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Socioeconomic Impacts of Land Restoration in Agriculture: A Systematic Review

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Stefan van der Esch[1]

Socioeconomic Impacts of Land Restoration in Agriculture: A Systematic Review

Abstract

At the onset of the United Nations' decade of ecosystem restoration, lessons from well-designed impact evaluations on land restoration programs are crucial for improving policymaking. This study presents findings from a systematic review of research on the socioeconomic impact of such interventions, namely within agroforestry, conservation agriculture, integrated soil fertility management and soil and water conservation. We focus on identifying rigorous impact assessments, and after careful methodological assessment select only 29 relevant publications. We identify three key knowledge gaps. First, we retained no studies on agroforestry, suggesting a need for impact evaluations in this domain. Second, most studies look solely at farm-level outcomes instead of socioeconomic outcomes. Third, two-thirds of studies report positive on farm- or socioeconomic outcomes, but impact does not appear ubiquitous and may emerge under certain circumstances only. Overall, we conclude that there is a lack of well-designed impact assessments in this field. Promises on land restoration leading to improvements in the socioeconomic situation of households cannot yet be backed up by existing studies and it remains unclear which interventions work under which conditions.

JEL-Codes: O13, O33, Q15, Q24, Q32

Keywords: Land restoration; systematic review; impact evaluation; rural development

June 2022

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1 Mandy Malan, Development Economics Group, Wageningen University and Research, and RWI; Ezra Berkhout, PBL - Netherlands Environmental Assessment Agency; Jan Duchoslav, International Food Policy Research Institute; Maarten Voors, Development Economics Group, Wageningen University and Research; and Stefan van der Esch, PBL - Netherlands Environmental Assessment Agency. *- We would like to thank Willem Verhagen (PBL) for help with compiling the list of keywords on land restoration interventions. For their support in gathering the studies under review, we would like to thank Dewy Verhoeven, Frank Koot and Joanne Rink (WUR). We would like to thank Emily Schmidt (IFPRI) for reviewing our final selection of studies. Finally, for creating some of the graphs of this study, we would like to thank Filip de Blois (PBL). - PBL Netherlands Environmental Assessment Agency received funding from the Netherlands Ministry of Infrastructure and Environment, Economic Affairs and Ministry of Foreign Affairs to conduct policy research supporting the activities of the United Nations Convention to Combat Desertification (UNCCD). PBL, in turn, used part of this funding to support the involved researchers at Wageningen University and Research (WUR) and the International Institute of Food Policy Research (IFPRI). This research was jointly designed and conducted by the involved researchers at PBL, WUR and IFPRI. We declare no competing interests. Neither the funders, nor UNCCD, had a role in the study design, data collection, data analysis, data interpretation, or writing.* *– All correspondence to: Ezra Berkhout, PBL - Netherlands Environmental Assessment Agency, Netherland, e-mail: ezra.berkhout@wur.nl*

1. Introduction

Land degradation is a significant obstacle to agricultural productivity and can lead to local declines in agricultural production if unaddressed (UNCCD 2017; FAO 2020; Van der Esch, Sewell et al. 2022). Reversing land degradation and restoring land and soils is essential for a long term sustainable food system and feeding growing populations while conserving biodiversity and limiting agriculture's impact on climate change (Tilman, Balzer et al. 2011; Alexandratos and Bruinsma 2012). Land degradation – the loss of soils, nutrients and water holding capacity – is typically caused by soil nutrient mining, erosion, loss of vegetative cover, or a combination of these, and affects between 15% and 75% of global landmass (depending on assumptions made and on the method of estimation, see Van der Esch et al. (2022) for an overview). The economic loss resulting from land degradation is estimated to amount to at least US$ 15 billion, or 0.07 % of annual global GDP (Nkonya, Anderson et al. 2016). Land restoration encompasses the improvement of natural ecosystems and the rehabilitation and sustainable management of lands under human use. Applying land restoration measures in agriculture is therefore synonymous to preventing, wholly or partially, further land degradation. Restoration measures are thus often similar to sustainable land management measures.

The need to combat land degradation and to invest in land restoration is quickly rising on policy agendas. The UN Decade on Ecosystem Restoration aims to mainstream land restoration in policies and investments. Existing commitments to restore or rehabilitate land by countries under the Rio Conventions and the Bonn Challenge add up to between 0.8 to 1 billion hectares, with almost half of these commitments made by Sub-Saharan countries (Sewell et al., 2020). Several initiatives aim to upscale land restoration, such as the Bonn Challenge, AFR100, and Initiative 20x20. In the EU, a proposal is expected by the European Commission with legally binding targets on nature restoration. The investment that would be required to implement the current restoration commitments by countries is estimated between US$ 300 and 1,700 billion (Verhoeven, Sewell et al. submitted).

Clearly, there is no shortage of ambitious plans, but the potentially high investments required for land restoration warrant a closer inspection of their expected benefits. Many of these will be public goods related to water management, biodiversity conservation and carbon sequestration (Roe, Streck et al. 2019; Pretty, Benton et al. 2018; Pretty 2018; Barbier and Hochard 2018; IPBES 2018; Navarro, Marques et al. 2017), but the projected private benefits to local stakeholders – enhanced resilience and productivity of agriculture, livestock and forestry – are often the selling point. Whether, when and where these benefits will materialize unfortunately remains an open question. At the onset of the decade of restoration (UNEP and FAO 2020), such knowledge is imperative. This systematic review aims to fill this void.

We assess the impact of land restoration practices in the agricultural domain on farm households, with a focus on four of the most common interventions (Pandit, Parrota et al. 2018): 1) soil and water conservation (SWC), 2) integrated soil fertility management (ISFM), 3) conservation agriculture (CA), and 4) agroforestry (AF).

There is substantial evidence from agronomic (often researcher-managed) trials, that land restoration interventions improve crop yields and reduce soil degradation (Droppelmann, Snapp et al. 2017, Brouder and Gomez-Macpherson 2014; Corbeels, Sakyi et al. 2014). However, there is less evidence available on whether these interventions also improve farming outcomes under farmer-managed conditions. Even more so, whether they also improve aspects of economic wellbeing such as household income and food security is poorly understood (Barbier and Hochard 2018; Prince, Von Maltitz et al. 2018). An aggregate positive impact is by no means guaranteed. First, the impact of some of the interventions on crop yields is strongly heterogeneous, as documented, for instance, in the case of conservation agriculture (Brouder and Gomez-Macpherson 2014). Moreover, many studies take only a partial view on income derived from a specific crop or land restoration method. Studies rarely control for possible reallocations of productive inputs, such as labor, across household activities and the aggregate effect on income. Such reallocations may explain why some promising sustainable agricultural technologies do not alter aggregate income (e.g. Takahashi and Barrett 2013), despite increases in crop-yields.

Because of this potential discrepancy between agronomic trials and the on-farm reality, we purposely move away from agronomic trials and focus solely on studies that investigate interventions under farmer-managed conditions. We further make a distinction between farming outcomes, such as crop yield and crop income, and aggregate socioeconomic outcomes such as household income and food security.

We seek to identify those rigorous studies that make the strongest case that observed changes in outcome indicators are *caused* by land restoration methods, and not simply correlated with them (when, for instance, wealthier households are more likely to adopt conservation and restoration methods). To that end, we follow the methodologies put forward by the International Initiative to Impact Evaluation (3ie) and Campbell Collaboration (e.g. Waddington, White et al. 2012) in this review.

Despite long-term promotion of land restoration methods, we identify just 29 relevant studies that meet the quality criteria. Together these studies assess impact for 35 combinations of an intervention and outcome indicators, although only six document impact on socioeconomic indicators such as income, poverty and food security. We find positive impacts for two-thirds of the interventions. For the remaining studies, impact is negative or not significantly different from zero. These findings resonate with similar systematic reviews in the agricultural domain[1] which suggest that private benefits from land restoration cannot be assumed as given, and that considerable variation exists across the type of restoration method and localities.

In the next section, we discuss the methods underlying this systematic review. Section 3 presents a quantitative descriptive analysis of the characteristics of the studies followed by an in-depth qualitative assessment. Section 4 concludes.

2. Methods

Below we describe the strategy used to identify, evaluate and analyze relevant studies on land restoration. First, we describe the database search, screening process and risk of bias assessment. Figure 1 provides an overview of the steps and papers retained at each step. Our final list contains 29 low and medium risk studies, of which we analyze the results below.

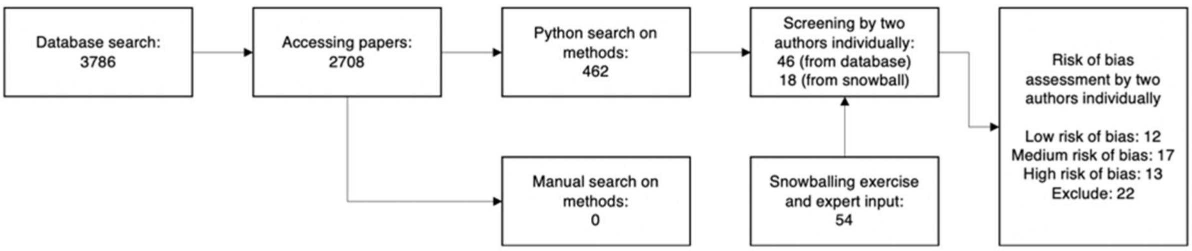

Figure 1. Flow diagram of systematic review process

2.1. Database search

The database search is based on a list of four sets of keywords associated with land restoration: 1) the processes that underlie land degradation, 2) the general aspects of sustainable land management, 3) specific land restoration approaches, and 4) modes of technological transfer and dissemination. We include several keywords (see Table 1) capturing distinct elements of each land restoration approach relating soil and water conservation structures (SWC), integrated soil fertility management practices (ISFM), conservation agriculture practices (CA) and agroforestry practices (AF).[2] For detailed insights on the agronomic principles underpinning these practices,

[1] See recent reviews on improvements in land tenure (Lawry, Samii et al. 2016; Higgins, Balint, H. Liversage and P. Winters et al. 2018), promoting farmer field schools (Waddington, Snilstveit, et al. 2014), and agricultural input subsidies (Hemming, Chirwa et al. (2018).

[2] As part of the process, we asked several experts to review these terms for correctness and completeness.

and how these improve productivity, see e.g. Vanlauwe, Bationo et al. 2010; Farooq and Siddique 2014; Adimassu, Langan et al. 2017; Nair, Kumar et al. 2021; and references therein.

Table 1: Keywords used in the structured literature searches

<table>
<tr><th></th><th colspan="2">Topic</th><th>Keywords</th></tr>
<tr><td>1</td><td colspan="2">Underlying processes on degradation</td><td>Land clearing; Erosion; Soil crusting; Soil compaction; Soil sealing; Nutrient depletion; Soil contamination; Soil organic matter loss</td></tr>
<tr><td>2</td><td colspan="2">General aspects of sustainable land management</td><td>Soil improvement; Sustainable Land Management; Agro-ecological farming practices; Soil management; Soil and water conservation; Agricultural soil; Sustainable intensification</td></tr>
<tr><td rowspan="4">3</td><td rowspan="4">Specific land restoration approaches</td><td>Construction of soil and water conservation structures (SWC)</td><td>Terracing; Contour bunds; Zaï; Water use efficiency; Water harvesting</td></tr>
<tr><td>Integrated soil fertility management practices (ISFM)</td><td>Nutrient management; Crop rotation; Manure; Manuring/composting; Fertilizer/fertilization; Organic fertilizer; Organic amendment; biochar</td></tr>
<tr><td>Conservation agriculture practices (CA)</td><td>Reduced tillage; Zero tillage; Mulching; Residue retention; Residue management; Soil cover; Vegetative cover; Cover crops</td></tr>
<tr><td>Agroforestry practices (AF)</td><td>Parkland; Home gardens; Vegetative barriers; Improved fallow; (tree) intercropping</td></tr>
<tr><td>4</td><td colspan="2">Mode of technological transfer</td><td>Technology transfer; Agricultural extension; Innovation platform; Agricultural service delivery; Public service delivery; Farmer field school; Public-private partnership; Farmer cooperative</td></tr>
</table>

The keywords included in Table 1 form the basis for our search strategy. Using several databases, we search through all titles and abstracts for studies containing at least one keyword associated with the first three categories on land degradation and sustainable land management practices, and at least one keyword associated with the mode of technological transfer. This set-up ensures that we primarily identify studies that focus on farmer-managed adoption (instead of researcher managed trials) shaped by a clearly defined mode of extension. Moreover, it keeps the search strategy manageable as only searching on categories 1-3 would yield hundreds of thousands of publications. The full search strings used for each database are provided in the online Supplementary Section (Table A1).

The choice of which databases to include, was motivated by several pragmatic considerations: the database must be open access or available to one of the co-authors via an existing institutional subscription; it allows for advanced Boolean search using sufficiently long strings; and is able to export citation lists in bulk. Of the 26 databases originally considered, 12 met these criteria: AgEcon, AGRICOLA, Agris, ArticleFirst, CAB Abstracts, ECO, EconLit, GreenFile, OpenGrey, Scopus, SocIndex, and Web of Science.[3] Given the large number of databases included in the search, it is unlikely that we systematically missed out on key studies. In addition, we asked key experts to screen the final list of retained studies. The search yielded a total of 3,786 publications after removal of duplicates.

2.2. Screening and quality assurance

Screening on methods

Moving from the long list of potentially relevant publications, we further refine our search to select studies that use rigorous impact evaluation methods, including: Randomized Controlled Trials (RCTs) (or experiments), Regression Discontinuity, Difference-in-Differences (DiD), Instrumental Variable (IV), and Propensity Score Matching (PSM).

We use an automated screening script in Python (see Supplementary Section A3) to select studies that mention one of these methods. We first download all full-text PDFs of the studies. This step reduced the number of publications to 2,708, as the remainder either could not be accessed or found online or were not written in English. We then use the resulting PDFs as input for the automated screening process, involving four steps:

1) Extract text from PDF files and set aside PDFs that cannot be extracted.[4]
2) Write text (.txt) files and set aside the studies for which text files are empty or too small (due to failed extraction).[5]

[3] A list of consulted databases is included in the online Supplementary Section (Table A2).

[4] In order to parse through text files and search for use of one of the relevant methods, we had to convert PDFs to text files. For some of the PDF files, the text extraction function in Python failed because of how these files were rendered. The Python script is written in such a way that the studies that could not be extracted were set aside for manual screening.

[5] The text extraction process is not always perfect. Some PDFs cannot be converted to .txt successfully due to the way in which they are rendered (e.g. when papers are scanned files). To automatically flag papers that are not extracted successfully, we devise a rule that sets aside extracted text files of a size below 10.000 bytes. We manually screen these files.

3) Parse through text files and evaluate whether any of the methods are mentioned, using regular expressions.[6]
4) Select papers that mention any of the methods.

This automated process leaves us with 462 papers that mention any of the methods. In addition, 259 studies that are not extracted are manually screened on mentioning of the methods. Of those manually screened, none of the studies are relevant for this review.

Screening on relevance of intervention, outcomes, and methodology

We then conduct a manual screening on the relevance of the 462 papers in terms of the interventions and outcomes studied. In addition, we confirm whether the papers actually apply any of the impact evaluation methods. For each paper, this screening is carried out by two authors independently, using four criteria:

1) The study should focus on a relevant intervention (soil and water conservation structures, integrated soil fertility management, conservation agriculture, or agroforestry).
2) The study should have a relevant outcome (farm production, farm productivity, farm income, household income, food security, or poverty).
3) The study should use one of the pre-specified evaluation methods (RCT, RD, DiD, IV, PSM).
4) The study should not be an agronomic field trial.

We also exclude studies that assess the impact of input subsidies, which was reviewed in Hemming, et al. 2018. We do, however, retain studies that consider packaged interventions, possibly including input subsidies, that also include any of the four land degradation measures. After this step, we have a list of 46 studies.

Expert opinion and snowballing exercise

To be certain that we do not miss any important studies, the final list of papers is sent to several experts in the field, yielding two additional studies. We then conduct a final snowballing exercise for all high-quality studies, in which we scan through the reference list and select 52 studies that might be relevant. These are subsequently screened, as described in the previous section. Those selected for further review are assessed in terms of their risk of bias, as described below. The snowball exercise yields 18 additional studies, bringing the total to 64 studies.

[6] The regular expressions used to select papers methodologically relevant are : ‘randomized', 'randomised', 'RCT', 'difference in difference', 'difference-in-difference', 'dif-in-dif', 'dif in dif', 'double difference', 'regression discontinuity', 'RDD', 'propensity score', 'PSM', 'instrumental variable'.

Risk of bias

As a final step, for each study we assess the risk of bias, to assess internal validity of the evidence presented. We follow the tool proposed by Waddington, Snilstveit et al. (2014), in which each paper is assessed on four aspects: 1) selection bias, 2) spillovers, 3) reporting bias, 4) other sources of bias. For each of these, we follow a list of criteria to evaluate whether the paper has a low, medium, or high risk of bias. We then establish the overall risk of bias (low, medium, or high risk) (see Table A4 in the online Supplementary Section).

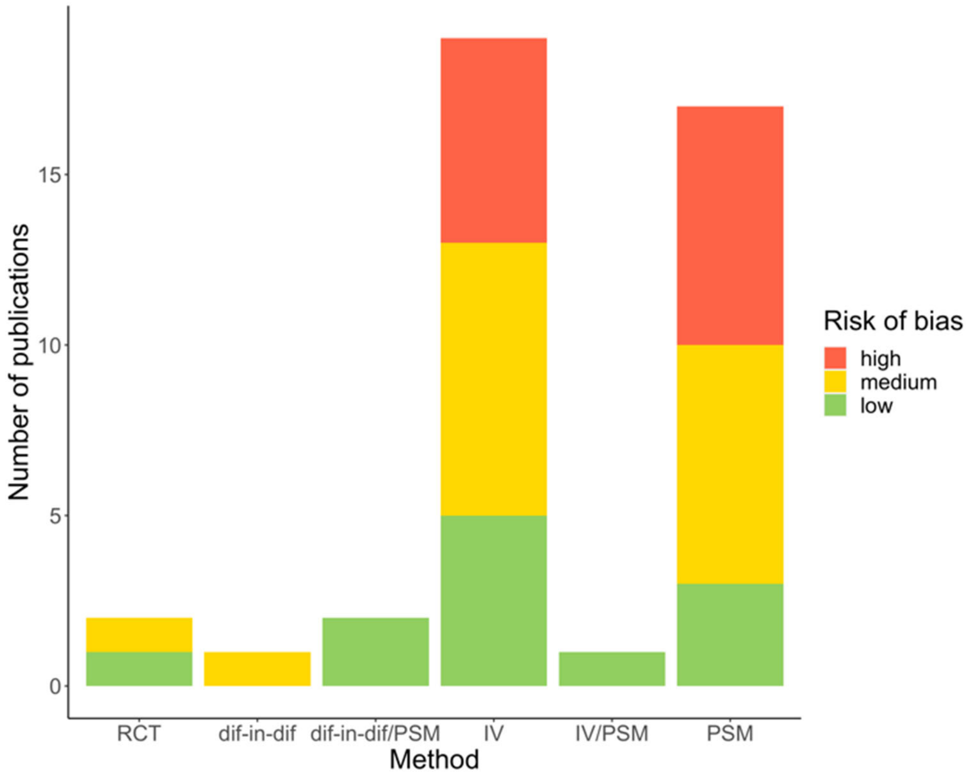

Figure 2: Methods and risk of bias

Notes: This figure shows the number of studies found per method. Methods are randomized controlled trials (RCT), difference-in-differences (dif-in-dif), instrumental variable (IV), and propensity score matching (PSM). In some studies methods are combined.

Each study is evaluated by one of the authors and checked by a second author. The study is evaluated by a third author if any disagreement occurs. Detailed outcomes of this evaluation are presented in the online Supplementary Section (Table A4) and summarized in Figure 2. We exclude 22 publications because they are not relevant in terms of interventions, outcomes or methods. Of the remaining 42 publications, 12 publications are assessed having a low risk of bias, 17 publications as having a medium risk of bias, and 13 publications as having a high risk of bias. For the subsequent review (Section 2.3) only the 29 studies with a low or medium risk of bias are considered. Studies with a high risk of bias often lack sufficient information on methodological choices in addition to incomplete result tables. All excluded studies use an IV or matching method. For IV-studies, the strength of the instrument is often not discussed, nor is a first stage regression always reported. In the matching studies, matching is often carried out on endline characteristics that could have been affected by participation in the program. None of the selected studies used RD methods.

Based on our experiences of applying the risk of bias tool (Waddington, Snilstveit et al. 2014) several issues are worth mentioning. Firstly, one of the criteria relates to the way studies deal with spillovers. This is irrelevant for most studies assessed (especially IV studies), we therefore sometimes score a study as having low risk of bias, even though spillovers are not explicitly discussed. Secondly, the risk of bias assessment tool does not penalize multiple hypothesis testing. However, many studies do present a large number of regressions and models. Relatedly, we suspect that there is a large chance of a publication bias, as many of the papers that we do find, show significant results. It is plausible, similar to other systematic reviews, that studies showing significant results are more likely to be published than studies that find null effects (Franco, Malhotra et al. 2014). Since we do not conduct a statistical meta-analysis (see Section 2.3), we also do not formally test for publication bias.

2.3. Analysis

We analyze the selected papers by summarizing some key characteristics of the studies (region, intervention type, and outcomes), and provide more in-depth qualitative discussion of the results, and interpretation of the results for each land restoration approach (following the approach of Higgins et al. 2018). The initial goal of this review was to synthesize the results by conducting a quantitative meta-analysis computing aggregate estimates of impact. But this turned out to be infeasible as either the data provided, or the research methods followed, in many studies are not apt for a formalized meta-analysis. Very few studies follow an experimental approach. Calculating aggregate effects requires a comparison group, which is not readily available. The latter (13 out of the total 29) studies are regression-based and include a number of control variables and interactions with the treatment variable, which makes it difficult to compare treatment effects across studies. Secondly, the quality of reporting for many studies is insufficient to extract the necessary data for doing a meta-analysis. Descriptive statistics are often missing, as are necessary p-values or t-statistics, and in some studies the sample size remains unclear. Lastly, as we will show later, the types of interventions and outcomes studied varied greatly, and we argue that computing standardized impact scores across such a diversity of land restoration practices obscures more information than it would yield.

3. Impact of land restoration

3.1. Quantitative descriptive assessment

Figure 3 summarizes the number of publications for each land restoration approach for each studied country. Close to all studies are conducted in Africa, with a regional focus on East Africa (Ethiopia, Kenya, Malawi, Tanzania and Zambia), and West Africa (Ghana and Nigeria). Research from other contexts is limited to three studies: a study on conservation agriculture (CA) done in Syria, a study on a package intervention in Honduras, and a study on integrated soil fertility management (ISFM) in India. There are no studies conducted in Latin America.

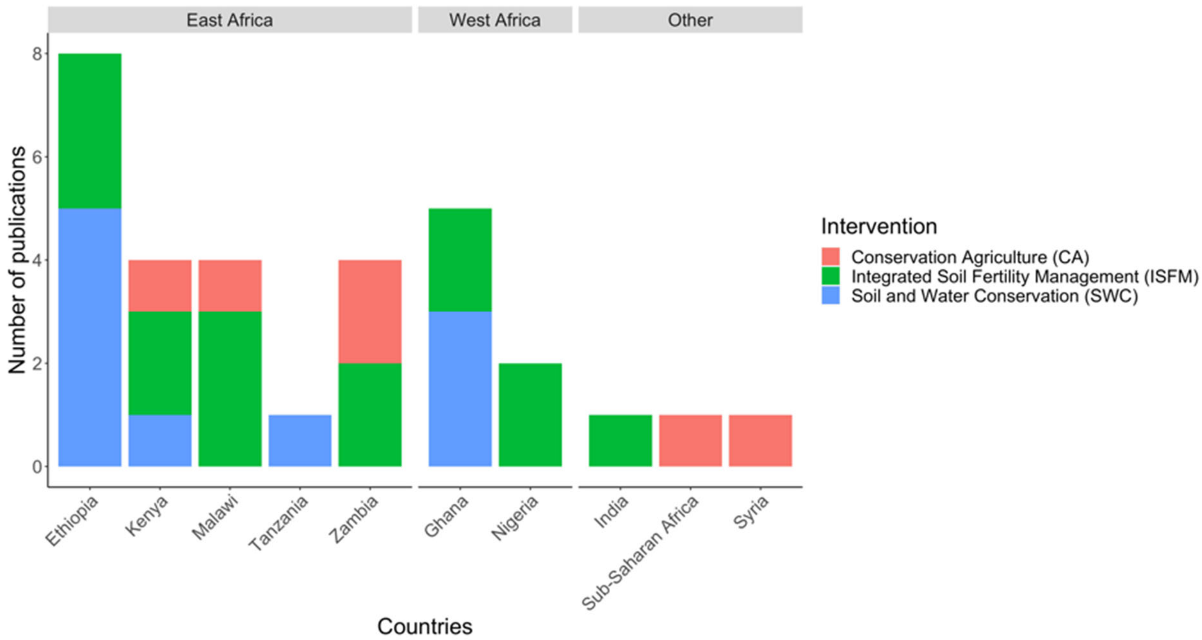

Figure 3: Number and types of studies by country

Notes: This figure shows the number of publications identified by country and region and colored by type of land degradation or restoration interventions. There were no publications found on Agroforestry.

There are also no studies with low and medium risk of bias on agroforestry (AF).[7] This is surprising given the widespread expectation that agroforestry is crucial for attaining some of the UN Sustainable Development Goals (Van Noordwijk, Duguma et al. 2018; Waldron, Garrity et al. 2017). A recent systematic review on agrofrestry interventions by Castle, Miller et al. (2021), paints a similar picture, concluding that agrofrestry has the potential to improve agricultural

[7] After the search, screening and risk of bias assessment we were left with only one study that considers a package intervention that includes an agroforestry component (Bravo-Ureta, Almeida et al. 2011). Unfortunately, the study assesses an extensive program (MARENA program in Honduras) in which agroforestry is one of multiple activities promoted, and the analysis does not allow for disentangling the effects of specific components of the program.

yields, but evidence on socioeconomic outcomes is extremely limited. Our review, and the one by Castle, Miller et al. 2021 both illustrate an obvious lack of evidence on the impact of agroforestry interventions, despite significant investment in agroforestry by donors, governments and NGOs. Next, we take the intervention-outcome combinations of the included studies and organize them in an evidence gap map to highlight where evidence is concentrated and missing. We also include information from the risk of bias assessment (low/medium risk). Close to all studies consider changes in farming outcomes due to SWC, ISFM and to some extent CA. As mentioned, there are no studies among the 29 that consider impacts of agroforestry. ISFM is the most studied land restoration intervention. SWC and CA are both studied less. As for the outcomes, we classify the outcomes into two different types: 1) farming outcomes (all outcomes that measure only partial output of a household (e.g. crop yields or value of production) and 2) socioeconomic outcomes (e.g. household income, food security or poverty). The majority of studies are limited to farming outcomes, and just six studies also report on socioeconomic indicators.

Figure 4: Evidence gap map

Notes: This figure shows all intervention-outcome combinations we found in the different publications. The color coding indicates whether a publication is expected to have a low or medium risk of bias.

3.2. Qualitative assessment

In this section, we present the results of a qualitative review of the included studies. Figure 5 syntheses the results by type of intervention and impact (positive, negative or no effect). Three of the six publications that study the impact of land restoration interventions on a socioeconomic outcome (e.g. household income or poverty) find a positive effect and two-thirds of the studies find a positive effect on farming outcomes (e.g. crop yields or value of production). Below, we describe the main insights for the three types of interventions (Soil and Water Conservation, Integrated Soil Fertility Management, and Conservation Agriculture).

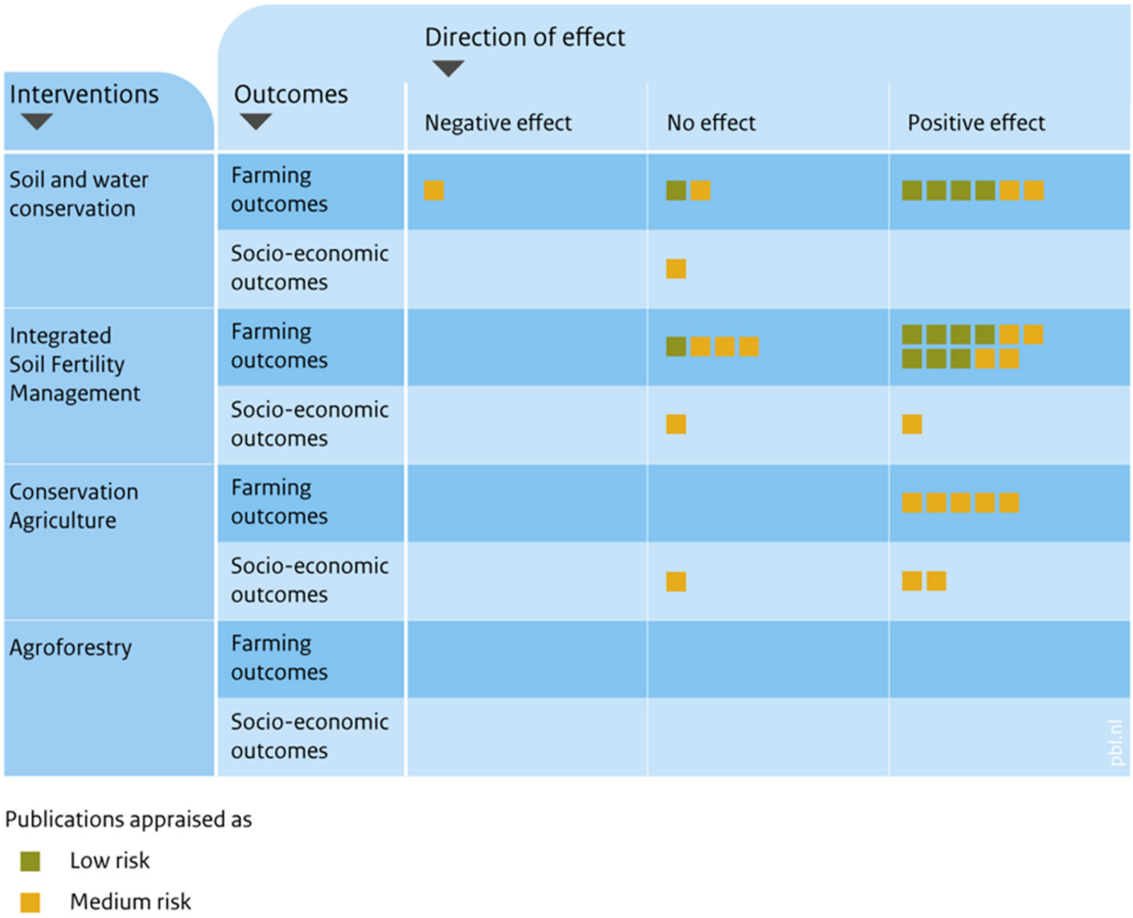

Figure 5: Results synthesis

Notes: This figure shows all intervention-outcome-effect combinations we found in the different publications. The color coding indicates whether a publication is expected to have a low or medium risk of bias.

3.2.1. Soil and Water Conservation

Ten studies explore the impact of Soil and Water Conservation (SWC) on farming and, to a limited degree, socioeconomic outcomes. Geographically, the studies provide a very narrow snapshot, with three studies done in Ghana, one in Kenya, one in Tanzania and the remaining five in Ethiopia. The types of interventions vary across studies. Usually, a combination of technologies is studied, including bund and terrace construction. Most of the studies look at ex-post adoption of a technology rather than the impact of an actual SWC-intervention.

With respect to changing farming outcomes, most studies find positive effects of SWC, with effect sizes ranging 20% - 24% on crop yield or value of production (Kassie, Pender et al. 2008; Abdulai and Huffman 2014; Arslan, Belotti et al. 2017; Schmidt and Tadesse 2017). Abdulai and Huffman (2014) also report impact on net rice profit and find a significant increase of 16%. Two studies report positive effects but do not report baseline values or effect sizes (deGraft-Johnson, Suzuki et al. 2014; Kato, Ringler et al. 2011). Two studies report null effects (Faltermeier and Abdulai 2009; Schmidt and Tadesse 2017). Whereas Kassie et al. (2008) find that for households adopting terraces, net value of crop income is reduced by 15%. Three studies also look at the heterogeneity of impact as a function of climatic variation and find that SWC methods are particularly useful in regions with low rainfall or high climatic variability (Kassie, Pender et al. 2008; Kato, Ringler et al. 2011; Arslan, Belotti et al. 2017). Schmidt and Tadesse (2017) estimate the marginal effect of each additional year of SWC adoption in Ethiopia, shedding some light on the long-term impact of SWC technologies. They estimate that SWC structures should be in place at least 7 years for the technologies to have a significant impact on value of production. Wainaina et al. (2018) is the only study that looks at impacts beyond the farm and find no significant effect of a number of technologies (including but not limited to SWC technologies) on per capita household income in Kenya.

In sum, while most studies report positive impact of SWC on farming outcomes, the impacts vary across contexts. SWC seems to hold most promise in areas with low rainfall and high climatic variability. There is a lack of evidence on socio-economic impacts due to missing data. This makes it hard to draw firm conclusions, as increased farm outcomes may come with higher input costs, making the net benefits for households uncertain.

3.2.2. Integrated Soil Fertility Management

Seventeen studies investigate the impact of Integrated Soil Fertility Management (ISFM). The study sites are largely in Eastern Africa (Malawi, Ethiopia, Kenya, Zambia and Tanzania) and some in Western Africa (Ghana and Nigeria) with only one non-African study, located in India. Fourteen studies explore impacts of fertilizer application, in some cases accompanied by a training intervention. Other types of interventions include intercropping and crop rotations. Nearly all studies explore a package intervention, including, besides ISFM technologies, other technologies such as improved seeds, pesticides/fungicides, SWC-technologies and CA-technologies.

In terms of outcomes, the studies present a narrow snapshot, with only two studies using a socioeconomic outcome whereas all others study a farming outcome. In these studies, the impact of ISFM on socioeconomic outcomes is negative or insignificant, whereas farming outcomes are usually affected positively. Ragasa & Mazunsa (2018), one of the two studies looking at a socioeconomic outcome, study the impact of fertilizer use and access to extension services on value of production and three different food security indicators, in the context of a subsidized input system in Malawi on maize and legume farmers. The authors look at any type of extension services ranging from advice on fertilizer use, crop-specific trainings and credit. They do not find significant effects of having access to extension services on production or any food security indicators. For the quantity of (subsidized) fertilizer used, they find no effect on production, and inconsistent, sometimes negative results on food security indicators. Wainaina et al. (2018) (also discussed in the previous section) study the impact of fertilizer, crop residue and manure application on household (per capita) income. Manure is the only ISFM technology that has a significant positive effect (of 20%) on per capita income. For farming outcomes, 11 studies show positive effects with large differences in effect sizes (from approximately 10% to 100% increase in production or productivity) (Deininger and Olinto 2000; Chakravarty 2009; Zeitlin, Caria et al. 2010; Bardhan and Mookherjee 2011; Asfaw, McCarthy et al. 2015; deGraft-Johnson, Suzuki et al. 2014; Liverpool-Tasie, Adjognon et al. 2014; Kassie, Teklewold et al. 2015; Burke, Jayne et al. 2017 ;Liverpool-Tasie 2017; Biggeri, Burchi et al. 2018). Four of the found studies show no effect on a farming outcome (Pender and Gebremedhin 2007; Arslan, Belotti et al. 2017; Abate, Bernard et al. 2018; Ragasa and Mazunda 2018). In addition, three studies that look at farm profitability of fertilizer use. Burke et al. (2017) find that depending on the specific fertilizer technology, fertilizer use may not be profitable for up to 92% of farmers. Liverpool-Tasie (2017) concludes that fertilizer use is not profitable for 65% of farmers. Both studies note that this lack of profitability can explain low adoption rates. The last of these studies does report profitability (Deininger and Olonto 2000).

Besides studying (in)organic fertilizer use, only few studies look at other ISFM practices. Kassie et al. (2015) looks at crop diversification (intercropping and crop rotation), in addition to minimum tillage, a conservation agriculture practice. They find positive effects of crop diversification on yield of around 30% increasing to 80% when used in combination with minimum tillage. Arslan et al. (2017) report no effect of intercropping (or organic and inorganic fertilizer use) on maize yield in Tanzania but do find yield gains for ISFM practices when they are used simultaneously, or in combination with SWC or improved seeds.

The only two experimental studies in this review were on ISFM technologies. Chakrarvarty (2009) studies the impact of a randomized fertilizer intervention on maize productivity for vulnerable farmers (HIV patients). Treated farmers increased yields by 9% on average compared to the control group. In addition, treated farmers increased maize sales by 70% (though this large effect can be explained by low baseline-level of sales as most farmers were net consumers). Abate et al. (2018), with an RCT on a package of training, inputs (improved seed on credit, fertilizer, gypsum) and marketing support on wheat yield in Ethiopia, find no significant impact on wheat yields.

In sum, even though ISFM is supposed to entail a variety of technologies aimed at improving soil fertility, nearly all studies focused on fertilizer alone. Most studies find predominantly positive effects on yields or other farm outcomes. We find no robust evidence that ISFM adoption also increases household incomes, and studies that try to explain low fertilizer adoption rates find that for many farmers, fertilizer use is not profitable at the farm level.

3.2.3. Conservation Agriculture

Seven studies look at the impact of conservation agriculture (CA). Five studies were conducted in Eastern Africa (Zambia, Malawi, Kenya, and Ethiopia), one in multiple countries across Sub-Saharan Africa, and one in Syria. Again, the evidence provides a geographically narrow picture. Four studies look at CA in combination with other technologies. The CA practice mostly studied is minimum or zero tillage. Just three studies also look at a socioeconomic outcome.

Most studies find positive effects of CA on farming and socioeconomic outcomes. Abdulai (2016) reports positive effects on socioeconomic outcomes measured by a reduction in poverty of 27% - 69% in Zambia. Tambo and Mockshell (2018) look at the impact of three main CA techniques (minimum soil disturbance, residue retention, and crop rotation) and combinations thereof for a range of Sub-Saharan African countries, also using observational data. They find no impact of the three practices separately but do find significant impacts when they are combined. Per capita household income increases by about 30%. Wainana et al. (2018) (also discussed in the previous section) evaluate, amongst other technologies, zero tillage in their study. Though they do find a significant positive impact on household income, this effect disappears when looking at per capita income. The remaining studies all find positive effects of CA on farming outcomes of 30 - 80% (Pender and Gebremedhin 2007; Kassie, Teklewold et al. 2015; Abdulai 2016; El-Shater, Yigezu et al. 2016; Abdulai and Abdulai 2017).

Taken together, similar to the other two types of interventions, there is little rigorous evidence out there on how CA affects farm households. Most studies are conducted in African countries and focus on zero/minimum tillage, often in combination with other technologies. In all but one of the found studies, CA is associated with improvements in farming and socioeconomic outcomes.

4. Discussion

Widespread land degradation poses a threat to long-term agricultural productivity and wellbeing. For this reason, projects which aim to promote land restoration are receiving more attention from policymakers. However, evidence on the effects of such measures on farmer and landowner welfare remains limited. This systematic review synthesizes the available evidence, focusing on the impact of land restoration on socioeconomic household-level indicators such as income, consumption, and poverty. We purposely move beyond farm-level indicators (such as crop yields or production) to better understand aggregate income and poverty effects on households. We focus on four key restoration methods (conservation agriculture, agroforestry, integrated soil fertility management and soil and water conservation), which together constitute the most commonly promoted restoration interventions in the agricultural domain. The review is centered around studies that apply a rigorous identification strategy, making it most likely that changes in outcome indicators reflect causal effects of the land restoration intervention.

Using database searches, a snowball exercise and input from experts, we identified 64 relevant studies, which we evaluated on methodological quality using a risk of bias assessment tool. We retain 29 studies for our final review.

For many of the included studies the risk of bias remains moderate. Only two experimental studies are identified. Most (23) studies use an instrumental variable regression (IV) or propensity score matching (PSM). In the first group, many studies report insufficiently on necessary statistics (e.g. first-stage regressions, or a motivation on the strength of instruments). In the latter group, many studies match on endline data using variables that could logically have been affected by the intervention. For these reasons a quantitative meta-analysis was deemed impractical and motivated a qualitative review instead.

The 29 included studies report on 35 intervention-outcome relations, of which 23 suggest a positive relation and the remainder non-significant or negative effects. Non-significant effects are particularly observed in 5 studies that investigate impact on household-level indicators. Somewhat more studies report positive impacts when considering on-farm impact. This warrants further investigation with a possible hypothesis being that, while restoration practices may increase on-farm productivity in sub-practices, the overall effects on households when taking account of labor re-allocation are negligible.

Taking account of these observations, this review concludes that no firm evidence emerges, at present, to support the claim that agricultural restoration interventions have a ubiquitous positive impact on households. The evidence-base revealed in this review is small, with considerable diversity in findings including many null results. No clear tendencies emerge across the types of restoration practices as impact (changes in indicators) range from relatively large to very small (or no impact). The diversity in impact observed strongly suggests practices do not raise incomes universally, but in some specific instances only.

Considering the specific land restoration interventions, the impact of promoting agroforestry practices remains particularly underreported. We retained only one study that investigates the impact of a package intervention with agroforestry as a component. Seven and ten studies were identified on conservation agriculture (CA) and soil and water conservation practices (SWC) respectively. Fifteen studies on Integrated Soil Fertility Management (ISFM) are included, in absolute terms the greatest number amongst the four practices. However, the impact of components within ISFM (like composting, manuring, specific crop rotations) remains unclear, as most of these assess packages also including inorganic fertilizer, improved seeds and pesticides.

Two issues warrant further investigation. First, some interventions may mitigate downside risks. This has been documented particularly for SWC. Three studies (Kassie, Pender et al. 2008; Kato, Ringler et al. 2011; Arslan, Belotti et al. 2017) show that the impact of SWC is especially significant in areas with temperature shocks or lower rainfall. In fact, mitigating downside risk could sometimes be more important than increases in mean income. Second, synergies between the restoration techniques require further investigation. Two studies (Kassie, Teklewold et al. 2015; Wainaina, Tongruksawattana et al. 2018) find synergistic effects when minimum tillage and ISFM-practices are used simultaneously, but other intervention combinations are possible.

In conclusion, this review does not imply that interventions in agricultural land restoration do not have an impact at the farm and household level. There is simply too little evidence at present to make a judgement on their effectiveness. Much greater effort should be placed on rigorous impact assessments of land restoration programs – shifting focus from estimating their impact on technology adoption to the impact on households as a result thereof, and on disentangling the different impact pathways and discerning which work under which conditions. Addressing this knowledge gap at the onset of the decade of ecosystem restoration is a prerequisite in developing effective and efficient policies.

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Supplementary section for 'Socioeconomic impacts of land restoration in agriculture: a systematic review'

Supplementary Table A1: Search strings

Date of search	Results	Database	Search string
30.11.2018	151	AgEcon	("land clearing" OR "clearing of land" OR erosion OR "soil crusting" OR "crusting of soil" OR "soil compaction" OR "compaction of soil" OR "soil sealing" OR "sealing of soil" OR "soil contamination" OR "contamination of soil" OR "soil organic matter loss" OR "loss of organic soil matter" OR "loss of organic matter in soil" OR "nutrient depletion" OR "depletion of nutrients" OR "soil improvement" OR "sustainable land management" OR "agro-ecological farming practice*" OR "soil management" OR "soil and water conservation" OR "soil conservation" OR "water conservation" OR "agricultural soil*" OR "sustainable intensification" OR "conservation agriculture" OR "reduced till*" OR "no till*" OR "zero till*" OR mulch* OR "residue retention" OR "residue management" OR "soil cover" OR "vegetative cover" OR "cover crop*" OR "integrated soil fertility management" OR "nutrient management" OR "crop rotation" OR manur* OR compost* OR fertiliz* OR "organic amendment" OR biochar OR terracing OR "contour bund*" OR zaï OR tassa OR "water efficiency" OR "water use efficiency" OR "efficiency of water use" OR "water harvesting" OR "harvesting of water" OR agroforestry OR parkland OR "home garden*" OR "vegetative barrier*" OR "improved fallow" OR intercropping) AND ("technology transfer" OR "transfer of technology" OR "agricultural extension" OR "innovation platform*" OR "agricultural service delivery" OR "delivery of agricultural service*" OR "public service delivery" OR "delivery of public service*" OR "farmer field school*" OR "public*private partnership*" OR "farmer cooperative*")
1.11.2018	1,655	CAB Abstracts	
3.12.2018	6	OpenGrey	
24.10.2018	382	AGRIS	("land clearing"~3 OR erosion OR "soil crusting"~3 OR "soil compaction"~3 OR "soil sealing"~3 OR "soil contamination"~3 OR "soil organic matter loss"~3 OR "nutrient depletion"~3 OR "soil improvement" OR "sustainable land management" OR "agro-ecological farming practice*" OR "soil management" OR "soil and water conservation" OR "soil conservation" OR "water conservation" OR "agricultural soil*" OR "sustainable intensification" OR "conservation agriculture" OR "reduced till*" OR "no till*" OR "zero till*" OR mulch* OR "residue retention" OR "residue management" OR "soil cover" OR "vegetative cover" OR "cover crop*" OR "integrated soil fertility management" OR "nutrient management" OR "crop rotation" OR manur* OR compost* OR fertiliz* OR "organic

			amendment" OR biochar OR terracing OR "contour bund*" OR zaï OR tassa OR "water efficiency"~3 OR "water harvesting"~3 OR agroforestry OR parkland OR "home garden*" OR "vegetative barrier*" OR "improved fallow" OR intercropping) AND ("technology transfer"~3 OR "agricultural extension" OR "innovation platform*" OR "agricultural service delivery"~3 OR "public service delivery"~3 OR "farmer field school*" OR "public*private partnership*" OR "farmer cooperative*")
1.11.2018	1,037	EconLit	((land N3 clearing) OR erosion OR (soil N3 crusting) OR (soil N3 compaction) OR (soil N3 sealing) OR (soil N3 contamination) OR (soil N3 organic N3 matter N3 loss) OR (nutrient N3 depletion) OR "soil improvement" OR "sustainable land management" OR "agro-ecological farming practice*" OR "soil management" OR "soil and water conservation" OR "soil conservation" OR "water conservation" OR "agricultural soil*" OR "sustainable intensification" OR "conservation agriculture" OR "reduced till*" OR "no till*" OR "zero till*" OR mulch* OR "residue retention" OR "residue management" OR "soil cover" OR "vegetative cover" OR "cover crop*" OR "integrated soil fertility management" OR "nutrient management" OR "crop rotation" OR manur* OR compost* OR fertiliz* OR "organic amendment" OR biochar OR terracing OR "contour bund*" OR zaï OR tassa OR (water N3 efficiency) OR (water N3 harvesting) OR agroforestry OR parkland OR "home garden*" OR "vegetative barrier*" OR "improved fallow" OR intercropping) AND ((technology N3 transfer) OR "agricultural extension" OR "innovation platform*" OR (agricultural N3 service* N3 delivery) OR (public N3 service* N3 delivery) OR "farmer field school*" OR "public*private partnership*" OR "farmer cooperative*")
14.11.2018	133	GreenFILE	
14.11.2018	26	SocIndex	
30.11.2018	4	ArticleFirst	((kw: land w "n3" w clearing) or (ti: land w "n3" w clearing) OR kw: erosion or ti: erosion OR (kw: soil w "n3" w crusting) or (ti: soil w "n3" w crusting) OR (kw: soil w "n3" w compaction) or (ti: soil w "n3" w compaction) OR (kw: soil w "n3" w sealing) or (ti: soil w "n3" w sealing) OR (kw: soil w "n3" w contamination) or (ti: soil w "n3" w contamination) OR (kw: soil w "n3" w organic w "n3" w matter w "n3" w loss) or (ti: soil w "n3" w organic w "n3" w matter w "n3" w loss) OR (kw: nutrient w "n3" w depletion) or (ti: nutrient w "n3" w depletion) or (kw: soil w improvement) or (ti: soil w improvement) OR (kw: sustainable w land w management) or (ti: sustainable w land w management) OR (kw: agro-ecological w farming w practice+) or (ti: agro-ecological w farming w practice+) OR (kw: soil w management) or (ti: soil w management) OR "soil and water conservation" OR (kw: soil w conservation) or (ti: soil w conservation) OR (kw: water w
30.11.2018	22	ECO	

			conservation) or (ti: water w conservation) OR (kw: agricultural w soil+) or (ti: agricultural w soil+) OR (kw: sustainable w intensification) or (ti: sustainable w intensification) OR (kw: conservation w agriculture) or (ti: conservation w agriculture) OR (kw: reduced w till*) or (ti: reduced w till*) OR (kw: no w till*) or (ti: no w till*) OR (kw: zero w till*) or (ti: zero w till*) OR kw: mulch* or ti: mulch* OR (kw: residue w retention) or (ti: residue w retention) OR (kw: residue w management) or (ti: residue w management) OR (kw: soil w cover) or (ti: soil w cover) OR (kw: vegetative w cover) or (ti: vegetative w cover) OR (kw: cover w crop+) or (ti: cover w crop+) OR (kw: integrated w soil w fertility w management) or (ti: integrated w soil w fertility w management) OR (kw: nutrient w management) or (ti: nutrient w management) OR (kw: crop w rotation) or (ti: crop w rotation) OR kw: manur* or ti: manur* OR kw: compost* or ti: compost* OR kw: fertiliz* or ti: fertiliz* OR (kw: organic w amendment) or (ti: organic w amendment) OR kw: biochar or ti: biochar OR kw: terracing or ti: terracing OR (kw: contour w bund+) or (ti: contour w bund+) OR kw: zaï or ti: zaï OR kw: tassa or ti: tassa OR (kw: water w "n3" w efficiency) or (ti: water w "n3" w efficiency) OR (kw: water w "n3" w harvesting) or (ti: water w "n3" w harvesting) OR kw: agroforestry or ti: agroforestry OR kw: parkland or ti: parkland OR (kw: home w garden*) or (ti: home w garden*) OR (kw: vegetative w barrier+) or (ti: vegetative w barrier+) OR (kw: improved w fallow) or (ti: improved w fallow) OR kw: intercropping or ti: intercropping) AND ((kw: technology w "n3" w transfer) or (ti: technology w "n3" w transfer) OR (kw: agricultural w extension) or (ti: agricultural w extension) OR (kw: innovation w platform+) or (ti: innovation w platform+) OR (kw: agricultural w "n3" w service+ w "n3" w delivery) or (ti: agricultural w "n3" w service+ w "n3" w delivery) OR (kw: public w "n3" w service+ w "n3" w delivery) or (ti: public w "n3" w service+ w "n3" w delivery) OR (kw: farmer w field w school+) or (ti: farmer w field w school+) OR (kw: public#private w partnership+) or (ti: public#private w partnership+) OR (kw: farmer w cooperative+) or (ti: farmer w cooperative+))
3.12.2018	254	Scopus	TITLE-ABS-KEY (((land W/3 clearing) OR erosion OR (soil W/3 crusting) OR (soil W/3 compaction) OR (soil W/3 sealing) OR (soil W/3 contamination) OR (soil W/3 organic W/3 matter W/3 loss) OR (nutrient W/3 depletion) OR "soil improvement" OR "sustainable land management" OR "agro-ecological farming practice*" OR "soil management" OR "soil and water conservation" OR "soil conservation" OR "water conservation" OR "agricultural soil*" OR "sustainable intensification" OR "conservation agriculture" OR "reduced till*" OR "no till*" OR

			"zero till*" OR mulch* OR "residue retention" OR "residue management" OR "soil cover" OR "vegetative cover" OR "cover crop*" OR "integrated soil fertility management" OR "nutrient management" OR "crop rotation" OR manur* OR compost* OR fertiliz* OR "organic amendment" OR biochar OR terracing OR "contour bund*" OR zaï OR tassa OR (water W/3 efficiency) OR (water W/3 harvesting) OR agroforestry OR parkland OR "home garden*" OR "vegetative barrier*" OR "improved fallow" OR intercropping) AND (technology W/3 transfer) OR "agricultural extension" OR "innovation platform*" OR (agricultural W/3 service* W/3 delivery) OR (public W/3 service* W/3 delivery) OR "farmer field school*" OR "public*private partnership*" OR "farmer cooperative*") AND (LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "ECON"))
3.12.2018	331	Web of Science	TS=(("land clearing" OR "clearing of land" OR erosion OR "soil crusting" OR "crusting of soil" OR "soil compaction" OR "compaction of soil" OR "soil sealing" OR "sealing of soil" OR "soil contamination" OR "contamination of soil" OR "soil organic matter loss" OR "loss of organic soil matter" OR "loss of organic matter in soil" OR "nutrient depletion" OR "depletion of nutrients" OR "soil improvement" OR "sustainable land management" OR "agro-ecological farming practice*" OR "soil management" OR "soil and water conservation" OR "soil conservation" OR "water conservation" OR "agricultural soil*" OR "sustainable intensification" OR "conservation agriculture" OR "reduced till*" OR "no till*" OR "zero till*" OR mulch* OR "residue retention" OR "residue management" OR "soil cover" OR "vegetative cover" OR "cover crop*" OR "integrated soil fertility management" OR "nutrient management" OR "crop rotation" OR manur* OR compost* OR fertiliz* OR "organic amendment" OR biochar OR terracing OR "contour bund*" OR zaï OR tassa OR "water efficiency" OR "water use efficiency" OR "efficiency of water use" OR "water harvesting" OR "harvesting of water" OR agroforestry OR parkland OR "home garden*" OR "vegetative barrier*" OR "improved fallow" OR intercropping) AND ("technology transfer" OR "transfer of technology" OR "agricultural extension" OR "innovation platform*" OR "agricultural service delivery" OR "delivery of agricultural service*" OR "public service delivery" OR "delivery of public service*" OR "farmer field school*" OR "public*private partnership*" OR "farmer cooperative*"))
3.12.2018	166	Agricola	(("land clearing" or "clearing of land" or erosion or "soil crusting" or "crusting of soil" or "soil compaction" or "compaction of soil" or "soil sealing" or "sealing of soil" or "soil

			contamination" or "contamination of soil" or "soil organic matter loss" or "loss of organic soil matter" or "loss of organic matter in soil" or "nutrient depletion" or "depletion of nutrients" or "soil improvement" or "sustainable land management" or "agro-ecological farming practice*" or "soil management" or "soil and water conservation" or "soil conservation" or "water conservation" or "agricultural soil*" or "sustainable intensification" or "conservation agriculture" or "reduced till*" or "no till*" or "zero till*" or mulch* or "residue retention" or "residue management" or "soil cover" or "vegetative cover" or "cover crop*" or "integrated soil fertility management" or "nutrient management" or "crop rotation" or manur* or compost* or fertiliz* or "organic amendment" or biochar or terracing or "contour bund*" or zai or tassa or "water efficiency" or "water use efficiency" or "efficiency of water use" or "water harvesting" or "harvesting of water" or agroforestry or parkland or "home garden*" or "vegetative barrier*" or "improved fallow" or intercropping) and ("technology transfer" or "transfer of technology" or "agricultural extension" or "innovation platform*" or "agricultural service delivery" or "delivery of agricultural service*" or "public service delivery" or "delivery of public service*" or "farmer field school*" or "public*private partnership*" or "farmer cooperative*")).ab,ti.

Notes: This table shows the search strings used in the systematic review process detailed for each database search.

Supplementary Table A2: Selection criteria used for scientific databases

Database	Accessibility	Advanced search	Max search string length	Bulk export	Used in review
AgEcon	Yes (open access)	Yes	No	Yes	Yes
AGRICOLA	Yes (WUR)	Yes	No	Yes	Yes
Agris	Yes	Yes	No	Yes (max 1000 records)	Yes
ArticleFirst	Yes (IFPRI)	Yes	No	Yes	Yes
ASSIA	No				No
British Library for Development Studies	Offline				No
CAB Abstracts	Yes (IFPRI)	Yes	No	Yes (max 1000 records)	Yes
ECO	Yes (IFPRI)	Yes	No	Yes	Yes
EconLit	Yes (IFPRI)	Yes	No	Yes (max 50 records)	Yes
ELDIS	Yes (open access)	Yes	100		No
FAO Gender & Land Rights Database	Yes (open access)	No			No
Google Scholar	Yes (open access)	Yes	256	No	No
Greenfile	Yes (WUR)	Yes	No	Yes	Yes
HeinOnline	No				No
International Bibliography of Social Science	No				No
JSTOR	Yes (IFPRI)	Yes	250	No	No
NBER	Yes (open access)	No		No	No
Networked Digital Library of Theses and Dissertations	Yes (open access)	Yes		No	No
OpenGrey	Yes (open access)	Yes	No	Yes	Yes
PAIS	No				No
Repec/Ideas (EconPapers)	Yes (open access)	Yes		No	No
Scopus	Yes (WUR)	Yes	No	Yes	Yes
SocIndex	Yes (WUR)	Yes	No	Yes	Yes
SSRN	Yes (open access)	No		No	No
WB and IMF Library search (JOLIS)	Yes (open access)	Yes	512	No (only IMF/WB employees)	No
Web of Science	Yes (WUR)	Yes	No	Yes, only EndNote users	Yes

Notes: This table shows the databases consulted in the systematic review process and the criteria which we used to select them. If a criterium is highlighted in green this criterium was met, if red then the criterium was not met.

Supplementary Table A3: Python screening script

```
##################      PDF conversion and parsing      ######################
##                      Mandy Malan
##                      January 2019
##                      Socioeconomic impacts of land restoration measures in agriculture: a systematic review
##################################################################################
##          This script does the following:
##                      1. extract text from PDF files sets aside PDFs that cannot be extracted
##                      2. write text files
##                      3. parse through text files and evaluate on a number of regular expressions
##                      4. move selected papers to new folde
##################################################################################

## Load packages
import re
import os
import sys, getopt
import PyPDF2
import csv
from shutil import copy2
from io import StringIO
from pdfminer.pdfinterp import PDFResourceManager, PDFPageInterpreter
from pdfminer.converter import TextConverter
from pdfminer.layout import LAParams
from pdfminer.pdfpage import PDFPage

## Define functions
# Converts pdf, returns its text content as a string
def convert(fname, pages=None):
    if not pages:
        pagenums = set()
    else:
        pagenums = set(pages)

    output = StringIO()
    manager = PDFResourceManager()
    converter = TextConverter(manager, output, laparams=LAParams())
    interpreter = PDFPageInterpreter(manager, converter)
    infile = open(fname, 'rb')
    for page in PDFPage.get_pages(infile, pagenums):
        interpreter.process_page(page)
    infile.close()
    converter.close()
    text = output.getvalue()
    output.close
    return text

# Converts all pdfs in directory pdfDir, saves all resulting txt files to txtdir and filters non-convertible PDFs
def convertMultiple(pdfDir, pdfDirNA, pdfDirConvert, txtDir, txtDirNA):
    if pdfDir == "": pdfDir = os.getcwd() + "\\" #if no pdfDir passed in
    for pdf in os.listdir(pdfDir): #iterate through pdfs in pdf directory
        fileExtension = pdf.split(".")[-1]
        fileExt = pdf.split(".")
        try:
            print(fileExt)
        except UnicodeEncodeError:
            print('error')
        if fileExtension == "pdf":
            pdfFilename = pdfDir + pdf
            try:
                if PyPDF2.PdfFileReader(open(pdfFilename, 'rb')).isEncrypted:
                    print('encr')
                    oldPath = os.path.join(pdfDir, pdf)
                    newPath = os.path.join(pdfDirNA, pdf)
                    os.rename(oldPath, newPath)
                else:
                    text = convert(pdfFilename) #get string of text content of pdf
                    if str.isspace(text): #evaluate whether text was extracted succesfully, if no: move pdf to other folder
                        print('space')
                        oldPath = os.path.join(pdfDir, pdf)
                        newPath = os.path.join(pdfDirNA, pdf)
                        os.rename(oldPath, newPath)
                    else: #if yes: write text file
                        pdfName = pdf[:-4] #remove .pdf from name
```

```
                txtName = pdfName + ".txt"
                textFilename = txtDir + txtName
                textFile = open(textFilename, "w", encoding='utf-8') #make text file
                textFile.write(text) #write text to text file
                oldPathPDF = os.path.join(pdfDir, pdf)
                newPathPDF = os.path.join(pdfDirConvert, pdf)
                os.rename(oldPathPDF, newPathPDF)
                if os.path.getsize(textFilename)<10000: # if .txt file is smaller than 10000 bytes we assume the pdf conversion
was unsuccessful and move the file
                    print('size')
                    oldPath = os.path.join(pdfDirConvert, pdf)
                    newPath = os.path.join(pdfDirNA, pdf)
                    os.rename(oldPath, newPath)
                    newPathT = os.path.join(txtDirNA, txtName)
                    os.rename(textFilename, newPathT)
        except Exception:
            print('exceptev')
            oldPath = os.path.join(pdfDir, pdf)
            newPath = os.path.join(pdfDirNA, pdf)
            os.rename(oldPath, newPath)

#Search for keyword in text files and move file to other folder if keyword is found
def screenMultiple(txtDir, pdfDirS, searchString):
    with
open("/Users/mandymalan/Documents/WUR/sys_review/screening/AGRICOLA_20181203.01_select/0_screen_results.csv",'
w', encoding='utf-8') as f:
        writer = csv.writer(f, dialect='excel')
        filesDir = [i for i in os.listdir(txtDir) if not os.path.isdir(i)] # ignore subdirectories in list of files
        for text in filesDir:
            fileExtension = text.split(".")[-1]
            if fileExtension == "txt":
                name = open(txtDir + text, 'r', encoding='utf-8', errors='ignore')
                x = re.findall(searchString, name.read(), re.IGNORECASE)
                if x:
                #print(text)
                    print(x)
                    pdfName = text[:-4] +'.pdf'
                    oldPath = os.path.join(pdfDirConvert, pdfName)
                    newPath = os.path.join(pdfDirS, pdfName)
                    copy2(oldPath, newPath)
                    writer.writerow([text, x])

## Script
# Define directory with pdfs that need to be converted to text:
pdfDir = "/Users/mandymalan/Documents/WUR/sys_review/screening/AGRICOLA_20181203.01/"
# Define directory where pdfs that could not be converted are moved and directory where converted papers are moved
pdfDirNA = "/Users/mandymalan/Documents/WUR/sys_review/screening/AGRICOLA_20181203.01_noConvert/"
pdfDirConvert = "/Users/mandymalan/Documents/WUR/sys_review/screening/AGRICOLA_20181203.01_convert/"
# Define directory where converted text files are saved
txtDir = "/Users/mandymalan/Documents/WUR/sys_review/screening/AGRICOLA_20181203.01_text/"
# Define directory where unsuccesful conversions are moved
txtDirNA = "/Users/mandymalan/Documents/WUR/sys_review/screening/AGRICOLA_20181203.01_textNA/"
# Define search string to select papers
searchString  = "|".join(['randomized', 'randomised', 'RCT', 'difference in difference', 'difference-in-difference', 'dif-in-dif', 'dif in
dif', 'double difference',
   'regression discontinuity', 'RDD', 'propensity score', 'PSM', 'instrumental variable'])
# Define directory where selected files are saved
pdfDirS = "/Users/mandymalan/Documents/WUR/sys_review/screening/AGRICOLA_20181203.01_select/"

# Run functions
convertMultiple(pdfDir, pdfDirNA, pdfDirConvert, txtDir, txtDirNA)
screenMultiple(txtDir, pdfDirS, searchString)
```

Notes: This table shows the databases consulted in the systematic review process and the criteria which we used to select them. If a criterium is highlighted in green this criterium was met, if red then the criterium was not met.

Supplementary Table A4: Risk of bias tool

SELECTION BIAS
Randomized controlled trial

Yes if:	
1	a random component in the sequence generation process is described (e.g. referring to a random number table)
2	and if the unit of allocation was at group level (geographical/social/ institutional unit) and allocation was performed on all units at the start of the study;
	or if the unit of allocation was by beneficiary or group and there was some form of centralised allocation mechanism such as an on-site computer system
3	and if the unit of allocation is based on a sufficiently large sample size to equate groups on average
4	and if baseline characteristics of the study and control/comparisons are reported and overall similar based on t-test or ANOVA for equality of means across groups
	or covariate differences are controlled using multivariate analysis
5	and the attrition rates (losses to follow-up) are sufficiently low and similar in treatment and control;
	or the study assesses that loss to follow-up units are random draws from the sample (e.g. by examining correlation with determinants of outcomes, in both treatment and comparison groups);
6	and problems with cross-overs and drop-outs are dealt with using intention- to-treat analysis or in the case of drop-outs, by assessing whether the drop- outs are random draws from the population;
7	and, for cluster assignment, authors control for external cluster-level factors that might confound the impact of the programme (e.g. weather, infrastructure, community fixed effects etc.) through multivariate analysis.
Unclear if:	
1	the paper does not provide details on the randomisation process, or uses a quasi-randomisation process for which it is not clear whether it has generated allocations equivalent to true randomisation;
	or insufficient details are provided on covariate differences or methods of adjustment;
	or insufficient details are provided on cluster controls.
No if:	
1	the sample size is not sufficient;
	or any failure in the allocation mechanism or execution of the method could affect the randomisation process.
Instrumental variable	
Yes if:	
1	an appropriate instrumental variable is used which is exogenously generated: e.g. due to a “natural” experiment or random allocation.
2	the instrumenting equation is significant at the level of $F \geq 10$ (or if an F test is not reported, the authors report and assess whether the R-squared (goodness of fit) of the participation equation is sufficient for appropriate identification);
3	the identifying instruments are individually significant ($p \leq 0.01$); for Heckman models, the identifiers are reported and significant ($p \leq 0.05$);
4	where at least two instruments are used, the authors report on an over-identifying test ($p \leq 0.05$ is required to reject the null hypothesis);
5	and none of the covariate controls can be affected by participation and the study convincingly assesses qualitatively why the instrument only affects the outcome via participation

6	and, for cluster assignment, authors particularly control for external cluster-level factors that might confound the impact of the programme (e.g. weather, infrastructure, community fixed effects etc.) through multivariate analysis.
Unclear if:	
1	the exogeneity of the instrument is unclear (both externally as well as why the variable should not enter by itself in the outcome equation).
2	relevant confounders are controlled but appropriate statistical tests are not reported or exogeneity of the instrument is not convincing;
	or if insufficient details are provided on cluster controls (see category f) below).
No if:	
	otherwise
Non-randomised programme placement and self-selection (excl. IV)	
Yes if:	
1	participants and non-participants are either matched based on all relevant characteristics explaining participation and outcomes;
	or all relevant characteristics are accounted for.
Unclear if:	
	it is not clear whether all relevant characteristics (only relevant time varying characteristics in the case of panel data regressions) are controlled.
No if:	
	relevant characteristics are omitted from the analysis.
Non-randomised trials using panel data (including DID) models	
1	the authors use a difference-in-differences (or fixed effects) multivariate estimation method
2	and the authors control for a comprehensive set of time-varying characteristics
3	and the attrition rate is sufficiently low and similar in treatment and control, or the study assesses that drop-outs are random draws from the sample (e.g. by examining correlation with determinants of outcomes, in both treatment and comparison groups);
4	and, for cluster assignment, authors control for external cluster-level factors that might confound the impact of the programme (e.g. weather, infrastructure, community fixed effects etc.) through multivariate analysis.
Unclear if:	
1	insufficient details are provided
	or if insufficient details are provided on cluster controls.
No if:	
	otherwise, including if the treatment effect is estimated using raw comparison of means in statistically un-matched groups.
Statistical matching studies including propensity scores (PSM) and covariate matching	
Yes if:	
1	matching is either on baseline characteristics or time-invariant characteristics which cannot be affected by participation in the programme;
2	and the variables used to match are relevant (e.g. demographic and socioeconomic factors) to explain both participation and the outcome (so that there can be no evident differences across groups in variables that might explain outcomes);

3	and for PSM Rosenbaum's test suggests the results are not sensitive to the existence of hidden bias;
4	and, with the exception of Kernel matching, the means of the individual covariates are equated for treatment and comparison groups after matching;
5	and, for cluster assignment, authors control for external cluster-level factors that might confound the impact of the programme (e.g. weather, infrastructure, community fixed effects etc.) through multivariate or any appropriate analysis.
Unclear if:	
1	relevant variables are not included in the matching equation, or if matching is based on characteristics collected at endline;
	or if insufficient details are provided on cluster controls.
No if:	
	otherwise
SPILLOVERS Was the study adequately protected against performance bias?	
Yes if:	
	the intervention is unlikely to spill over to comparisons (e.g. participants and non-participants are geographically and/or socially separated from one another and general equilibrium effects are unlikely).
Unclear if:	
	spillovers are not addressed clearly
No if:	
1	allocation was at individual or household level and there are likely spillovers within households and communities which are not controlled for in the analysis;
	or if allocation at cluster level and there are likely spillovers to comparison clusters.
SELECTIVE REPORTING Was the study free from outcome and analysis reporting biases?	
Yes if:	
1	there is no evidence that outcomes were selectively reported (e.g. all relevant outcomes in the methods section are reported in the results section);
2	and authors use "common' methods" of estimation and the study does not suggest the existence of biased exploratory research methods.
No if:	
1	some important outcomes are subsequently omitted from the results or the significance and magnitude of important outcomes was not assessed;
	or authors use uncommon or less rigorous estimation methods such as failure to conduct multivariate analysis for outcomes equations where it is has not been established that covariates are balanced.
Unclear if:	
	otherwise
OTHER Was the study free from other sources of bias? Important additional sources of bias may include: concerns about blinding of outcome assessors or data analysts; concerns about courtesy bias from outcomes collected through self-reporting; concerns about coherence of results, for example between descriptive statistics and outcome questions; data on the baseline collected retrospectively; information is collected using an inappropriate instrument (or a different	

instrument/at different time/after different follow-up period in the comparison and treatment groups).	
Yes if:	
	the reported results do not suggest any other sources of bias
Unclear if:	
	other important threats to validity may be present
No if:	
	it is clear that these threats to validity are present and not controlled for.
FINAL EVALUATION	
Low risk of bias	Clear measurement of and control for confounding was made, including selection bias, where intervention and comparison groups were described adequately (in respect of the nature of the interventions being received) and risks of spillovers or contamination were small, and where reporting biases and other sources of bias were unlikely.
Medium risk of bias	Threats to the validity of the attribution methodology, or likely risks of spillovers or contamination, arising from inadequate description of intervention or comparison groups or possibilities for interaction between groups such as when they are from the same community, or possible reporting biases.
High risk of bias	All the others, including those where comparison groups are not matched or differences in covariates are not accounted for in multivariate analysis, or where there is evidence for spillovers or contamination to comparison groups from the same communities, and reporting biases are evident.

Notes: This table shows the risk of bias assessment used, as developed by: Waddington, H., B. Snilstveit, J. Hombrados, M. Vojtkova, D. Phillips, P. Davies and H. White (2014). "Farmer Field Schools for Improving Farming Practices and Farmer Outcomes: A Systematic Review." *Campbell Systematic Reviews* *10(1): i-335.*

Supplementary Table A5: Risk of bias assessment

Database	First author	Year	Method	Selection bias	Spillovers	Reporting bias	Other	Risk of bias	Comments	Final evaluation
Econlit_2	Abate	2018	RCT	yes	unclear	unclear	unclear	medium		medium
Econlit_2	Abdulai	2014	IV	unclear	unclear	yes	yes	medium		medium
Econlit_2	Abdulai	2016	IV	unclear	unclear	yes	yes	medium		medium
Econlit_2	Abdulai	2017	PSM	unclear	unclear	unclear	unclear	medium		medium
Econlit_2	Adégbidi	2004	OLS / IV	unclear	yes	unclear	yes	medium	Method NA	EXCLUDE
Econlit_2	Akinola	2012	PSM	no	unclear	yes	no	high		high
snowball	Amare	2012	PSM/IV	unclear	unclear	yes	yes	medium	Intervention NA	EXCLUDE
Econlit_1	Ariga	2013	panel	no	unclear	no	unclear	high	Method NA	EXCLUDE
Econlit_2	Arslan	2017	OLS / IV	yes	yes	yes	yes	low		low
snowball	Asfaw	2014	IV	unclear	unclear	unclear	yes	medium		medium
Econlit_2	Bardhan	2011	OLS / IV	yes	yes	yes	yes	low		low
CAB	Benin	2006	NA	NA	NA	NA	NA	NA	Method NA	EXCLUDE
CAB	Biggeri	2018	IV/PSM	unclear	yes	yes	yes	low		low
Econlit_2	Brainerd	2014	NA	NA	NA	NA	NA	NA	Method NA	EXCLUDE
snowball	Bravo-Ureta	2011	PSM/DiD	yes	yes	yes	yes	low		low
Econlit_2	Burke	2017	OLS / IV	yes	yes	unclear	yes	low		low
Econlit_1	Chakravarty	2009	RCT	yes	unclear	yes	yes	low		low
snowball	Cocchi	2007	IV	unclear	unclear	high	yes	high		high
Econlit_1	Darko	2016	panel	unclear	unclear	yes	yes	medium	Method NA	EXCLUDE
Econlit_2	De Graft - Johnson	2014	IV	unclear	yes	yes	yes	low		low
Econlit_1	Deininger	2000	IV	unclear	yes	unclear	yes	medium		medium
Econlit_1	Diiro	2013	N/A	NA	NA	NA	NA	NA	Method NA	EXCLUDE
Econlit_2	Duflo	2008	RCT	unclear	unclear	yes	unclear	medium	Intervention NA	EXCLUDE
CAB	Ekbom	2008	Heckman selection	no	unclear	unclear	unclear	NA	Method NA	EXCLUDE

Econlit_2	El-Shater	2016	PSM	unclear	unclear	yes	yes	medium		medium
Agricola	Emmanuel	2016	PSM	no	unclear	yes	unclear	high		high
Econlit_2	Faltermeier	2009	PSM	unclear	unclear	yes	yes	medium		medium
Econlit_1	Foltz	2012	panel-IV	unclear	yes	yes	no	high		high
snowball	Kassie	2007	PSM	yes	unclear	yes	yes	low	Duplicate	EXCLUDE
snowball	Kassie	2008	PSM	unclear	unclear	yes	yes	medium	Matching done on time invariant variables, selection bias should be yes.	low
Econlit_1	Kassie	2011	PSM	no	unclear	yes	no	high		high
snowball	Kassie	2011	PSM	no	unclear	yes	yes	high	They do take measures to deal with bias, selection bias should be unclear	medium
Econlit_2	Kassie	2015	IV	unclear	yes	unclear	yes	medium		medium
Econlit_2	Kato	2011	IV	unclear	unclear	yes	yes	low/medium	Method may be valid and but confusing reporting style makes it difficult to assess	medium
snowball	Kijima	2012	PSM	no	unclear	yes	yes	high	Intervention NA	EXCLUDE
snowball	Kuntashula	2014	PSM	no	yes	yes	yes	high		high
Econlit_2	Kuntashula	2015	PSM	unclear	unclear	yes	yes	medium	Intervention NA	EXCLUDE
AgEcon	Laurence Jumbe	2016	OLS	no	unclear	no	unclear	high	Method NA	EXCLUDE
snowball	Liverpool-Tasie	2015	PSM/IV	yes	yes	yes	yes	low		low
Econlit_2	Liverpool-Tasie	2017	panel-IV	unclear	yes	yes	yes	low		low
snowball	Mango	2017	PSM	no	unclear	yes	yes	high		high
CAB	Mapila	2012	PSM	unclear	unclear	no	unclear	high		high
Econlit_1	Mason	2011	IV	unclear	unclear	unclear	yes	medium	Intervention NA	EXCLUDE
Econlit_2	Matchaya	2013	PSM	unclear	yes	yes	unclear	medium		medium
Econlit_1	Matsumoto	2011	DiD	no	unclear	yes	unclear	high	Intervention NA	EXCLUDE
snowball	Nkala	2011	PSM	no	unclear	yes	unclear	high		high

AgEcon	Nkonya	2005	IV	unclear	unclear	yes	yes	medium	Too many reporting and methodological issues to assess as medium risk	high
CAB	Ogunniyi	2017	PSM	no	unclear	no	unclear	high	Intervention NA	EXCLUDE
CAB	Olarinde	2012	IV	no	unclear	no	unclear	high		high
CAB	Pender	2004	IV	yes	unclear	yes	yes	low	Intervention NA	EXCLUDE
snowball	Pender	2006	IV	unclear	unclear	yes	yes	medium	Duplicate	EXCLUDE
CAB	Pender	2008	IV	unclear	unclear	yes	yes	medium		medium
CAB	Ragasa	2018	panel/IV/ PSM	unclear	unclear	unclear	yes	medium		medium
snowball	Schmidt	2012	PSM	unclear	unclear	yes	yes	medium	Duplicate	EXCLUDE
snowball	Schmidt	2013	PSM	yes	unclear	yes/unclea r	yes	low		low
snowball	Schmidt	2017	PSM/DiD	unclear	unclear	yes	yes	medium	PSM and DiD instead of PSM only, selection bias should be yes	low
CAB	Solis	2009	IV	unclear	no	no	yes	high		high
Econlit_2	Tambo	2018	PSM	unclear	unclear	yes	unclear	medium		medium
Econlit_2	Teklewold	2012	NA	NA	NA	NA	NA	NA	Method NA	EXCLUDE
snowball	Tsegaye	2017	IV	no	unclear	yes	yes	high		high
Econlit_2	Wainaina	2018	PSM	unclear	unclear	yes	yes	medium		medium
Econlit_1	Xu	2008	panel	no	unclear	NA	NA	high	Method NA	EXCLUDE
snowball	Yigezu	2015	model	no	unclear	yes	yes	high	Method NA	EXCLUDE
Econlit_1	Zeitlin - Teal	2010	DiD	unclear	unclear	yes	yes	medium		medium

Risk of bias evaluation criteria:

high	One or more of the four categories is answered with 'no'
medium	Two or more of the four categories is answered with 'unclear'
low	If otherwise

Notes: This table details the results of our risk of bias assessment. Each paper was assessed by two co-authors. Sometimes a paper was not assessed because it did not meet earlier set criteria (e.g.: an appropriate method or intervention).

Supplementary Table A6: Final list of papers and classification

Study	Method	Country	Intervention	Intervention type	Outcome	Outcome type	Risk of bias
Abate, G. T., Bernard, T., de Brauw, A., & Minot, N. (2018). The impact of the use of new technologies on farmers' wheat yield in Ethiopia: evidence from a randomized control trial. *Agricultural Economics*, *49*(4), 409-421.	RCT	Ethiopia	Package of training, inputs (improved seed on credit, fertilizer, gypsum) and marketing support. Groups are full-package farmers and farmers who only received marketing support	ISFM	Wheat yield in kg/ha (measured in three ways: crop cut, output prediction, farmer recall)	Farm level	Medium
Abdulai, A. N. (2016). Impact of conservation agriculture technology on household welfare in Zambia. *Agricultural economics*, *47*(6), 729-741.	IV	Zambia	Adoption of conservation agriculture	CA	Maize yield, throughput accounting ratio, poverty headcount, poverty gap, severity of poverty	Farm level Poverty	Medium
Abdulai, A., & Huffman, W. (2014). The adoption and impact of soil and water conservation technology: An endogenous switching regression application. *Land economics*, *90*(1), 26-43.	IV	Ghana	Adoption of bunds	SWC	Rice yield (bags/ha) and net returns (GHS/ha)	Farm level	Medium
Abdulai, A. N., & Abdulai, A. (2017). Examining the impact of conservation agriculture on environmental efficiency among maize farmers in Zambia. *Environment and Development Economics*, *22*(2), 177-201.	PSM	Zambia	Adoption of conservation agriculture	CA	Technical and environmental efficiency	Farm level	Medium

Arslan, A., Belotti, F., & Lipper, L. (2017). Smallholder productivity and weather shocks: Adoption and impact of widely promoted agricultural practices in Tanzania. *Food policy*, *69*, 68-81.	IV	Tanzania	SWC, organic fertilizer, inorganic fertilizer, intercropping	SWC	Maize yield (kg/ha)	Farm level	Low
Bardhan, P., & Mookherjee, D. (2011). Subsidized farm input programs and agricultural performance: A farm-level analysis of West Bengal's green revolution, 1982-1995. *American Economic Journal: Applied Economics*, *3*(4), 186-214.	IV	India	Intensity of subsidized inputs program on village level (inputs are seeds and fertilizer, they can only test impact of entire kit provided: seeds, fertilizer, insecticides), measured as cumulative number of kits per household	ISFM	Log value added per acre of all crops	Farm level	Low
Biggeri, M., Burchi, F., Ciani, F., & Herrmann, R. (2018). Linking small-scale farmers to the durum wheat value chain in Ethiopia: Assessing the effects on production and wellbeing. *Food Policy*, *79*, 77-91.	PSM	Ethiopia	Package intervention: 1) technical aspects of production, including proliferation of appropriate agronomic practices, introduction of adapted durum wheat varieties and the provision of key assets at the cooperative level. 2) overall institutional architecture of value chain, capacity-building among cooperatives, establishing links between cooperatives and public agricultural research centres and using cooperatives to establish contract farming arrangements	ISFM	Growth of cereal production value	Farm level	Low

Burke, W. J., Jayne, T. S., & Black, J. R. (2017). Factors explaining the low and variable profitability of fertilizer application to maize in Zambia. *Agricultural economics*, *48*(1), 115-126.	IV	Zambia	Fertilzer application rate	ISFM	Maize yield (kg/ha)	Farm level	Low
Chakravarty, S. (2009). *Harvesting health: Fertilizer, nutrition and AIDS treatment in Kenya*. Columbia University.	RCT	Kenya	Randomized training and free fertilizer	ISFM	Maize yield (90 kg bags per acre), income from maize (ksh)	Farm level	Low
deGraft-Johnson, M., Suzuki, A., Sakurai, T., & Otsuka, K. (2014). On the transferability of the Asian rice green revolution to rainfed areas in sub-Saharan Africa: an assessment of technology intervention in Northern Ghana. *Agricultural Economics*, *45*(5), 555-570.	IV	Ghana	Modern inputs + bunding + leveling Package adoption	SWC ISFM	Paddy yield (tons/ha), Profit (USD/ha)	Farm level	Low
Deininger, K., & Olinto, P. (2000). *Why liberalization alone has not improved agricultural productivity in Zambia: The role of asset ownership and working capital constraints*. The World Bank.	IV	Zambia	Fertilizer application	ISFM	Profitability	Farm level	Medium
El-Shater, T., Yigezu, Y. A., Mugera, A., Piggin, C., Haddad, A., Khalil, Y., ... & Aw-Hassan, A. (2016). Does zero tillage improve the livelihoods of	PSM	Syria	Zero tillage adoption	CA	Net wheat income (SP/ha) and wheat consumption (kg/year adult qeivalent)	Farm level Other	Medium

smallholder cropping farmers?. *Journal of Agricultural Economics*, *67*(1), 154-172.							
Faltermeier, L., & Abdulai, A. (2009). The impact of water conservation and intensification technologies: empirical evidence for rice farmers in Ghana. *Agricultural Economics*, *40*(3), 365-379.	PSM	Ghana	Bund construction, dibbling seed, intensification technological package, dibbling seed and fertilizer. All dummies	SWC	Net rice returns in ghc/acre and average rice output in bags/acre	Farm level	Medium
Kassie, M., Teklewold, H., Marenya, P., Jaleta, M., & Erenstein, O. (2015). Production risks and food security under alternative technology choices in Malawi: Application of a multinomial endogenous switching regression. *Journal of Agricultural Economics*, *66*(3), 640-659.	IV	Malawi	Crop diversification (maize–legume intercropping and/or rotations) and minimum tillage	ISFM CA	Expected maize yield (kg/acre)	Farm level	Medium
Kato, E., Ringler, C., Yesuf, M., & Bryan, E. (2011). Soil and water conservation technologies: a buffer against production risk in the face of climate change? Insights from the Nile basin in Ethiopia. *Agricultural Economics*, *42*(5), 593-604.	IV	Ethiopia	SWC technology adoption (soil bunds, stone bunds, grass strips, waterways, trees planted at edge of farm fields, contours, and irrigation) All dummies	SWC	Value of crop production per ha	Farm level	Medium
Liverpool-Tasie, L. S. O. (2017). Is fertiliser use inconsistent with expected profit maximization in sub-Saharan Africa?“Evidence from Nigeria”. *Journal of*	IV	Nigeria	Nitrogen application rate	ISFM	Rice yield (kg/ha)	Farm level	Low

Agricultural Economics, *68*(1), 22-44.							
Matchaya, G. C., & Perotin, V. (2013). The impact of cooperative patronage: The case of National Small Holder Farmers' Association (NASFAM) of Malawi in Kasungu District. Agrekon, 52(2), 75-103.	PSM	Malawi	Participation in cooperative, one of the objectives is to improve land use management practices	Undefined	Income per capita – unclear if its per day or per year	Household level	Medium
Pender, J., & Gebremedhin, B. (2008). Determinants of agricultural and land management practices and impacts on crop production and household income in the highlands of Tigray, Ethiopia. *Journal of African Economies*, *17*(3), 395-450.	IV	Ethiopia	Use of fertiliser, improved seeds, manure or compost, burning to clear the plot, contour plowing, reduced tillage, intercropping or mixed cropping	ISFM CA	Value of crop production per ha	Farm level	Medium
Ragasa, C., & Mazunda, J. (2018). The impact of agricultural extension services in the context of a heavily subsidized input system: The case of Malawi. *World Development*, *105*, 25-47.	IV	Malawi	Quantity of fertilizer subisidy received (kg/ha), received advice (dummy's) and interactions thereof	ISFM	Value of production per ha (maize + legume farmers) and three food security indicators (household dietary diversity score, food consumption score and food variety score)	Farm level Food security	Medium
Tambo, J. A., & Mockshell, J. (2018). Differential impacts of conservation agriculture technology options on household income in Sub-	PSM	Sub-Saharan Africa	Three conservation agriculture techniques (minimum soil disturbannce, residue retention, crop rotation) and combinations of the three	CA	Annual hh income (USD) and income per adult equivalent	Household level	Medium

Saharan Africa. *Ecological Economics*, *151*, 95-105.							
Wainaina, P., Tongruksawattana, S., & Qaim, M. (2018). Synergies between different types of agricultural technologies in the Kenyan small farm sector. *The Journal of Development Studies*, *54*(11), 1974-1990.	PSM	Kenya	Different technologies and combinations (improved seeds, fertilizer, terraces, soil bunds, crop residue, zero tillage, manure)	SWC ISFM CA	Total annual income generated by the household in KES and Total household income per person in KES	Household level	Medium
Zeitlin, A., Caria, S., Dzene, R., Janský, P., Opoku, E., & Teal, F. (2010). Heterogeneous returns and the persistence of agricultural technology adoption.	DiD	Ghana	Adoption of hi-tech package (fertilizer, pesticides and fungicides that had to be repaid and training on application)	ISFM	Cocoa output in kg	Farm level	Medium
Asfaw, S., McCarthy, N., Lipper, L., Arslan, A., Cattaneo, A., & Kachulu, M. (2015). *Climate variability, adaptation strategies and food security in Malawi* (No. 1008-2016-80228).	IV	Malawi	Adoption of modern inputs (improved seed or inorganic fertilizer) and sustainable land management practices (trees or soil and water conservation or organic fertilizer or intercropping)	ISFM, Undefined	maize productivity (kg/acre)	Farm level	Medium
Kassie, M., Pender, J., Yesuf, M., Kohlin, G., Bluffstone, R., & Mulugeta, E. (2008). Estimating returns to soil conservation adoption in the northern Ethiopian highlands. *Agricultural economics*, *38*(2), 213-232.	PSM	Ethiopia	Adoption of soil bunds	SWC	Value of crop production per ha	Farm level	Low
Schmidt, E., & Tadesse, F. (2014). Sustainable agriculture in the Blue Nile Basin: land and watershed management practices in	PSM	Ethiopia	Adoption of sustainable land and watershed management techniques (terraces, bunds, check dams)	SWC	Value of crop production	Farm level	Low

Ethiopia. *Environment and Development Economics*, *19*(5), 648-667.							
Kassie, M., Köhlin, G., Bluffstone, R., & Holden, S. (2011, May). Are soil conservation technologies “win-win?” A case study of Anjeni in the north-western Ethiopian highlands. In *Natural Resources Forum* (Vol. 35, No. 2, pp. 89-99). Oxford, UK: Blackwell Publishing Ltd.	PSM	Ethiopia	Adoption of terraces	SWC	Net value of crop production per ha	Farm level	Medium
Schmidt, E., & Tadesse, F. (2017). *The sustainable land management program in the Ethiopian highlands: An evaluation of its impact on crop production* (Vol. 103). Intl Food Policy Res Inst.	PSM DiD	Ethiopia	Participation in sustainable land management program (watershed and land management structures, water retention, tillage practices, land tenure security)	SWC	Value of crop production	Farm level	Low
Liverpool-Tasie, L. S. O., Adjognon, S., & Kuku-Shittu, O. (2014). *Productivity effects of sustainable intensification: The case of Urea deep placement for rice production in Niger State, Nigeria* (No. 329-2016-13225).	PSM IV	Nigeria	Adoption of intensification practice urea deep placement (UDP)	ISFM	Rice yield (kg/ha)	Farm level	Low
Bravo-Ureta, B. E., Almeida, A. N., Solís, D., & Inestroza, A. (2011). The economic impact of Marena’s investments on sustainable agricultural systems	PSM DiD	Honduras	Participation in project with agroforestry and soil conservation components as well as coffee and livestock production and irrigation systems	Undefined	Value of crop production	Farm level	Low

in Honduras. *Journal of Agricultural Economics*, *62*(2), 429-448.							

Notes: This table details all the selected low and medium risk papers in our study including a categorization of the method, country, intervention and risk of bias assessment.