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Effects of training, innovation and new technology on African smallholder farmers' economic outcomes and food security

July 2016

Systematic Review Summary 6

Agriculture

3ie International Initiative for Impact Evaluation

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This summary report, *Effects of training, innovation and new technology on African smallholder farmers' economic outcomes and food security, 3ie Systematic Review Summary 6* is based on a full review that is available on the 3ie website.

Funding for this report was provided by the Global Affairs Canada (formerly the Department for Foreign Affairs, Trade and Development Canada) and 3ie's core donors, which include UK aid, the Bill & Melinda Gates Foundation and the Hewlett Foundation.

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Suggested citation: Stewart, R, Langer, L, Da Silva, RN, and Muchiri, E 2016. *Effects of training, innovation and new technology on African smallholder farmers' economic outcomes and food security*, 3ie Systematic Review Summary 6. London: International Initiative for Impact Evaluation (3ie).

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Cover photo: Alliance for a Green Revolution in Africa

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Acknowledgements

This review was made possible thanks to the generosity of many individuals and organisations. It was funded by Global Affairs Canada (formerly Department of Foreign Affairs, Trade and Development, Canada), managed through the International Initiative for Impact Evaluation (3ie). 3ie also offered additional financial support for this review. In addition, the Centre for Anthropological Research at the University of Johannesburg generously allocated additional staffing to the review. We would also like to thank our international advisory group and peer-reviewers for their input to this review.

This summary report is based on a full systematic review technical report, The effects of training, innovation and new technology on African smallholder farmers' economic outcomes and food security: a systematic review by Ruth Stewart, Laurenz Langer, Natalie Rebelo Da Silva, Evans Muchiri, Hazel Zaranyika, Yvonne Erasmus, Nicola Randall, Shannon Rafferty, Marcel Korth, Nolizwe Madinga and Thea de Wet, 2015.

Summary

The majority of the rural poor in Africa engage in smallholder farming as a livelihood strategy. At the same time, supporting the practice of smallholder agriculture holds the potential to improve farming households' level of food security as well as local economies in rural areas. Agricultural productivity in Africa stands at one-third to half of global productivity and, although the Green Revolution has rapidly improved social and economic livelihoods in other former developing regions, it is by and large absent from the continent.

Programmes that support African smallholder agriculture by implementing training programmes and introducing new technologies and agricultural innovations aim to help release the untapped potential of the African agricultural sector. But we know little about which programmes and approaches are most effective at improving smallholders' food security and economic outcomes.

This is the first systematic review of the available research evidence to address this issue. Our objectives were to systematically review the evidence on the effects that training, innovation and new technology have had on African smallholder farmers' economic outcomes and food security.

Interventions

This review assessed the effects of two types of interventions on the livelihoods of African smallholder farmers: training and innovation and new technology.

Training interventions are those that facilitate a transfer of knowledge or skills to smallholder farmers. Training approaches varied from farmer field schools to extension programmes and the provision of information materials.

Innovation and new technology interventions facilitate the introduction of a 'new' farming method, product or service, which we divided into three categories:

- Agricultural practice innovations, including the introduction of new ways of practicing smallholder farming such as conservation agriculture;
- Agricultural input innovations, including the introduction of new biological or chemical inputs to support smallholders such as fertilisers or bio-fortified vegetable varieties;
- Technical input innovation, including any form of machinery applied to improve smallholder farming, such as tractors.

The review was only concerned with economic and food security outcomes.
We aimed to investigate the effects of training, innovation and new technology interventions on the level of income or assets and the food security of African smallholder farming households. We collected additional information relevant to our causal pathway to understand the intermediate outcomes the interventions had on smallholders.

Findings

We identified 19 studies (comprising a total of 4,493 participants) that met the review's inclusion criteria. Of these studies, 14 assessed the effects of innovation and new technology programmes, while five examined the effects of training programmes. The overall

quality of the included studies was mixed and we assessed that only 11 consisted of reliable evidence about programme effects. There was great heterogeneity across programme designs, socio-economic contexts and outcome measures.

This limited evidence base that we identified did not allow us to reach a definitive conclusion regarding the overall effects of smallholder farming interventions on farmers' economic outcomes and food security. The analyses that we were able to conduct are based on very small samples of evidence (at most six studies). Keeping in mind these caveats, we can nevertheless draw some tentative conclusions from this review. In detail, these are the results of our analyses:

- Synthesising the effects of six agricultural input innovations – all programmes to introduce new or improved agricultural products – we identified an improvement in farmers' food security levels, as measured by nutritional indicators (32.3 per cent increase in vitamin A levels);

- Synthesising the effects of five of these programmes, which all introduced orange flesh sweet potato, we identified an improvement in farmers' food security levels, as measured by nutritional indicators (39.8 per cent increase in vitamin A levels);

- Synthesising the effects of three agricultural input innovations, we identified an improvement in farmers' income levels, modelled on the increased monetary value of their total harvest (12.4 per cent increase in harvests) and

- Synthesising the effects of five training interventions, we failed to find an effect on farmers' income as modelled on the monetary value of their total harvest. However, the evidence did suggest that the three participative farmer field school programmes were more effective than those using top-down delivery methods.

We were unable to identify enough evidence to statistically synthesise the effects of agricultural practice and technical input innovations.

Given the small number of included studies – and their heterogeneity –we urge users to interpret these impacts with caution. However, our results do offer some tentative evidence on the effects of innovation, new technology and training interventions to support smallholder farmers in Africa. Within the reviewed interventions, we found that farming orange flesh sweet potatoes, a vitamin A-rich staple food, presented the most promising intervention approach. These programmes yielded positive effects on nutrition in four contexts and programmes have successfully been scaled up.

Implications

The evidence we identified in our systematic review does not allow for definitive conclusions on the effects of training, innovation and new technology interventions on smallholder farmers' economic outcomes and food security in Africa.

The evidence suggests that agricultural input innovations might increase the nutritional status of farming households and to a lesser degree, the monetary value of famers' harvest. But we could not conclude that training programmes increase farmers' harvests in general. Although bottom-up approaches such as farmer field schools may be more effective, there is

a need for more rigorous research – specifically theory-based impact evaluations of smallholder farming interventions – to explore these findings.

We initially identified a large number of relevant research studies, but could not include most evidence because the studies had not applied rigorous randomised or prospective non-randomised research designs. We have to issue a strong call for improved research designs when evaluating the effects of smallholder farming interventions in Africa. The recent increase in funding for such interventions might yield more effective results if they are accompanied by a similar increase in funds for more prospective evaluations.

Contents

List of figures and tables

Abbreviations and acronyms

AE	agricultural extension
AGRA	Alliance for a Green Revolution in Africa
ES	effect size
FAO	Food and Agriculture Organization
HAZ	height-for-age z-score
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
KSh	Kenyan shilling
NAADS	National Agricultural Advisory Services (Uganda)
RA	Rainforest Alliance
RCT	randomised controlled trial
SE	standard error
SMD	standardised mean difference
WAZ	weight-for-age z-score

1. Introduction

Of the 800 million people who live in sub-Saharan Africa, around 500 million (63 percent) live in rural areas (Livingston *et al. 2*011). The rural poor are predominantly smallholder farming households, whose agricultural production and income is insufficient to maintain secure livelihoods (FAO *et al. 2*013). At the same time, agriculture remains the primary sector of most national economies in Africa (Masset *et al.* 2011), and African states obtain most of their national food supply from smallholder farmers (AGRA *2*013). National and international development policymakers regard rural development as key to sustainable national socio-economic development (IFAD *2*011; Word Bank *2*007). As a result, they are increasingly supporting smallholder farmers.

Despite their potential to improve national food supply and foster local economic growth, smallholder farmers in Africa are one of the most impoverished population groups. With less than US$2 per day, a smallholder farmer's average income from agricultural production is not enough to meet household needs and to finance investment (AGRA *2*014; IFPRI *2*011). Subsistence farmers are at constant risk of food insecurity due to small plot size, low use of agricultural inputs such as fertilisers and unfavourable soil and climate conditions. The Alliance for a Green Revolution in Africa (AGRA) estimates that 223 million people in Africa, most of whom live in rural areas, do not meet their dietary needs and are undernourished (AGRA *2*014). The 2014 Global Nutrition Report found high rates of stunting and wasting are particularly prevalent in smallholder households (IFPRI *2*014).

The African agricultural sector underperforms when compared to global productivity and output rates (IFPRI *2*011; AGRA *2*013). For example, between 2000 and 2010, average grain yields in Africa were 1.1–1.5 tonnes per hectare: between one-third to one-half of the global average of 3.2 tonnes per hectare. This discrepancy in performance is largely attributed to the slow spread and adoption of green revolution technologies in Africa (Terry *2*012; World Bank *2*007). High-yielding seed varieties, the use of fertilisers and irrigation techniques are the main inputs that have been driving rural development since the 1980s, resulting in large-scale development successes, particularly in Asia (Word Bank *2*007). But African smallholder farmers have been slow to make use of such technologies for various reasons, including limited market access and climate conditions (Terry *2*012).

Africa possesses abundant natural resources to accommodate a green revolution. With the continent comprising 60 percent of the world's arable land (AGRA *2*013), increasing productivity is a main rural development objective. There are different ways to improve agricultural productivity and programmes designed to do this need to take into consideration a complex set of contextual, political and socio-economic factors. The 2013 Africa Agriculture Report singles out the 'increased use of agricultural inputs, modern farming techniques, and reduced market inefficiencies' (AGRA *2*013) as necessary to improve agricultural productivity in the region. Recent systematic reviews present farmer field schools and land property rights as promising interventions to increase agricultural productivity (Waddington *et al.* 2014; Lawry *et al.* 2014). Specific examples of technological innovations to improve the efficiency and output of smallholder famers include: treadle pump irrigation technology (Adeoti *et al.* 2009); bio-fortification and health information (de Brauw *et al.* 2013); and adopting export crops and marketing techniques (Ashraf *et al.* 2008).

These interventions could benefit smallholders through two different mechanisms. First, increasing smallholders' agricultural production might lead to higher revenues from sales at

domestic (and potentially international) food markets. This, in turn, could allow for increased investment and employment in the sector, unlocking the potential of rural economies. Second, an increased output of agricultural products might allow for more stable and improved household diets due to the larger availability of, and access to, foodstuff. By improving the food security of the rural poor, this mechanism could lead to long-term benefits such as better health and human capital (World Bank *2*007; IFPRI *2*011).

Development policymakers are showing renewed interest in attempts to improve agricultural productivity in Africa. This has led to increased funding for such initiatives, as seen by the establishment in 2007 of the Alliance for a Green Revolution in Africa and the G8's L'Aquila Food Security Initiative, which pledged US$22 billion for agriculture in developing countries. But it is crucial that policymakers target this funding at effective initiatives. While many agricultural interventions have been beneficial in field trials under controlled conditions, their impact in a real world setting often differs.

Rigorous impact evaluations are a crucial step to assessing the effects of individual programmes, but these lack the external validity that a synthesis of all available research can offer. We therefore conducted a systematic review with the explicit objectives set out in Section 1.1. In Chapter 2, we describe the reviewed interventions in detail, and in Chapter 3 we use a causal pathway to illustrate how such interventions affect African smallholders in theory. We then present detailed findings about the programmes included in the review in Chapter 4, and discuss their impacts on food security and economic outcomes in Chapter 5. Chapter 6 concludes with an outline of the implications for policy, practice and research.

1.1 Review objectives

The objectives of our review were to systematically review the available evidence on the effects of innovations, new technologies and training interventions on the economic outcomes and food security of smallholder farmers in Africa.

We singled out these two intervention domains after extensively mapping the existing evidence available, including ongoing reviews (Stewart *et al.* 2014a). This mapping exercise revealed a gap in the evidence base around training and innovation or new technology interventions.

Our review only included rigorous research evidence that assessed the effects of smallholder farming interventions. In other words, we only included research designs that assessed the programme effects against a valid counterfactual – what happened to similar farmers not participating in the intervention – and which used more rigorous methods including the collection pre- and post-intervention data. We applied these design criteria to ensure that we included study designs that provide strong causal link between the intervention and any outcomes achieved.

We identified relevant high-quality evidence in an exhaustive search of academic and grey literature between April 2013 and February 2015,[1] making use of predefined inclusion criteria. For the purpose of this review, we formulated our definition of smallholder farmers according to farm size, agricultural resources, type of labour and consumption.

[1] We updated these searches between September 2014 and February 2015.

Our search identified 18,470 citations. Of these, 19 studies covering 21 projects and programmes were eligible for the review[2] and we subjected all 19 to a rigorous assessment of bias.[3] We used statistical meta-analysis to synthesise findings. Meta-analysis enables the pooling of individual study findings in order to determine the magnitude of the change in outcomes across programmes and its statistical likelihood (see Stewart *et al.* 2015 for more information on the review methods). We also conducted a causal chain synthesis, drawing on information we extracted on intermediate and final outcomes.

[2] Studies published between 1990 and 2014 were eligible for inclusion in the review and we initially identified 462 potentially relevant full-text studies. The most common reason for exclusion at full-text level was uncertainty about the rigour of the studies' research methods to evaluate programme effects, particularly retrospective evaluations drawing mainly on cross-sectional datasets.

[3] We used the guidelines established by the Cochrane Collaboration (Sterne *et al.* 2013) to determine the risk of bias. Eleven studies consisted of reliable evidence (nine had low and two had moderate risk of bias ratings). Eight studies presented less reliable evidence (six had a serious risk of bias and two a critical risk). We did not include findings from studies we identified as having a critical bias in the synthesis. See Table A1 for details.

2. Interventions

Our systematic review focused on two types of interventions: new technology and innovation; and training interventions.

2.1 New technology and innovation

Interventions that are categorised as new technology and innovation emphasise the introduction of a 'new' farming method, product or service. Famous examples of interventions promoting new technologies and innovations in Africa include the provision of genetically improved crops, such as the new Bt cotton variety (Bennett *et al* 2004).[4] They can also refer to the introduction of different farming methods, such as conservation agriculture as a less resource-intensive and more sustainable farming practice (Wanyama *et al.* 2010) or promoting orange flesh sweet potatoes as a vitamin A-rich staple food (Gilligan 2014).

Table 1: A framework of innovation and new technology interventions

Component	Example
Agricultural practice innovation	Commercial agriculture, soil management
Agricultural input innovation	Fertilisers, bio-fortification, new crop varieties
Technical input innovation	Tractors, drip irrigation, information and communication technology

Source: Stewart *et al.*

Table 1 illustrates our intervention categories for this review. We simplified a framework initially developed by Sunding and Zilberman (2001) to formulate three distinctive and mutually exclusive technology and innovation intervention categories:[5]

1. **Agricultural practice innovations:** On the micro level, this approach introduces farming processes, such as legume intercropping to prevent soil nutrient loss (Wanyama *et al.* 2010). On the macro level, it leads to wider changes, such as a fundamental shift from subsistence cultivation to producing crops for export markets (Ashraf *et al.* 2008). The emphasis is on processes and practices rather than inputs and products.

2. Agricultural input innovations: This approach introduces new biological or chemical inputs to support smallholders. It emphasises the production input itself rather than how it is cultivated or marketed. Common forms of input innovations include:

- Bio-fortified crop varieties that have, for example, greater nutritional value or higher yields (Akalu *et al.* 2010; Hotz *et al.* 2012a);
- fertilisers; and

[4] Bt cotton is an insect-tolerant, higher-yielding cotton crop that was introduced to smallholder farmers' in South Africa aiming to establish a commercially viable cotton industry cluster.

[5] In cases where interventions applied multiple programme components, we assigned them to the intervention category that applied to the programme's main component.

- foreign crop varieties that are not necessarily biologically modified: for example, the establishment of Arabica coffee farms in Uganda can be regarded as the introduction of a new crop (Isoto *et al.* 2014).

3. **Technical input innovations:** This approach introduces machinery to improve the process of smallholder farming. Such inputs can range from large-scale investments in tractors or storage facilities, to basic technologies such as drip-irrigation (Burney *et al.* 2010). This category also includes the most recent innovations from the field of information and communication technology – for example, the increased use of mobile phones is quickly affecting smallholders' purchase and sale habits (Aker 2010).

2.2 Training

We defined agricultural training interventions as any type of programme that aims to facilitate a transfer of knowledge or skills on topics that are of agricultural benefit to farmers. Training interventions for farmers vary considerably. Some interventions focus directly on teaching farmers new skills using top-down 'training and visit' methods. Governments often package such interventions as extension services, a broad term for programmes which aim to 'support and facilitate people engaged in agricultural production to solve problems and to obtain information, skills and technologies' (Anderson *2*007).

Although traditionally considered a top-down approach to training, extension services have over time become more participatory in nature (Waddington *et al.* 2014). Farmer field schools in particular, which may be one component of broader agricultural extension services, use a more bottom-up approach to training and knowledge transfer. Farmer field schools aim to be participatory, empowering and experiential in nature, focusing on problems and priorities identified by the farmers, rather than on issues and challenges determined by outsiders (Waddington *et al.* 2014). Initially developed to tackle an over-reliance on pesticides, field schools have aimed to address a range of different issues across over 80 countries (van den Berg *2*004).

The Japan International Cooperation Agency (JICA)'s work to enhance Ugandan rice production is a good example of the range of top-down agricultural extension training programmes available (Kijima *2*014). These range from a year-long extension service where JICA staff regularly visit smallholder farmers and demonstrate new cultivation practices on experimental plots on the farmer's land to projects where smallholder farmers travel to local demonstration plots. In an effort to save staffing costs –a major factor disabling the sustainability of its work –one JICA pilot programme produced and issued detailed agricultural guidebooks with information and illustrations on effective cultivation practices to smallholder farmers in the belief that they could teach themselves relevant practices (Kijima *2*014).

3. How the interventions are supposed to work

The review focuses on the impacts of training, innovation and new technology on economic outcomes and food security. We defined economic outcomes as any form of financial income or assets that a household generates. For example, income from selling food products or savings from not having to buy food products could both improve disposable household income. A farmer's economic outcome can change with the acquisition of assets such as land or machinery.

According to the 2009 Declaration of the World Summit on Food Security, food security exists when all people, at all times, have physical and economic access to sufficient, safe, nutritious food to meet their dietary needs and food preferences for an active life (FAO *et al.* 2013). So food security is essentially the availability of food and one's access to it. This is the definition of food security we used in our review. Based on this, we took into account improved access to, availability and the nutritional value of, food.

Training, new technology and innovation interventions might affect final economic and food security outcomes for smallholder farmers through a number of intermediate outcomes. These can mitigate or enforce the effects of interventions. As a result, our review assessed the effects of interventions along a detailed causal pathway of how we assumed the applied programmes worked.

Figure 1 provides this detailed causal pathway on how innovation, new technology and training interventions can lead to improved economic outcomes and food security for smallholder farmers in Africa. The pathway lays out a number of steps that illustrate the processes that might allow the applied programmes to affect the desired final outcomes. On the right hand side of the diagram, we state a number of key assumptions associated with each step.

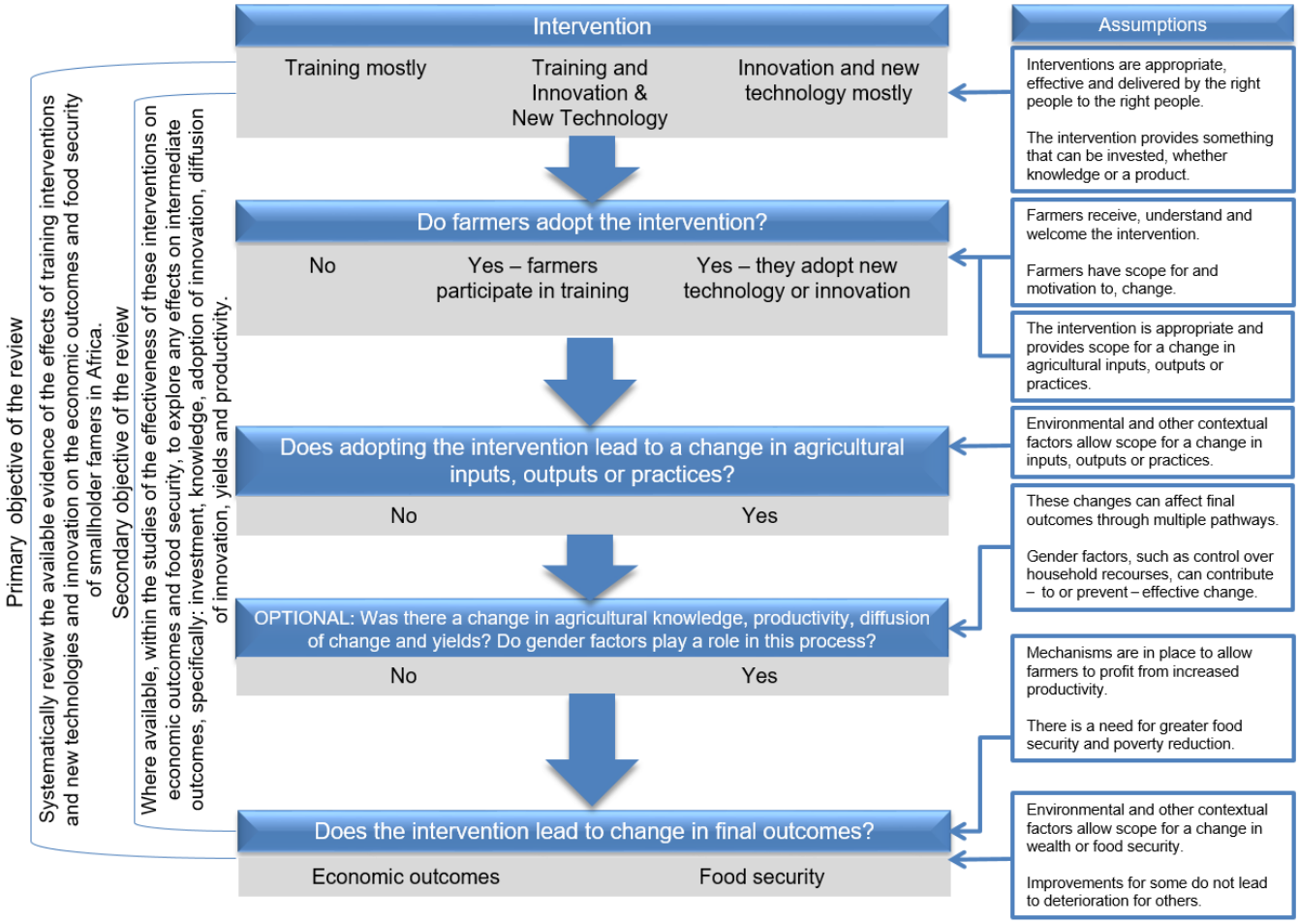
The first step in the causal pathway refers to the adoption of the interventions. If smallholder farmers have no demand for the interventions, or if the programmes are not appropriate to local contexts, farmers will at best not participate in – and may actively resist – the activities. It is thus essential to assess factors of adoption and whether or not farmers understand and welcome the received programmes.

Having adopted the interventions, farmers may experience a change in agricultural inputs, outputs or practice. The introduction of a bio-fortified crop variety on its own presents a change in inputs and could result, for example, in an improved output (more nutritious staple foods). Interventions, particularly training programmes, might not have the primary aim to change agricultural inputs or outputs but rather to change farming practices – for example, through integrated pest management techniques. The mechanisms through which interventions might have a beneficial impact on smallholder farmers are thus diverse.

Our review further assumed that a number of intermediate outcomes might play a role in the translation of these changes in agricultural inputs, outputs and practices into final economic and food security outcomes. Besides the above-mentioned changes in yields, the diffusion of new technologies might determine the total effects on farmers. Changes in productivity or agricultural knowledge could equally moderate the programmes' effects. Lastly, we aimed to assess whether gender factors might contribute or prevent effective changes in smallholder farmers' livelihoods.

The last step of the causal pathway represents the final outcomes that the reviewed interventions could ideally achieve. Our review focused on economic and food security outcomes. We admit that contextual factors might mitigate the effects of potentially beneficial interventions. For example, a training programme might succeed in changing farmers' levels of agricultural knowledge, but a drought in the area could prevent participants from experiencing improvements in income or food security.

Figure1: Programme causal pathway



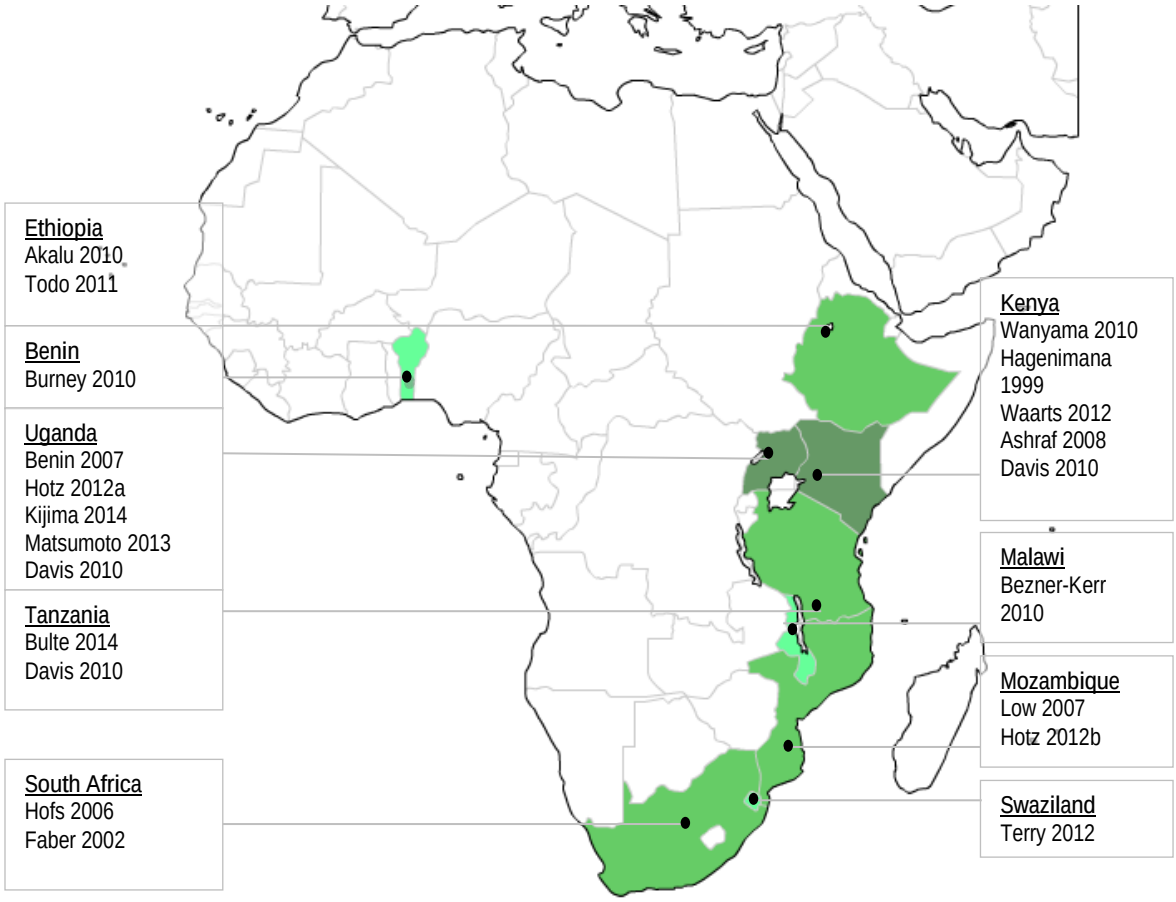
Source: Stewart *et al.*, 2016

4. Implementation evidence

We identified rigorous evidence from 21 projects and programmes reported in 19 studies involving a total of 4,639 participants. Figure 2 illustrates the geographical spread. All projects and programmes were in sub-Saharan Africa, and the large majority were located in east and southern Africa. Only one focused on a West African country, and there were no rigorous evaluations of projects from Africa's most populous state, Nigeria. The fast-growing region of East Africa features most prominently within the sample of included studies, with Ethiopia, Kenya, Tanzania and Uganda contributing more than half of the total (12). Training interventions were focused on East African countries, while innovation and new technology programs had a more even geographical spread.

In general, most (14) of the reviewed interventions applied new technology or innovation programmes; only a minority (5) assessed the effects of training programmes. While all programmes focused on smallholder farmers as a target group, they assessed the effects of interventions in diverse populations. Studies investigating food security levels across farming households, for example, measured outcomes exclusively in infants and their mothers. More information on included studies is provided in the Appendix A.

Figure 2: Map of included programmes



Source: Stewart *et al.*, 2016

The process data from the studies suggests that farmers were willing to adopt the reviewed interventions, which were all successfully implemented and completed within their scheduled time frames. Farmers reportedly organised their time to participate in training activities or experiment with new agricultural inputs. This lends some support to the observation that farming systems and practices are not inherently resistant to external inputs, which some commentators assessing the absence of a green revolution in Africa suggested was the case (Terry 2012).

Process information also indicates that farmers regarded the behaviour change the reviewed interventions aimed to facilitate – for example, planting a new crop or altering diets – as acceptable. Farmers reportedly used new vegetable products and were open to engaging with new agricultural practices. For example, smallholders accepted the inclusion of orange flesh sweet potatoes – a foreign staple – into their diets. This reinforces the observation that African smallholder farmers are willing to experiment with new farming practices and inputs.

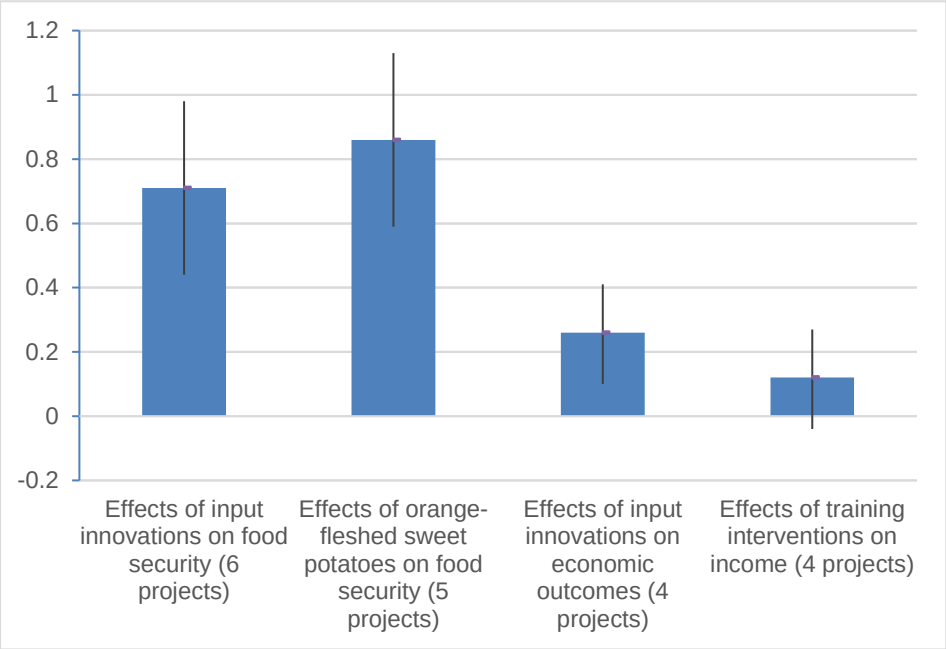
We also identified evidence on intermediate outcomes in a minority of studies. Reviewing these outcomes suggested that there might be a relationship between agricultural knowledge and programme adoption. For example, individual studies reported that changes in agricultural and nutritional knowledge influenced the production and consumption of specific crops. This was particularly the case with orange flesh sweet potato programmes.

5. Impacts on food security and income

In this chapter, we report the results of our synthesis of the effects of training, new technology and innovation on smallholder farmers' food security and economic outcomes. We have structured the synthesis results according to intervention type, reporting with outcome categories for each intervention type separately.

We measured individual study outcomes by the effect size – which quantifies the difference between outcomes in the intervention group and the comparison group using a standardised scale. We used meta-analysis to pool individual effect sizes across programmes, in order to determine the average value of effect across programmes as well as likely range of those values, indicated in a confidence interval. Figure 3 shows the average size of each intervention's effect as bars, together with vertical lines which provide the confidence intervals indicating the likely range of effects in different contexts.[6] Overall, the evidence base we identified for the effects of training, new technology and innovation interventions on smallholders' level of economic outcomes and food security is limited in both number and quality.[7]

Figure 3: Effects of smallholder agriculture interventions



Source: Stewart *et al.*, 2016

Note: Bars show standardised mean differences in outcomes between participants and non-participants. Vertical lines show 95 per cent confidence intervals.

[6]All our analyses express effect sizes as standardised mean differences, which compare average changes in outcomes of the smallholders receiving the intervention (the experimental groups) to average changes in outcomes of smallholders not receiving it (the control group). The pooled effect size measures the average number of standard deviation changes in the respective food security and economic outcomes of experimental groups over control groups. The 95 confidence interval indicates the likely range of the effect sizes across different contexts. In the text, we have further converted effect sizes into percentage changes to allow for a less abstract reflection of the changes in outcomes.

[7] See Table A1 for a summary of the characteristics of included studies.

5.1 Agricultural input innovations

5.1.1 Effects on food security

We identified six studies that investigated the effects of input innovation – such as introducing new agricultural products –on food security. Each of these studies assessed nutritional outcomes as an indicator of changes in food security, and measured them with comparable instruments. Four of the six studies assessed serum retinol concentration as a proxy for smallholders' nutritional status in South Africa (Faber *et al. 2*002), Mozambique (Low *et al. 2*007; Hotz *et al. 2*012b) and Uganda (Hotz *et al.* 2012a); one in Kenya (Hagenimana *et al*. 1999) observed vitamin A intake; and another in Ethiopia (Akalu *et al*. 2010) examined anthropometric measures such as weight-for-age.

The meta-analysis suggests that agricultural input innovations, such as the introduction of bio-fortified varieties of staple crops, might lead to big improvements in smallholder farmers' food security. The pooled effect size of 0.71 is equivalent to a 33.2 percent increase in vitamin A levels for smallholders who received the input innovations compared to those who did not. But the small number of studies and the nutrition-focused outcome measures caution against extensive claims of the interventions' positive effects on farmers' overall food security. We controlled for the identified large degree of heterogeneity within the included evidence using sensitivity and moderator analysis.

Five of the six studies introduced orange flesh sweet potatoes – a vitamin A-rich staple crop –in South Africa (Faber *et al.* 2002), Mozambique (Low *et al.* 2007; Hotz *et al.* 2012b), Kenya (Hagenimana *et al.* 2009) and Uganda (Hotz *et al.* 2012a), making this the dominant programme approach in east and southern Africa. These sweet potatoes programmes seem to have achieved proof of concept and there is evidence of scale up. Low *et al.* (2007), for example, evaluated a successful pilot that developed into the Harvest Plus programmes. More than 10,000 farmers took part in the Harvest Plus programmes in Uganda and Mozambique (Hotz *et al.* 2012a and 2012b).

The meta-analysis found a large positive effect of programmes introducing orange flesh sweet potatoes on farmers' food security. The effect size of 0.86 translates into an increase of 39.8 percent in vitamin A levels among participating farmers. Based on this limited, but relatively high quality, sample of studies, we see some promise for orange flesh sweet potatoes interventions to improve farming households' vitamin A intake and support their overall food security.

With the above caveats in mind, we conclude that there may be large increases in smallholders' food security from input innovations. These increases are robust to sensitivity analysis. All reviewed input innovations facilitated the introduction of two bio fortified staple crops: orange flesh sweet potatoes as a vitamin A-rich crop and quality protein maize as a protein-rich staple. Analysing orange flesh sweet potatoes interventions separately increases the magnitude of the overall effect size.

5.1.2 Effects on economic outcomes

We identified only three studies that investigated the effects of agricultural input innovations on smallholder farmers' income. The meta-analysis of the three studies in South Africa (Hofs *et al*. *2*006), Tanzania (Bulte *et al*. *2*014) and Uganda (Matsumoto *2*013) yields an overall

positive pooled effect size of 0.26. This represents a 12.4 percent change in the levels of income among smallholders receiving the input innovation.

But this finding is based on a small sample of evidence and we are therefore cautious to present this result as rigorous evidence of input innovations' positive effects on the income of smallholders. We also note that none of the studies measured income indicators empirically; instead they relied on modelling techniques to estimate income outcomes.

Two studies providing the most reliable evidence (Bulte *et al. 2*014; Matsumoto *2*013) identified the provision of higher-yielding and more drought-resistant maize varieties as an effective approach to increase smallholders' harvest and, presumably, their income. This offers some support for the hypothesis that input innovations also have the potential to improve farming households' economic outcomes.

5.2 Practice innovations

5.2.1 Effects on economic outcomes

The studies we reviewed did not report the statistical information we required to conduct a statistical analysis of agricultural practice innovations, or how programmes were facilitating a reorganisation of the way in which smallholders cultivate their farms.

We did identify two interventions that aimed to change the prevailing practice of subsistence agriculture. Two studies, both in Kenya (Wanyama *et al.* 2010 and Ashraf *et al.* 2008), reported that these programmes had a positive financial effect on farming households. In particular, Ashraf *et al.*'s randomised control trial of DrumNet's programme in Kenya provides reliable evidence of a 32 percent increase in household income for farmers switching to the production of export crops, while the programme was in operation.

5.2.2 Effects on food security

Our review identified only one study –on a participatory agriculture programme in Malawi (Bezner-Kerr *et al.* 2010) – that assessed the effects of agricultural practice innovations on food security. It was unable to identify any effects of the programme. With this single study, we were unable to make any general conclusions on the effects of practice innovations on food security among African smallholder farmers.

5.3 Technical input innovations

We did not identify any rigorous evidence assessing the effects of technical input innovations – like mechanical tools, irrigation or information and communication technology – on smallholder famers' level of economic outcomes or food security.

5.4 Training interventions

5.4.1 Effects on economic outcomes

We identified five studies that evaluated the effects of training interventions on African smallholders' levels of income. Within these, three programmes made use of a farmer field school approach in Kenya (Waarts *et al*. 2012), Tanzania and Uganda (Davis *et al*. 2011); one applied an agricultural extension approach (Benin *et al* 2011); and the other provided agricultural guidebooks to farmers (Kijima 2014). We measured income outcomes as the revenue farmers would have gained through their increased harvests.

Overall, the meta-analysis found no overall effect of training interventions on farmers' income. Furthermore, the evidence suggests that top-down agricultural extension is not effective. However, bottom-up participatory training methods such as farmer field schools may help improve farmers' income. We estimate that participatory training through farmer field schools leads to an increase in income of 35 percent.[8]

5.4.2 Effects on food security

We did not identify any evidence assessing the effects of training interventions on smallholder farmers' food security.

5.5 Conclusion

Guided by the review's causal pathway, Figure 4 presents our assessment of the reported data against programme adoption, intermediate outcomes and final impacts.

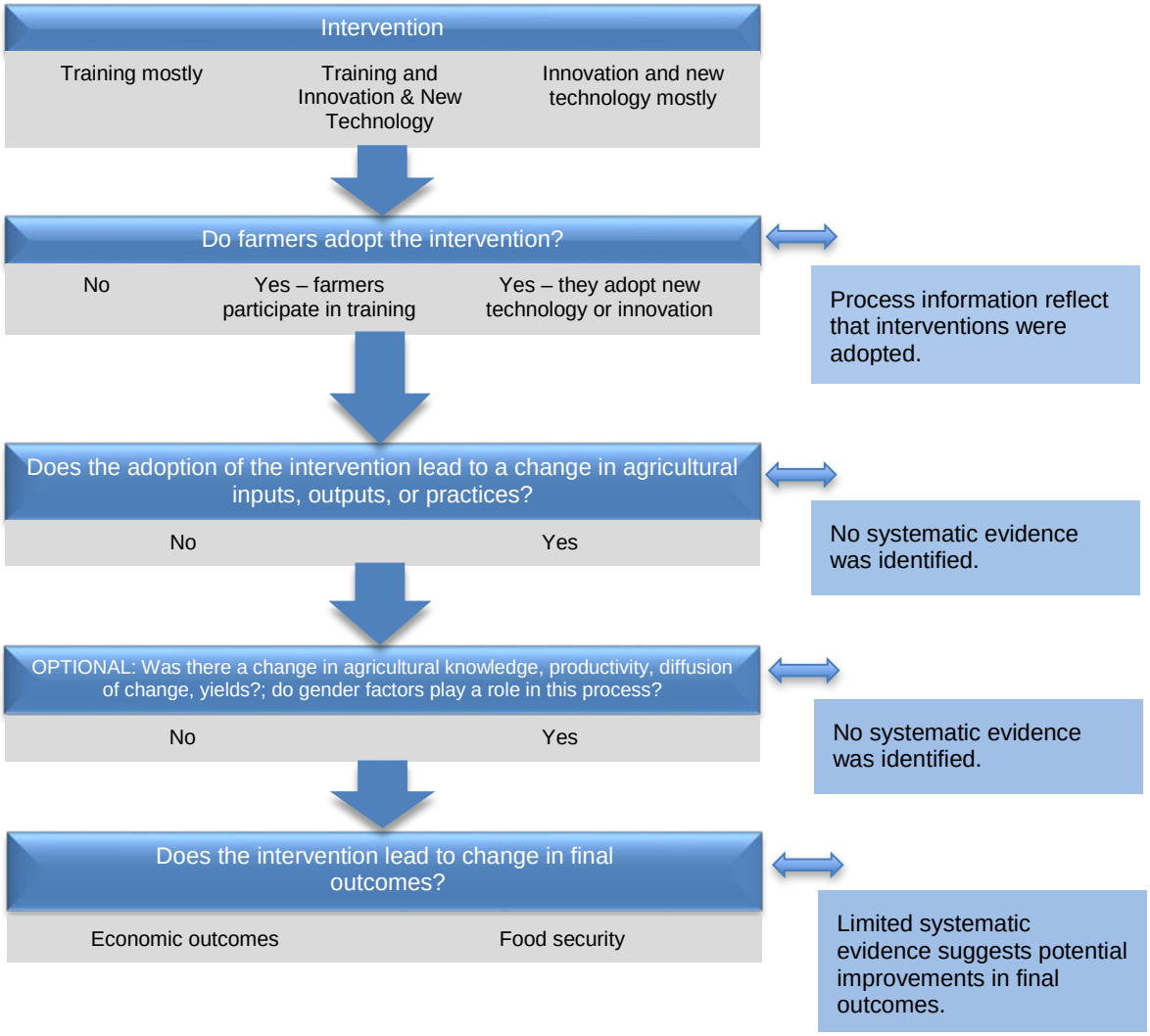
We caution against interpreting the significant meta-analysis results as conclusive evidence of the positive effects of the reviewed interventions on smallholder farmers' livelihoods in Africa. Important caveats to keep in mind include: the small number of included studies; the relatively few studies that we consider to provide reliable evidence of effects; and the heterogeneity of outcome measures used.

That said, it appears that agricultural input innovations using bio-fortification as a programme mechanism do hold promise for improving the food security of smallholder households. Introducing higher-yielding, more drought-resistant crop varieties might further increase household income. Training programmes do not seem to improve farmers' incomes, particularly when they are delivered using top-down methods such as traditional agricultural extension.

Of the reviewed interventions, orange flesh sweet potatoes presented the largest potential improvements in outcomes. But we also believe that, despite the thin evidence base, overall, bottom-up training, innovation and new technology interventions hold potential to support smallholder farmers in Africa.

[8] This is based on a meta-analysis of four studies in Kenya (Davis *et al*. 2011), Tanzania (Davis *et al*. 2011), Ethiopia (Todo and Takahashi 2011) and Kenya (Waarts *et al*. 2012), measuring the proportionate change in outcomes in the intervention group over the comparison group.

Figure 4: Annotated causal pathway



Source: Stewart *et al.*, 2016

6. Implications

6.1 Implications for policy and practice

The limited identified evidence does not allow for the formulation of specific policy implications, as we did not identify sufficient research to compare different programme and policy designs against each another. The synthesised evidence suggests that training, innovation and new technology interventions to support smallholder farmers in Africa have the potential to improve income and food security.

Policymakers in African countries and development organisations can use this finding to sustain the already increased focus on smallholder farming as a central aspect of the rural development process. Investment in smallholder farming interventions appears to be a promising approach to reduce rural poverty. In particular, this systematic review establishes that there is evidence that:

- Agricultural input innovations, most significantly orange flesh sweet potatoes, have the potential to lead to improvements in farming households' levels of food security;
- Training interventions that use bottom-up delivery methods (such as farmer field schools) might be able to contribute to improvements in farming households' income levels; and
- Innovation, new technology and bottom-up training approaches present an acceptable and feasible programme approach to support small-scale farmers in Africa.

We did not find enough evidence to help us ascertain that:

- Agricultural practice innovations have an effect on smallholder farmers' income or food security levels;
- Technical input innovations have an effect on smallholder farmers' income or food security levels;
- Training interventions have an effect on smallholder farmers' food security levels;
- Smallholder farming interventions have effective or sustainable long-term effects; and
- Smallholder farming interventions cause harm to farmers or their communities.

6.2 Implications for future research

We have to issue a strong call for improved research designs when evaluating the effects of smallholder farming interventions in Africa. Although we identified a large number of research studies, we could not include most of this evidence because the studies had not applied a prospective research design. The recent increase in funding for smallholder farming interventions might yield more effective results if accompanied by a similar increase in funds for the rigorous evaluation of these interventions. Longer follow-up periods and more standardised outcome measures would also enable better synthesis work.

We identified a common practice across the reviewed evidence to extrapolate results measured in surrogate outcome constructs to make conclusions on final outcomes. Studies assessing smallholders' economic outcomes almost exclusively modelled and projected changes in household income based on the presumed revenue farmers could have gained from selling their increased harvests. These outcome constructs – while based on sophisticated economic models that factor in household labour, for example – are

nevertheless based on the strong assumption that farmers have effective market access and bargaining power. Future research could benefit from aiming to observe changes in household income with the help of more empirical outcome constructs.

Additional research syntheses into the effects of smallholder farming interventions is available (Waddington *et al.* 2014) or forthcoming (Dorward *et al.* 2013). At this stage, we believe that funding primary evidence gathering will give a greater return on investment. We also recommend updating the systematic map produced during the inception phase of this review (Stewart *et al.* 2015) to include it in 3ie's evidence gap map programme, which only launched in late 2014, to enable access by researchers and policy makers to the available studies.

Appendix A: Details of included studies

The methodology we applied in this systematic review was published in a review protocol prior to conducting the full review (Stewart *et al.* 2014b). The full review is available at: www.campbellcollaboration.org/lib/project/310

Table A1: Characteristics of included studies

	Study details			Intervention details			Outcome details	
	Design/ comparison	*Risk of bias*	*N*	*Country*	*Population*	*Intervention/ sub-category*	*Outcome and measures*	*Findings and effect size*
[1] Akalu *et al.*(2010)	Cluster randomised control trial (RCT) *Quality protein maize vs conventional maize* Completely randomised trial: *Quality protein maize vs conventional maize*	Low	362	Ethiopia	Rural households with children aged 12 months +	*Innovation and new technology* *Product innovation; biological and chemical* Quality protein maize (biofortification)	*Food security* *Other* Anthropometric measures: *WAZ and /or HAZ*	*For Cluster RCT*: A 0.05 increase in height for age (HAZ); A 0.2 increase in weight for age (WAZ) *For completely randomised trials*: A0.13 increase in HAZ A 0.13 increase in WAZ
[2] Ashraf *et al*. (2008)	Cluster RCT *Full treatment vs no treatment* *Full treatmentvs no credit*	Low	1,117	Kenya	Farmers from self-help groups in Gichugu division, Kirinyaga district	*Innovation and new technology* *Product innovation; agronomic* Horticultural exports: French beans, baby corn and passion fruits Better access to credit linkages to retailers, transportation services and exporters	*Financial wealth* *Household income* Household income log Values of harvested produce in KShs 1000 Deposit in formal institutions	Increased production of export crops, reduced marketing costs, resulting into increased household income. More effective for first-time adopters No difference between credit and non-credit Full treatment: 0.087 (SE 0.11) [household income] 4.883 (6.269) [value in Kenyan shillings (KSh)[9]] 0.07 (0.036) [deposits] Partial treatment: 0.162 (SE 0.119) [household income]

[9] US$1 = KSh70 (2008).

	Study details			Intervention details			Outcome details	
	Design/ comparison	*Risk of bias*	*N*	*Country*	*Population*	*Intervention/ sub-category*	*Outcome and measures*	*Findings and effect size*
								7.338 (SE 6.175) [value in KSh] 0.062 (SE 0.037) [deposits]
(3) Bulte *et al.* (2014)	RCT Two trials: open RCT and blinded RCT *New vs traditional cowpeas*	Low	583	Tanzania	Farmers in Mikese, Morogoro region	*Innovation and new technology* *Product innovation; biological and chemical* New cowpeas with a higher yield	*Financial wealth* *Other* Yields and/or harvest measured in kg	New seeds resulted in a higher harvest Open RCT: yield in seeds per kg/m^2 increased by 0.024 kg/m^2 Blinded RCT: Yield in seeds per kg/m^2 increased by 0.015 kg/m^2
(4) Hotz *et al.* (2012a)	RCT (regression) *Reduced vs control programme* *Reduced vs intensive programme*	Low	3,246	Uganda	Households that were part of community-based farmer groups in rural villages	*Innovation and new technology* *Product innovation; biological and chemical* Orange sweet Potatoes Information or growing techniques Health benefits of vitamin A	*Food security* *Other* Serum retinol (vitamin A) concentration Vitamin A intake Dietary intake measures	Eating more orange sweet potatoes led to increased vitamin A intake in children aged 5–35 months No difference between intensive and reduced programmes Beta-carotene levels in milli grams per day among children aged 6–36 months increased by 2.09 (SE 0.51) in the reduced programme and 1.65 (SE 0.45) in the intensive programme
(5) Hotz *et al.* (2012b)	RCT (regression) *Reduced vs control programme* *Reduced vs intensive programme*	Low	10,800	Mozambique	Women and children in rural communities of Zambezia province	*Innovation and new technology* *Product innovation; biological and chemical* Orange sweet potatoes Information or growing techniques	*Food security* *Other* Serum retinol (vitamin A) concentration Vitamin A intake Dietary intake measures	Eating more orange sweet potatoes resulted in increase in vitamin A intake in children aged 5–35 months No difference between intensive and reduced programmes Effect size (ES): vitamin A intake in micro-gram retinol activity equivalents per

	Study details			Intervention details			Outcome details	
	Design/ comparison	*Risk of bias*	*N*	*Country*	*Population*	*Intervention/ sub-category*	*Outcome and measures*	*Findings and effect size*
						Health benefits of Vitamin A		day increased by 280.6 (SE 74.0) in the reduced programme and by 222.7 (SE 76.6) in the intensive programme
(6) Kijima (2014)	RCT: controlled trial randomised at the individual farmer Resource book training vs no training	Low	570	Uganda	Randomly selected practicing farmers in villages part of the national extension programme	*Training* - Agricultural Guide Book	*Economic outcomes*– *Household income measured in $ price of yields per ha* *Intermediate: Yields (kg/ha)*	No changes in HH income SDM: +0.02 (--0.14, 0.19) Increased adoption of rice cultivation
(7) Low *et al.* (2007)	Quasi-experimental, prospective, controlled and longitudinal *Orange flesh sweet potatoes vs no treatment (which means they received vitamin A capsules)*	Low	741	Mozambique	Children in farmer households in three districts: Mopeia, Namacurra and Nicoadala	*Innovation and new technology* *Product innovation; biological and chemical* Orange sweet Potatoes	*Food security* *Other* Vitamin A levels (serum retinol) WAZ/HAZ Food intake	Integrated promotion of orange flesh sweet potatoes can complement other approaches and contribute to increases in vitamin A intake and serum retinol concentrations in young children in rural Mozambique and similar areas in sub-Saharan Africa. ES: Serum retinol increased by 0.074 (SE 0.020) between groups
(8) Matsumoto (2013)	RCT: controlled trial randomised at household level Hybrid maize vs no inputs	Low	639	Uganda	Farming households randomly selected within villages participating in the RePEAT programme	*Innovation & New Technology* *- Product Innovation / Biological & Chemical* Improved hybrid maize seeds, base fertilizer, top-dressing fertilizer	*Economic outcomes* *-Household income as measured by median price of yields* *Intermediate: Yields (kg/ha)* *Demand measured as input purchase during commercial sale*	Increased HH income SDM: SDM: +0.33 (0.11, 0.56) Increased Demand for fertilizer but not for hybrid seeds

	Study details			Intervention details			Outcome details	
	Design/ comparison	*Risk of bias*	*N*	*Country*	*Population*	*Intervention/ sub-category*	*Outcome and measures*	*Findings and effect size*
(9) Todo and Takahashi (2011)	Quasi-experimental design, prospective, controlled *Participation vs non-participation in farmer field schools*	Low	1,328	Ethiopi	Farmers from one of the 30 villages or 80 sub-villages in Gera district, and 14 villages and 46 sub-villages in Shabe Sombo district	*Training* *Farmer field schools* Forest management: learned new agricultural technologies and practices, such as farm management, seedbed preparation, proper spacing, new varieties and sowing methods	*Financial wealth* *Household income* Income measured in US$ Agricultural practices	Participation in farmer field schools leads to higher incomes and adoption of new practices Agricultural households participating in the farmer field schools increased their real income per worker by an average of US$60–160 s in two years
(10) Davis *et al.* (2010)	*Quasi-experimental design; controlled and matched from baseline [PSM] Participation in farmer field schools vs Nonparticipation (PSM)*	Moderate	1,125	Uganda, Kenya, Tanzania	Farming households randomly selected within villages participating in the IFAD-FAO farmer field schools (FFS) project	*Training* *- Farmer field schools* Integrated Production & Pest Management [IPPM]	*Economic outcomes - Agricultural income (Value of harvest in local currency)* *Intermediate* *Productivity (value of production per unit area)* *Empowerment (sub-group analysis impact on female farmers)*	Productivity increased by 31% in the combined sample; Income increased by 62% in the combined sample. Different effects for female farmers, and farmers located closer to the main road.
(11) Waarts *et al.* (2012)	*Quasi-experimental, prospective, controlled Participation in farmer field schools vs non-participation Participation in farmer field schools vs*	Moderate	356	Kenya	Tea-producing farmers that provide green leaf tea to four Kenya Tea Development Agency factories	*Training* *Farmer field schools* Training on tea production methods, empowerment and diversification	*Financial wealth* *Household income* Income calculated on yields and production factors Yields Agricultural practices	Improved income, based on yields and production factors Improved production practice Measures of livelihood perceptions *Farmer field schools:* Net income from tea production increased by KSh11,300

	Study details			Intervention details			Outcome details	
	Design/ comparison	*Risk of bias*	*N*	*Country*	*Population*	*Intervention/ sub-category*	*Outcome and measures*	*Findings and effect size*
	participation in RA training						Agricultural knowledge	Output input ratios increased by 3.77 Agricultural knowledge increased by 0.12 *FFS+RA:* Net income from tea production increased by KSh8,800. Output input ratios increased by 7.43 Agricultural knowledge increased by 0.71
(12) Benin (2011)	Cross-sectional, retrospective and constructed **control** *Participation vs non-participation in training* Sub-group analysis for distance (indirect benefits)	Serious	894	Ugand	Households that belong to farmer groups in Ugandan villages	*Training* *Other* National Agricultural Advisory Services (NAADS)	*Financial wealth* *Household income* Income estimated as value of crops per household members Household assets Adoption of technology	NAADS programme has had significant positive impact on agricultural revenue. Any form of participation is associated with an average increase of 32–63% in agricultural revenue per AE between 2004 and 2007
(13) Bezner-Kerr *et al.* (2010)	Quasi-experimental, prospective, matched-control and phase-in *Participatory vs conventional agriculture and nutrition*	Serious	3,838	Malawi	Children in farmer households in a rural village in northern Malawi	*Innovation and new technology* *Process innovation* Participatory agriculture (including the introduction of new crops) *Training:* Nutrition education	*Food security* *Other* WAZ and HAZ	Long-term efforts to improve child nutrition through participatory agricultural interventions has had a significant effect on child growth ES: WAZ increased by 0.102 HAZ increased by 0.228

	Study details			Intervention details			Outcome details	
	Design/ comparison	*Risk of bias*	*N*	*Country*	*Population*	*Intervention/ sub-category*	*Outcome and measures*	*Findings and effect size*
(14) Faber *et al.*(2002)	Quasi-experimental, prospective and controlled: *Home gardens vs no home gardens*	Serious	164	South Africa	Children in farmer households in Ndunakazi village, KwaZulu Natal	*Innovation and new technology* *Process innovation; product Innovation* Home gardens New vegetables grown in home gardens	*Food security* *Other* Serum retinol concentration Food consumption	Vitamin A intake increased ES: serum retinol concentration increased by 0.15 moles per litre
(15) Hagenimana *et al.* (1999)	Quasi-experimental, prospective and controlled: *Orange flesh sweet potatoes vs no treatment*	Serious	163	Kenya	Women's groups in two districts: Ndhiwa/Nyarongi and Rongo	*Innovation and new technology* *Product innovation; biological and chemical* Orange sweet potatoes (Heath and nutrition training also provided)	*Food security* *Other* Food frequency Vitamin A consumption (Helen Keller International scale)	Increases the frequency of vitamin A consumption ES: Number of days eating vitamin A–rich foods increased by 1.3
(16) Hofs *et al.*(2006) [* participant numbers represent households, not individuals]	Quasi-experimental, prospective, controlled *Insecticide vs noinsecticide*	Serious	20 *	South Africa	Cotton farmers n Makathini, KwaZulu Natal	*Innovation and new technology* *Product innovation; agronomic* Bt cotton Insecticide use	*Financial wealth* *Other* Relative cost-effectiveness Yields	New pesticide use increases income ES: Non-Bt farmers paid ZAR168.5[10] more for cotton protection
(17) Wanyama *et al* (2010)	Quasi-experimental, prospective and controlled *Programme participants vs non-participants*	Serious	192	Kenya	Farmers in Matunda in Trans-Nzoia and Chobosta in Uasin Gishu	*Innovation and new technology* *Biological and chemical; agronomic* Integrated soil fertility management technologies *Training*	*Financial wealth* *Other* Yield Social capital Food security Poverty status	The project had a positive impact in terms improving food availability, enhanced human and social capital accumulation ES: Increase in the yield of maize by 3.1 90 kg bags per acre of maize Decrease in the number of 90 kg bags of beans by

[10]US dollar – South African rand exchange rate: US$1= ZAR7 (June 2006).

	Study details			Intervention details			Outcome details	
	Design/ comparison	*Risk of bias*	*N*	*Country*	*Population*	*Intervention/ sub-category*	*Outcome and measures*	*Findings and effect size*
						Not discussed in paper		--0.21 bags per acre Increase in the yield of sweet potatoes by 5.7 90 kg bags per acre
(18) Burney *et al.* (2010) [* participant numbers represent households, not individuals]	Quasi-experimental, prospective and matched control *Solar-powered drip irrigation vs conventional practice*	Critical	115*	Benin	Farmers in rural northern Benin and the Sudano-Sahel	*Innovation and new technology* *Mechanical* Solar-powered drip irrigation	*Food security* *Household food consumption* Food availability (kilograms) Additional Food intake (grams) Survey of frequency of not meeting food needs Household food consumption expenditure	Food security increases Household food consumption expenditure increases ES: The percentage of non-projects members below poverty line (living on less than US$1.25 a day) increased from 73% to 89% Among project households, the figure remained constant at 85% Project beneficiaries were 17% less likely to feel chronically food insecure than non-project members
(19) Terry (2012) [* participant numbers represent households, not individuals]	Quasi-experimental, prospective and controlled *Access vs no-access to technologies*	Critical	154*	Swazil and	Farmers in the Komathi and Usuthu valleys	*Innovation and new technology* *Mechanical; biological and chemical* Green	*Financial wealth* *Household income* Household income (average US$ per capita) Wealth indicators Household food expenditure	Political rent-seeking occurred and intervention cannot be disentangled from that ES: Project members reported an increase in household assets. The quantity of this change is not available in the paper. Project members reported that they could afford to pay the fees for better schools, compared to non-members.

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The majority of people living in economic poverty in rural Africa engage in smallholder farming. Though the Green Revolution rapidly improved social and economic livelihoods in other former developing regions, innovative farming practices have not been implemented as widely in Africa. Supporting smallholder agriculture through training, innovations and new technology has the potential to improve households' food security and boost rural economies. This report is based on a systematic review that synthesises evidence on the effects of these interventions on African smallholder farmers' income, assets and food security. There is tentative evidence that agricultural input innovations may increase the nutritional status of farming households and, to a lesser degree, the monetary value of farmers' harvests. There is also evidence that bottom-up training interventions may be able to improve farmers' income levels.

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