The scientific basis of climate-smart agriculture
A systematic review protocol

Working Paper No. 138

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

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Titles in this Working Paper series aim to disseminate interim climate change, agriculture and food security research and practices and stimulate feedback from the scientific community.

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Abstract

Background: 'Climate-smart agriculture' (CSA)—agriculture and food systems that sustainably increase food production, improve resilience (or adaptive capacity) of farming systems, and mitigate climate change when possible—has quickly been integrated into the global development agenda. However, the empirical evidence base for CSA has not been assembled, complicating the transition from CSA concept to concrete actions, and contributing to ideological disagreement among development practitioners. Thus, there is an urgent need to evaluate current knowledge on the effectiveness of CSA to achieve its intended benefits and inform discourse on food, agriculture, and climate change. This systematic review intends to establish the scientific evidence base of CSA practices to inform the next steps in development of agricultural programming and policy. We will evaluate the impact of 73 promising farm-level management practices across five categories (agronomy, agroforestry, livestock, postharvest management, and energy systems) to assess their contributions to the three CSA pillars: (1) agronomic and economic productivity, (2) resilience and adaptive capacity, and (3) climate change mitigation in the developing world. The resulting data will be compiled into a searchable Web-based database and analytical engine that can be used to assess the relative effectiveness and strength of evidence for CSA, as well as identify best-fit practices for specific farming and development contexts. This represents the largest meta-analysis of agricultural practices to date.

Methods/Design: This protocol sets out the approach for investigating the question: *How do farm-level CSA management practices and technologies affect food production and/or farmers' incomes, resilience/adaptive capacity, and climate change mitigation in farming systems of developing countries*? The objective of this ongoing systematic review is to provide a first appraisal of the evidence for CSA practices in order to inform subsequent programming. The review is based on data found in English-language peer-reviewed journals with searches using terms relevant to CSA practices and CSA outcomes. Searches were conducted via Web of Science (WoS) and Scopus. Articles located were screened first by abstract and then full text according to predefined eligibility criteria for inclusion in the review. Data capturing the context of the study (e.g., geographic location, environmental context), management practices, and impacts (e.g., indicators of CSA outcomes) will be compiled from those studies that meet the predetermined criteria. Statistical relationships between practices and impacts will be evaluated via meta-analytical approaches including response ratios and effect sizes. Mechanisms to identify bias and maintain consistency continue to be applied throughout the review process. These analyses will be complemented

with an analysis of determinants of/barriers to adoption of promising CSA practices covered in the meta-analysis. Results of the review will be incorporated into a publicly available Web-based database. Data will be publicly available under Creative Commons License in 2016.

Keywords

Climate-smart agriculture; adaptation; mitigation; synergies and trade-offs; meta-analysis

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Contents

Acronyms

ACSAA	Alliance for Climate-Smart Agriculture in Africa
CAADP	Comprehensive African Agricultural Development Program
CCAFS	CGIAR Research Program on Climate Change, Agriculture, and Food Security
CIAT	International Center for Tropical Agriculture
CGIAR	Consultative Group on International Agricultural Research
COMESA	Common Market for East and Southern Africa
CRS	Catholic Relief Services
CSA	Climate-smart agriculture
DFID	Department for International Development
FAO	Food and Agriculture Organization of the United Nations
GACSA	Global Alliance for Climate-Smart Agriculture
GCF	Green Climate Fund
GEF	Global Environmental Facility
ICRAF	World Agroforestry Centre
IFAD	International Fund for Agricultural Development
NEPAD	New Partnership for Africa's Development
NORAD	Norwegian Agency for Development Cooperation
USAID	United States Agency for International Development
WoS	ISI Web of Science

Rationale

Agricultural development strategies have shifted from promoting one-size-fits-all technologies aimed at increasing productivity, to advocating for improved agricultural practices that account for both livelihood and environmental outcomes [1-6]. The most recent approach to an integrated development agenda is 'climate-smart agriculture' (CSA). CSA refers to agricultural systems that increase food security in the face of climate change, enhance adaptive capacity of farmers to the impacts of climate change, and mitigate climate change where possible [7].

CSA's approach to simultaneously addressing multiple sustainability and development challenges has garnered significant attention at global forums since its conception in 2010, when it was defined and presented by the Food and Agriculture Organization of the UN (FAO) at the Hague Conference on Agriculture, Food Security and Climate Change. It has since been repeatedly spotlighted at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (CoP), first in Durban, South Africa, then in Warsaw, Poland and most recently in Lima, Peru. Development organizations and countries are pursuing the approach. A 'Global Alliance for Climate-Smart Agriculture' (GACSA) was recently launched at the United Nations Secretary Generals' Climate Summit in September 2014 with the goal of helping 500 million smallholder farmers practice CSA [8]. At the same time, regional efforts to increase the uptake of CSA are underway. For example, the New Partnership for Africa's Development (NEPAD) convenes a diverse group of development and technical partners as part of the Alliance for Climate-Smart Agriculture in Africa (ACSAA) [9], which plans to help catalyse the scaling up of CSA to 25 million and 6 million farm households across the continent by 2025 and 2021, respectively. Individual countries are also taking actions on CSA. There are examples of success stories on CSA implementation in Tanzania (agroforestry), Peru (genetic diversity), and China (sustainable grazing) amongst other national initiatives [10]. Recently, the Green Climate Fund (GCF) named CSA in Africa and Asia as one of its five priority investment areas, and the Global Environmental facility (GEF) has a focal area on CSA and food security in Africa. Thus, it is clear that NGOs, policymakers and development partners at multiple levels are planning and implementing CSA activities.

The pace at which CSA has been integrated into the development agenda has caused some controversy. Much of this controversy can be traced to confusion about what constitutes CSA

and why [11,12] and the inclusion of agricultural mitigation as a goal. Simply put, a lack of criteria and boundaries leaves CSA open to interpretation, leading to concerns such as the CSA agenda merely 'greenwashing' corporate interests [13]. But the concerns are not only the result of a vague definition. Initial discussions were perceived to concentrate too heavily on climate change mitigation and climate finance, leaving some to suspect that the true aim of CSA was to trap smallholders in complex carbon contracts [14]. These issues, amongst others, have splintered the development community and raised questions about the added value of CSA.

It is important to emphasize that CSA is not a new set of practices to be promoted to farmers, but rather an integrated approach to the implementation of agricultural development policies and programmes that strives to improve food security, livelihoods, and resilience under the realities of climate change, while at the same time capturing mitigation co-benefits where possible. We generally subscribe to three principles for understanding, identifying, and selecting which farm-level management practices constitute a climate-smart approach.

- **CSA addresses risk:** CSA technologies address climate or weather related risk while improving food security. The risks addressed may include extreme events (such as floods) as well as slow-onset hazards (such as delayed onset of seasonal rains). CSA technologies should help ameliorate the impacts of these risks both in the short term (increase the amount of production per farm, hectare, season, etc) and in the long term (decrease the variability in production over time in spite of climate change).
- **CSA has multiple benefits:** CSA technologies achieve at the minimum two benefits among productivity, resilience and mitigation, where productivity is the priority in developing countries dependent on agriculture for subsistence. Progress can be measured using metrics that are nested under these broad CSA categories relative to a reasonable baseline. For example, improved productivity might be measured as yields, income, or internal rate of return. CSA aims to harness synergies and reduce tradeoffs across its pillars.
- **CSA is context specific in both space and time:** CSA technologies are socially and culturally appropriate for the area in which they are to be practiced. Given that biophysical and social conditions change, whether a technology is CSA or not is a dynamic delineation. What is CSA in a location today may not be CSA in the same location in 20 years.

A CSA approach to agricultural development includes not only the promotion of farm/field level practice changes that provide CSA benefits, but also changes in the decision environment in which farmers adopt practices, such as infrastructure development and

provision of social safety nets [10,11]. Yet, practice changes at the farm and field level will be a critical component of agricultural development in the context of climate change [11] and field and farm level practices remain the cornerstone of the CSA agenda.

Little empirical evidence, however, has been put forth so far to systematically evaluate the outcomes of CSA practices [16,17]. Instead, CSA is often supported with case studies or anecdotes, lacking sufficient detail to confidently attribute outcomes to interventions. The lack of comprehensive information on CSA is not surprising, given its novelty as a concept, its inclusion of a wide diversity of food system/rural livelihood practices, a lack of common understanding of the outcomes of CSA, and relevant information residing in disparate literatures ranging from agronomy to atmospheric science to social sciences. The lack of a coherent evidence base is one factor contributing to the controversy surrounding CSA, with the uncertainty undermining practitioners' and policy makers' ability to develop efficient and effective programming on agricultural development under climate change.

This review is not a holistic attempt to define, support, or refute CSA. Instead, it is a first attempt to unpack the farm/field level interventions component of CSA in a way that enables us to bring data and empirical evidence to the discussion. The scope of this effort has required the review team to make many decisions that have affected the outcome of the review, such as which practices to investigate, what indicators represent the three outcomes (agronomic and economic productivity, resilience/adaptive capacity, and mitigation) and which databases to search. Consequently, this effort represents just the start of what is necessary to fully assess the evidence base for farm/field level interventions. Decisions have been and continue to be made to constrain the scope to match available resources while providing a transparent accounting of the process. Despite these caveats, this work will inform the discussion on sustainable agricultural development that is productive and adaptive with low emissions, which is undeniably critical to the future of rural populations in developing countries and the sustainability of the planet.

The motivation for this systematic review and meta-analysis was derived from repeated conversations (since 2011) among scientists, development specialists and donors about the need to move CSA from the meeting room into the field, by prioritizing and scaling up best-fit agricultural practices and technologies. Discussions with national governments, the World Bank, FAO, NORAD, DFID, IFAD, USAID, CARE International, Concern Worldwide, Catholic Relief Services, World Vision, Oxfam, the Comprehensive African Agricultural Development Program (CAADP), and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), amongst others, helped develop the research question. Upon completion, the output of the review will be integrated into a publicly

available database hosted on the CCAFS' CSA Web Portal. Future activities can build on this effort by including data from grey literature, expanding the scope to additional sustainable land and water management practices and additional CSA outcome indicators, crowd-sourcing information from development specialists, updating the information as new research emerges and incorporating non-English language scientific literature.

Objective of the review

The objective of this systematic review is to evaluate the scientific evidence on the impacts that changing from conventional agriculture to improved agricultural systems will have on productivity, resilience/adaptive capacity, and climate change mitigation. In the context of this review, "conventional" refers to the usual or baseline agricultural practice in a given system and region, whereas "improved" means using an agricultural practice that has been cited as having CSA benefits. We first aim to map the available literature and evidence across a range of highly-cited potential CSA practices to evaluate the evidence base supporting this potential, as well as to identify knowledge gaps. Second, a quantitative meta-analysis will be conducted to understand the depth of scientific evidence for each of the three components of CSA, highlighting the synergies and trade-offs of potential CSA practices. A complementary analysis of barriers to/determinants of adoption of CSA practices will be conducted to provide a comprehensive understanding of the enabling environments for the practices covered in the meta-analysis.

The research question for this review is "How do farm-level CSA technologies affect food production, resilience/adaptive capacity, and climate change mitigation in farming systems of developing countries?" This review is being conducted by CCAFS, a cross-institutional research program of the CGIAR. Specifically, the World Agroforestry Centre (ICRAF) is leading the review with support from International Center for Tropical Agriculture (CIAT) (both independent CGIAR research centers) as well as from FAO and the University of Vermont.

Methods

Scope of the review

The scope of this systematic review is necessarily broad to capture the breadth of practices being considered for CSA programming and the multidimensionality of desired outcomes from CSA. However, each study included in this review conforms to four main inclusion criteria: 1) It examines at least one of the chosen CSA management practices or technologies, 2) It includes information on at least one indicator for one outcome (purported benefit) relevant to CSA objectives, 3) the study location is in a developing country, and 4) the study

design includes primary data with a comparison between an improved/potentially CSA practice, and a conventional or baseline practice. We detail each of these inclusion criteria below.

Practices: The CSA concept has been used to describe a wide range of agricultural and rural livelihood interventions that can be implemented at multiple scales. We choose to include potential CSA practices at the scale of field and farm in this review, as that scale is most represented in research and is of most interest for CSA implementation programs. We selected practices through a combination of literature review (e.g., FAO CSA Sourcebook, IPCC) and discussions with development partners. Experts interviewed represented research centers (e.g. CGIAR, FAO), international NGOs (e.g. Care International, Concern International, Oxfam, World Vision, CRS, etc.), development partners (e.g. World Bank), and continental and regional institutions (e.g. NEPAD, COMESA). Practices identified as potentially CSA and of high interest were organized into five general themes: agronomy, agroforestry, livestock and aquaculture, post harvest management, and energy systems. Under these themes we chose 73 practices to review (see Table 1).

Outcomes: The objective of CSA is to sustainably increase food production and/or farmers' incomes, resilience or adaptive capacity, and mitigate climate change when possible. For each of these three main outcomes, there are many dimensions and potential indicators that can be measured. For example, increased food security may result from changes in availability of food (e.g. increased yield), accessibility of food (e.g. increased income, access to market), utilization of food (e.g. increased food safety, diet diversity), or stability of access to food [18]. Stability of access also addresses the resilience of the system, as stability depends on resilience. Given the difficulties in quantifying resilience, we selected metrics that reflect biophysical, social and economic resilience that help buffer the system against shocks and stresses (e.g., soil organic carbon for biophysical resilience, input use efficiency for household economic resilience, women's work hours for social resilience). Mitigation benefits are more straightforward to quantify and may come from emission reductions, increased removal of GHGs (including carbon sequestration), or emissions avoided through adoption of CSA technologies [19]. For each outcome of CSA and outcomes, measures of 'climate-smartness' were selected (see Table 2).

Table 1: Description of practices included in the meta-analysis

Theme	Practices	Description
AGRONOMY		
Conservation Agriculture	Conservation Agriculture	Combination of three practices: reduced soil disturbance, crop rotation, and continuous soil cover
Soil amendments including organic and inorganic fertilizer	Organic + Inorganic	Using a combination of both organic and inorganic inputs
	Inorganic inputs (NPK)	Using a combination of synthetically derived materials containing nitrogen (N), phosphorus (P), and/or potassium (K)
	Compost	Application of organic material to the field that has gone through some process of aerobic digestion
	Manure	Application of animal excreta to the field or pasture either through direct deposition or through purposeful transfer
	Green manure	Use of nitrogen-fixing perennial or annual plants parts, in rotation or intercropped, either applied to surface or incorporated into the soil
	Biochar	Application of organic materials that have gone through pyrolysis at high temperatures to the soil
	Integrated soil fertility management	The combined system of a suite of soil and nutrient management practices
Fertilizer application method	Fertilizer banding	Field application of fertilizer directly in area of root-zone to increase the potential for uptake
	Microdosing	Applying small, affordable quantities of fertilizer onto the seed a planting time and a few weeks after emergence
	Subsurface fertilization	Field application of fertilizer under soil surface
	Precision agriculture	On field use of technologies such as GPS that can help deliver nutrients and water in necessary locations at the necessary amounts techniques
Crop Rotations	Crop order or sequence	Changes in the order or sequence of crops in a rotation
	Crop combination	Changes in the types of crops in a crop rotation
Intercropping	Intercropping with Legumes	Intercropping with leguminous annual crops
Mulching	Plant residues	Mulching with plant residues that are not explicitly green manure
	External material	Mulching with materials such as plastic
Tilling	Reduced till	A reduction in soil disturbance
	No till	A land preparation system without the inversion of the soil
pH control	Liming or Ca	application of lime/Ca on the field
Crop Tolerance to Stress	Heat tolerance	Planting of cultivars for their resistance to heat stress
	Drought tolerance	Planting of cultivars for their resistance to water stress (generally a lack of water)
	Salinity Tolerance	Planting cultivars for their resistance to salts in soils
Diversification	Increased diversity of cultivars	Increasing the number of cultivars in field/farm. e.g. varieties of maize
	Increased diversity of crops	Increasing the diversity in the types of crops grown in the field/farm

	Increased diversity in rotation	Increase the number and kind of crops in the rotation
	Polyculture system	Multiple crops in an area in a given time, including integration of livestock
Water management in upland soils	Drip irrigation	The use of plastic pipes to drip water into the soil at low pressure
	Water harvest/storage	Collection and storage of water runoff for irrigation purposes
	Deficit irrigation	Application of water below full crop requirements
	Zai	Small pit in degraded land, filled with manure/compost/nutrients before rainy season to capture water and grow plants
	Alternate partial root zone irrigation	Also called partial root zone drying PRD - part of the root is exposed to drying soil and the remaining is irrigated in accordance with crop requirements and soil drying rate
Water management in flooded rice systems	System of Rice Intensification (SRI)	Early transplant of rice seedlings (8-12 days), 25cm distance, and alternate wetting and drying
	Alternate wetting and drying (AWD)	Flooding and draining at intervals as dictated by soil moisture levels
	Mid-season drainage	Field is drained midseason and not re-flooded
AGROFORESTRY		
Boundary planting	Boundary planting	Hedgerows, living fences, windbreaks, trees/shrubs along field border
Evergreen agriculture	Evergreen agriculture	A combination of agroforestry practices that may include fertilizer trees, intercropping, conservation agriculture with trees, etc.
Farmer managed natural regeneration	Farmer managed natural regeneration	Control succession of tree species either through protection of young trees or intentional planting of some tree species
Intercropping	Rows/alleys (N-fix)	Woody species arranged in rows; agricultural species in alleys in between hedges; microzonal or strip arrangement; Interaction of woody perennials (fast growing, leguminous that coppice) and crops.
	Rows/alleys (non-N-fix)	Intercropping with non-N-fixing trees and shrubs
	Rows/Alleys (Multiple species)	Intercropping with trees or shrubs, both N-fixing and not N-fixing
	Mixed	Trees/shrubs scattered in the field
	Parklands	Mature trees scattered in cultivated or fallow fields
Multi-strata agroforestry	Multi-strata	Several strata of trees occupied by tree crops (coffee, tea, cacao, etc.) with shade trees that include two or more vegetation layers and more than one tree species
LIVESTOCK AND AQUACULTURE		
Diet management	Non-conventional feeds	Use of any feed ingredient not known for human consumption (e.g. *Jatropha*, brewers mash, orange pulp)
	Improved feed quality	Use of additives to improve feed conversion efficiency (e.g. probiotics, prebiotics)
	Increased digestibility	Feed manipulations to improve acceptability and palatability of feed (e.g. molasses, fermentation)

	Improved protein content	Feed manipulations to increase the quantity of protein in livestock diets (e.g., by fodder shrubs and other leguminous plants)
	Improved use supplements	e.g. hay, silage and nutritional/mineral blocks. Include nutritional/ mineral/ anti-stress blocks/ additives as part of supplementary feeding regime.
Improved pasture	Planting N fixing legumes	Planting legumes (e.g. clover, medics, peas, etc.) for consumption by livestock
	Fodder Shrubs	Planting shrubs grown to be consumed by livestock
	Introduction of suitable non-native fodders	Planting grass, legumes, or shrubs not native to the region to be consumed by livestock
	Increased pasture palatability and acceptability	Planting species or cultivars of higher nutritional value
Rangeland Management	Carrying-capacity improvement	Adjusting animal stocking rates to more closely match the carrying capacity of rangelands and avoid overgrazing
	Rotational Grazing	Strategic movement of livestock through partitioned pasture areas to allow optimal regrowth of forage
	Cut-and-Carry	
Manure management	Manure collection	For use in pasture (i.e. as fertilizer), or bio energy
	Manure Storage	Altering manure storage to reduce CH_4 emissions (e.g. covering, reducing storage time)
	Manure Treatment	Composting, biodigesters, solids separation, or other technologies to reduce emissions or make manure easier to apply
Genetic improvement	Hybridization	Cross breeding, targeted specifically towards traits/ products.
	Assisted reproduction	Artificial insemination, embryo transfer/ surrogacy, semen quality assessment, genetic marker-assisted breeding of livestock.
	Changing breeds	Improved genetics for meat or yield or milk
Aquasilviculture	Integrated Multitrophic Aquaculture (IMTA)	Rearing of a fed aquatic species in association with species that occupy other trophic levels, making use of the waste products of the fed organisms
	Aquasilviculture	Reclaiming' a swamp or lake within a forest for aquaculture (eg. mangrove swamp forest opened up to produce fish)
Disease Management	Disease resistant breeds	Breeding animals for lower susceptibility to certain diseases; resistance to some diseases is heritable
	Biological control of vectors	Using plant extracts, parasitoids, natural enemies and other biological methods to control livestock disease vectors such as ticks.
POSTHARVEST MANAGEMENT		
Harvesting Technique	Alternate harvesting techniques	Horticulture and grain- proper harvesting techniques to reduce product breakage and bruising
	Changing harvest time	Horticulture and grain- harvesting at optimal moisture conditions to avoid losses due to mold and product decay
Improved storage	Improved drying techniques	Improved drying techniques to avoid mold and decay
	Improved preservation	Food/ feed/ seed preservation technique to reduce contamination or product loss
	Improved physical storage	Improved physical storage (off-ground storage, improved packaging, chilling)
FOOD ENERGY SYSTEMS		
Biogas	Biogas production	Biogas from anaerobic-, bio-digesters
Cookstoves	Improved cookstoves	Improved cookstove energy conversion efficiency

Table 2: Description of Included Outcomes and Indicators

Outcome	Indicator	Rationale	Examples
I. Food production			
	Yield	Increased yield increases food availability	Maize yield (kg/ha/yr); Weight gain (kg); Milk production (L/cow/day); Biomass (kg/ha/yr)
	Income	Increased income increases food accessibility and can contribute to poverty alleviation	Production cost ($/yr); Net Present Value; Household energy costs ($/yr); Net Returns ($/ha/yr); Payback Period (yrs)
	Food Security	May be measured directly at the individual or household level	Consumption (Kcal/pers/day); Food Deficit (Kcal/pers/day)
II. Resilience/adaptive capacity			
Biophysical	Biodiversity	Increases in biodiversity enhances agro-ecosystem services	Number of pollinators (#); Soil microbe diversity (#);
	Soil Resources	Lack of water and soil nutrients is a major limiting factor to agricultural productivity in the developing world. Undegraded soil stabilizes yields	Soil Organic Carbon (g/m^3); Soil Nitrogen (g/m^3); Erosion losses (t soil/ha/yr)
Economic	Resource Efficiency	Increased resource use efficiency reduces reliance on inputs and increases economic resources	Water Use Efficiency (L/kg); Nutrient Use Efficiency (g/kg); Protein Utilization (%);
	Labour	Reduced labour frees up time for income diversification	Person-hours (hrs/ha/yr); Value of labour ($/hr)
Social	Gender	Workload of women has been related to a number of household, including nutritional, outcomes	Female-person-hours (hrs/ha/yr);
III. Mitigation			
	GHG Emissions	Reduced emissions mitigates GHGs from agriculture	CO_2 flux (mg C m^{-2} hr^{-1}); N_2O flux (mg N m^{-2} d^{-1})
	Emission Intensity	Reduced emissions per unit product mitigates GHGs from agriculture while accounting for food security goals	GHGs/product (Kg CH_4 /kg milk or grain);
	Carbon Stocks	Enhanced removal of C from the atmosphere into on-farm C reservoirs mitigates GHGs from agriculture	Aboveground biomass (t/ha); Total soil carbon (t/ha);
	Consumption	Reduced fuel consumption avoids GHGs emissions	Fuelwood Consumed (kg/yr);

Locations: The areas of concern for this systematic review are agroecosystems in low- and middle-income countries as identified by the World Bank [20]. Although CSA concepts are relevant to agriculture and food systems globally, early discussions surrounding CSA have occurred largely within the international development community [21]. The intent of our review is to provide decision-relevant information for agricultural transformation in developing countries. As such, the geographical bounds have been set to include research based in, or relevant to, all regions and countries defined as "developing", as listed in [20].

Study Designs: We limited the scope of this review to studies that met the following criteria for experimental design: 1) studies must include primary data and not be literature reviews, model outputs, or meta-analyses; 2) studies must include a relevant comparator, or a control practice that represents baseline or conventional agricultural management, as well as a 'treatment', or improved CSA practice; 3) studies must take place at the farm, field or household scale[1]; and (4) studies must contain data on a CSA-relevant outcome as defined above. Socio-economic literature included in the review, though not usually experimental in design, adheres to the same principles based on comprehensive household surveys and rigorous statistical/econometric analyses to identify the impact of improved practices on CSA relevant outcomes.

Searching the literature

Database: Searches were conducted in English language peer-reviewed journals accessible on the internet. This review did not include grey literature such as institutional reports or academic dissertations, or many peer-reviewed articles published prior to 1990 that are not digitally available. We chose to limit our search to the databases Web of Science (WoS) and Elsevier's Scopus because of the breadth of available literature, the ability to support complex search strings, and the accessibility of these databases at ICRAF headquarters in Nairobi and FAO headquarters in Rome.

Search Strings: Search strings consisted of three components: a 'practice' string, an 'outcome' string, and a 'location' string. Because of the large number of outcomes of interest, we created separate search strings for 'productivity', 'adaptation', and 'mitigation' outcomes, as

[1] Because of the very limited amount of *in-situ* measurements of soil GHG flux measurements, laboratory investigations were also included in this part of the analysis.

well as a search string related to 'barriers' to adoption. The location search string included developing countries [20] and broader geographic regions of interest (e.g. 'Africa', 'Sahel', 'Amazon', etc.). For each of these three components, search terms were combined with the Boolean 'OR' operator to be as inclusive as possible. The practice, outcome, and location search strings were then combined using the 'AND' operator for input in WoS and Scopus. This string for each practice was run in both search engines three times, once for each of the four outcome categories, 'productivity', 'adaptation', 'mitigation', and 'barriers'. The search strings used are included in Appendix 1. Running these search strings in WoS and Scopus resulted in more than 144,000 references. The titles and abstracts of these references were exported to EndNote v7.0 (Thompson Scientific) for screening, and duplicate records were removed.

Screening search results

We used a two-stage screening strategy to determine the relevance of articles returned from search strings to our primary research question. In stage one, article abstracts and titles were screened according to our predetermined inclusion criteria for practices, outcomes, and locations of interest (see Table 3). In stage two, the full texts for those abstracts meeting the initial inclusion criteria were downloaded and screened by the same eligibility criteria.

Table 3: Inclusion/exclusion criteria

Inclusion criteria	Exclusion description
Practices	
Relevant to one of the selected themes*	Not relevant to one of the selected themes
Includes one of the selected practices*	Relevant to the selected themes, but does not include one of the selected practices
Outcomes	
Reports data relevant to at least one of the selected CSA outcomes**	Does not report on any indicators for any of the selected CSA outcomes
Location	
Study takes place in or is directly relevant to developing countries	Study is not focused on developing countries
Design	
Study includes primary data	Study uses only secondary data, is a review, or is a meta-analysis
Study includes field collected data	Study includes only model generated data
Comparators used in the study	No use of controls
Study is at farm or field scale	Study is at larger spatial scale and does not report farm or field level data

* See Appendix 1 for more details on themes and practices

** See Appendix 2 for more details on indicators and outcomes

Stage 1: Title and abstract screening: In order to ensure inter-reviewer agreement, iterative rounds of pilot screening were conducted on 100 abstracts to ensure that reviewer decisions met the minimum Cohen's kappa statistic of 0.6. Each reviewer was then assigned a practice theme, and conducted screening based on the inclusion criteria (Table 1). Of the 144,767 references identified in the search, 12,803 (8.8%) met the inclusion criteria (or could not be excluded) based on title and abstract screening.

Stage 2: Full text screening: All articles that passed the title and abstract screening were sourced in full text. This secondary screening considered all criteria but focused largely on the criteria less commonly described in titles and abstracts, such as outcomes, comparators and the presence of primary data. The full text screening resulted in a final library of 7,311 references (5.1% of the initial search results) that met all of our inclusion criteria, and forms the basis of this review. This final library was later complemented by two systematic recursive searches: one conducted using the reference lists of each publication in the library that was conducted in Africa, and another conducted using the reference lists of each publication obtained using mitigation search strings (which identified an additional 799 publications). The resulting analysis (8,610 references) is the largest meta-analysis of agricultural practices by more than an order of magnitude (see Pittelkow et al 2014 with ~600 articles [22]).

Data extraction and analysis

Each paper included in the systematic review after full-text screening entered data extraction. Data extraction is the process of mining information from the papers, including its component text, tables, and figures, and entering it into a database. Figures were digitized so that their data (means of control and treatment outcomes) could be extracted with available software (e.g., GraphClick, http://www.arizona-software.ch/graphclick/).

Data extraction was designed to be as comprehensive as practically possible. Data extracted from studies include location, variables relevant to the study context (e.g. climatic conditions, soil conditions, animal breed or crop variety, etc.), variables relevant to the experimental design (e.g., duration, replications, treatments used etc.) and the mean effects of both the treatment (i.e., CSA practice) and control (non-CSA or baseline). Measures of variability around the mean (standard deviation or standard error) were also extracted when reported,

though very few studies were found that report these critical pieces of information. In addition, the review team collected data from socio-economic studies that also report the determinants of/barriers to adoption of practices to characterize the conditions of CSA adoption.

Data will be analysed primarily through common meta-analytical techniques followed in ecology. The effect size will be calculated based on response ratios:

$$response\ ratio\ (RR) = \ln(\frac{\bar{X}_T}{\bar{X}_C})$$

where, *RR* equals the natural logarithm of the measured mean of the treatment group (X_T) relative to the mean of control group (X_c) [23]. Overall effect sizes can then be calculated as the weighted means of the response ratio for any subgroup of the dataset. Means will be weighted by the number of replications per study, and inversely weighted by the number of observations per study, in order not to give one study undue impact on the results [23]. Similarly, socio-economic analyses with higher numbers of observations have a greater weight than those based on small samples.

Our analytical design supports a flexible approach to answer the key questions around the evidence base for CSA, by exploiting the richness of data in terms of practices, context, and outcomes at the most disaggregated level feasible. Further, because we are calculating our effect size based on log ratios, we have a non-dimensional response and hence can combine various indicators under broader categories if desired. For example, we can calculate the effect of irrigation technology on water use efficiency and nutrient use efficiency individually, or have the potential to combine these categories into agronomic efficiency and analyse the latter together with other indicators of adaptive capacity/resilience. The disaggregated and log ratio approaches allow countless opportunities to categorize and calculate the effect sizes and then examine the relationships (e.g., synergies and trade-offs) among the metrics or CSA components.

Analytical methods for the socio-economic and barrier data will depend on data availability and quality. If appropriate, analysis will mirror that of the full dataset. However, we will also explore developing regressions through typical econometric methods to determine the effect sizes of interest.

Because of the scope of the review, we will conduct the analysis in steps. End-users of the information (development partners) have tacitly influenced the priorities for analysis. To begin with, we will focus on research that has been conducted in Africa. Then, we will conduct a pan-tropical mitigation analysis. Lastly, we will finish the entire tropical developing country CSA Compendium.

Data availability

All data will be publically available in 2016 through multiple outlets including a Web-based searchable database, Dataverse, and Figshare.

Conclusion

Everywhere you turn in agricultural development and climate change communities it seems someone is referencing CSA. Rapid adoption of the CSA concept into the global development lexicon places a premium on understanding what is really known about CSA practices and technologies, the synergies and tradeoffs among its three pillars, and the socio-ecological niches where CSA works. Without such information, at best CSA will be a passing fad and at worst a large of influx of resources– both time and money–will be wasted, distracting from other productive agendas or generating unintended consequences for the communities and issues CSA aims to help solve. Here, we outline the protocol we designed for the meta-analysis (e.g., search terms, data extraction, data analysis) that aims to help calibrate expectations and inform discourse about the efficacy of CSA by collecting, integrating, and evaluating the evidence base for CSA practices and technologies.

Appendix I: Search strings

Terms used when searching on-line databases. Terms in green were added for the SCOPUS search and not run in the original WoS search.

1 Practice Search Strings

1.1 Agronomy

("conservation agriculture" OR "direct seed*" OR "direct sowing" OR "direct planting" OR "direct drill" OR "no till*" OR "reduced till*" OR "min* till*" OR "zero till" OR "minimum soil disturbance" OR "limit soil disturbance" OR mulch* OR "permanent soil cover" OR "permanent ground cover" OR ("max* biomass prod*" AND soil) OR "stale seed bed" OR "Integrated soil fertility management" OR "integrated soil nutrient management" OR ("organic residue" AND soil) OR ("fertili$er inputs" AND soil) OR "soil amendment" OR "organic input*" OR "organic amendment*" OR "precision agriculture" OR ("micro-dose" OR "microdosing") OR "fertili$er banding" OR (fertili$er NEAR efficient) OR ("efficient use" NEAR Nitrogen) OR ("efficient use" NEAR phosphorus) OR ("efficient use" NEAR fertili$er) OR ("efficient use" NEAR input) OR (soil NEAR manure) OR (soil NEAR "animal waste") OR (compost* NEAR soil) OR ("Soil organic matter" NEAR management) OR "soil inoculation" OR (soil NEAR biofertili*) OR (soil NEAR lime) OR (soil NEAR bioinput) OR (soil NEAR biosolid) OR (soil NEAR biochar) OR "rock fertili$er" OR "small-scale irrigation" OR "water saving irrigat*" OR "drip irrigation" OR "micro irrigation" OR "trickle irrigation" OR rainfed OR ("micro catchment" OR microcatchment) OR (pits NEAR "water harvesting") OR "dam" OR "stone lines" OR "sprinkler irrigation" OR "terrac*" OR "fanya" NEAR "terrace*" OR (bund AND contour) OR "soil and water conservation" OR "grass strips" OR "vetiver grass" OR "on-farm water retention" OR "water storage" OR "water harvesting" OR "water collection" OR "water conservation" OR ((rainwater OR rainfall OR precipitation) NEAR harvesting) OR ((rainwater OR rainfall OR precipitation) NEAR collection) OR ((rainwater OR rainfall OR precipitation) NEAR storage) OR ((water OR rainwater OR moisture) AND conservation) NEAR "in situ") OR "deficit irrigation" OR "partial root drying" OR "supplement irrigation" or "supplementary irrigation" OR "Lift irrigation" OR "alternate partial root zone irrigation" OR ("alternate wetting and drying" NEAR rice) OR "midseason drainage" OR "system of rice intensification" OR SRI OR (transplan* NEAR rice) OR "green manure" OR "cover crop*" OR covercrop* OR "ground

cover" OR groundcover OR "legum* cover" OR "plant residue*" or "crop residue*" OR ((intercrop* OR "inter crop*") NEAR legum*) OR (("nitrogen fix*" NEAR intercrop*) OR ("N fix*" NEAR intercrop*) OR ("N2 fix*" NEAR intercrop*)) OR (("nitrogen fix*" NEAR "intercrop*") OR ("N fix*" NEAR "intercrop*") OR ("N2 fix*" NEAR "intercrop*")) OR "improv* fallow*" OR ("heat resistant cultivar" OR "heat resistant crop") OR "drought resistant cultivar" OR "drought resistant crop" OR "heat resistant cultivar" OR "heat resistant crop" OR "salt resistant cultivar" OR "salt resistant crop" OR "cropping system diversification" OR "crop diversification" OR "diversif* crop*" OR "crop rotation*" OR ("crop succession" OR "crop sequence" OR "crop pattern") OR "local cultivar*" OR "local crop*" or "local accession*" OR polycultur* OR ((farm* OR "production system") NEAR divers*) OR "double crop*" OR "relay crop*" OR "Integrated Pest management" OR "IPM" OR "integrated pest control" OR ((pest* OR insect* OR weeds* OR pathogen*) NEAR "action threshold*") OR ((pest* OR insect* OR weed* OR pathogen*) NEAR "econom* threshold*")

1.2. Agroforestry

(agr*forest* OR agr*silv* OR agr*hort* OR "evergreen agriculture" OR (parkland* AND agr*) OR "farmer managed natural regeneration" OR "commun* natural resource* management" OR "commun* forest* management" OR taungya OR (("mix* crop*" OR "multi* crop*" OR legum* OR indigenous OR exotic OR introduc* OR domesticat* OR farm* OR medicinal OR nut* OR fruit* OR timber* OR nitrogen fix*) NEAR tree) OR (("mix* crop*" OR "multi* crop*" OR legum* OR indigenous OR exotic OR introduc* OR domesticat* OR farm* OR medicinal OR nut* OR fruit* OR timber* OR nitrogen fix*) NEAR shrub) OR "alley crop*" OR "alley system*" OR "alley farm*" OR "fertilizer tree*" OR "fertiliser tree*" OR "farm* forest*" OR "tree crop interaction*" OR (((multifunction* OR multipurpos* OR "multi functional*" OR "multi purpos*" OR multistrata OR "multi strata") NEAR tree*) OR ((multifunction* OR multipurpos* OR "multi functional*" OR "multi purpos*" OR multistrata OR "multi strata") NEAR shrub*) OR ((multifunction* OR multipurpos* OR "multi functional*" OR "multi purpos*" OR multistrata OR "multi strata") NEAR farm*) OR ((multifunction* OR multipurpos* OR "multi functional*" OR "multi purpos*" OR multistrata OR "multi strata") NEAR agr*)) OR "woody perennial*" OR "non timber forest product*" OR NTFP* OR "agroforestry tree product*" OR "fruit orchard*" OR "nut orchard*" OR "food forest*" OR woodlot* OR ((tree* OR management) NEAR shad*)

OR "overstor* tree*" OR "understor* tree*" OR "understor* crop*" OR (((firewood OR "fire wood" OR fuelwood OR "fuel wood") NEAR tree*) OR ((firewood OR "fire wood" OR fuelwood OR "fuel wood") NEAR shrub*) OR ((firewood OR "fire wood" OR fuelwood OR "fuel wood") NEAR bush*)) OR "boundary plant*" OR "liv* fence*" OR hedgerow* OR "riparian buffer strip*" OR "riparian forest buffer*" OR "buffer zone*" OR windbreak* OR shelterbelt* OR "shelter belt*" OR (((plant* OR farm* OR barrier* OR "buffer strip*") NEAR tree* NEAR contour) OR ((plant* OR farm* OR barrier* OR "buffer strip*") NEAR shrub* NEAR contour)) OR "shifting cultivation" OR "improved fallow*" OR "slash* and burn*" OR "swidden agricult*" OR silv*past* OR silv*arable* OR "cut and carry" OR "tree belt*")

1.3 Livestock

((Livestock OR "mono gastric" OR cattle OR sheep OR goats OR pigs OR poultry OR ruminant OR aquaculture OR fish*) AND ("non-conventional feed" OR "Forage productivity" OR grass OR "pasture additive" OR "grass-legume" OR "feed conversion" OR "feed intake" OR "protein intake" OR "energy intake" OR "feed availability" OR “feed supplement*” OR "energy retention" OR "growth rate" OR "feed acceptability" OR "feeding frequency" OR "stover digestibility" OR "paddock" OR "free*range" OR "hay" OR "silage" OR "fodder shrub*" OR "nomadic" OR pastoral OR "signal*grass" OR (pasture NEAR cerrado) OR "crop residue" OR "animal husbandry" OR "pasture species" OR "crop-pasture" OR "pasture crop*" OR "zero graz*" OR "rotational graz*" OR "conti* graz*" OR "stocking density" OR "organic* livestock" OR "ammonia volatil*" OR "N-retention" OR "cover* manure" OR "biogas capture" OR "Manure acidification" OR "Cover* manure" OR "Manure collection" OR "manure treatment" OR "artificial insemination" OR "trait selection" OR "heat period" OR ovulation OR hybrid OR "desirable traits" OR "progeny test" OR "semen analysis" OR "cross breed*" OR "Aquasilviculture" OR "Integrated multi-trophic aquaculture" OR "Organic Aquaculture" OR "fishing intensity" OR "culture based fishery" OR "vulnerable" OR "susceptible" OR "resistan*" OR "quarantine" OR "antibiotic" OR "vaccine" OR "dewormer" OR "ectoparasite" OR "innoculation" OR (Livestock AND (antistress OR "anti-stress"))))

1.4. Post Harvest

("post harvest loss" OR "food loss" OR "food waste" OR (improved NEAR "harvest technique*") OR "harvest technolog*" OR "harvest maturity" OR (improved NEAR "harvest method*") OR "harvest time*" OR "post harvest storage" OR ("post harvest" NEAR silo*) OR "storage bin" OR "hermetic systems" OR (storage NEAR warehouse) OR ("improve* stor*" AND (Crop OR grain OR harvest OR feed)) OR "on farm storage" OR "off farm storage" OR ("post-harvest" AND (pest OR insect) AND control) OR (("post harvest" OR storage) AND cooling) OR (("post harvest" OR storage) AND drying) OR ("post harvest" AND (preservation AND drying OR salting OR dehydration)))

1.5. Energy Systems

((cookstove* OR "cook* stove*" OR "improv* stove*" OR "anaerobic digest*" OR "anaerobic ferment*" OR "bio* digest*" OR "biodigest*"))

2 Outcome Search Strings

2.1. Production

(yield* OR "yield stability" OR output* OR outturn OR product* OR efficien* OR tonne* OR ton OR tons OR bags OR bushel* OR harvest* OR "crop production" OR "crop productivity" OR "grain fill*" OR "dry matter" OR protein* OR "feed consumption" OR "feed conversion rate*" OR "feed conversion efficiency" OR "reproduction rate*" OR "lambing rate*" OR "calving rate*" OR "kidding rate*" OR "litter size*" OR litre* OR liter* OR "kg/ha" OR "kilogram* per hectare" OR "kg per hectare" OR "turnoff rate*" OR "live weight gain*" OR "liveweight gain*" OR "carcase weight*" OR "carcass weight*" OR "dressed weight*" OR egg* OR catch* OR "maximum sustainable catch*") OR (variability OR variance OR "standard deviation" OR variation) OR ((income* OR receipt* OR payment* OR revenue*) OR "change inventory") OR (cost* OR expense* OR debit*) OR ("capital destruction" OR tax OR ("interest rate*") OR lease) OR (profit* OR "gross margin*" OR ("earnings before interest tax") OR "operating profit*" OR "bottom line" OR "net income*" OR "gross income*" OR "net farm income*") OR (return* OR "net present value*" OR "gross added value*" OR "net added value*" OR "net worth" OR "equity" OR "payback period*" OR "breakeven period*" OR "break even period*" OR "cost benefit analy*" OR "benefit cost analy*" OR "cost effectiv* analy*" OR "opportunity cost*" OR "econom* evaluation*" OR "econom* valuation*" OR "econom* analy*" OR "economic impact*" OR

"discount* cash flow*" OR "partial budget*") OR ((("direct use" OR "passive use" OR "non market" OR contingent OR consumptive OR consumption OR subsistence OR livelihood*) AND (value* OR valuation*)) OR "willingness to pay") OR ((labour* OR labor* OR worker* OR employee*) OR ("full time equivalent*" OR "working day*" OR "man day*" OR "man power"))

2.2. Mitigation

("nitrous oxide" OR N2O OR methane OR CH4 OR "carbon dioxide" OR CO2 OR CO2e OR "CO2 eq" OR "CO2 equivalent" OR emission* OR "greenhouse gas*" OR "global warming potential" OR GWP OR "yield scaled" OR "carbon accumulat*" OR "biomass carbon" OR "carbon stock*" OR "trace gas*" OR "soil carbon sequestration" OR "enteric fermentation" OR "global warming intensity" OR "carbon intensity" OR "emission intensity" OR "carbon footprint" OR "carbon efficiency" OR "atmospheric carbon")

2.3 Resilience

((Adapt* OR toleran* OR resilien* OR "adapt* capacity" OR "adapt* management" OR "capacity building" OR "climate vulnerab*" OR "climate risk" OR "climate change" OR "indigenous knowledge" OR "local knowledge" OR "tradition* knowledge" OR "ecolog* knowledge" OR "commun* awareness" OR "commun* assessment*" OR "vulnerab* assessment*" OR "risk assessment*" OR "participatory assessment*" OR "soci* ecological system*" OR "land use change*" OR "global warming" OR "adaptation to climate change " OR "changing climate") AND ("food access" OR kilocalorie* OR "household consumption" OR "food expenditure" OR "total expenditure" OR "consumption expenditure" OR "meals per day" OR "dietary diversity" OR nutrition* OR hunger OR "food security" OR "food scarc*" OR "nutrition* security" OR "food safety" OR malnutrition OR malnourishment OR undernutrition OR undernourishment OR anaemia OR ((smallholder* OR household* OR agricult*) AND diet) OR "food affordab*" OR "food system*" OR "value chain*" OR poverty OR (micronutrient* NEAR food) OR famine OR "food insecurity" OR "food volatility" OR "food consumption*" OR "food intake" OR "food stability" OR "food availab*" OR "food distribut*" OR "food utilization" OR "food utilisation" OR "Shannon* index" OR "Simpson* index" OR "Species richness" OR "Species diversi*" OR "species evenness" OR "species resilien*" OR "crop divers*" OR "cultivar divers*" OR agr*bio*divers* OR biodiversity OR "indigenous species" OR "neglect* species" OR "native

species" OR "landscape diversi*" OR "income diversi*" OR "red list*" OR "pest* and pathogen*" OR "population* dynamic*" OR ((livestock* OR crop*) NEAR infestation*) OR "species presence" OR "species resistance" OR "species tolerance" OR "pest cost*" OR "implement* cost*" OR ("yield loss" NEAR cost*) OR susceptib* OR erosion OR runoff OR ((loss* OR formation OR aggregation OR fertility OR cover* OR degrad* OR decline) NEAR Soil) OR landslide OR "land slide*" OR desertification OR degrad* OR deforest* OR "soil organic matter" OR "soil organic carbon" OR "soil biomass" OR "soil humus" OR "water use efficiency" OR "water use" OR "water loss" OR "water waste" OR irrigation OR "water availability" OR "water uptake" OR "water consumption" OR "water conservation" OR "water lifecycle*" OR "water footprint" OR "transpiration rate*" OR "water stress" OR "water utility" OR (water NEAR yield) OR "integrated water resource* management" OR "water recycling" OR "water reuse" OR "water productivity" OR "use efficiency" OR "nutrient balanc*" OR "nutrient flow*" OR "nutrient loss*" OR "nutrient uptake" OR "nutrient enrichment" OR ((potassium OR phosphorus OR nitrogen) NEAR uptake) OR "phosphorus uptake" OR "nitrogen uptake" OR "nutrient accumulation" OR "fertilizer management" OR "eco efficien*" OR "embodied energy" OR "energy flow*" OR "energy balance" OR "energy input*" OR "energy output*" OR (energy NEAR management) OR "energy return on energy investment" OR "energy resource*" OR "energy source*" OR "energy use efficiency" OR "energy footprint*" OR "net energy" OR "energy consumption" OR "energy value*" OR "energy saving*" OR (labour OR labor) OR ("labour saving" OR "labor saving") OR income OR wage OR "cash flow*" OR revenue* OR livelihoods OR "on farm activit*" OR "off farm activit*" OR "income earning means" OR "income earning activities" OR "income diversification" OR "seasonal labo*" OR "direct use" OR "own use" OR "women* group*" OR cooperative* OR "employ* opportunit*" OR (Women OR gender AND ("division of labo*")) OR "gender equality" OR entitlement* OR "gender inequality" OR "gender equity" OR "gender relation*" OR "female livelihoods" OR "female entrepreneur*" OR "female headed household*" OR (female AND participation) OR (women AND budget) OR gender* OR "power relation*" OR "gender vulnerability" OR "gender role*" OR "gender knowledge" OR "gender adapt*" OR "gender asset*" OR "female asset*" OR "female propert*" OR (female NEAR finance) OR (female NEAR credit*) OR (female NEAR capital*) OR (women NEAR capital*) OR (women NEAR forag*) OR (women NEAR harvest*) OR matriarchy OR patriarchy OR empowerment OR "cost revenue*" OR membership* OR "farmer* association*" OR "peasant* association*" OR "farmer* union*"

OR "farmer* group*" OR "gender analysis" OR (women NEAR income) OR "women* association*" OR "women* farm* association*"))

2.4 Barrier Search String

(barrier* OR "financ* capital" OR "access* financ*" OR "credit" OR "insurance" OR "financ* risk" OR "Risk avers*" OR "Risk attitude*" OR "Risk preference*" OR "Risk profile" OR "Discount rat*" OR "High discount*" OR "Time preference*" OR Tenure OR "property right*" OR "open access*" OR "shared access*" OR "comm* access*" OR "common* pool" OR "common* resource*" OR "free rid*" OR "extension servic*" OR "extension capa*" OR "extension resourc*" OR "resource compet*" OR (competition NEAR crop*) OR (competition NEAR livestock*) OR "resource incompatib*" OR "resource crowd*" OR "resource scarc*" OR "land availab*" OR "land scarc*" OR "opportunity cost*" OR "foregone revenue*" OR "foregone income" OR "alternative revenue*" OR "alternative income" OR "transition cost*" OR "transition period" OR "transition burden*" OR "upfront cost*" OR "upfront invest*" OR "initial cost*" OR "initial invest*" OR "startup cost*" OR "startup invest*" OR "input cost*" OR "input pric*" OR "fixed cost*" OR "variab* cost*" OR "labor cost*" OR "labour cost*" OR "labor requirement*" OR "labor intensive" R "labour requirement*" OR "labour intensive" OR "maint* cost*" OR "upkeep cost*" OR "monitor* cost*" OR "income stream*" OR "income flow*" OR "cash flow*" OR "diffuse benefit*" OR "income support*" OR "pric* support*" OR "produc* subsid*" OR "road access*" OR "transport* access*" OR "lack of information" OR " information constraint* " OR " input NEAR constraint* " OR " input NEAR access* " OR "delayed return*" OR "lack of knowledge" OR "aware* of benef*" OR "improved information" OR "technolog* access" OR "cultur* preference*" OR "cultur* norm*" OR "cultur* taboo*" OR "cultur* inertia" OR "social capital" OR "input* access*" OR adopt* OR disadopt* OR attrition* OR pseudo-adopt* OR innovator* OR "early majorit*" OR "late majorit*" OR laggard* OR diffusion OR "abandon* technique*" OR "new technique*" OR "poor enforc*" OR "poor compliance" OR corrupt* OR governance OR (gender NEAR norm*) OR (gender NEAR perception*) OR (gender NEAR belie*) OR (gender NEAR attitude*) OR (women NEAR norm*) OR (women NEAR perception*) OR (women NEAR belie*) OR (women NEAR attitude*) OR "benefit* sharing" OR "transaction cost*" OR "price volatil*" OR "human capital" OR "ecological dynamic*" OR "technical knowledge" OR "technical training" OR "special* training" OR "rainfall NEAR unpredictable" OR "temperature NEAR unpredictable")

3. Newly added search terms, after search was completed with the above combinations. Only used in the SCOPUS search.

PRACTICES:

"pruning" OR "coppicing" OR "agrosilvopasto*" OR "agropasto" OR "crop-livestock" OR "basin irrig*" OR "saline irrig*" OR "improved groundwater management" OR "fertigation" OR "micronutrient" OR "microdosing" OR "micro-dosing" OR "inorganic fertilizer" OR "diversion ditch" OR "bunds" OR "dibble stick" OR "disc-plant*" OR "(strip NEAR tillage) OR "ripping" OR "stubble NEAR tillage" OR "ridge and furrow" OR "pitting" OR "pits NEAR (zai OR zay OR matengo)" OR "(conservation NEAR tillage)".

OUTCOMES:

"benefit cost ratio" OR "benefit-cost ratio" OR "cost benefit ratio" OR "cost-benefit ratio" OR "livelihood diversif*" OR "bulk density" OR "water productivity"

Appendix II: Number of references returned from WoS search

Theme	Outcome	Number References Returned
Agronomy	Barriers	6847
	Productivity	63343
	Adaptation	7583
	Mitigation	8238
Agronomy Total		**86011**
Livestock	Barriers	3006
	Productivity	52248
	Adaptation	2836
	Mitigation	2329
Livestock Total		**60419**
Agroforestry	Barriers	2541
	Productivity	21358
	Adaptation	3133
	Mitigation	1975
Agroforestry Total		**29007**
Postharvest Management	Barriers	841
	Productivity	13889
	Adaptation	681
	Mitigation	1957
Postharvest Total		**17368**
Food Energy Systems	Barriers	365
	Productivity	7136
	Adaptation	235
	Mitigation	3774

Energy Total	**11510**
Total References Returned	204315
Total After Removing Duplicates	**144767**

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