and South Asia. Agric., Ecosyst. Environ. 187, 1–10.

Stevenson, J.R., Vlek, P., 2018. Assessing the Adoption and Diffusion of Natural Resource Management Practices: Synthesis of a New Set of Empirical Studies. Independent Science and Partnership Council (ISPC), Rome, Italy.

Suri, T., 2011. Selection and comparative advantage in technology adoption. Econometrica 79, 159–209.

Tilman, D.K., Cassman, G., Matson, P.A., Naylor, R., Polasky, S., 2002. Agricultural sustainability and intensive production practices. Nature 418 (6898), 671.

Tittonell, P., Muriuki, A., Shepherd, K.D., Mugendi, D., Kaizzi, K.C., Okeyo, J., Verchot, L., Coe, R., Vanlauwe, B., 2010. The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa—a typology of smallholder farms. Agric. Syst. 103, 83–97. https://doi.org/10.1016/j.agsy.2009.10.001.

Vanlauwe, B., AbdelGadir, A.H., Adewopo, J., Adjei-Nsiah, S., Ampadu- Boakye, T., Asare, R., Baijukya, F., Baars, E., Bekunda, M., Coyne, D., Dianda, M., Dontsop-Nguezet, P.M., Ebanyat, P., Hauser, S., Huising, J., Jalloh, A., Jassogne, L., Kamai, N., Kamara, A., Kanampiu, F., Kehbila, A., Kintche, K., Kreye, C., Larbi, A., Masso, C., Matungulu, P., Mohammed, I., Nabahungu, L., Nielsen, F., Nziguheba, G., Pypers, P., Roobroeck, D., Schut, M., Taulya, G., Thuita, M., Uzokwe, V.N.E., van Asten, P., Wairegi, L., Yemefack, M., Mutsaers, H.J.W., 2017. Looking back and moving forward: 50 years of soil and soil fertility management research in sub-Saharan Africa. Int. J. Agric. Sustain. https://doi.org/10.1080/14735903.2017.1393038.

Vanlauwe, B., Coe, R., Giller, K.E., 2016. Beyond averages: new approaches to understand heterogeneity and risk of technology performance in smallholder farming. Agric. Syst. 1–23. https://doi.org/10.1017/S0014479716000193.