frontiers in Sustainable Food Systems

REVIEW
published: 16 March 2022
doi: 10.3389/fsufs.2022.761498

Heterogenous Factors of Adoption of Agricultural Technologies in West and East Africa Countries: A Review

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This review brings to light, extensive body of research on the evolvement of agricultural technology in Sub-Saharan Africa with focus on adoption studies in West and East Africa countries. The review highlights historical green revolution events and the heterogeneity in the determinants of the adoption of agricultural technology. Three key popular indicators in adoption studies were reviewed for their heterogeneity; this includes land, extension & social institutions, and gender in light of comparison of studies in West and East Africa. The review shows that there is so much to be gained from enhancing the understanding of the heterogeneity that exists in key popular indicators in adoption studies considering the importance of adoption of agricultural technology in reducing poverty and food insecurity and the evolving impact of climate change and other human attributes that has defined the modification of various agricultural technology. Also, the review highlights the need to tailor extension and social learning toward existing heterogeneity to aid in promoting the adoption of agricultural technology. An important highlight includes the need to be wary of the downsides of the earlier green revolution while driving the efforts of new green revolution in West and East Africa and Sub-Saharan Africa in general.

Keywords: agricultural technologies, agricultural innovations, Sub-Saharan Africa, adoption determinants, factors of adoption, heterogeneity, developing countries, review of literature

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Specialty section:
This article was submitted to Land, Livelihoods and Food Security, a section of the journal Frontiers in Sustainable Food Systems

Received: *19 August 2021*
Accepted: *19 January 2022*
Published: *16 March 2022*

Citation:
Oyetunde-Usman Z (2022) Heterogenous Factors of Adoption of Agricultural Technologies in West and East Africa Countries: A Review. Front. Sustain. Food Syst. 6:761498. doi: 10.3389/fsufs.2022.761498

INTRODUCTION

The Green Revolution Narrative

In recent years, technological advancement in the field of agriculture has been instrumental in ensuring food security and reducing poverty (De Janvry and Sadoulet, 2001). A highly revered example is the boom of the Asian economies credited to the Green Revolution (GR) era which was inspired by the need to respond to food-deficit problems. One major shift in this era was the outright change from common traditional practices such as the extensification of land and water areas and the use of traditional crop varieties. Intensification of agricultural inputs such as fertilizers and Modern Varieties (MV) of rice, wheat, and maize were introduced in some developing countries including India, Bangladesh, China, Turkey, Mexico, and Pakistan (Gollin et al., 2005). There was also a huge concentration on capital investment and improved information and management skills among farmers in the Asian, Latin, and Caribbean countries (Evenson and Gollin, 2003). This has over the years resulted in doubling and tripling the productivity of rice, wheat, and maize in South Asia, East, and South-East Asia, and Latin America & the Caribbean (Evenson and Gollin, 2003). In East and South-East Asia and the Pacific, for example, plantation of modern varieties of maize had increased from only 39.5% in 1975 to 89.6% in 2000. Also, in South-East Asia, as of the year 2000, 71, 94.5, and 53.5% of land areas were planted with MVs of rice, wheat, and maize, respectively.

In contrast to other developing regions, Sub-Saharan Africa (SSA) lags in its pace to increase agricultural technology adoption. As of the year 2000, only about 31, 47.4, and 16.8% of land areas were covered with MVs of rice, wheat, and maize, respectively (Evenson and Gollin, 2003). This stems from SSA's poor participation in the Green Revolution era in the 1970s−80s. Although SSA's GR was quite slow and different from the Asian experience. One obvious difference in both regions was the political undertones directed toward technology adoption. As argued by Frankema (2014), the political momentum that built up during the cold war led to the pro-active role of the governments in Asian economies in the diffusion of agricultural technologies. This includes channeling substantial resources into rural credit facilities, protecting infant industries from emerging fertilizer industries, and providing technical support to farmers. Such encompassing political roles are, however, found wanting in most technological interventions in SSA with limiting adoption and diffusion of agricultural technology. Also, contemporary SSA agriculture was driven by neo-liberal political agenda such as the Structural Adjustment Policies (SAP) in the mid-1980s (Smith and Urey, 2002). This was at a time when new and emerging exporting countries (created by the GR era) such as Vietnam and Thailand gutted the food self-sufficiency status of most countries in SSA by exploding their dependency on imported crops, specifically for rice (Moseley et al., 2010). As a result, agricultural policies were not driven toward improving productivity through the input intensification aspect but were free-market focused. The impact of this was a depletion of value of traditional cereal varieties that could not compete with global produces. One would say that the re-emergence of SSA GR that came much later after a free-market-focused policy was a case of putting the cart before the horse.

While it is important to reckon the early impact of GR in Asia and Latin America on poverty reduction and huge industrialization (Jara-Rojas et al., 2012; Ward et al., 2016). The Asian countries as well-experience a downside similar to SSA which is the loss of indigenous crops (Eliazer Nelson et al., 2019). Also, there are reported environmental consequences as a result of intensification include micronutrient deficiency and build of salinity, and increased incidences of soil toxicities, some examples are linked to large saline areas in Pakistan as a result of poor irrigation systems (Pingali, 1994). Other indirect impacts include the presence of chemical residues in food and the environment, high expenses in purchasing improved seeds and chemicals, food inflation, and farmers' diversification into non-agricultural practices due to high expenses and debts (Eliazer Nelson et al., 2019).

While taking cognizant of the downsides of GR, one cannot rule out its importance in improving productivity, food security, and welfare of rural farm households in developing countries. In SSA to be specific, the experience of improved seeds and other agricultural technologies was at a varying pace at the national contexts across SSA. In East Africa, Ethiopia's experiences of a national-context green revolution have taken place since the 1990s and were strongly pushed by the State government, this significantly led to growth in production in the cereal sector and production of crops per capital more than tripled (Rohne Till, 2021). In West Africa, countries like Nigeria experience a similar push for improved varieties, for example, improved maize varieties were introduced as early as the 1970s (Nigerian Seed Portal Initiative, 2021). Also at the regional context, the development of varieties such as the mangrove rice in West Africa carried out by the West Africa Rice Development Association (WARDA), these varieties was targeted for growing conditions in six countries in West Africa: Guinea, Guinea Bissau, Senegal, Gambia, Sierra Leone and Nigeria (Adesina and Baidu-Forson, 1995).

Besides, the early years' improvement in agricultural technologies, the re-emergence of GR at various national and regional contexts in SSA was partly spurred by global food prices in 2007–08 when average food prices rose by about 50% over 12 months, with the price rise of rice being the highest at 100% during that period (Kansanga et al., 2019). There were policy reforms and the emergence of forums such as the 2007 World Economic Forum tagged "*Alliance for a Green Revolution in Africa (AGRA)*" in Cape Town, South Africa. This forum was specially modeled to build on achievements and lessons from the GR in Asia (Moseley, 2017). A similar forum was the "*Malabo Declaration*" in 2014 to combat the imminent food crisis to end hunger and post-harvest losses by 2025 under the Comprehensive Africa Agriculture Development Programme (CAADP). At the country level, national governments have revolutionized their concept of GR characterized by the use of high yield varieties and fertilizer. Some examples of the government policy initiatives are "*Rwanda land policy in 2004*", "*Crop Intensification Program (CIP)*" in 2008 (Dawson et al., 2016; Clay and King, 2019); and *Malawi Fertilizer and Input Subsidy Program* (FISP) (Bezu et al., 2014). A further example is the agricultural modernization revolution in Ghana which includes the use of tractors, fertilizers, improved credit facilities, and the provision of small-scale agricultural input suppliers (Kansanga et al., 2019).

Although SSA continues to struggle with intensification and increase yield as population increases, there has been continuous focus on intensification through the use of high yield crop varieties, fertilizer technologies, soil, and water conservation technologies including capital-intensive ones such as irrigation technologies. As well, the impact of the adoption of these technologies is quite rooted in several empirical studies in SSA (Bezu et al., 2014; Manda et al., 2016; Abdoulaye et al., 2018). Despite the stated impact on productivity and welfare, low adoption suggests there are emerging factors limiting the adoption of agricultural technology among farm households. Low adoption problems extend back to the early GR period, for example, there were records of poor adoption of new varieties of rice in the Gambia, Zimbabwe, and South Africa during the GR era (Moseley, 2017). To date, the adoption of modern agricultural technology in SSA is persistently low (Abebe et al., 2013; Kagoya et al., 2018; Ward et al., 2018). Poor adoption of agricultural technology in SSA in earlier agricultural years can be compared with the pre-GR era of Asian economies where extensive agriculture was widespread and a sole means of increasing productivity. Although this approach increased productivity in absolute terms it did not keep pace with the growing population growth and their food needs (Radelet, 2010).

From the early years of the technological revolution in developing countries, high productivity and profitability were the main focus of technology designs and as well as a popular factor of adoption which featured in the inventions of high-yield varieties of cereals (Evenson and Gollin, 2003). For a while, these factors were believed to solely whet farm households' appetite for adoption. However, productivity and profitability did not reign solely as factors driving technological designs scientifically (Ruttan and Hayami, 1972; Zvi, 2011), but continuous acceptance by farm households was also due to unfolding heterogeneity in factors determining adoption, non-adoption, and dis-adoption (Feder, 2010). By way of example, risk and uncertainties were cogent perceived external factors in farmers' decision to adopt or not in the GR era, as a result, the post-GR era highly considered the risk and uncertainty to suffice for the shortfalls in the GR era. Adoption studies thereafter continue to incorporate various exogenous and endogenous indicators including psychological and behavioral effects to further understand decision-makers' perspectives of adoption.

While there are several factors of adoption in SSA in past studies, this review is limited to assessing natural resources, institutional and demographic factors proxied by land, extension & social institutions, and gender, respectively. The justification for selecting these factors is based on their popular feature in most adoption studies. These factors are deep-rooted in exogenous and endogenous interactions in most theoretical and empirical adoption studies and most times feature as the basis of policy implications in most studies in developing countries. This review as well limits the niche of comparison in adoption factors across West and East Africa countries as background to how differences in factors such as land, social institutions, and gender, respectively influence heterogeneity in the adoption of agricultural technologies. It is also important to note that the push for technology adoption has huge relevance in the West and Eastern Africa region due to their prominence in the large production of staple food crops and large farming communities. In literature, there are quite popular adoption studies on agricultural technology that offers relevance for comparison of heterogeneity based on regional contexts (Kassie et al., 2013; Teklewold et al., 2013b; Bezu et al., 2014; Shiferaw et al., 2014; Wossen et al., 2017).

Further, this review captures the heterogeneity of these factors in the context of various technologies and existing patterns driving or constraining adoption. It summarizes key results in the selected article, presents, and classifies results. The main contribution of this review is to provide the growing heterogeneity in factors of adoption considering existing differences in West and East Africa countries.

The next section reviews the adoption process and popular theories in empirical studies. The third section discusses reviews on land, extension & social institutions, and gender while the last section concludes.

ADOPTION PROCESS AND THEORIES

Transitioning from traditional practices to modern technologies is a critical step toward attaining broad development objectives in the agricultural sector (Gars and Ward, 2019). From the theoretical perspective, the decision to adopt a particular technology is a gradual process and is a sum of three components which include: (a) the Discovery Stage Lags (DSL), the Evaluation Stage lags (ESL), and the Trial Stage Lag (TSL) (Lindner et al., 1982). The DSL is the period from when a new technology is available and the time when decision-makers are aware of its availability. This period essentially covers the awareness period indicating the spread of information about the technology, this process is known as "diffusion" (Beaman and Dillon, 2018). In most classical adoption studies, awareness is a key component of the adoption process and as such generally perceived as the first step in the adoption process (Rogers, 1983). In experimental studies, it has fostered the process of technology adoption (Nakano et al., 2018; Shikuku, 2019). While this is important for new technology, the awareness process follows various patterns and can be quite specific to the technology, people, and location in question (Shikuku, 2019).

The Evaluation Stage Lag (ESL) is defined as the time lag from awareness to first use. This stage requires in-depth information from the awareness stage, and it is the first approach from which a farmer decides to try out new technology. The decision to try out takes the process of information gathering which can include taking a step to learn from a neighbor's perspective or learning by doing (Foster and Rosenzweig, 2010). At this stage, farmers want to know the cost of the whole adoption stage and thus seek information such as input costs, market prices, and acceptance of the technology. This stage is quite crucial and determines farmers' decision to continue adopting or not which is the third stage called Trial Stage Lag (TSL). The ESL and TSL stages require in-depth information and are quite intertwined and crucial in completing the adoption process over time.

The timeframe from the discovery to the trial stage varies among decision-makers when plotted against time. In (Rogers, 2003) popular adoption theory, adoption of new technology is a gradual process and takes a *sigmoid S shape curve* (**Figure 1**). The sigmoid S shape curve signifies the dynamics in the adoption process in which very few individuals adopt an innovation immediately after it is introduced, however, increases over time, it is measured by the relative length of time required by a certain percentage of a populace to adopt an innovation. The S-curve also signifies heterogeneity of farmers in defining variation in adoption in which typically some farmers may be *innovators, early adopters, early majority, late majority, and laggards*. The innovators constitute 3% of the adoption curve and are usually known as technology enthusiasts and can understand complex technical knowledge and are risk-tolerant. This group is described as technocratic and seeks knowledge and information from various sources about the technology. The *early adopters* are careful evaluators of technology attributes and are usually sought after for learning and experience with technology use. They makeup 13% of the S-curve and are made of key farmers

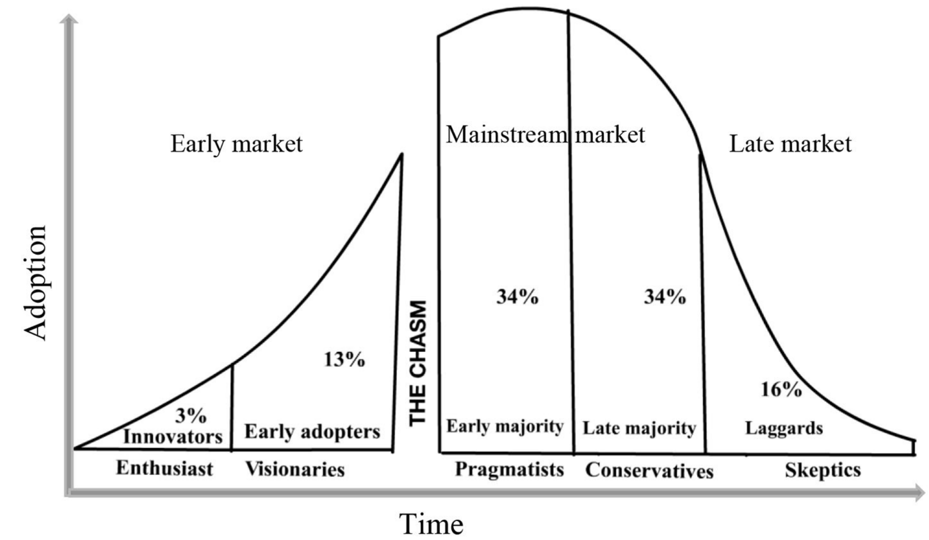

FIGURE 1 | Roger's Sigmoid S shape/Moore's Technology adoption life cycle model (Rogers, 1983; Moore, 2014).

in a locality or are heads or leaders of groups, also, this group may constitute farmers who are highly exposed or educated and highly willing to take up risks from adopting new technology. The early majority usually constitutes a higher percentage of adopters which is 34% of the S-curve, they are a group of adopters in the categories before half of the populace adopts. The late majority are quite conservative, and adoption is driven by economic gain or necessity, and most times they are influenced by peer pressure. The laggards form the last part of the S-curve and constitute 16% of the populace, they are behind in grasping the knowledge of technology and are quite skeptical.

The Roger's S-shape curve theory is quite relative to (Moore, 1991) technological adoption curve which rather described adopters at various stages, respectively, as enthusiasts, visionaries, pragmatists, conservatives, and skeptics (**Figure 1**). In adopting new technology, the diffusion of innovation from the early adopters' stage (visionaries) and the early majority (pragmatists) is attributed to what is defined as a "chasm (Moore, 1991. The chasm model is defined as the tendency of a group of the populace to adopt an innovation based on the perception of early adopters. This usually occurs soon after the early majority (visionaries), expectedly tries out an innovation without considering the risks, however, the pragmatists only try out based on reports from the visionaries and from seeing others adoptingf (Martínez-García et al., 2013).

The issues of low adoption of a particular technology are linked to not crossing the chasm, in this case, the qualities of the technology are acceptable by the visionaries but not acceptable by the Pragmatist (Moore, 1991). Progressing through the life cycle to ensure technology acceptance as advised in (Moore, 2014) is that "The key to getting beyond the enthusiasts and winning over a visionary is to show that the new technology enables some strategic leap forward, something never before possible, which has an intrinsic value and appeal to the non-technologist." Beyond the technical attributes, the issues of crossing the chasm equally be affected by a number of factors (Gombault et al., 2016). In literature, influencing the decision-making process to include majority of early and late adopters involves addressing several exogenous factors, hover over the year the complexities exist in the adoption of technology and heterogeneity exists in the perception of the technology attributes which can jointly be influenced by individual characteristics. In the next section, this review assesses the heterogeneity in selected factors of adoption using some studies in West and East Africa countries.

HETEROGENOUS FACTORS OF ADOPTION: LAND, EXTENSION, SOCIAL LEARNING, AND GENDER

Land Attributes in Adoption Studies

In developing countries, land represents the key asset in household agriculture and is central to development policies (Goldstein and Udry, 2014). Most importantly, it is a productive resource for agricultural development and poverty reduction measures (Khonje et al., 2015). Land, as a key factor of production, is relevant in fostering agricultural growth for development gains (Lawry et al., 2014) and as such has been a common feature in adoption studies. In SSA, land rights differ across regions and countries, this review however considers the contexts of common land laws across regions with respect to limiting differentials and adoption studies comparison to West and East Africa.

The type of rights to land is defined by the ownership or rental status in most adoption and indicates the farm households' level of tenure security. Land tenure security has been considered as the first attribute that drives modern technology adoption (Besley, 1995). It is defined as the right to use, control, and transfer land and in adoption studies, the degree of land rights matters for investments and can also heterogeneously varies across other attributes such as gender and immigration status amongst others (Bambio and Bouayad Agha, 2018). The varying differences in rights depend on ownership and ease transferability approach. In most West African countries, the pressure on land is high and they are usually informally cash related and sometimes laid on the traditional or customary platform as opposed to scenarios in most East African countries, for example in Ethiopia where all lands are state-owned; sales are prohibited and as such land rentals are prevalent (Holden and Ghebru, 2016).

Heterogenous opinions on land ownership and rentals and adoption probabilities are widely rooted in empirical studies. A common argument in empirical studies is that land ownership drives technology adoption while lack of land ownership in terms of land rental can preclude farmers from investing in technology due to the risk of eviction (Abdulai et al., 2011a; Zeng et al., 2018; Bedeke et al., 2019). As backed up by earlier studies, where land is perceived to be secure and eviction from land use is improbable, there are opinions that it reduces uncertainty and incentivise investments in agricultural technology (Feder et al., 2004). While this is true in most adoption studies for a long-term investment such as soil and natural resources management practices (Abdulai et al., 2011a; Oostendorp and Zaal, 2012), variation exists in the need to adopt among various sustainable land practices and land attributes in adoption studies. A key finding in this respect is that other land attributes or consideration of economic gains in some cases may influence farmers' decision to adopt a technology, in this case, attributes may be interdependent. For example, Wainaina et al. (2016) and Bedeke et al. (2019) found land tenure security to be significant for use of terraces in Kenya and Ethiopia, respectively, however, did not find it significant in the use of manure in both cases. The underlying argument was that tenure-secured farmers considered other attributes such as farm size as it is quite economical to construct terraces on large land sizes than apply manure. This shows that while considering the effect of an attribute on technology adoption, there is the interdependence of effects of other attributes of either the technology or farm households or both.

A similar illustration is that of the effects of future economic gains, Bedeke et al. (2019) revealed that tenure-secured farmers tend to invest in terraces or soil bunds to increase the cost of leasing out, and guarantee collateral for accessing cash credits. In retrospect, this is in agreement with (Besley, 1995) "*collateral effect* in which secure land rights enables the farmer to seek a loan to finance agricultural investment using the land as collateral. On the contrary, land right impact on long-term investment can be on the other way around in what (Besley, 1995) tagged "*gains of trade*". In this case, farmers undertake soil-improving and natural resources management investments such as tree planting in other to gain tenure security (Brasselle et al., 2002). To illustrate, Brasselle et al. (2002) argued that as long as the customary system of land tenure is well-established, immigrant farmers with low levels of tenure security usually adopt long-term improvement on lands to secure tenure rights. Similarly, Quisumbing et al. (2001) in their study stated that young, unmarried males secured land tenure rights through the appropriation of primary forests for food crop production and in return received land rights for the substantial labor input plowed into clearing forests. From this context, the quest for land rights can as well be a driving force to adopting agricultural technologies. While the aforementioned studies have critically focused on land rights with full ownership and long-term investment technologies, it is erroneous to generalize these findings for short-term investments such as improved crop varieties and fertilizers which are quite common in modern technologies. These short-term investments are key drivers of agricultural productivity, welfare improvements, and food security in SSA (Evenson and Gollin, 2003; Kassie et al., 2011; Shiferaw et al., 2014). Studies have shown that contrary views hold for short-term investments and can differ where individuals do not own full right to land, e.g., "*sharecroppers*" (Abdulai et al., 2011a; Zeng et al., 2018).

Besides land rights, other land attributes can jointly influence the decision to adopt a technology. This includes the quality of land (Arslan et al., 2014; Beyene and Kassie, 2015), farm size (Kassie et al., 2015b; Bedeke et al., 2019), location of land in Highland or low lands (Ghimire et al., 2015), land terrain such as steep and gentle slope (Wainaina et al., 2016; Bedeke et al., 2019), and farm distance (Abebaw and Haile, 2013; Kassie et al., 2015a).

To illustrate some scenarios in adoption studies; soil fertility status is at the center of the adoption of agricultural technology for both short and long-term investments. In Beyene and Kassie (2015) and Wainaina et al. (2016), the quality of land in terms of fertility was a driving factor of the adoption of improved maize varieties among farmers in Tanzania and Kenya, respectively. The reason stated was that returns from the adoption of improved maize varieties on fertile soil are high as farmers do not have to expend the cost of fertilizer. In contrast, the adoption of fertilizers technology, crop diversification, and manure was prominent among farmers with poor fertile land (Kassie et al., 2015a).

Farm size is another common factor assessed in adoption studies, In Bedeke et al. (2019), households with large farm sizes significantly adopted improved maize varieties and mineral fertilizer in Ethiopia. In addition to this finding, farm size was significant in the adoption of crop diversification, minimum tillage, soil, and water conservation in Malawi, whereas the effect was positive for crop diversification and manure use in Tanzania. In addition,

Also, the endowment of land types, highland, and lowland can be a key factor influencing the probability of adoption (Ghimire et al., 2015). Moreover, soil and water conservation techniques are prominent on a steep slope to reduce a nutrient loss (Bedeke et al., 2019) including the use of terraces, zero tillage, and mineral fertilizer to improve nutrients (Wainaina et al., 2016). From various studies, it is important to note that relationships between land attributes and technology types are important determinants of technology adoption. Examples of such studies are illustrated in **Table 1** below.

Extension and Social Learning Platforms as Factors of Adoption

In empirical studies, extension and social learning platforms play a cogent role in the adoption and diffusion of agricultural technology and can include the use of extension agents, farmers groups, learning from neighbors, and learning from farmers' own

TABLE 1 | Examples of studies on land attributes and adoption of agricultural technology.

References	Location	Types of technology adopted	Land attributes	Sign
Bambio and Bouayad Agha (2018)	Burkina-Faso	Trees, Drillings, hedgerows/fence, land fallow	The degree of land rights (right to plant trees, right to give as inheritance, right to traditionally lend, right to give as a family, right to rent out for cash, and right to sell)	Positive (+ve) Stronger land rights increase investment
Abdulai et al. (2011b)	Ghana	Soil-improving and conservation methods: planting trees, mulching, and application of organic manure and mineral fertilizers	Tenure security owned- operated with full rights, under fixed-rent contract, under sharecropping contract, and owner- operated without rights.	Positive (+ve) 1. farmers who owned land with secured tenure were more likely to invest in tree planting, mulch, manure, but not in mineral fertilizer. 2. fixed-rent farmers were more likely to invest in yield-increasing inputs such as mineral fertilizers Negative (-ve) Sharecropping contracts were found to less likely to attract soil-improving measures such as mulch and organic manure.
Oostendorp and Zaal (2012)	Kenya & Philippines	Soil and water conservation techniques:	Transfer rights (change of ownership).	Positive (+ve)
Zeng et al. (2018)	Ethiopia	Improved maize varieties	Cash rentals, Sharecropping	Positive (+ve) in driving the adoption of improved maize varieties.
Teklewold et al. (2013a)	Ethiopia	Sustainable Agricultural Practices. Maize-legume rotation; conservation tillage; introduction of modern trees.	Land size	Positive +ve in driving adoption of all packages.
Bedeke et al. (2019)	Ethiopia	Multiple Climate adaptation techniques (Soil and water conservation techniques (SWC) and drought-tolerant maize varieties).	Steep slope, Gentle Slope, Large land size and land ownership	1. Positive (+ve): SWC adoption increases with farmers on steep slopes. 2. Positive (+ve), farmers having plots on gentle slopes were more likely to adopt drought-resistant maize. 3. The large land size was positive (+ve) for the adoption of drought-tolerant maize variety and mineral fertilizer. 4. Land ownership was negative (–ve) for the adoption of conservation tillage, but positive (+ve) for soil-bund preparation and terracing.
Beyene and Kassie (2015).	Tanzania	Improved Maize varieties.	Land quality (soil fertility status)	Positive (+ve) for households with good fertile plots.
Kassie et al. (2015a)	Eastern & Southern Africa (Kenya, Malawi, Ethiopia, Tanzania).	Crop diversification (CD), minimum tillage (MT), improved maize varieties (IMV), manure, soil & water conservation (SW).	Tenure security, Farm size	1. Tenure security was positive (+ve) in the adoption of sustainable practices. 2. Farm size was positive (+ve) for CD, MT, SW in Kenya, and Malawi. Positive (+ve) for manure, IMV, and fertilizer in Ethiopia, +ve for CD and manure in Tanzania 3. Farm distance was positive (+ve) for manure use in Kenya, and SW in Malawi; CD and manure use (Ethiopia); manure use, IMVs, and Fertilizer in Tanzania.
Wainaina et al. (2016)	Kenya	Improved seeds, fertilizer, terraces, soil bunds, crop residues, zero tillage, and manure	Soil fertility, Steep slopes, Land size	1. Soil fertility: Positive(+ve) for the adoption of improved seeds and terraces; 2. Steep slopes: Positive (+ve) for terraces, zero tillage, and mineral fertilizer. 3. Land size: Positive (+ve) for terracing, crop residues, and negative (–ve) for manure.

experience which is also known as "learning by doing" in Foster and Rosenzweig (2010). These platforms play significant roles in creating awareness, demonstrating on-farm trials and practices, and influencing continued adoption. Besides, they minimize the risk of adoption through the provision of quality information, inputs, credits, and stable markets and also reduce farmers' uncertainty about the payoffs of adopting new technology (Wang et al., 2013).

Extension access is endogenous to the adoption of agricultural technology because the propagation of innovations is promoted through the use of various extension services in the adoption processes. The impact of extension services spread across the processes of adoption and are important in different stages of the adoption process; awareness, tryout, adoption, and continued adoption (Lambrecht et al., 2014). From the awareness stage, extension agents facilitate try-out through training and encourage the adoption of technology (Nakano et al., 2018). Various studies have reported the impact of extension access concerning one or all of these adoption processes. For example, awareness, as a result of participation in membership and contact from extension officers was significant in the speed-up of adoption of technologies in Tanzania and Ethiopia, respectively (Beyene and Kassie, 2015; Gebremariam and Tesfaye, 2018). Wossen et al. (2017) reported that households' access to extensions services increased the adoption of improved cassava varieties by up to 12.3%. Through increasing adoption, access to extension services has an impact on productivity and welfare outcomes. As reported, access to extension services improved crop productivity in Zimbabwe and Ghana (Emmanuel et al., 2016; Makate and Makate, 2019), improved welfare outcomes among cassava farmers in Nigeria (Wossen et al., 2017), and improved food security in Uganda (Pan et al., 2018). Other highlighted effects of use and access to extension services include a reduction in supply-side constraints and efficient input utilization (Wossen et al., 2017), reduction in yield gaps (Anderson and Feder, 2007), and of importance is extension role in facilitating new technology adoption and transfer among rural farm households (Emmanuel et al., 2016; Wossen et al., 2017).

Although extension services may have recorded a huge impact as reported by the above studies, few other studies do not find it positive in driving through all adoption process. This suggests that sometimes extension services may promote awareness, but it may not have an impact on the overarching goals of technology adoption. As argued in Van Campenhout (2017) in Uganda's case study, the availability of information and communication technology for smallholder farmers increased the number of farmers to adjust their crop portfolios, for example moving from low-risk crops to high-risk crops, it, however, did not increase productivity. In a similar case using different extension strategies to promote agronomic performance and nutritional benefit of Quality Protein Maize (QPM), the findings revealed that while farmers better understood the agronomic performance as equal or superior to traditional varieties, farmers had a low understanding of its nutritional properties (De Groote et al., 2016). Furthermore, the exclusion of target beneficiaries from the extension process and lack of credibility and incentive to transfer information are a prominent causal effects of the poor impact of extension services (Davis, 2008). Also, because knowledge transfer is essential in most agricultural technology, this can be marred by the availability of fewer extension workers which is common in most developing countries (Ragasa et al., 2013; Baloch and Thapa, 2018).

Some of the shortcomings of the use of extension agents, especially where they are fewer or lacking, social learning platforms such as farmers-to-farmers extension services were key farmers are trained and are meant to diffuse technologies to the rest of the farmers through learning from key farmers or neighbors are quite important These approaches have an impact on the technology adoption process. Nakano et al. (2018) in their assessment of the effectiveness of farmers-to-farmers extension services in rice cultivation technologies in Tanzania revealed improved adoption rates first among key trained farmers which rose steadily over the years among intermediate and ordinary farmers. On the other hand, dissemination of agricultural technology may not necessarily emanate from contact or key farmers, ordinary farmers can provide adequate training as much as extension officers (Takahashi et al., 2019).

Social learning includes social membership or farmers' groups' platforms which are crucial in individual learning and try-out experiences and they play significant roles in adoption processes with successful impact on overarching goals relative to the technology in question (Beyene and Kassie, 2015; Khanal et al., 2018; Launio et al., 2018). In several case studies, for example, in Launio et al. (2018), social learning was positive and significant in influencing the adoption of peanut seed inoculant technologies adoption in Ghana and according to Lambrecht et al. (2014), social learning played a significant role in creating awareness about mineral fertilizer adoption in the Eastern Democratic Republic of Congo.

Furthermore, social learning through learning from neighbors can foster adequate use of inputs based on successful previous usage from neighbor. To highlight, in Conley and Udry (2010) study in Ghana, pineapple farmers aligned their input use to neighbors' successful usage in the previous period. In Bandiera and Rasul (2006), Mozambique sunflower farmers were found to be influenced by their neighbors and friends in the adoption of sunflower technologies. Similarly, Munshi (2004), revealed that the adoption of high-yield varieties of rice seeds was highly influenced by neighbors' experiences. More comparatively, Krishnan and Patnam (2012) nested "learning by neighbor" and extension mechanism in Ethiopia and found that social learning is a powerful tool for adopting new technologies suggesting that while extension services may have a high initial impact, its impact wore off over time, but learning from social networks is far more persistent. The underlying argument is that social learning naturally enforces trust and behavioral cooperation (Hunecke et al., 2017; Khanal et al., 2019).

Conversely, while these institutions and social groups may play significant roles in the adoption of agricultural technologies, in certain theories, changes in farmers' information set is dependent on the social network characteristics he or she belongs to (Bandiera and Rasul, 2006; Foster and Rosenzweig, 2009), socio-economic and biophysical status of who to learn from or get trained from (Shikuku, 2019), farmers' perception of the relevance of the message to them (Krishnan and Patnam, 2012; Hunecke et al., 2017; Nakano et al., 2018) and social behavior such as innate differences (Tsusaka et al., 2015).

Overall, formal and informal knowledge transfer platforms in rural agricultural settings play significant roles in households' adoption decisions. Present studies have shown mixed findings, especially with implication on the variations of indicators of extension and social techniques suitable for different environments and technology (see **Table 2**).

Gender in Adoption Studies

The share of women in the agricultural labor force varies across countries in Sub-Saharan Africa. According to Palacios-López and López (2015), female labor share is slightly over 56, 52, 52, 37, 29, and 24%, respectively, in Uganda, Tanzania, Malawi, Nigeria, Ethiopia, and Niger. These differentials are dependent on several factors and vary across the region in some countries, for example, within Nigeria, the estimated female labor share is 51 and 32% in southern and northern Nigeria, respectively (Palacios-López and López, 2015). While women in agriculture represent a reasonable share of the agricultural labor force in developing countries, their contributions span across the farm and non-farm activities with a crucial role in food and nutritional securities (Ndiritu et al., 2014).

There is persisting low productivity among women farmers creating an existing gender gap as exemplified in various studies (Udry, 1996; Quisumbing and Pandolfelli, 2010; Vargas Hill and Vigneri, 2010; Kilic and Goldstein, 2013). Several studies have attributed low productivity among women farmers to low adoption of agricultural technology, differentials in technology preferences, cultural acceptability, and suitability of a particular technology for women agricultural tasks are one of the factors constraining adoption (Doss and Morris, 2000; Peterman et al., 2010; Quisumbing and Pandolfelli, 2010).

With the variations in the sample of women in empirical studies, for example, comparing female household head with wives in male households heads (Doss and Morris, 2000), differences in the impact on crop productivity between the female household head and women who are plot managers exist (Peterman et al., 2010; Fisher and Kandiwa, 2014). To illustrate, in Fisher and Kandiwa (2014), the adoption of modern maize was 12 and 11% lower for wives in male households' heads and female households' heads, respectively, compared to male households' heads. This, however, informs the effects of households' decisions making on women's decision to adopt or not.

Constraints to technology adoption among women are pronounced across stages of technology adoption, which include awareness, tryout, and continued adoption. These constraints are similar to the ones faced in traditional agricultural practices meant to be solved by new technologies in the first place (Theis et al., 2018). To illustrate, in traditional agricultural practices, women are faced with the usual rigors of access to and use of agricultural inputs, land tenure security, access to credit and market, access to institutions, human and physical capital (Kilic and Goldstein, 2013). Albeit, similar events unfold with access to new technology (see Doss and Morris, 2000; Ragasa et al., 2013; Achandi et al., 2018; Quaye et al., 2019). In terms of institutional role, a comparative analysis of women's access to agricultural technologies in rice production in Ethiopia, Madagascar, and Tanzania, Achandi et al. (2018) found institutional and cultural impediments as major constraints to adoption. Complementary inputs can also play a role as seen in Doss and Morris (2000), where women were constrained in the adoption of chemical fertilizers and improved maize varieties in Ghana as a result of poor access to complementary inputs which include land and labor.

On the other hand, constraints to adoption can vary according to technology as exemplified in Ndiritu et al. (2014). To illustrate, while significant gender differences exist in the adoption of minimum tillage and animal manure adoptions, no significant difference was found in the adoption of soil and water conservation measures, improved seed varieties, chemical fertilizers, maize-legume intercropping, and maize-legume rotation (cite). In a similar study, Theriault et al. (2017) in their assessment of gender and sustainable intensification of cereal production in Burkina Faso, found that female plot managers were less likely to adopt yield-enhancing (Inorganic fertilizer and or improved seed variety) and soil-restoring strategies (fungicide, herbicide/pesticide) however no differences in yield protecting strategies (e.g., manure, compost, planting pits, etc). The underlying argument, however, rests on resource requirements peculiar to the new technology to which women do not have access. Besides, demand for input use can be a constraining option for technology adoption as revealed (Theriault et al., 2017; Quaye et al., 2019) this is not different for women farmers. By way of example, in (Quaye et al., 2019), women farmers planted more soybean because of their demand for fewer inputs compared to maize which requires high input technologies.

Certain studies have shown that reducing these constraints can close the gender gap in the adoption of agricultural technology. To illustrate, in Fisher and Kandiwa (2014), input subsidies on chemical fertilizer were significant in driving the overall increase of 222% in the probability of adopting improved maize varieties for female household heads in their study in Malawi. In a similar vein, the availability of household labor enhanced the adoption of soil-restoring strategies by female plot managers in Burkina Faso (Theriault et al., 2017). **Table 3** below highlights some studies on the role of gender as a dependent and control variable in adoption studies.

DISCUSSION AND IMPLICATION ON EXISTING NARRATIVES IN ADOPTION STUDIES

This review paper attempts to discuss the heterogeneity in adoption determinants of agricultural technology in SSA with a focus on studies in West and East Africa countries. The review paper first highlighted historical events on the success of the early GR in Asian economies and the poor participation of SSA in the adoption of agricultural technology. It highlighted critical views and roles of political-economic undertones in Asia and SSA and how they differ in the promotion of GR

TABLE 2 | Examples of studies that used formal and informal institutions as the main variable of adoption decision.

References	Country	Type of technology adopted	Extension & social learning indicators	Sign
Wossen et al. (2017)	Nigeria	Improved cassava varieties	Access to extension	Positive (+ve)
Lambrecht et al. (2014)	Eastern Democratic Republic of Congo	Mineral fertilizer	Membership in non-agricultural groups	No effect on awareness, positive for Tryout and adoption stage
Emmanuel et al. (2016)	Ghana	Chemical fertilizer	Receive extension service (binary)	Access to extension contacts significantly promotes the adoption of chemical fertilizer and increases the rice yield.
Nakano et al. (2018)	Tanzania	Improved rice varieties	Farmer to farmer extension programme (key farmers, intermediate farmers, and ordinary farmer).	Positive in increasing adoption.
Beyene and Kassie (2015)	Tanzania	Improved Maize varieties.	Membership in rural institutions/group Number of grain traders Number of relatives in the village	Positive (+ve) Positive (+ve) Positive (+ve)
Gebremariam and Tesfaye (2018)	Ethiopia	Organic fertilizer, chemical fertilizer, irrigation, and crop rotation.	Extension	Positive for the adoption of organic and inorganic fertilizer, crop rotation, and improved seeds.
Ricker-Gilbert and Jones (2015)	Malawi	Storage chemicals	Extension (distance to extension services)	Positive (+ve)

in the early years. The review shows that productivity and profitability attributes were major considerations in driving designs and diffusions of agricultural technology in the early years. However, over time, several events led to modifications of agricultural technology designs beyond considering productivity and meeting food needs of the growing populace, one of such is the need to adapt to changing climatic events to fit with adaptability to changing agricultural needs, this ranges from production to post-harvest. While this was important and has led to several technology modifications across developing countries including SSA till date, low adoption defined by several exogenous and endogenous factors is a major setback to the spread of agricultural technology and the success of the new green revolution in SSA. As such, a part of this review considered empirical discussions on some of the key attributes defining the adoption of agricultural technology in developing countries.

From the selected studies used in this review, it is obvious that complexities in factors of adoption of agricultural technology continue to define adoption choices. This is inherent in critical institutional and human attributes in adoption studies as expressed in this review. The heterogeneity extends to within and across technology characteristics, in the case of long and short-term investments. A critical look at land as an institution is important in terms of reformation for investment purposes to enable increasing adoption of agricultural technology. The same applies to extension approach, which is limiting, however, learning platforms that promote the transferability of ideas should rather be encouraged. The role of gender continues to feature in adoption studies and the heterogeneity reveals that deprivation from access to resources is far deepening across the gender types in adoption studies. Overall, this review concludes that the promotion of agricultural technologies should be relative to farm households' attributes conditioned on probable factors that may drive their adoption. For example, where land rental is common and farm households' decision to adopt is conditioned on the perceived investment period which may not be favorable, it may be important to seek to redefine the need for policies to restructure the land policies to favor more adoption. While this may not be enough, institutional drive to promote adoption is critical, most especially offering continuous learning platforms or groups for farmers.

The review however has implications on existing theories/narratives on adoption studies, it is critical to note that adoption complexities in current times have impacted existing theories of the adoption process, this review shows a narrative of heterogeneity across individual and technological attributes defining farmers at various stages of the adoption processes and highly relative to contexts of studies. This equally suggests the need to redefine technology positioning in Sub-Saharan Africa. The implication of refined strategies in promoting adoption, suggests opportunities for several future research to define the adoption concepts in their interdependence nature with the technology of concern and the varying attributes influencing or driving farm households' pace at adoption. Given that promotions of agricultural technology are quite common in integrated packages, the complexities and diversities across attributes also tend to varies (Teklewold et al., 2013b; Kassie et al., 2015a; Khonje et al., 2018). For example, as illustrated in **Table 1**, complexities in the decision to adoption can vary based on land ownership, in, land

TABLE 3 | Examples of gender indicators driving/constraining adoption decisions.

References	Country	Type of technology	Gender indicator used	Sign
Doss and Morris (2000)	Ghana	Chemical fertilizer Modern varieties.	Female in Female-headed household; Female in a male-headed household	Adoption of modern varieties (MV) within male-headed households, does not differ significantly (in a statistical sense) between male and female farmers. However, the MV adoption rate for female farmers living in male-headed households is significantly higher than the rate for female farmers living in female-headed households.
Ndiritu et al. (2014)	Kenya	Sustainable agricultural intensification practices	Female and male household head	1. Positive (+ve) for minimum tillage and animal manure in crop production. 2. Negative (–ve) for the adoption of soil and water conservation measures, improved seed varieties, chemical fertilizers, maize-legume intercropping, and maize-legume rotations
Theriault et al. (2017)	Burkina Faso	Yield-enhancing (inorganic fertilizer), yield protecting (fungicides & herbicides), and soil-restoring (manure, compost pit, refuse, half moons, etc.) technologies.	Plot managers (1 = plot manager is female, 0 otherwise)	1. Female plot managers are significantly less likely to adopt either the yield-enhancing or the soil-restoring strategy sets. 2. No gender differential is evident in the probability of adopting yield-protecting (damage control) inputs, which are divisible, scale-neutral, and widely available through agro-dealers.
Muriithi et al. (2018)	Western Kenya	Push-pull technology (to address stem borer pests and parasitic Striga weed). Sustainable agricultural practices (maize-grain legume intercropping).	Male plot managers, female plot managers, and joint managers (male and female)	No heterogeneity exists regards the adoption of PPT, meaning technology can equally be adopted by men and women farmers. Positive gender differences in the adoption of sustainable agricultural practices technologies. Animal manure application and soil and water conservation practices were more likely to be conducted on - jointly managed plots, compared to male- or female-managed
Shiferaw et al. (2014)	Ethiopia	Improved wheat technologies	Gender of the household head	Not significant
Bezu et al. (2014)	Malawi	Improved maize varieties	Female-headed household Female adult labor	1. Not significant for female-headed household 2. Probability of adoption decreases with the availability of female adult labor.
Khonje et al. (2015)	Eastern Zambia	Improved maize varieties	Sex of household head, female = 1	No effect on adoption of improved maize varieties
Jaleta et al. (2018)	Ethiopia	Improved maize varieties	Sex of household head (male = 1. Female = 0)	No effect on adoption of improved maize varieties
Manda et al. (2016)	Zambia	Sustainable Agricultural practices (residue retention, maize-legume rotation, improved maize varieties).	Gender of household head (male = 1. Female = 0)	Negative (–ve) in driving adoption of sustainable agricultural practices:
Emmanuel et al. (2016)	Ghana	Chemical fertilizer	Gender (male = 1. Female = 0)	Positive and significant
Abebe et al. (2013)	Ethiopia	Improved Potato varieties	Male plot managers	1. Positive (+ve) in driving decision to adopt. 2. No effect on the persistence of adoption. 3. Positive (+ve) in impacting intensity of adoption

ownership attribute influenced the adoption of tree planting, mulching and manure but does not influence the adoption of fertilizer.

While redefining policies and strategies may be complex in integrated technology packages, it is vital to reiterate the continuous evolvement of technology design in agriculture in Sub-Saharan Africa, especially the shift to digital agricultural technologies (Kim et al., 2020). It is equally important to focus on similar issues of low adoption problems which may impact new technologies. Addressing key drivers that influence the decision processes becomes important, to highlight, the role of institutions that informs a bottom-top approach to adoption. To reiterate, poor extension officers' availability at the local levels continues to be a barrier to diffusion and adoption of agricultural technology, as highlighted and discussed in section Extension and Social Learning Platforms as Factors of Adoption, this review implies the need to redefine the approach to diffusion of agricultural technology in the contexts of the interdependent technologies and farm households' attributes. An example is ensuring individual farmers drive extension information via peer-to-peer and digital platforms. Also, one cannot rule out social learning and the need to strengthen farmers' groups' platforms. There is as well the need for future research to assess the role of social learning however considering the complexities and heterogeneities in the adoption process.

Overall, promoting agricultural technology adoption is critical to agricultural development, meeting food needs, and improving the welfare of farmers in developing countries. While this review has highlighted promotion pathways to further enhance the adoption of agricultural technology in SSA, it is important to acknowledge the downsides of GR. Environmental impact such as pollution for example was a notable impact in post GR era and in till date features as a common effect of agricultural technology. It will be important to factor in addressing the promotion of sustainable use of agricultural technology such as chemical fertilizers and as well-promote conservation practices. Equally, training farmers in sustainable use of agricultural technologies in a way that is not detrimental to the environment should be inculcated in the promotion and field trial programmes. Also, indirect effects such as pressure on farmers' funds due to the cost of accessing agricultural technologies should be catered for via increased flexibility toward credit access.

This review has provided a recent insight into empirical research on agricultural technology. It is important to note that this review is limited to selected attributes in empirical studies on adoption factors and has made efforts to cover some popular adoption studies and it is important to note the views are limited to these studies and their contexts. Also, this review study covers a niche out of several underlying issues impacting agricultural technology adoption in SSA. It does not capture the effect of issues such as local politics, unrest, corruption, the impact of colonialism, flaws in world trade organization (WTO) regulations, the European Union's detrimental agricultural policies, physical-geographical constraints, landlockedness, distance to urban markets among several others. These are however fruitful topics and should be considered for future research.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

FUNDING

This review paper is part of ZO-U's doctoral dissertation at the Natural Resources Institute of the University of Greenwich. ZO-U is a 2018 Commonwealth Ph.D., Scholar funded by the Commonwealth Scholarship Commission in the United Kingdom.

ACKNOWLEDGMENTS

I appreciate the support of my first supervisor - Dr. Apurba Shee (Associate Professor at the Natural Resources Institute, University of Greenwich) and my entire supervisory team for their inputs and guidance.

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Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.