Sustainable Agriculture Production, Innovation Spillovers, Adoption Challenges and Opportunities: A Systematic Review

MUHAMMAD USMAN[1,*], LAL KHAN ALMAS[2]
[1]Department of Economics, Faculty of Management Sciences,
National University of Modern Languages (NUML),
Rawalpindi Branch,
PAKISTAN

[2]Agricultural Business and Economics, Paul Engler College of Agriculture & Natural Sciences,
West Texas A&M University,
Canyon, Texas,
USA

[*]*Corresponding Author*

Abstract: - This research emphasizes on review of existing empirical and theoretical literature on impacts of Research and Development (R&D) innovation spillovers for sustainable agriculture productivity. Furthermore, it identifies the challenges and opportunities that agrarians have in innovation adaptation for sustaining the agricultural output. Government and private sector intervention performs a productive role in agriculture adaptation and adoption measures of innovation spillovers. The review is based on 101 existing bodies of publication in scientific journals internationally. This research provides a qualitative review of studies from 2000 to 2022 addressing sustainable agriculture, R&D innovation, innovation spillovers, embracing, and returns on agricultural R&D for sustainable food security and economic development. This study aims to identify the role of innovation spillovers, knowledge spillovers, innovative capacity, absorptive ability, and other challenges faced in sustainable agriculture output. Specifically, this research highlights the challenges and opportunities that contain the farmers in sustainable agriculture through innovation adoption and spillover shocks that are anticipated in previous literature. The evidence shows that innovation spillover performs a mediator role in sustainable agriculture productivity, while agrarian absorptive ability, knowledge capital, adoption capacity, and government extension services are key challenges.

Key-Words: - Agriculture Sustainability, Innovation Spillover, Ecosystem Services, Knowledge Capital, Adoption Challenges, Absorptive Capacity.

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1 Introduction

Research and Development (R&D) spillover is an essential factor for innovation in any field of study. Globally, innovation and its adoption are vital components to enhancing agricultural productivity, food security, economic growth, and instruments those helpful for enhancing the country's welfare. Level of innovation adoption provides the orientation about agriculture sector development towards actual yield to achieving the higher future potential output. The measurement of agricultural innovation is a novel task that has remarkable significance in attaining food security through sustainable agriculture productivity, [1]. Numerous economists have creative techniques and established models to highlight the effects of innovation spillovers for higher agriculture, industrial or economic growth, [2], [3], [4], [5], [6]. The Everett Rogers method of "innovation diffusion" is generally acceptable for all sectors to explain the innovative technology adoption and its process of spillovers across state, country, or region, [7].

Mostly in literature, the expression innovation and technology are used synonymously. The process through which technological innovation is transmitted by following different sources over time is called diffusion (or spillover). The adoption rate in innovative technology is dependent on technology attributes, compatibility with existing requirements, adoption cost and benefits, absorptive ability, trial-ability, and simplicity with potential adjustment. The fundamental driver which affects innovation adoption in agriculture is the decision process, [8].

The agriculture outlook for 2020-2029 predicts that the short-term demand is declining while the long-term trajectory demand of agri-commodities remains unchanged. In 2025, the global population will still drift between 9 to 10 billion public even with a reduction in growth rate. It is vital to enhance the agriculture TFP growth as agriculture productivity is facing pressures from climate vulnerability, increasing cost of inputs, complexity in agricultural production systems, and agricultural land degradation, [9], [10]. Global Food requirements is going up due to population preacher while agricultural productivity is declining because of climatic vulnerability, agricultural land degradation, less public R&D expenditures, [11], [12], soil degrade, water scarcity, pollution, greenhouse gas emission, loss of biodiversity, and unsustainable irrigation practices, [13], [14], [15], [16]. The result highlighted that climate change has a negative influence on agriculture output and provision of extension services, agriculture education and research, and food security are essential challenges for sustainable agriculture.

The TFP growth of the agriculture sector was calculated for more than two-thirds of total global output, from 2008-17, the agriculture TFP increased globally at an average annual growth of 1.63%. Agriculture TFP growth is lower than the projected population-driven demand for food increases till 2050. The agriculture average TFP requirement is 1.73 percent to sustain and achieve twice the agriculture output during 2010-50. Agriculture R&D innovation is required to fill the gap between food demand and supply. Agriculture productions require a high intensity of knowledge spillover, which needs more investment in R&D, [17]. The higher aggregate R&D spending in agriculture provides unique agriculture product varieties, advanced production structures, product resilience, cost-efficient crops, and profitability, [18]. The private and public organizations are integrated parts of agriculture R&D, and perform a vital role in technology fostering and diffusion by facilitating the farmers to acquire new insight (knowledge) and capacity building via extension services, [19], [20].

The Canadian Agriculture and Agri-food Report 2016 shows 91 percent of farmers opted for and implemented the innovative technology by utilizing their knowledge and experience. Further, results highlight that 68 percent adopted technology getting information received from colleagues in spillover and networking effect. The assumption about farmer rationality and complete information theory emphasizes that the potential innovative adopters show a cognitive attitude towards new technology. The results of technology adoption show that 32 percent of farmers typically wait for the per-testation of new technology before adoption, [21]. The report shows that 71 to 100 million individuals additionally the COVID-19 closure, pushed 235 million people into extreme poverty and increased their risk of acute hunger. The report also discloses that 75% of new and incipient human diseases are transmitted from animals (like COVID-19, Mosquito Infection, etc.) Besides, the livestock animals are also affected by Infectious diseases (such as Avian Influenza, African Swine Fever, Peste Des Petits Ruminants, etc.). Globally, every year pest assaults cause a loss of crop productivity by around 20 to 40 percent, whereas nearly 81 million public feed can be eaten by an enormous swarm annually.

For this purpose, this research focused on an adequate volume of literature to examine the socio-economic factors of R&D spillovers, adoption, and absorption challenges and opportunities for sustainable agriculture. This research tries to address the following research questions with the support of prevailing literature. Does the innovative technology have a productive impact on sustainable agriculture output? Do farmers have enough human and social capital to opt the R&D innovation? What types of challenges are faced by farmers in the adoption of R&D innovation? What are the opportunities farmers have in the early adoption of innovative technology? For qualitative analysis, we summarize the existing literature to provide unanimous policy and research tools to enhance the R&D innovation adoption, and innovation diffusion process for achieving the sustainable agriculture output to avoid the further food insecurity challenges across the globe.

This research aims to synthesize the information from published literature about the extent of innovation adoption, R&D spillovers, and agrarian absorptive ability, by highlighting the challenges and opportunities for achieving sustainable agriculture output. Agriculture innovation performs a dynamic role in productivity and profitability. Further, this study focuses on the review of existing literature to evaluate the role of foreign and domestic R&D spillovers in agriculture growth. There is a need for a unanimous approach to measuring innovation intensity, innovation adoption, return on innovation, and absorptive ability. The spares of existing research advocated that sustainable agriculture growth in advanced or emerging countries is reliant on innovation investment, knowledge shocks, innovation acceptance, and workforce absorptive ability, [22], [23], [24], [25], [26].

2 Methodology

This research focused on sustainable agriculture output through the challenges of innovation adoption challenges and opportunities. Sustainable agriculture productivity never is possible through agriculture innovation, early adoption, farmer's knowledge capital, and aligned challenges and opportunities. In this review paper, we adopted the systematic approach to gather and synthesize the relevant research articles, scientific publications, reputed research reports, review papers, and book chapters including both theoretical and empirical studies. This research focused on highly cited sources of literature for review for the referencing process. The relevant review papers are gathered from Google Scholar and Scopus indexed journals. To assess the quality of papers the authors reviewed the most cited publications, the quality of the journal and publication specialization, and the relevancy of publication contents. This study reviewed the 101 research publications, research reports, and book chapters concerning R&D spillovers, innovation adoption, knowledge spillovers, absorptive ability, and returns on R&D adoption for sustainable agriculture. This research focused on investigating the challenges and opportunities that farmers have in innovation adoption to achieve higher productivity. The R&D in agriculture performs an essential role in the rate of returns and achieves higher profitability through agriculture R&D innovation adoption, [27]. Figure 1 (Appendix) shows the R&D flow in agriculture sector, which consists of four major sectors such as cropping, livestock fishery, and forestry.

2.1 Challenges for Agriculture Innovation Spillovers

The chosen innovative technology is to be prescribed by the availability of historical data. Consequently, the farmer should be careful in selecting appropriate technologies. Some technologies are available for a longer time period and others become obsolete earlier, [28]. In order to overcome adoption limitations and drawbacks, expert opinions should be given due weight to age.

The fundamental challenge of agriculture R&D innovation is to fulfill the demand for food items as the population grows is higher than the TFP growth. Agriculture innovation is facing slow R&D cycles and poor adoption rates, especially in lower-income countries. The successful R&D innovation and adoption at an extensive level take a long time at least 25 years. For example, the USA hybrid corn technology developments began in the early 1890s, the uneven adoption of hybrid corn started in the 1930s commercially, and the USA almost grew hybrid corn during 1960, [29]. The agriculture innovations are capital intensive, while dominant farmers are small stakeholders and have limited capital access. The climate change vulnerability and changing patterns of weather also affect agriculture productivity, [30].

The R&D incentive can be achieved by strengthening the long-term policy for continued provision of information about the challenges and opportunities in agriculture productivity. The challenges and pressures faced by the current agriculture sector are overpopulation, climatic changes, gas emissions, water shortages, energy shortages, emerging economies, food security, and land growth instability. In this scenario, agriculture innovation plays a sustainable role in combating agriculture challenges. [31] identified the two major problems of R&D spillovers, first the changes in knowledge spillover and their alternative R&D and second the current research structure is dependent on previous research activities and the country's R&D environment. [32] argued that old household heads are negatively associated with the acceptance of innovative technology. [33] argued that women in agriculture are suffering from lists of problems such as lack of information accessibility, R&D innovation, decision-making supremacy, and control of resources and assets. Mitigate such problems requires technological innovation, practices, and workable policies that ensures the participation of women in agriculture and decision-making, [34].

In agriculture, the private sector share in R&D investment is high, which positively increases the agriculture yield, profitability, and investment returns. While in developing countries, innovation does not rival good, and farmers adopt inferior innovation because of the absence of information, access to resources, less education, and regulatory delays, [35]. The dilemma of developing countries is the farmer's low absorptive ability which lowers the innovation adoption. A meta-analysis on returns on R&D spillover in agriculture relative to dealt with and distribution determinants of R&D benefits in agriculture. Many studies have concentrated on time series data but lack suitable long-term data on productivity and R&D investment. The time series analysis requires long-time data unless the analysis gives biased and distorted findings, [36].

The rural support programs can work to increase the future targets towards innovation adoption. In this scenario, the technology adoption rate increases through farmer absorptive ability, improving farmer participation in the agri-innovation system, financial incentives, and mechanisms for market-based innovation, [37]. The increase in innovation and technological progress in agriculture are the main contributors to productivity growth. Since 1948, the input mix in agriculture productivity has shifted, and the share of labor and land has decreased, the contribution of technological inputs has increased. Further, the productivity of the crop growing is faster than livestock production. [38] found that in developed countries, the public R&D in the agriculture sector has shown markedly slow growth in recent decades and has now turned negative. The reduction in R&D expenditure in high-income countries produces new challenges for agriculture productivity and food availability globally.

2.2 Agriculture R&D Spillovers and Innovation Adoption

The R&D knowledge spillover occurs when the innovation in one region/country is adopted in another geographical region or country, [39]. R&D spillover is an impression (innovation) attained from other research (innovative activities) actions in agriculture or the industrial sector. The innovation spillovers have both indirect and direct effects on sustainable productivity. Through, direct impact the agrarians adopt innovative technology to gain high yield and profitability, while the indirect consequences are the farmers gain knowledge about their competitors, market demand, and goods produced by trade partners, [40]. The innovation spillovers in agriculture follow the properties of public goods which have to combined properties of both non-rival and non-excludable goods through such characteristics are essential for achieving sustainable agriculture growth, [41]. However, the R&D spillover is an impure public good, and the benefits of innovation conducted at one place become flawed and available to another location.

The R&D spending provides agricultural innovation through new cultivation techniques, crop varieties, and alternative sources of production and disbursement of information to the agriculture producers to achieve sustainable productivity, absorb the crisis impact, and adapt to the upcoming challenges. The R&D knowledge spillovers require strengthening both human and social capital. The human capital comprises agriculture knowledge, skills, experience, and community-led innovation, while social capital can be generated through networking among farmers, field workers, and innovators, [42]. [43] conclude that all attributes of R&D spillovers officiate in agriculture productivity implicitly or explicitly. Through implicit effect, R&D innovation includes changing weather patterns, economies of size, institutional transformation, and knowledge spillovers are linked with the adaptive structure of agriculture, [44], [45], [46], [47], while the explicit factors of R&D innovation bring new sowing and harvesting technique, crop switching, new seed varieties, and climate resilient agriculture, [48], [49], [50]. Additionally, [51] found the existence of spillover impact on neighbor farmers also exerts influence on adoption decisions. The farmer's interaction and communication with each other significantly influence the adoption decision. Further, the social norms and farmers' attitudes have a notable impact on innovation spillover, [52].

The private agriculture R&D spending crowd out because of the substitution effect of R&D from public spillover. In agriculture, [53] found a significant positive spillover effect of R&D investment from private. The agriculture production volatility in Pakistan, India, and Bangladesh is high because of climate variation, [54]. Further, the country's inner volatility shocks have a robust spillover impact on agriculture productivity compared to cross-country shocks. The existing literature in agriculture concentrates on innovation development and adoption, but the innovation dissemination pattern is less attended, [55]. The direction of innovation can be determined through mechanization, vulnerability, concentration, stability, and innovation adoption. The results revealed that the paddy crop is more innovative as compared to other crops. The agriculture sector of India has a complex pattern in technology generation, technology adoption, and utilization. Additionally, the technology dissemination gap is found within the crop sector and across states. Agriculture crops face negative externalities risk of innovation and innovation adoption inefficiency. The results show that wealth and price factors do not have any significant impact on innovation, while the farmer's linkages with the industrial sector and extension instruments promote innovation adoption, [56]. Figure 2 and Figure 3 in Appendix shows the R&D expenditures as a percentage of GDP in developed and developing countries during 2022-2023.

Innovation matrix and indexing methodologies were developed0 for analyzing the effectiveness of agriculture innovation in productivity. The results of agriculture analysis show that few agriculture firms are leaders in innovative business. The outcome of participation in regional innovation and R&D shows positive effects on innovation spillovers to achieve sustainability and productivity. [57] argued that the latest irrigation technology increased water efficiency. New crop irrigation technology proffers water precisely, direct irrigation, minimizes evaporation, and reduces water usage. The stochastic frontier analysis technique and concluded that both foreign and domestic R&D have a strong influence on agriculture productivity. [58] argued that the industrial sector harms agriculture output due to vulnerable environmental damages, while, the services sector has a positive influence on agriculture output in the long run. Further, the stable association is established among industrial and services sectors with agriculture sector performance. The latest technology adoption (such as planters, tractors, harvesters, etc.) enables agrarians to receive a high yield. Further, Global Positioning System (GPS) tracking (like sensors, monitors, software, smartphone, etc.) provides optimum forming procedures and generates detailed farming which helps track and monitor inputs and output mechanisms. The Green Revolution performs efficiency in input-output ratio, the adoption of crop cultivars and inputs in the form of technology, fertilizers, innovative seeds, and irrigation as a result gains high productivity. The green revaluation period improved the crop varieties, high-yield crops, changed the cultivation process, and land fertility through variation in crops and technologies exponentially enhanced food production globally.

The patent right in the agriculture sector is creating difficulty in attaining the fruits R&D spillover and high agriculture yield. [59] argued that the regulatory rule about genetically modified technology has a detrimental impact on agriculture R&D funding, breeding innovation, and international trade in the European Union (EU). The agriculture R&D cost is staggering in the EU. So, the message coming from EU agriculture innovation is deterring future R&D investment in agriculture. In the mid-1990s, the EU commercialized biotechnology, and EU investment was one-third of global due to regulatory rules this share has fallen to less than 10 percent. Globally, biotechnology R&D investment was around 1.2 billion dollars out of $8.6 billion in agriculture R&D investment in 2010, [59]. [60] emphasize agriculture human capital, experience, skill development, risk preferences in technology adoption, farm management skills, knowledge of patent rights, and biodiversity in the agriculture sector.

2.3 Drivers for Adoption of AgricultureInnovation

The agriculture R&D spillover generates wisdom through the combined expertise of researchers, farmers, and field workers. The farmers and field workers have grassroots knowledge about soil type and fertility through traditional wisdom (inclusive knowledge). The important drivers of innovation in agriculture are high productivity, profitability, and competitiveness in world agriculture markets. The innovation drivers are further segregated into two parts technical and non-technical innovation. The technical drivers consist production process, such as the adoption of new seeds, production methodology, agriculture technology, fertilizers, biotechnology, and harvesting technology, [61]. Whereas non-technical innovation consists of off-farm activities like yield processing, refining, packaging, and marketing to earn high profitability, [62], [63].

The existing literature demonstrated significant differences in innovation adoption across the countries, regions, and states. The institutional setting provides routine knowledge, laws (like climatic policy) and their regulation, and interaction between innovation and farmers, [64], [65]. The geographical proximity to the innovation center, encouraging innovation atmosphere and existing agriculture system are fundamental drivers opt innovation for agriculture growth. Existing research highlights some important drivers for potential agriculture innovation and productivity growth. Such drivers consist of innovation policy and its implementation across the country either at the federal or state level, R&D-based institutional infrastructure and environment, knowledge diffusion process, domestic and regional efforts for innovation, trading partners, existing agriculture system, and geographical proximity also affect the innovation, trading partners, [66], [67], [68].

Agriculture innovation and adoption play a vital role in productivity growth. The main drivers of R&D spillovers are agriculture innovation, agriculture research, agriculture research institutes (like universities, etc.), institutional environment, and agrarian's willingness to opt for new technology, education, skill, and extension services to diffuse innovation among farmers, [69]. Similarly, [70], [71] explored the positive influence of technology adoption on agriculture productivity. The outcomes demonstrated that fertilizer consumption has a significant impact on agriculture output in Ethiopia, while, the adoption of innovative technology is dependent on different factors including education, extension visits, access to financial facilities, off-farm activity, distance from the market, and ownership structure. [72] found the driver of agriculture growth and highlights that the irrigation, use of cover crops, and conservation tillage techniques with optimal usages have a significant contention with output. Farmers can reduce the risk by selecting new cultivation methods, especially for marginal lands. The low-cost Labranza Minima technology provided by NGOs has multiple benefits to achieve agriculture production sustainability.

The R&D is dependent on access to disseminate information, financial capital, networking of extension services, and farmer attitude towards innovation. These implements have positive influences to enhance the adoption of new technology and productivity, [73]. [74] examined the adoption factor of technologies in agriculture and concluded that the farm size, land tenure arrangements, extension services, human capital, and the way farmers see risks and uncertainty important determinants of technology adoption. [75] worked on the values of agricultural R&D and argued that agriculture financial support and public R&D policies are fundamental factors in enhancing agricultural output, and economic and environmental performance. R&D in USA agriculture enabled the formers to gain more yield per acre with smaller inputs through sustaining the agricultural workforce. Research in agriculture improves the share in commodity markets, achieves environmental sustainability, nutritious food, cost-efficient inputs, reducing adverse externalities, the well-being of producers, feed, fiber, and biotechnology for energy. The agriculture yield grows as a result of R&D inputs (like fertilizers, improved seeds, machinery, herbicides, fuel, and irrigation process) and changes in inputs quality (such as new verity, hybrid varieties, and genetically engineered varieties).

The essential determinants for rural farmers' technology adoption include cultural attributes, social attributes, economic attributes, self-innovation, and environmental goals. The high relative advantage of innovation is adopted when they easily accessible, [76]. Furthermore, [77], [78] investigated the use of innovative agriculture technology and found that household head age, human capital, and farmer’s income reductive role in innovative adoption. In addition, the farmer's access to financial capital, land irrigation, land ownership, and fertilizers has a positive role in fostering technological innovation, [79], [80]. However, [81] emphasized innovative potential and growth drivers of agriculture innovation. Knowledge acquisition is a continuing phenomenon, the farmer's activities and efforts for innovation are the main drivers of knowledge spillovers. In knowledge spillovers, innovation experts, the system of innovation containing education, research, agribusiness, and extension and advisory services are facilitating the farmers to adopt the new technology and general innovation in the agriculture sector, [82].

2.4 Returns on R&D Innovation

R&D paybacks are measured through the supply elasticity which has essential implications when it is utilized for horizontal to vertical shifts or vice versa, [83], [84]. In addition, the R&D benefits distribution is also dependent on supply and demand elasticities. The research spillover has a controversial impact on the supply side especially, the distribution benefits for those producers who adopt innovative technology are better off due to cost and production efficiency, while those who are not opting for innovation are even made worse off because adoption of other leads price reduction and product efficiency.

Additionally, [85] examined the 2186 evaluation publications and 356 separate publications and investigated the return on agriculture R&D from 1958 to 2011. The agriculture investment in R&D is profitable, and the evidence shows the average internal rate of return (IRR) is 49.4 percent, and the median rate of return is 40.7 percent. The IRR is lower because of the underinvestment of public sector R&D. Furthermore, a meta-analysis on 292 empirical studies with 1886 observations of return on investment on R&D; the existing evidence stipulates the R&D in agriculture has generous pay off for society in terms of agriculture output. Further, this study highlights biased estimation problems which are R&D lag distribution, focused on the most successful investment evaluation, failure to calculate the role of spillover from both the public and private sectors, and methodological usage. The results indicate the average rate of return of R&D adoption is 64.6 percent, the extension shows an 80.1 percent rate of return while the combined activities of extension and research have 46.6 percent returns.

Similarly, [86] concludes that robust intellectual property rights (IPR) have potential consequences regarding the expenses and advantages for technological innovation, and technology spillover, especially in developing countries. In developing countries, the stronger IPR provides the reap rewards to the domestic innovators; if a country has little adoption capacity, it may impose the additional cost with insufficient innovation capacity and factor endowments. The study determine on the basis of the review papers that a trend has been found in those studies that have larger spillover impact and longer research lags, further, inappropriate models ignore the spillovers and results find high payoff.

2.5 Agrarians Innovation Absorption Capacity

In agriculture, farmers are less educated, which affects the decision-making power to adopt the innovation. An innovative technology adoption decision involves five stages; at the first stage, the farmer must have sufficient knowledge or awareness about innovative technology. Secondly, persuasion/ influence through enough potential gain and cost-benefit characteristics of innovative technology. Thirdly, decision-making power to opt for the innovation, fourth, implementation or absorptive ability of innovative technology, and fifth confirmation. The fundamental assumption is low innovation spillover in agriculture is due to the lack of adequate transactional behavior and absorptive ability of agriculture farmers. The research also finds that regional innovation networking in agriculture, and inter-farm R&D spillovers influence the innovation processes, [87].

The knowledge stock performs a crucial role in driving the sustainable agriculture output. In the choice of innovation, the farmers are primary stakeholders who uplift agriculture productivity. Furthermore, [87] worked on agriculture resilience and highlights three essential for the agriculture sector strategies to minimize the loss. First is the farmer's capacity to absorb the negative externalities with immediate minimal loss. Second is the capacity to adapt to the on-farm crisis with minimal loss through farm management and strategic planning. Third is the capacity to transfer the farm production to prevent the upcoming crisis.

A comprehensive incentive system for innovation will anticipatively increase the innovative capacity. The inventive system improves the skill and absorptive capacity through facilitating, labor education, mobility, extension services, training, and ensuring equal access to green and general education, [87]. Agriculture innovation is experiencing vertical integration, product differentiation, precision technology, and biotechnology. In this scenario, researchers from universities are sources of discoveries in agriculture advancement, those providing new techniques and agricultural innovation for sustainable output, [88]. [89] argued that technology adoption has a constructive influence on agriculture output. Deficiency of human capital, farmers' income, and access to financial services performs a reductive role in innovation adoption for sustainable agriculture output, [90]. For innovation adoption in agriculture, farmers require coordination, networking, and cooperation among innovative actors.

2.6 Government Onus in R&D Adoption

The government can perform fundamental roles in the adoption and fostering of innovation in different ways, firstly, providing resources (like services, knowledge, and finances) to the innovators and researchers through building a suitable research environment. Secondly, the government should remove the obstacles, to the adoption of innovation including governance, trade, and investment barriers, and develop a legal framework, [91]. Thirdly, the OECD emphasizes the reinforcement of human capital through a practical-based education system like vocational training, skilled base workshops, innovation adoption training, innovative and critical thinking practices, etc. Fourthly, effective agriculture research policies and plans to boost the R&D investment in the agriculture sector. Fifthly, develop linkages among field workers and innovators through extension services, [92]. Sixthly, creates an environment and opportunities for the private sector to contribute to innovation such as technological development, product value chains, competitive technology, innovative models, and structures, [93]. The government's innovative thinking platform should perform a central role in developing a bridge, between innovation processes by coordinating with public and private stockholders, fostering innovation, and opting for strategies for farmers and field workers.

The public sector investment in R&D a has high share and accounts for 55 percent share globally in 2011, recently the public sector R&D in agriculture has been declining, meanwhile, the private sector R&D innovation has increasingly filled the gap of the public sector, [94]. The agriculture R&D investment is an essential driver for growth in agriculture TFP, meanwhile, the public sector investment in R&D is going down, especially in high-income countries, and the R&D investment is falling 20 percent from 2008 to 2013. The private sector filled that gap; R&D investment is robustly growing in agriculture because of innovative technology and high profitability. The private sector agriculture R&D spending has been fuelled because of extraordinary technological advancement (called 'digital agriculture), which contains farming methodology, hybrid seeds, farm diversification, agronomy, biotechnology, plant and animal breeding, digitization, and robotics in agriculture. The adoption of R&D innovation provides significant progress in productivity, improves natural characteristics, and makes crops more resistant to pests, drought, weeds, disease, and climatic vulnerability.

The extension services work as a bridge in connecting actors (like government, private sector entities, universities, etc.) with the agriculture community. The government provides fundamental services and agriculture information to bear unexpected shocks and events like natural disasters, pest outbreaks, animal disease, climate vulnerability, etc. The extensive service provides long-term information to the agrarians to equip them with knowledge, technical skills, and technological resources, [95]. The technological growth and subsidy policy hold a positive association with land productivity conservation. The subsidy for agriculture R&D is harmful to economic growth in the condition of an indeterminate balanced growth path, [96]. The vision of agriculture innovation rotates around the comprehensive policy, innovation foundation, and determination towards promoting invention and a friendly environment. The government policy with a suitable institutional framework executes vital contributions in supporting innovation, rewarding entrepreneurial struggle, and developing value chains for agriculture innovation and adoption.

In 2015, the OECD worked on innovation for the Netherlands agriculture productivity and sustainability. The government should give incentives; to private investors in transaction cost reduction, registering new products (patents), and architecture of support programs, especially in taxation and subsidization systems. [96] suggested a policy frame and argued that the government needs to reverse the R&D investment and produce the spillover impact on lower-income countries. The public sector should support agri-extension services to disseminate knowledge about agriculture innovation and develop links between R&D investment and farmers, ranchers, and field workers. The extension service is essential to educate the farmers and motivate adoption innovation to gain profitability, [97].

2.7 Agricultural Innovation Towards Economic Development

In high-income countries, the sole source of TFP growth is agricultural productivity, which is attained by opting for innovative technology. The agriculture TFP growth is dependent on the adoption of advanced seed varieties, veterinary services, animal care, farmers' training, extension services, access to agriculture innovation, and markets, [98], [99]. The low-income countries can achieve high agriculture TFP by investing in agriculture research and education, improving seed genetics, irrigation extension and improvement, provision of mechanization services, and fostering innovation, [100].

The USA R&D share in agriculture and food spending declined from 16.7 percent in 1980 to 13.4 percent in 2009, highlighted by USA National Research Council. In global agriculture R&D and food, the combined share of Brazil, India, and China was 16.2 percent in 1980, which is now 31.2 percent in 2009. So the investment in R&D increased the global competition and meets the domestic needs to ensure food availability, nutrition, and food accessibility. The reduction in R&D investment shrinks innovation, slows down knowledge growth, increases resource scarcity, raises environmental concerns, and rapidly reduces agriculture productivity. Pakistan, India, and Mexico (during the 1960s and 1970s the Green Revolution period in the), again high agriculture output by bringing high-yield seed varieties, precision mechanization, technology adoption, fertilizers, and pesticides. Extensive R&D spending in agriculture in such countries chronically reduces food insecurity, saves millions of lives, and attains sustainable agriculture output, [101].

R&D innovation spillover in every sector provides a different and pivotal role for sustainable growth. In the agriculture sector, technological innovation improves the production process, and food safety, and legitimates sustainable productivity growth. The benefits from innovation in the agriculture sector are crucially dependent on where the R&D emerges and what opportunities farmers have through the adoption of agriculture innovative, [101]. R&D innovation in developing nations has a modest effect on developed countries; however, the R&D innovation that occurs in developed countries has a large and economically essential impact on sustainable productivity growth in developing countries. Profitability guidance provides a way for resource allocation decisions for technology spillover, adoption, and absorptive efficiency in the agriculture sector. The services provided to the producer guidelines, research intuitions, and policymakers are helpful in making prudent decisions to invest in technological development. The market distortions, environmental externalities, and government policies have an effect on the estimate but have little effect on returns on R&D agriculture. The evidence suggests that marginal benefits are greater than cost and R&D investment in agriculture provides profitability, [101].

2.8 Conclusion and Policy Suggestions

The research concludes that, without urgent action, the world's agricultural systems will be unable to meet the global food requirement according to a growing population. Based on a review of existing studies, it is highlighted that agricultural sustainability is not only essential for food security and environmental challenges but also assists the farming system as a driver of innovation. Innovation spillovers enabled framers to adopt advance technology, share new knowledge and have the potential to accelerate the adoption of sustainable practices in agriculture sector. In addition, there are numerous challenges faced by the farmers, including financial constraints, institutional barriers, limited access to information and resources, lack of technical knowledge, and inadequate policy support. To attain the potential level of agricultural productivity, the government, policymakers, researchers, and stakeholders need to collaborate to develop workable strategies according to ground reality to overcome the farming challenges.

2.9 Challenges for Farmers in the Adoption of Innovative Technology

- Lacking the financial facility and expensive innovative technology is difficult to adopt immediately
- Innovative technologies often come with a significant cost, including the purchase of equipment, installation, and maintenance.
- Farmers are facing the challenges of poor infrastructure such as road, water, electricity, and poor irrigation distribution systems.
- Slow process of innovation spillovers
- Farmers have problems of poor education, weak training, facilities and weak knowledge capital.
- Integrating new technologies with existing farming systems can be a challenge.
- Some innovative technologies may be complex to understand, set up, and operate.
- Farmers are not aware of the innovative technology and lack knowledge about how these technologies can benefit their specific farming operations.
- Farmers are reluctant to take risks in accepting innovative technology, like new crop varieties, innovative farming techniques, pests and disease control, and climate reluctant adoption.
- Regulation and patent registration also create difficulty in the adoption of innovative technology.
- Farmers' behavior regarding traditional farming
- Farmers are facing a gap of extension services

2.10 Opportunities for the Adoption of Innovative Technology

- Innovative technology adoption increases agriculture productivity and helps formers to attain higher productivity to earn high profits.
- New technology adoption provides unique and high-quality products.
- Innovative technology is helpful for formers to diminish the cost of production and grow the profitability.

2.11 Policy Suggestion

- Providing farmers with education and training about the benefits of innovative technologies and how to use innovative technology effectively.
- Making new technologies more affordable for farmers.
- Improving infrastructure in rural areas.
- Reducing the risks involved in adopting new technologies.
- Streamlining the regulatory process for new technologies.
- Designing and implementing effective technology adoption programs that take into account the unique preferences and decision-making processes of farmers.
- Investing in agricultural research and development.
- Providing farmers with access to affordable inputs.
- Protecting agricultural land from degradation.
- Adapting agricultural production systems to climate change.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Both authors contributed equally to the data collection and manuscript preparation. Muhammad Usman led the development of the idea, abstract, introduction, scientific review, conclusion, and policy recommendations, as well as other technical aspects of the manuscript. Lal Khan Almas revised the article, conducted the systematic review analysis, and contributed significantly to the research methodology, results, discussion, and bibliography.

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Conflict of Interest

The authors have no conflicts of interest to declare.

APPENDIX

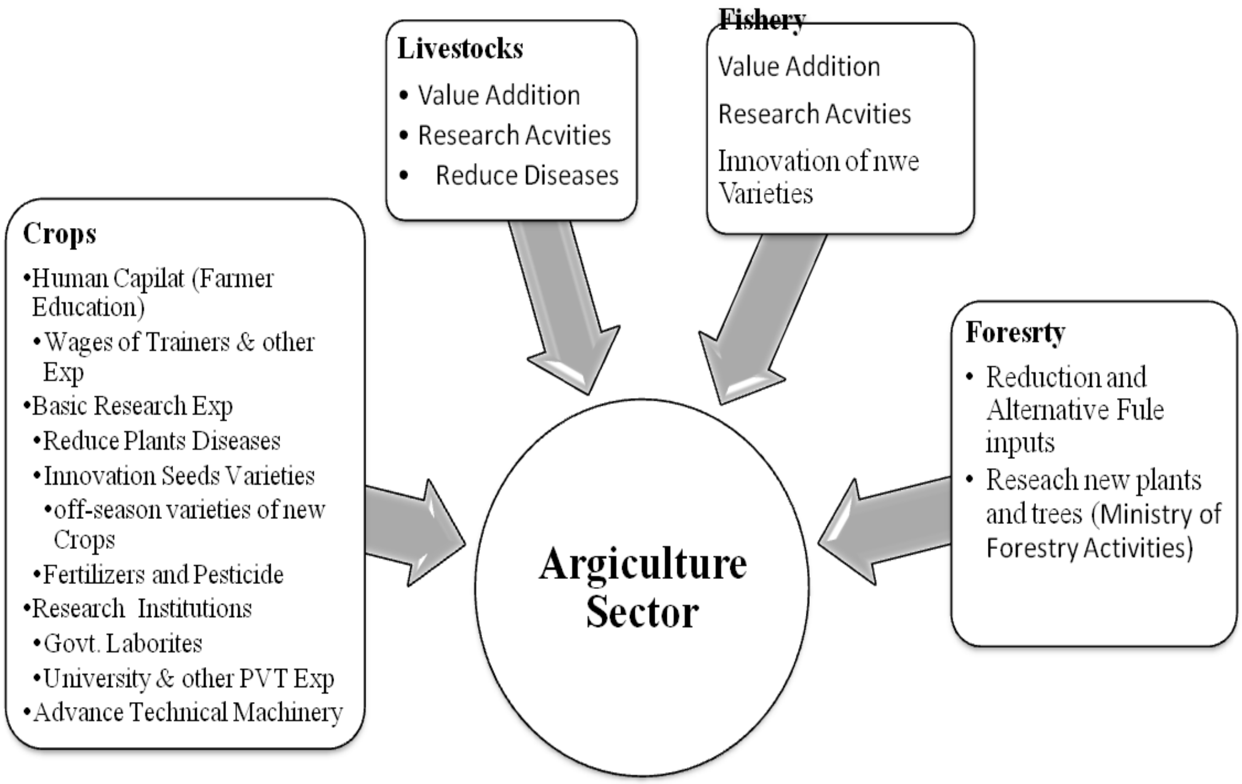

Fig. 1: R&D inflow in the Agriculture Sector
Source: Author's own

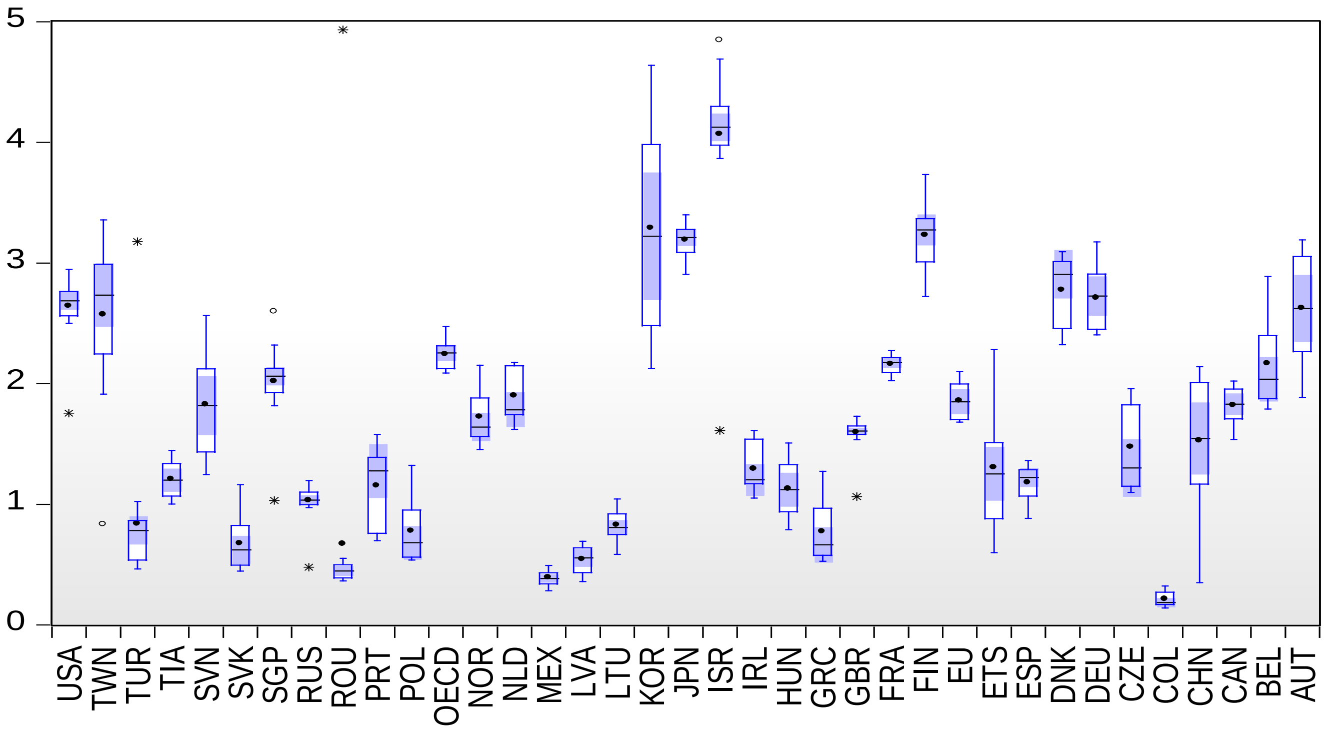

Fig. 2: Agriculture R&D expenditure in developed countries
Source: Author's own

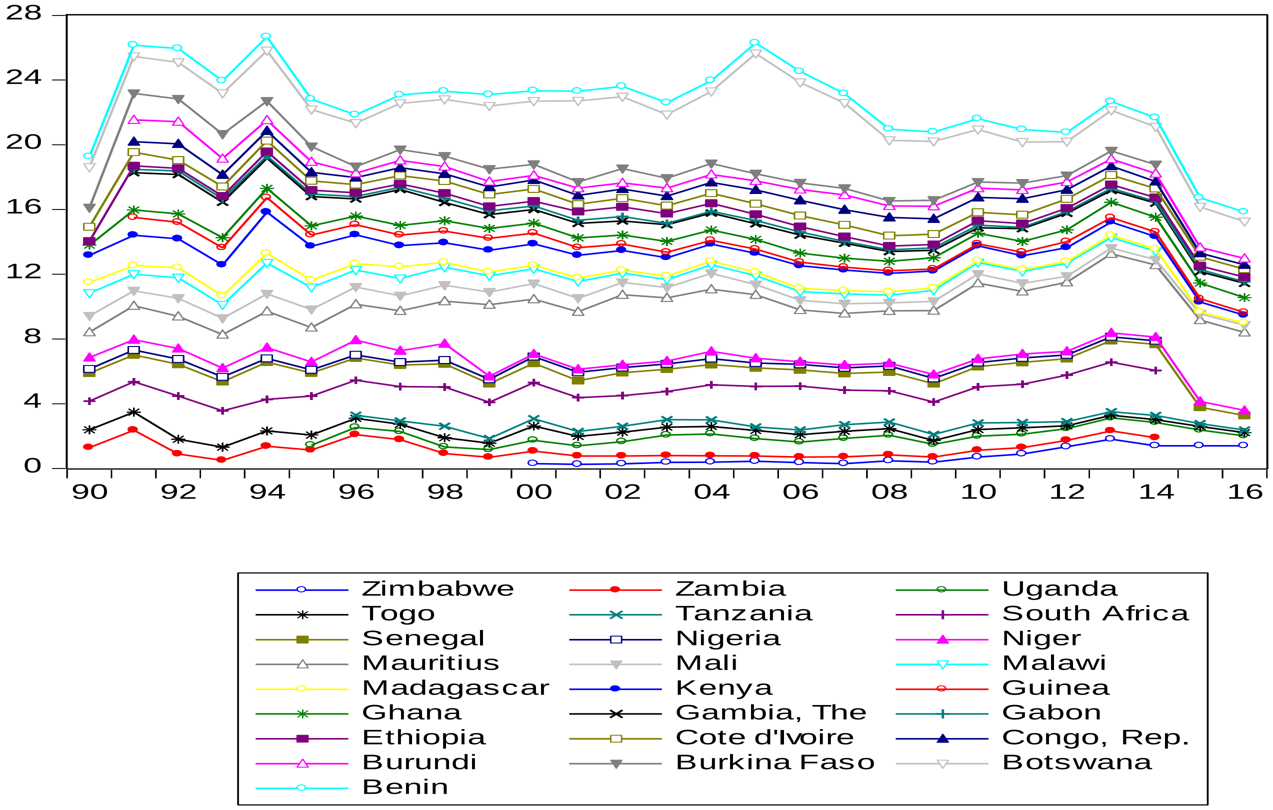

Fig. 3: Agriculture R&D Spending Lower-Income Countries

Source: Author's own