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Review And Synthesis of Sustainable Land Management on Small Family Farms in Developing Countries

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Abstract

Despite efforts to restore land and fight food insecurity, sustainable land management (SLM) technologies are not yet widely adopted in developing countries. This article reviews and synthesizes studies that have been conducted in developing countries over the last few decades. A total of 145 documents were used in this synthesis. A key finding of this paper is the identification of a theoretical gap that provides information for future studies on SLM practices.

Another one is that, studies focusing on adoption in this synthesis have not considered awareness of technology as a key part of the adoption process. Most econometric studies focus on econometric regression and consider SLM adoption as a dichotomous choice. The use of mathematical models such as existing dynamic Discrete Stochastic Programming (DSP) models could provide more robust results to overcome this limitation observed in statistical regression results. Additionally, it would be interesting to analyze smallholder farmers' preferences for SLM practices because very little is currently known about their preferences.

Keywords: soil and water conservation, perception, preference, developing countries, mathematical programming, sustainable land management

1. Introduction

In the context of increasing population growth, the challenges to guaranteeing food security lie in agriculture, which is mainly concentrated in rural areas. Agriculture is the main activity of these rural households, resulting in a low income. Additionally, these smallholder farmers face numerous challenges, including declining yields due to land degradation. Smallholder farmers in developing countries are affected by this issue, as most have few resources. Several soil degradation studies have recently been conducted in these areas (Banadda, 2010; Blake et al., 2018; Diao & Sarpong, 2011; Fleskens et al., 2014; Mulale et al., 2014; Silas, 2014). This degradation leads to a decrease in soil fertility. Reduced soil fertility undermines the sustainability of production systems and remains a major problem for agriculture, threatening both food security and producer income and harming rural poverty reduction (Adégbola & Adékambi, 2006, Unpublish report). In fact, despite a slight decrease in the number of people who are food insecure, 795 million people remain food insecure. Even more glaring is the issue concerning nutrition. Approximately 2 billion more people are at risk of hidden hunger or malnutrition due to micronutrient and protein deficiencies (Lal, 2016; Ruel-Bergeron et al., 2015). Land management affects the nutritional quality of food. A deficiency in soil nutrients affects the composition of food. Soil degradation leads to some nutritional imbalances in primary nutrients (nitrogen, phosphorus, and potassium), secondary nutrients (calcium, magnesium, and sulfur), and micronutrients (boron, chlorine, copper, iron, molybdenum, zinc, and manganese). Pal et al., (2017) confirmed this imbalance in a study conducted in India showing deficiencies in certain soil nutrients. For example, more judicious use of nitrogen in legumes and nitrogen fertilizers improves food quality (Blumenthal et al., 2008). These findings show the role of soil composition and quality and the effect that production from different production systems can have on human health. Poor land management also affects agronomic performance and consequently generates low income in a situation of price stability.

In the context of these socioeconomic and human consequences of declining fertility, empirical studies show that a trend reversal is still possible, but that production systems urgently need to be adapted. Agricultural yields of staple crops can still be tripled or quadrupled in sub-Saharan Africa, South Asia and the Caribbean with the widespread adoption of better management practices for sustainable intensification (Lal, 2016). The same study reports that sustainable land management (SLM) that promotes sustainable intensification can produce enough grain on 0.045 ha of arable land to feed one person for a year (Lal, 2016). Therefore, some technologies to improve soil fertility that can help smallholder farmers to increase crop yields have been developed by Benin's agricultural research and disseminated over the years. At the same time, these technologies make it possible to limit the pressure on natural resources and offer smallholder farmers ecological, economic, and social benefits. The benefits are many and vary from place to place. To better understand the state of the art on this concept, we reviewed the literature and synthesized SLM practices.

There is no review paper on the theoretical approaches used to analyse the impacts of SLM adoption. Therefore, this article aims to fill this gap with a particular focus on theoretical approaches to identify existing gaps. To conduct this review, we limited this study to geographic areas that share the same social and economic frameworks, with some differences, namely, sub-Saharan, Asia and South America. After presenting the methodology used for this literature review and synthesis, we present the results and discussion section, which provides an overview of the notion of SLM. The examined SLM types are then presented. The next section addresses the socio-economic impact of adopting SLM practices, followed by the analysis methods used in publications. The last section addresses the theoretical and methodological gap regarding the adoption of SLM. This synthesis ends with a conclusion that outlines the main lessons learned.

2. Methodology

We conducted literature research for articles published in the AGORA program and a global online agriculture research system that is part of Research4Life. This program is managed by the Food and Agriculture Organization of the United Nations and the major global publishers. For this review and synthesis, we focused on articles from the SCOPUS database, one of the publishers of AGORA and the world's leading scientific publication. It is the largest abstract and citation database for peer-reviewed literature, providing intelligent tools to track, analyze, and visualize research results. We selected all articles and literature reviews published between 1983 and 2019 on SLM practices related to developing countries in Africa, Asia and Latin America. We have excluded from this synthesis all articles from North America, Europe and Oceania (particularly New Zealand and Australia); which are global temperate areas including developed countries. We first used two terms, "sustainable land management" and "adoption", to extract documents compatible with the goal of this review and synthesis of the literature. The period considered ranges from the start of the publication of articles dealing with SLM-related aspects in SCOPUS. In this first stage, 727 papers were selected. After this first series of papers, we sorted and analyzed the papers by area. The area of “ECONOMY, ECONOMETRY AND FINANCE", "SOCIAL SCIENCES", "AGRICULTURE AND BIOLOGICAL SCIENCES" and "ENVIRONMENTAL SCIENCES" were taken into account. From this second set of sorted papers, we analyzed the relevance of the sorted papers with the aim of this paper. Therefore, some items in the second-sorted group of papers have been removed. This process allowed us to retain 145 publications (Figure 1). We used descriptive statistics as the main analytical tool in this literature review.

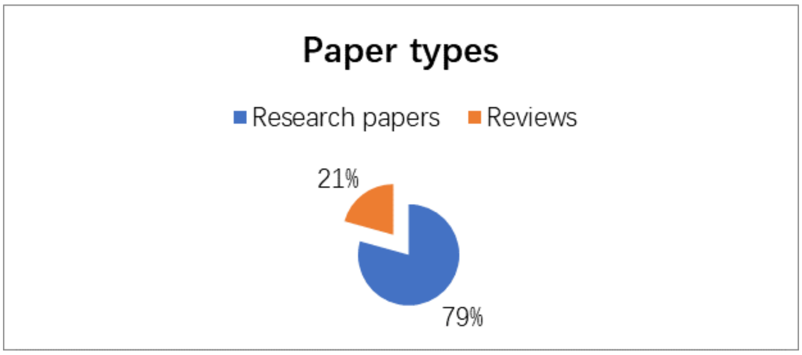

Fig. 1. Paper types

3. Results And discussion

3.1 Characteristics of Selected Publications

Most of the articles come from East Africa (38%). Ethiopia is the most mentioned country, followed by Kenya, and this result is due to the relief of the region. Farmers often farm the highlands in this area. West Africa and Asia are the second most cited regions, both accounting for 21% of the papers. However, other documents cover several regions at the same time. In fact, 17% of articles cover multiple continents or multiple territories at the same time. We have labelled these papers WORLD (Figure 2).

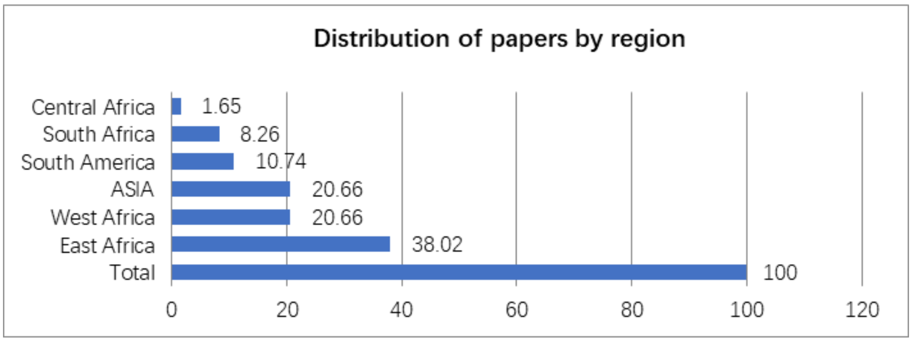

Fig. 2. Distribution of papers by region

Out of the 145 articles, 79% are research articles, and 21% are reviews and syntheses of the literature on SLM practices. The selected publications were published from 1994 to 2019, with a resurgence of publications on SLM practices related to the selected areas beginning in 2014. Most publications (22) were published in 2018 (Figure 3).

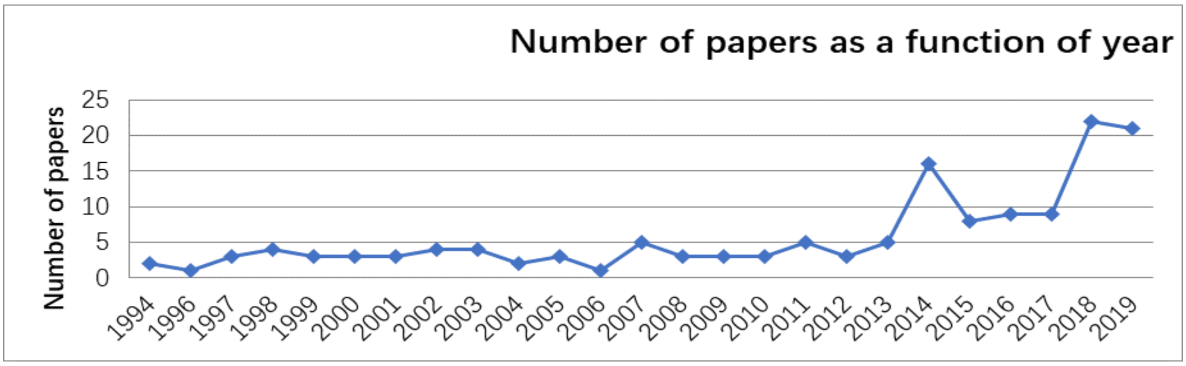

Fig. 3. Number of papers as a function of year

Thus, the papers in the database considered in this review and synthesis cover sub-Saharan South, North Africa, Asia, South America, and the Caribbean areas. This range is because most SLM studies are located in arid, semi-arid, and subhumid areas. Liniger et al., (2019) corroborate this concept by indicating that depending on the type of land use, the most reported SLM practices take place in semi-arid and sub-humid areas (80%). The same study shows that on cultivated land, most SLM practices take place in sub-humid zones (Sommer et al., 2018), while cases of grazing are concentrated in semi-arid areas (Abi et al., 2018; Amede et al., 2007; Belay & Bewket, 2013; Cholo et al., 2018). This information gives us a mappable overview of where land degradation and SLM issues are located (Liniger et al., 2019). As a result, small-scale farmers in these environments are often at risk due to the resources available to them to cope with land degradation. They are often poor households typical of developing countries. This choice of geographic focus is supported by Lal, (2016), who used the same geographic sphere to define his study.

Based on the methods used to collect data on SLM practices, we categorized all articles into three groups. The primary group consisted of mixed studies, representing 61% of the articles. These studies used tools specific to both quantitative studies (structured interviews) and qualitative studies (key stakeholders, focus groups, and semi-structured interviews). The other two groups were purely quantitative studies, accounting for 23% of the studies, or qualitative studies accounting for approximately 17% of the studies. The average number of people in the studies was 1427 with a standard deviation of 6854 (n=79). The lowest sample size was 16 people for a mixed study (Silas, 2014). On the other hand, the highest number of people was 60,000 (Tennigkeit et al., 2013). For articles that also performed plot-level analyses, the mean was 2665 plots with a standard deviation of 3205 plots (n=16). The highest sample number of plots was 1,208 plots and the lowest was 14 plots.

3.2 General Information on SLM

The concept of SLM was introduced in the early 1990s to combat land degradation (Tennigkeit et al., 2013) and has been promoted ever since. Most of the papers discussed in this review and synthesis address SLM technologies and approaches. The concepts of SLM practices, technologies, or approaches are sometimes confused and scholars need clarification for a more judicious use. Therefore, it is essential to differentiate between the three concepts of SLM technologies and SLM approaches that are grouped in SLM practice.

There is no unanimously agreed upon definition for SLM. This synthesis review has shown that few studies have attempted to define SLM. According to Cholo et al., (2018), SLM is defined as "a knowledge-based process that helps to integrate the management of land, water, biodiversity, and the environment (including input and output externalities) to meet the growing demand for fiber and food while maintaining ecosystem services and livelihoods". This definition emphasizes rationality in using resources to meet human and environmental needs. SLM is also the use of land resources, including soil, water, animals, and plants, for the production of goods that meet evolving human needs, while securing the long-term productive potential of these resources and ensuring their environmental functions (Liniger et al., 2019). This definition is almost similar to the first one, but the latter provides clarification on the temporal and dynamic aspects of the needs these practices seek to address. The dimension of sustainability was introduced in this definition. Regarding the definition of Schwilch et al., 2012), SLM encompasses soil, water, and vegetation conservation measures and is based on the key principles of enhancing productivity and protecting natural resources while at the same time being economical and socially acceptable. According to (Cordingley et al., 2015), SLM includes practices such as soil fertility and crop management, soil erosion control measures, water harvesting, and grazing and forest management. These last two definitions provide an overview of the technologies involved in the SLM concept. In the definition of Schwilch et al., (2012), we find that SLM concerns different natural resources, such as soil, water, and flora, but in an ecosystem integration process that focuses on the overall well-being of the population using the resource. Based on all of the above definitions, SLM is understood in this article as a comprehensive set of land management practices that have the potential to make significant and sustainable differences in terms of reducing land degradation and improving land productivity in the near and long term (Liniger et al., 2019). In contrast to SLM technology, an SLM approach is much more holistic. According to WOCAT, an SLM approach includes "the means that help to introduce, implement, adapt, and apply SLM technologies in the field" (Cordingley et al., 2015). An approach is therefore more holistic than technology. Therefore, an SLM approach can be defined as the mechanism or methodological arsenal put in place to achieve the objectives set for SLM technologies in the field.

3.3 Types of SLM practices and Types of Intervention

A diverse set of 63 SLM practices were identified across all 145 publications considered in this study. The 5 most frequently studied practices were soil and water conservation (SWC), agroforestry, manure (green manure, organic manure, and animal manure), agroforestry, conservation agriculture (CA), and crop rotations with a share of 26%, 23%, 19%, 14% and 14% of the studies, respectively (Fig. 4). Fig. 4 shows the practices addressed by at least 5% of the papers. A total of 21 SLM practices were represented. On the other hand, 21 practices occurred only once, such as eco-friendly nets (Vidogbéna et al., 2016), *zai* (Etongo et al., 2018), enset (Cholo et al., 2018), minimal fertilizer use or microdose (Lokonon & Mbaye, 2018), and retention walls (Paudel & Thapa, 2004). These practices should be furthermore investigated.

Practices can be classified into physical or structural SLM and agronomic SLM (Adimassu et al., 2016; B. A. Shiferaw et al., 2009). This classification is based on the results of the work of Liniger et al., (2011), who used the payback period of the practices as the basis for the classification. Thus, practices that have long-term economic benefits are referred to as physical or structural SLM, and those with short-term economic benefits are called agronomic SLM. Examples of agronomic SLM include terracing (*fanya juu* as it is called in East Africa), stone bunds, soil bunds as physical SLM and minimum tillage, organic and inorganic fertilizers, grass strips, agroforestry and water harvesting practices such as drainage and planting pits (B. A. Shiferaw et al., 2009).

Not all SLM practices have been comprehensively studied in the literature. Studies have focused on some practices given the specifics of the places. In the eastern African highlands, structural practices such as terraces, stone terraces, stone and soil bunds, and *fanya juu* are the most studied (Abi et al., 2018; Cholo et al., 2018; Nigussie et al., 2017; Pender & Gebremedhin, 2007; E. Schmidt et al., 2017; Tesfaye et al., 2014; Teshager Abeje et al., 2019; Zeweld et al., 2018). In contrast, agronomic measures are often applied on less steep surfaces or moderate slope (Belay & Bewket, 2013; Hassen, 2018). Some studies have also reported that CA practices are implemented primarily in moderate and low slopes areas (Chalak et al., 2017; Chinseu et al., 2019; Kassam et al., 2014; Sommer et al., 2018; Thierfelder, Mutenje, et al., 2015; Thierfelder, Rusinamhodzi, et al., 2015).

SLM practices can also be classified according to the objective of solving soil degradation. A distinction is made between Integrated Soil Fertility Management (ISFM), which encompasses a set of practices that combine the use of improved varieties (Gollin et al., 2005), mineral fertilizer (Martey et al., 2019) and the incorporation of organic fertilizer (Belay & Bewket, 2013; Hassen, 2018; Mrabet, 2002; Wollni & Andersson, 2014). Some studies have addressed ISFM as a whole (Agegnehu & Amede, 2017). On the contrary, CA includes all practices that involve minimal soil disturbance and crop residue management (Chalak et al., 2017; Chinseu et al., 2019; Kassam et al., 2014; Sommer et al., 2018; Thierfelder, Mutenje, et al., 2015; Thierfelder, Rusinamhodzi, et al., 2015). In 2014, Africa represented 0.81% of the global CA area (Kassam et al., 2014) and was ranked as the location with the lowest adoption rate. In contrast to Africa, the results of (Kassam et al., 2014) also showed that South America had the largest arable land area (44%) covered by CA. SWC practices are another type of SLM practices (Ahaneku, 2010; Ashoori et al., 2016; Baptista et al., 2016; Bodnár & De Graaff, 2003; Dessie et al., 2012; Gao et al., 2018; Kabubo-Mariara, 2015; B. A. Shiferaw et al., 2009; Sietz & Van Dijk, 2015; Teklewold & Kohlin, 2011; Tesfaye et al., 2014). An example is physical conservation measures, particularly terraces, and stone bunds. Based on the degree of degradation, WOCAT defines 3 types of SWC practices. First, Soil Fertility (SF) measures refer to agronomic practices such as composting, mulching, manure applications, planting pits (*zai* and *tassa*) and micro-catchments (Sietz & Van Dijk, 2015). Second, erosion control (EC) practices include structural and vegetative measures such as stone bunds, grass strips, and contour vegetation barriers (Sietz & Van Dijk, 2015). Third, mixed measures (MM) include mainly farmer-managed natural regeneration, conservation agriculture (CA), and other agroforestry technologies (Sietz & Van Dijk, 2015). Finally, agroforestry is a practice that combines the cultivation of a tree species with a seasonal crop, preferably cereal (Bond, 2009; Iiyama et al., 2018).

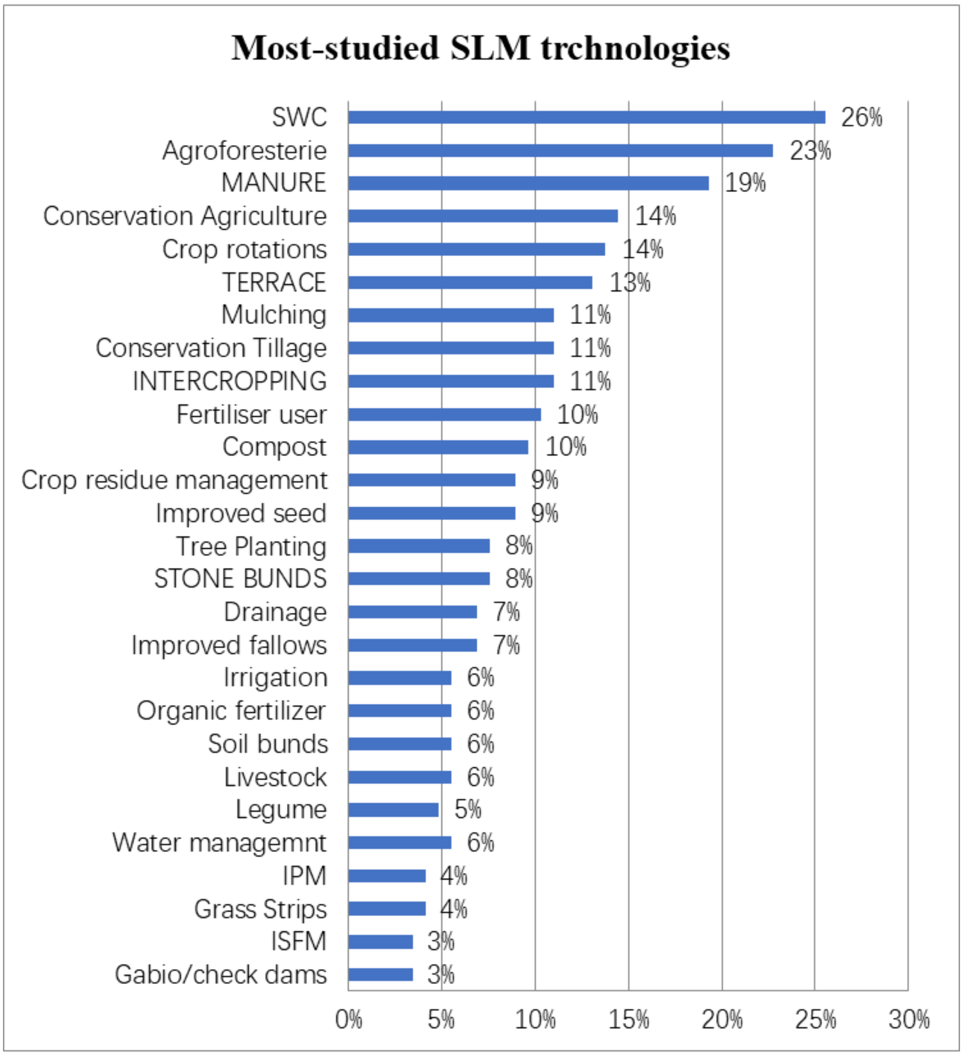

Fig. 4. Most-studied SLM technologies

There are three types of interventions in SLM practices (Liniger & Critchley, 2007; Schwilch et al., 2012). First, prevention refers to SLM practices that conserve natural resources and their environmental and productive functions on land at risk of degradation. This type of practice implies that good land management practices are already in place. Goals of soil conservation are, for example, the prevention of soil loss and the management of soil fertility (Teklewold & Kohlin, 2011). Second, mitigation refers to interventions on land where degradation has already started. The aim of mitigation is to stop degradation and improve resources and their ecosystem functions. Mitigation effects are usually felt in the short to medium term and provide a strong incentive to continue efforts (B. Shiferaw & Holden, 2000). Finally, rehabilitation is necessary when the soil has already degraded to the point of unproductive. It is also necessary when future use is no longer possible and the ecosystem is seriously disturbed. Rehabilitation generally involves high investment costs, but the benefits becomes apparent only in the medium and long term. In summary, these interventions aim to improve soil quality and soil degradation neutrality (Kust et al., 2017).

3.4 Socio-economic Impacts of SLM Adoption Practices

The adoption and implementation of SLM practices lead to several impacts. Farmers will only adopt and adapt new practices and technologies moving old to new methods offers additional gains in the forms of higher net returns, lower risk, or both (B. A. Shiferaw et al., 2009). Some recent empirical studies also come to this conclusion (Agegnehu & Amede, 2017; Branca et al., 2013; Diao & Sarpong, 2011; Etsay et al., 2019; Kassie et al., 2018; Marques et al., 2016; Martey et al., 2019; Pender & Gebremedhin, 2007; E. Schmidt et al., 2017; Teklewold et al., 2013; Thierfelder, Mutenje, et al., 2015). Pender & Gebremedhin, (2007) conducted a study in the Tigray region of Ethiopia, and the data revealed that plots with stone terraces had the highest yields compared to the other plots. Empirical evidence from East Africa showed that smallholder farmers who continued to use SLM practices had on average 77-100 % higher income than non-continuous users (Etsay et al., 2019). This study also stated that a significant improvement in yield was observed after combining at least two (2) practices. This significant increase in performance implied that the productivity effect of one conservation practice is amplified by the use of the other practices, confirming the complementarity between SLM practices (Asfaw et al., 2016; Etsay et al., 2019; Teklewold et al., 2013; Zeweld et al., 2018). Empirical evidence in southern Africa has shown that maize and cowpea yields increased significantly compared to those with conventional control treatment (Thierfelder, Mutenje, et al., 2015). The same study also reported that compared to conventional control treatment, animal traction seeding systems, which is a CA practice, excelled and significantly increased maize productivity by up to 235% (1761 kg/ha^{-1}) and cowpea productivity by 173% (265 kg/ha^{-1}). The same positive trend was observed in Ghana in West Africa, where mineral fertilizer use increased land productivity and farm income by 55% and 30%, respectively (Martey et al., 2019). Another SLM practice that has a high impact on yield and productivity is CA. CA increased crop productivity and reduced farm labor, especially when no-till practice and herbicides are used (Thierfelder, Mutenje, et al., 2015). These impacts were related to general SLM practices and were based on survey data in uncontrolled environments. Other studies have reported the results of trials. This is the case in a study in Ethiopia in which Nitisols and Holleta crop yields increased by 51-158% by combining an application of 20 kg P ha^{-1} with non-inoculated strains (Agegnehu & Amede, 2017). The impact of SLM practices on water was also mentioned in a study. Different water management practices in agriculture have shown very positive multifaceted impacts (Marques et al., 2016). In the synthesis by Marques et al., (2016), these impacts were widespread and occurred on biodiversity, water availability, soil quality, economic benefits, and social impacts. The economic impacts revealed an improvement in income, crop, and livestock production that could increase food security and nutrition.

Not all of these impacts are dynamic. Studies did not take into account the temporal dimension in measuring impact. Only 13% of studies analyzed SLM practices with a long-term approach. To correct this bias, programming models have made it possible to spread impacts over time (Fleskens et al., 2014; E. Schmidt et al., 2017). A study in Ethiopia suggested that SLM investments must be sustained for at least seven years (7) to show a significant increase in production value, and terraces on moderate and steep slopes were most effective in increasing agricultural yields (E. Schmidt et al., 2017). The same study found that SLM investments should be combined with other investments in inputs and infrastructure, as well as subsidies for initial labor costs, to encourage SLM adoption and long-term sustainability. A predictive study on this topic was conducted in Ghana. It has been found that the combination of agricultural and traditional practices and the use of mineral fertilizer can increase maize yield by 50-200% (Diao & Sarpong, 2011). These results were obtained in a forested area, but the results need to be put into context, as this land is often very fertile. However, another study in Ethiopia demonstrated the negative effect of SLM practices showing that soil and stone bunds caused pest infestations (and even flooding) reducing crop yields for farmers (B. Shiferaw & Holden, 2000). These findings were supported by the results of a review that found that hedges, terraces, minimum tillage, and improved fallows areas had a negatively impacted yield. However, some studies have approached the impact of SLM practices by measuring efficiency (Issahaku & Abdul-Rahaman, 2019; Selejio et al., 2018). These studies attempt to determine how productive resources are allocated. The results showed that smallholder farmers who adopted SLM practices performed better in terms of technical efficiency than those who did not adopt these practices. Even so, those adopting SLM still need to make efforts to help them be fully effective.

3.5 Analysis Methods Used in the Papers

Articles focusing on technologies are usually econometric studies (Adimassu et al., 2016). These empirical studies are characterized by analysis of household, but some focus only on the household level. In this synthesis, some studies simultaneously focused on the household and plot level (Asfaw et al., 2016; Hassen, 2018; Kabubo-Mariara, 2015; Ndiritu et al., 2014; Nigussie et al., 2017; Pender & Gebremedhin, 2007; E. Schmidt et al., 2017; Selejio et al., 2018; Teklewold et al., 2013; Teklewold & Kohlin, 2011; Wollni & Andersson, 2014). However, other studies are specific at the household level only (Belay & Bewket, 2013; Martey et al., 2019; Obayelu et al., 2016).

Various methods were used to analyze the articles selected in this review of the literature. Descriptive statistics are the most commonly used method (36%), using frequencies, means, and chi-square or Fisher ANOVA and F tests. Narrative discourse is the second most widely used method to analyze documents (Figure 5). This method combines tools specific to sociologists.

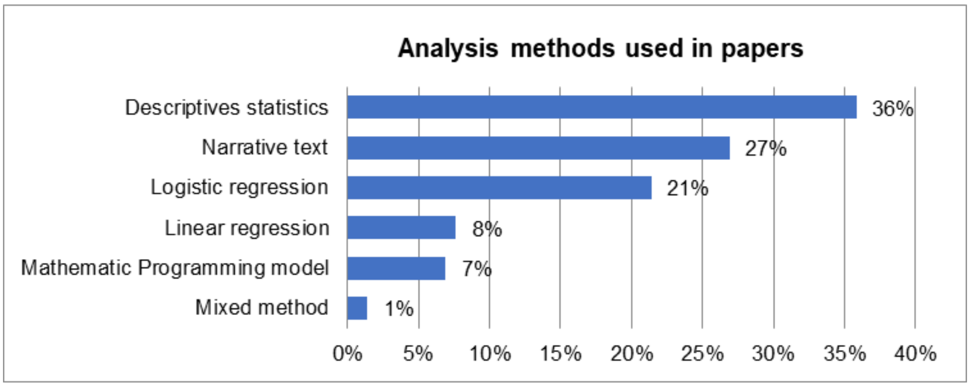

Fig. 5. Analysis methods used in papers

On the other hand, 29% of the studies used econometric approaches. Logistic regression was the most widely used type of regression and was used in 21% of documents (Figure 5). Specifically, the logit, probit, and Tobit models were used. The difference between these models lies like the dependent variables and in the objective sought. The logit and probit models are similar only in the distribution of the error term between them. While the logit model (Belay & Bewket, 2013; Etsay et al., 2019; Kabubo-Mariara, 2015; B. A. Shiferaw et al., 2009; Teklewold & Kohlin, 2011) assumes a logistic distribution, the probit model (Gao et al., 2018; Hassen, 2018; Lokonon & Mbaye, 2018; Nkomoki et al., 2018; Pender & Gebremedhin, 2007; Saïdou et al., 2007; Teklewold et al., 2013; Teshager Abeje et al., 2019; Vidogbéna et al., 2016; Wossen et al., 2013; Zeweld et al., 2018) assumes the standard normal distribution of error terms (Adimassu et al., 2016). However, different variants of these two types of initial models have been discussed. In this synthesis, the binary logit (Belay & Bewket, 2013; Etsay et al., 2019; Tesfaye et al., 2014), the multinomial logit (Kabubo-Mariara, 2015; Teklewold & Kohlin, 2011) and the ordinal logit (B. Shiferaw, 1998) were developed for the logit models. For probit models, there is the ordinal probit (Hassen, 2018; Teklewold et al., 2013; Teshager Abeje et al., 2019; Zeweld et al., 2018), which generates important determinants that affect the number of SLM practices adopted (Zeweld et al., 2018), bivariate or binary probit (Gao et al., 2018; Lokonon & Mbaye, 2018), probit model (Nkomoki et al., 2018; Pender & Gebremedhin, 2007; Saïdou et al., 2007; Vidogbéna et al., 2016; Wossen et al., 2013) and multivariate probit (MVP) (Asfaw et al., 2016; Cholo et al., 2018; Etongo et al., 2018; Etsay et al., 2019; Lokonon & Mbaye, 2018; Ndiritu et al., 2014; Nigussie et al., 2017; Teklewold et al., 2013; Zeweld et al., 2018).

The MVP model is particularly suitable when the decision to adopt a particular practice depends on the adoption of another complementary practice (direct relationship between the error terms of the adoption equations) or can be influenced by other available substitutes. Given this complementarity of practices, which leads smallholder farmers to choose 1 to n practices from a set j, the MVP model was the most used (26% of all logistics models n=9). However, the logit and probit models do not precisely predict the intensity with which SLM practices are adopted. Adoption intensity is defined as the overall level of use of a given technology (Obayelu et al., 2016).

Thus, the Tobit model not only reports whether smallholder farmers are adopting a practice but also provides increased accuracy in terms of the level or degree of adoption (Chalak et al., 2017; Issahaku & Abdul-Rahaman, 2019; Obayelu et al., 2016). As with the previous two types of models, we have the bivariate Tobit (Issahaku & Abdul-Rahaman, 2019), the endogenous Tobit (Issahaku & Abdul-Rahaman, 2019), and the Tobit models (Chalak et al., 2017; Obayelu et al., 2016). In summary, regarding the adoption of SLM practices by farmers, the logit and probit models identified factors that affected whether farmers invested or adopted SLM practices on their plots, while the Tobit model identified factors which influenced the level of investment by farmers or the intensity of adoption (Adimassu et al., 2016). Only 8% of the publications used linear regression methods. This model has been prioritized in cases where the dependent variable is quantitative (Kabir & Rainis, 2015), such as yield or production.

Only 7% of the studies included mathematical programming models. Very often, smallholder farmers operate in an environment where they are both consumers and producers. Any decision (decision to adopt a technological innovation following the example of SLM practices) related to operations is subject to multiple considerations about the balance of the operating unit, and several non-visible parameters must be considered. *Using mathematical programs and optimization models that integrate these decision-making factors is appropriate*. Shiferaw & Holden, (2000) used a non-separable farm household model based on mathematical programming to study the role of alternative policy instruments for SLM in Ethiopia. This model identified a production plan that maximized annual net returns defined as current net returns. However, this type of model was static. The authors did not take into account the time dimension in their analysis. This shortcoming was mentioned in a study in Ethiopia (Zeweld et al., 2018). To correct this issue, dynamic models are best suited. Several dynamic models have been used to assess the impact of SLM adoption (Dessalegn et al., 2018; Diao & Sarpong, 2011; E. Schmidt et al., 2017; Teklewold & Kohlin, 2011).

In a study on the Blue Nile basin in Ethiopia, (E. Schmidt et al., 2017) used a multi-market model to assess the impacts of alternative investments on agricultural production, prices ,and incomes over time. Derived from neoclassical microeconomic theory, this model has the advantage of being a dynamic model that integrates time by considering the labor costs required to maintain SLM investments over time. Therefore, this model can simulate and predict the long-term effects of complex ecological and economic systems required for policy and investment decisions (Diao & Sarpong, 2011; E. Schmidt et al., 2017). This multi-market model can also highlight the economic ties that shape the sustainability of programs (e.g., an SLM program). For example, an investment in SLM that aims to increase agricultural production can have an indirect effect on reducing the prices of agricultural goods, thus partially compensating for the effect of increased production on household incomes (E. Schmidt et al., 2017). On the other hand, there are models (for example, multiple goal linear programming) that are static and dynamic or can be tested at the scale of a single farm but can be expanded to a regional scale (Zander & Kächele, 1999); however, the shortcoming of this model is that it does not consider the ecological dimension. One study used a linear programming model to measure sustainability through profit maximization and the adoption of sustainable practices (Agbonlahor et al., 2003). Another type of model identified in this review was the farm simulation model. This model operates in annual time units and combines soil management practices, nutrient availability, crop and livestock productivity, and agricultural economics (Shepherd & Soule, 1998). However, these programming models are biased by the environment in which the producer operates. The climatic conditions have a great influence on their results and their replicability in different climate zones. To correct this bias, the Pan-European Soil Erosion Assessment-Desertification Mitigation Cost Effectiveness model (PERESA-DESMISSE) was developed. The PERESA-DESMISSE model has been used in some recent studies (Baptista et al., 2016; Fleskens et al., 2014). It is applied to understand spatial variations in required investment and performance of technologies in a given site. Specifically, this model provides the different climate variations that allow for the optimization of investments in land with the dual objective of improving food security and reducing soil and land degradation. Because of this model, the biophysical and socioeconomic benefits of soil improvement technology are known. Through trials, this model has identified better yield indices in subhumid climates than in semi-arid zones, but in terms of cost, this can be excessively expensive for production that requires no inputs (Baptista et al., 2016). However, this model is also limited because it does not include any risk.

It is also important to note that the impact of SLM practices has also been addressed by other econometric methods. The impacts of SLM practices adoption have been assessed using Propensity Score Matching (PSM) in some very recent studies (Etsay et al., 2019; Martey et al., 2019; L. Schmidt et al., 2019; Sileshi et al., 2019). PSM is a nonparametric estimation technique that does not depend on functional form and distribution assumptions (Martey et al., 2019). In contrast, the impact of the adoption of agricultural intensification technologies has been measured using the Multinomial Treatment Effect (MTE) in Malawi (Asfaw et al., 2016). These methods do not correct for biases in unobservable variables. They control only for observable variables. For example, PSM and MTE consider the selection of a SLM technology as exogenous when it is endogenous. So, to deal with unobservable variables, the Endogenous Switching Regression (ESR) is the suitable model (Martey et al., 2019).

3.6 Theoretical and Methodological Gaps in the Analysis of SLM Practices

Globally, SLM studies focus on SLM adoption and the impact of SLM adoption. SLM publications on adoption use unobservable determinants such as smallholder perceptions and preferences. Very few studies have mentioned preferences in their research (only 8%), although they also determine the adoption of SLM practices (Roussy et al., 2015). Only three studies clearly address preferences (Chalak et al., 2017; Dessalegn et al., 2018) with econometric methods. Little is known about smallholder farmers preferences regarding SLM practices. This gap needs to be addressed. On the other hand, perceptions were addressed slightly more. Perceptions play a crucial role in the adoption of SLM practices. However, some studies have investigated perceptions of the land degradation process (Jones, 1997; B. Shiferaw, 1998), while others have focused on perceptions related to the technology being used (B. Shiferaw, 1998). In contrast, some perception studies focus on the financial aspects of the technology as determined by a study conducted in South America, which states that permanent adoption of SLM practices depended on the perception of the costs and benefits of these practices compared to the costs and benefits of a conventional system (Montagnini & Finney, 2011). Therefore, the perception of profitability is a determining factor in the adoption of SLM practices (Nigussie et al., 2017). This scenario explains why some studies have addressed the profitability of these different practices. However, these studies address profitability through performance indicators based on the basis of a single year (Abdulai & Huffman, 2014; Rasul & Thapa, 2007). It would be preferable to use multiyear cash flow financial analysis methods to address profitability in the context of SLM investments (De Groote et al., 2010).

Studies that analyze adoption using observable determinants consider adoption as a dichotomous decision, which is a truncated consideration of decision-making in SLM. Investments in SLM will be spread over at least two years and largely adjusted over the short and long term. However, the majority of econometric analyses are based on cross-sectional data. Based on the assumption that the dynamics of adoption change over time (Kassie et al., 2018;

Kondylis et al., 2016; Sietz & Van Dijk, 2015; Zeweld et al., 2018), it is essential to analyze the dynamics of adoption. Another weakness of the econometric models discussed above is that they view the producer as a single-purpose economic agent. If a new agricultural technology, for instance, SLM technology, is introduced, the production behavior is immediately and directly influenced. The resulting increase in net production will lead to changes in the consumption of goods (Ahmed et al., 2000) and in household leisure activities. Therefore, the overall impact of the introduction of SLM technology can only be assessed by applying a model that simultaneously integrates the farm household's decision-making process related to production and consumption in an environment at risk. One of the most important aspects is the risk aversion of smallholders, which is increasingly examined in the SLM literature today. About 10% of the literature (Dessalegn et al., 2018; Teklewold & Kohlin, 2011) mentions various risks that influence the adoption behaviour of smallholder farmers. *Therefore, it is important to include risks in the analysis*. A study in West Africa found that smallholder farmers are not at risk (Abdulai & Huffman, 2014), which is not entirely true. Decisions as dynamic and complex with certain risks as the adoption of SLM practices have been addressed with discrete stochastic programming models (DSP) of SLM in developing countries in recent years (Dai & Li, 2013; Ridier et al., 2016; Siegfried & Kinzelbach, 2006) with more robust results. Future research on the impact of agricultural intensification based on agro-ecological practices such as SLM would have much to gain by using these models that incorporate risk using mathematical optimization through linear programming.

In this synthesis, as stated above, many studies related to SLM technologies focus on the adoption process. Another shortcoming of this study is misspecification adoption estimation. In fact, (Rogers, 2003) stated that producers cannot begin the adoption process without knowing the innovation. To account for this, a two-stage procedure for adoption models is applied to avoid errors that occur when estimating the adoption rate. However, studies focusing on adoption in this synthesis have not considered this key part of the adoption process as mentioned by Rogers, (2003). Many econometric studies focus on the adoption process, began to correct that shortcoming (Mango et al., 2017; Mwaura et al., 2021).

Land use functions have an impact on the social, economic, and environmental dimensions of sustainable development (Reidsma et al., 2012). The economic impact of adopting SLM practices is measured using indicators such as income (Abdulai & Huffman, 2014; Kabir & Rainis, 2015; Kassie et al., 2018; Marques et al., 2016; Wyckhuys & O'Neil, 2010), economic profitability (Abdulai & Huffman, 2014; Kondylis et al., 2016; Reidsma et al., 2012), yield (Marques et al., 2016; Tougiani et al., 2009) or productivity (Pal et al., 2017). Regarding the social aspect, the impact has been determined through livelihoods assessments (Belay & Bewket, 2013; Pender, 2004; Tougiani et al., 2009), food security (Lal, 2016; Marques et al., 2016; Nkomoki et al., 2018; Sileshi et al., 2019; P. K. Singh et al., 2015) and increasingly nutritional security (Kim et al., 2019; Marques et al., 2016; Shew et al., 2019; P. K. Singh et al., 2015; R. K. Singh et al., 2014; Tougiani et al., 2009). However, studies have mentioned the impact of SLM adoption on the environment through ecosystem services (Shew et al., 2019) and biodiversity conservation (Marques et al., 2016; Montagnini & Finney, 2011; Sonwa et al., 2011). These different indicators are intertwined, leading some studies to establish cause-and-effect relationships that are not always demonstrable. Tougiani et al., (2009) state that improving productivity implies improving food consumption and income. This causal relationship has not yet been verified, since an increase in productivity is often not accompanied by an improvement in the food security of a household (Yai et al, 2019). Through a synthesis study, this author determined that agricultural productivity reduces food insecurity according to the thesis of orthodox economists through self-consumption and the purchase of food products. However, the effect of agricultural productivity on reducing food insecurity is not always mechanical, heterodox economists argue. For this reason, there is an urgent need to analyze the decision-making processes used in the adoption of SLM practices by households in order to better understand these relationships between the various indicators mentioned above.

In terms of impact assessment methods, only one study using the before-and-after approach stand out (Pal et al., 2017). However, all other studies used the counterfactual approach, that is, with and without. A group of adopters and non-adopters was formed to assess the impact of adopting SLM practices on operational parameters (Abdulai & Huffman, 2014; Etsay et al., 2019; Kabir & Rainis, 2015; Kassie et al., 2018; Kim et al., 2019; Martey et al., 2019; E. Schmidt et al., 2017; Sileshi et al., 2019). On the other hand, to assess the impact of a factor on the adoption of SLM, some studies used a control group (Kondylis et al., 2016).

Another limitation noted in this synthesis concerns methodological issues. Studies on SLM require a mixed approach, for instance, a combination of qualitative and quantitative approaches, although 23% of the studies used only quantitative methods. Focus groups and key stakeholders allow for a better understanding of realities among stakeholders before econometric studies determine economic indicators. This concept is supported by a study in South Africa where, despite the profitability of certain practices, smallholder farmers did not prefer these practices (Emerton & Snyder, 2018).

4. Conclusions

SLM practices are now recognized worldwide as an effective way to combat land degradation to ensure income and food security for producers. This synthesis and the literature review allowed us to determine the areas where land degradation problems exist in developing countries. The focus was on subhumid, arid, and semiarid climate zones of developing countries. SLM practices have various impacts on smallholders and their communities. Regarding smallholder farmers, some of the SLM practices have negative impacts, but most have overall positive impacts. This review found that SWC practices, agroforestry, and CA were the best studied SLM practices. For future studies, it would be valuable to examine less studied practices. Another key finding is that studies focusing on adoption in this synthesis have not considered awareness of technology as a key part of the adoption process.

Therefore, improved interpretations of the results of the econometric analysis are only possible through a suitable selection of the analysis approach. Some omissions in the analytical methodology may lead to truncated results and lead to inappropriate policy formulations. Farmers covered by this study are in high-risk environments. The use of mathematical models that involve risks, such as DSP, can provide robust results for improved future interpretations, and thus the formulation of appropriate guidelines. Unfortunately, few studies have implemented this method. This method is an area for future studies to explore. Aspects such as preferences for SLM practices remain relatively unknown, and future research would add to the body of knowledge on these aspects.

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