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ECONOMIC IMPACT OF AGRICULTURAL INNOVATION: A LITERATURE REVIEW AND THE CONTRIBUTION OF THE PROSMALLAGRIMED PRIMA PROJECT

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Abstract

With the substantial water scarcity and recurrent food insecurity in Northern Africa's low-income and arid and semi-arid regions, there has been a continuing interest in the adoption of new technologies and its influence on productivity. In this context, the *ProSmallAgriMed* project funded in the frame of the *Partnership for Research and Innovation in the Mediterranean Area - PRIMA*, aims at improving the agronomic practices of North African small farmers by promoting the rational use of beneficial soil microbiota and their positive effects on productivity of intercropped perennial (cactus-pear) and short-term (field crops and winter-grown vegetables) species, as well as to support synergistic cooperation between farmers and the food-value chain. This article examines the economic literature on technology adoption in agriculture and its effects in terms of productivity and welfare, in order to identify similar results, inadequacies, and key outstanding challenges, as well as to offer an overview of the topic.

Keywords: agriculture innovation, cactus pear, conservation agriculture, impact evaluation, literature review.

JEL classification: D24, I32, L66, Q01, Q12, Q16, Q24, Q25.

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1. Introduction

This paper offers a review of the most recent literature in the field of agriculture economics and namely of contributions concerning the assessment of the impact of agricultural innovations on social welfare and economic growth. We do so in reference to the *ProSmallAgriMed* (*Promoting soil fertility, yield and income in smallholder agriculture of semiarid and arid Mediterranean regions by management of beneficial soil microbiota, conservation agriculture and intercropping*) project, whose outcomes are expected to contribute to increasing farmer incomes, boosting economic activities, reaching higher social equity and a healthier environment for rural populations in arid and semiarid areas. The ProSmallAgriMed project is promoted by the Partnership for Research and Innovation in the Mediterranean Area (PRIMA) Foundation and carried on by a consortium of 11 units, distributed over 5 different countries, and led by an Italian one[5].
The project aims at improving North African small farmers' agronomic practices through the promotion of the rational use of beneficial soil microbiota and their positive effects on productivity of inter-cropped perennial and short-term species. The perennial species concerned by the project are cactus-pear and the short-term species are field crops and winter-grown vegetables. The cultivation of the cactus-pear, also known as prickly-pear, *Opuntia ficus-indica* or *Opuntia robusta*, spans thousands of years, since its beginnings and development are intimately related to those of the ancient Mesoamerican civilizations, particularly the Aztec culture (Kumar et al., 2018), that have first cultivated these succulent plants, according to archaeological evidence (Pimienta-Barrios, 1994). After being brought from Mexico to Spain, *O. ficus-indica* has quickly expanded throughout the Mediterranean basin (Barbera et al., 1992). Due to its capacity to flourish even in a water shortage and its significant nutritional benefits, *O. ficus-indica* demonstrates to be a plant of fundamental importance for agriculture and food in these desert places.[6] Indeed, it has proven to be a rather fruitful crop, since many of its parts can be used for different purposes; the most prized food resource is the fruit, which can be consumed fresh as well as used to make juices, liqueurs, jams (called *mustard* in the Italian region of Sicily), jellies, sweeteners, and more. The seeds can also be used for the extraction of the oil, a highly regarded cosmetic ingredient, because of its antioxidant, antimicrobial and hydrating properties (Alqurashi et al., 2022). Moreover, the blades, or more precisely the "*cladodes*," can also be consumed fresh, pickled, candied, and in the form of jam. They're also utilized as animal feed. Finally, a flour made from fruit peels can be as an ingredient in the preparation of baked goods (Bouazizi et al., 2020).
Cactus-growing countries are linked to a sizable portion of the world's arid and semi-arid regions, as the Northern Africa ones, and people living in these habitats look for plant species that can flourish there and offer resources like food and building materials (Kumar et al., 2018). The sustainable use of water resources is frequently a prerequisite for these regions' economic development: for instance, the lack of water resources continues to be a significant constraint on the agriculture in Tunisia (Foltz, 2003) and Algeria (Rouabhi, Mekhlouf, et al., 2016). In this context, *O. ficus-indica* is an intriguing crop choice for farmers in hard and desert locations, since it may guard against soil erosion and water loss (Alary et al., 2007). Therefore, the adoption of farming innovations, aimed at boosting the efficiency of water use and promoting soil conservation and fertility in arid and semiarid climates, is a relevant lever of economic growth not only in relation to the cultivation of *O. ficus-indica* but, more generally, in circumstances characterized by similar environmental and socio-economic conditions. In particular, innovations related to the so-called Conservation Agriculture (CA), like the ones proposed by the *ProSmallAgriMed* project, may be a sustainable alternative to intensive conventional agriculture, for the ability to limit, arrest or revert a number of problems such as soil erosion, soil organic matter decline, and excessive pesticide and fuel use (Azeiez, 2020; Kassam et al., 2012; Wall, 2007). Indeed, the scientific literature has shown that CA may increase productivity and, ultimately,

[5] http://www.primaprosmallagrimed.ovh
[6] Cactus pear is an aridity-resistant plant that requires temperatures above 6 °C for an optimal development.

augment crop output in arid Mediterranean regions (Chalak et al., 2017; Kassam et al., 2012), through the creation of new inventions, technology transfer, and capacity building (Jovanovic et al., 2020), that may help supporting smallholder farmers and rural communities' food security.
The literature in agricultural economics and economic development has thoroughly explored the impact of new agricultural technologies and innovations in terms of both direct and indirect effects, also considering technology combinations and the associated (direct and indirect) impact beyond the household level. However, evaluating the impact of innovations and technology adoption in a *causal way* requires controlling for potential selection bias and unobserved heterogeneity which in turn entails collecting appropriate data on socio-economic and agricultural variables and employ them in suitable methodologies.
The rest of the work is organised as follows. Section 2 describes the economic use of the cactus-pear, while Section 3 provides a review of the most recent economic literature on the adoption of innovation in agriculture. For each paper, we will highlight the methodology employed and the data used for the empirical investigation, as well as the implications in terms of economic policy. Section 4 describes the *ProSmallAgriMed* project and the challenges linked to the economic evaluation of its impact. Section 5 concludes.

2. Economic valorisation of cactus-pear industrial processing

The industrial processing of cactus-pear holds significant economic importance in arid and semi-arid regions around the globe. These areas are typically regarded as unsuitable environment for conventional crop production, due to the scarcity of water and the substantial amounts of additional nutrients required (Louhaichi et al., 2022). However, cactus pear thrives in such conditions, which makes it a promising alternative for local farmers and industries as nutrient food and input (Novoa et al., 2014)[7]: indeed, cactus pear yields sweet, nutrient-dense fruits that are edible; moreover, in arid and semi-arid areas, cactus cladodes are widely employed as a cheap supply of nutrients and water for animals, especially during severe droughts.
The key aspects concerning the economic importance of industrial processing based on cactus-pear fruits and cladodes may be found in the in following domains:

- *Food and beverages*: Cactus-pear fruits are high in crude protein, fibre, lipids, minerals, and carbohydrates but high in water, sugar, and calcium (Ben Salem et al., 1996; Abidi et al., 2009; El-Hawary et al., 2020). Thanks to their unique flavour profiles and potential health benefits, they can be processed into various food and beverage products such as juices, jams, jellies, candies, syrups, and alcoholic beverages, whose market demand represents an economic opportunity for growers, processors, and manufacturers.

- *Dietary supplements*: Cactus-pear products contain useful nutrients for regulating blood sugar levels, reducing cholesterol, and providing dietary fibre (Feugang et al., 2006). Extracts from the plant are used to produce dietary supplements such as capsules, powders, and extracts that cater to the growing demand for natural and functional health products. This segment presents promising economic prospects for dietary supplement manufacturers and pharmaceutical companies.

- *Cosmetics and personal care*: Cactus-pear oil extracted from the seeds of the fruit has gained popularity in the cosmetics industry for its nourishing properties (Andreu-Coll et al., 2020). It is rich in vitamin E and essential fatty acids, making it beneficial for skincare and haircare. Cactus-pear-based cosmetics, including moisturizers, serums, shampoos, and conditioners, represent a flourishing market niche especially for small cosmetic companies willing to create innovative products or to start a new brand.

[7] This plant belongs to the *Cactaceae* family and has a high water-use efficiency due to its *crassulacean acid metabolism* (CAM) photosynthetic pathway, making it ideal for arid-land production systems (Louhaichi et al., 2017, 2022).

- *Animal feed*: Cactus-pear pads, also known as *nopalitos*, can be processed into animal feed for livestock, including cattle, goats, and sheep (Abidi et al., 2009). Consequently, the cultivation and processing of cactus-pear generate a cost-effective alternative to traditional animal feed sources and, as such, an economic advantage for farmers and feed producers.

- *Pharmaceuticals*: Cactus-pear contains bioactive compounds such as betalains, flavonoids, and polysaccharide that have potential pharmaceutical applications for their antioxidant, anti-inflammatory, and anticancer properties. Pharmaceutical companies may explore the extraction and purification of these compounds for the development of new drugs (Feugang et al., 2006).

- *Sustainable agriculture and income generation*: Cactus-pear cultivation and processing have a positive impact on sustainable agriculture practices (Kumar et al., 2018). Being highly a resilient plant, apt to thrive in arid and semi-arid regions with minimal water requirements, its cultivation can contribute to soil conservation and erosion control. Additionally, the cultivation and processing of cactus-pear can generate income and employment opportunities, particularly in regions where suitable agricultural options are limited.

Overall, the industrial processing of cactus-pear provides diverse economic opportunities across various sectors, including food and beverages, dietary supplements, cosmetics, animal feed, pharmaceuticals, and sustainable agriculture. The wide range of products derived from cactus-pear contributes to regional economic growth, job creation, and the utilization of a natural resource that offers unique qualities and benefits.

3. The economic impact of innovative technology adoption in agriculture: a literature review

Agriculture is a dynamic and complex sector that is constantly evolving. The adoption of innovations is a critical component of this evolution, as it allows farmers to improve their productivity, efficiency, and profitability. However, the adoption of innovations is not always a straightforward process, and there are many factors that can influence whether or not farmers decide to adopt new technologies. One of the most important is the availability of information. Farmers need to be aware of new technologies and how they can benefit their operations before they can adopt them. Access to information can be a challenge in rural areas, where farmers may not have access to the internet or other sources of information. Another important factor is the cost of adopting new technologies. Farmers may be reluctant to invest in new equipment or technologies if they are not confident that the benefits will outweigh the costs. In addition, there may be a lack of financing options available to farmers, which can further limit their ability to adopt new innovations. Social and cultural factors can also play a role in the adoption of innovations in agriculture. Farmers may be more likely to adopt new technologies if they are widely accepted by their peers or if they fit with their cultural or social values. On the other hand, farmers may be hesitant to adopt new technologies that are seen as threatening to traditional farming practices or cultural norms.

There are many different types of innovations that can be adopted in agriculture. One among them is precision agriculture, which involves using technology to optimize farming practices. This can include using sensors and other technologies to monitor soil moisture, temperature, and other factors, as well as using GPS and other tools to improve the precision of planting, fertilizing, and harvesting. Another important area of innovation is biotechnology, which involves using genetic engineering and other techniques to develop crops that are more resistant to pests and disease, or that have other desirable traits such as higher yields or improved nutritional content. However, biotechnology can also be controversial, with concerns about the safety and environmental impact of genetically modified crops. Finally, there is a growing interest in sustainable agriculture practices, which aim to minimize the environmental impact of farming while also improving yields and profitability. This can include practices such as conservation tillage, cover cropping, and integrated pest management.

Agriculture innovations have had a profound impact on human civilization, particularly in the areas of food production and distribution. Here are some of the most important scientific empirical papers on the impact of agriculture innovations. Each study provides valuable insights into the ways in which agricultural innovations can improve productivity, increase food security, and reduce poverty in developing countries.

Takahashi et al. (2020) provide a comprehensive review of the recent literature on technology adoption, impact on productivity, and extension in agriculture in developing countries, examining a wide range of studies that focus on different types of agricultural technologies, crop varieties, irrigation systems, and farm machinery, as well as different methods of technology dissemination, such as extension services, farmer field schools, and social networks. The paper finds that the adoption of technology is influenced by a variety of factors such as farmers' socioeconomic characteristics, access to credit and markets, and institutional support. Furthermore, it highlights the role of government policies in promoting technology adoption and extension services: in particular, policies are needed to support research for the development of appropriate technologies, to improve the access to credit and markets and to promote the development of rural infrastructure.

Likewise, Wossen, Alene, Feleke, Rabbi and Manyong (2019) provide a comprehensive analysis of the link between agricultural technology adoption and household welfare, with a focus on sub-Saharan Africa. The authors argue that while agricultural technology adoption has been widely promoted as a means of enhancing agricultural productivity and reducing poverty, empirical evidence on its impact on household welfare remains limited and inconclusive. In particular, the authors highlight the need for rigorous empirical analysis that takes into account the potential endogeneity of technology adoption and the complex nature of household welfare.

The concern about welfare had previously been addressed by Lence and Hayes Dermot (2005), who explore the market and welfare impact of genetically modified (GM) crops and discuss the benefits of the latter, such as increased yields, reduced use of pesticides, and improved resistance to pests and diseases. These benefits can lead to lower costs for farmers and higher profits, as well as increased food production to meet the demands of a growing global population. However, the paper also discusses the potential drawbacks of GM crops, such as concerns over their safety and the potentially negative effects on biodiversity. The authors note that these concerns can lead to regulations limiting the adoption of GM crops, with substantial economic implications for farmers and consumers. Overall, the paper concludes that the market and welfare impact of GM crops are complex and depend on a variety of factors, including the specific traits of the GM crops and the regulatory environment in which they are grown. The authors suggest that a balanced approach to GM crop adoption, that takes into account both the potential benefits and risks, is needed, to ensure sustainable agricultural development.

By focusing on poverty reduction, Mendola (2007) investigates the impact of agricultural technology adoption in rural Bangladesh through propensity-score matching analysis, and find that farmers who adopted modern agricultural technologies, such as improved seeds, fertilizers, and irrigation, experienced higher agricultural productivity, income growth, and poverty reduction than non-adopters. Moreover, the study reveals that the impact of technology adoption on poverty reduction is stronger for smaller farmers and landless households, who are more likely to be poor. These findings suggest that agricultural technology adoption can be an effective strategy for poverty reduction in rural areas, particularly for smallholders and landless farmers. Likewise, the paper by Alene et al. (2009), leveraging on an economic surplus analysis, examines the economic and poverty impact of maize research in West and Central Africa, specifically focusing on the adoption of improved maize varieties. The authors conduct a survey of maize farmers in eight countries in the region, collecting data on the adoption of improved maize varieties, yields, and household characteristics. They show that the adoption of improved maize varieties has a positive impact on both farmers' income (with a 22% to 33% increase) and poverty levels. The authors note that these results vary somewhat across different countries in the region, with some countries seeing larger impacts than others. However, overall, the results suggest that investments in maize research in West and Central Africa have been effective in improving the livelihoods of smallholder farmers in the region, which is a promising conclusion for research on the economic impact of innovation in agriculture.

Also Kassie et al. (2011) and Zeng et al. (2015) focus on poverty reductions attainable through innovations in agriculture. Specifically, the former examines the impact of agricultural technologies on crop (namely, maize) income and poverty alleviation in Uganda. By leveraging on household survey data and a propensity score matching approach, the authors examine the factors that influence farmers' decisions to adopt these varieties, including access to credit, extension services, and social networks, and argue that the adoption of improved maize varieties has a significant positive impact on farmers' crop income, with adopters earning significantly more than non-adopters. The study also finds that the adoption of improved maize varieties reduces the probability of being in poverty by about 7-9%.
Zeng et al. (2015) analyse instead the impact of improved maize varieties on poverty in rural Ethiopia; they also examine the factors that influence farmers' decisions to adopt these varieties, including access to credit, extension services, and social networks. The authors, leveraging on cross-sectional household survey data, suggest that the adoption of improved maize varieties have led to a 0.8–1.3 percentage drop of poverty headcount ratio and relative reductions of poverty depth and severity; such impact is larger for female-headed households and households with smaller landholdings. As a consequence, policies aimed at improving access to credit and extension services could help promoting the adoption of improved maize varieties among these groups. Similar results are reported by Manda et al. (2019), Wossen et al. (2019) and Tufa et al. (2019), who describe the impact of adopting improved crops varieties and agronomic practices in African countries in terms of poverty-reducing effects, improved soil fertility and reduced use of fertilizers, which has positive environmental implications. The authors agree that these effects are highest among female-headed households and households with low initial levels of asset ownership.
Innovations aimed at improving crop resistance to pests also play a key role in improving crop yields and reducing pesticide use, with obvious health benefits and cost savings. Moyo et al. (2007) study the problem in Uganda, where peanut viruses have had a devastating impact on peanut yields and hence on the livelihoods of small-scale farmers. The authors find that the adoption of the new virus-resistant varieties results in a significant increase in peanut yields and household income and in a reduction in poverty among small-scale farmers. Similarly, Krishna and Qaim (2008) examine the potential impact of insect-resistant *Bacillus Thuringiensis* (BT) eggplant cultivation in India, on farmers' health and economic surplus, leveraging on a farm-level survey and economic surplus models. Their analysis suggests that BT eggplant has the potential to generate significant economic surplus gains (ranging from 27% to 52%) and to reduce the use of pesticide, which in turn can lead to a reduction in pesticide-related health problems, such as pesticide poisoning. However, the authors also caution that the success of BT eggplant cultivation will depend on various factors such as the availability of seeds, regulatory policies, and access to markets.
More recently, Midingoy et al. (2019) examine instead the impact of adopting integrated pest management (IPM) practices on farmer welfare and the environment in Kenya. By using a combination of survey data and environmental monitoring data, the authors find that farmers who adopt IPM practices achieve yields that are, on average, 33% higher than those of farmers' who do not adopt IPM practices, while also using 78% less pesticide. They also find that the adoption of IPM practices has a positive impact on farmer income, with IPM adopters earning, on average, 45% more than non-adopters. Additionally, the adoption of IPM practices is associated with a significant improvement in environmental quality, as measured by the reduction in pesticide residues in soil and water samples. The paper highlights the importance of promoting the adoption of IPM practices as a means of improving farmer welfare and reducing the environmental impact of pesticide use. Promotion may come from policies and programs that provide information and training on IPM practices as well as support for the development and dissemination of IPM technologies.
Very recently, Olagunju et al. (2020) evaluate the distributional impact of drought-tolerant maize varieties (DTMVs) on productivity and welfare outcomes among smallholder farmers in Nigeria. They do so by leveraging on a panel dataset of 1,200 households, collected over three agricultural seasons. The authors show that DTMVs have a positive impact on maize yield and income, especially

for households in the lower quantiles of the distribution. Moreover, DTMVs have a significant 10% poverty-reducing effect on the poorest households.

The number of empirical works on the economic impact of technology adoption and innovation in agriculture has constantly grown during the last five years. The paper by Kassie et al. (2018) evaluates the economic impact of improved maize production technologies, i.e. improved maize varieties, integrated soil fertility management (ISFM) and post-harvest management (PHM) practices, in Ethiopia, at both farm and market level, by leveraging on panel data from maize-producing households. The authors find that the adoption of these innovations significantly increase maize yields (by a minimum of 19% to a maximum of 32%) and income for farmers (with a 23% to 39% increment). At market level, the adoption of improved maize varieties has a significant positive impact on maize prices, suggesting the potential to not only increase incomes for farmers but also benefit other actors in the maize value chain, such as traders and processors. It follows that economic policies aimed at facilitating the access to these resources could help increasing the adoption of improved maize production technologies and further promote the agricultural development in the country. In another work, Kassie, Stage et al. (2018) evaluate the economic and social impact of the push-pull farming systems (i.e. combinations of intercropping, trap crops, and the use of insect pheromones) to control pests and improve crop yields. Authors rely on a randomized control trial that was conducted in Western Kenya (where maize is the main staple crop) and survey data from 930 households: they estimate that the adoption of the push-pull system increases household income by 44% and reduces the incidence of food insecurity by 50%. Moreover, the authors highlight a positive impact at social level, such as reduced child labour (by 9.3%) and increased women's empowerment (by 11.5%). Results show the importance of promoting the adoption of the push-pull system as a mean of improving economic and social welfare in rural communities in Kenya and other developing countries. The promotion may take place through development and dissemination of push-pull technology, support for access to credit, extension services, markets.

Multiple agricultural technologies are analysed also by Khonje et al. (2018), who analyses on the adoption of improved maize varieties, inorganic fertilizers, and herbicides in eastern Zambia. The authors find that the adoption of improved maize varieties and inorganic fertilizers is associated with a significant increase in per capita consumption expenditure, while the adoption of herbicides has a smaller but still positive impact. In addition to confirming that policies that improve access to credit and extension services could help promote technology adoption and ameliorate household welfare, they highlight the importance of considering the joint adoption of multiple technologies in agricultural development programs, as the impact of individual technologies can be influenced by complementary inputs and practices. The results also suggest that the welfare impact of technology adoption can vary across different technologies and contexts. Further research is needed to understand the mechanisms behind this result and to design effective policies and programs that can promote technology adoption and improve household welfare.

Differently from previous papers on the field, Wossen, Alene et al. (2019) present an empirical analysis using data from five African countries (Ethiopia, Malawi, Nigeria, Tanzania, and Uganda), suggesting that agricultural technology adoption has a positive impact on household welfare, although the magnitude of the effect varies across countries, technologies, and welfare indicators. The authors also find evidence of heterogeneity in the impact of technology adoption, with the poorest households and female-headed households benefiting less from technology adoption than other households. Similar results can be found also in Biru et al. (2020), who argue that that the adoption of agricultural technologies has a significant poverty-reducing impact on smallholder farmers in Ethiopia. Specifically, the authors estimate that the adoption of improved maize and wheat varieties, irrigation, and chemical fertilizers reduces the probability of being poor by 7.8, 6.5, and 5.1 percentage points, respectively.

Still on the Ethiopian side, Marenya et al. (2020) scrutinize the adoption and impact of sustainable intensification practices among smallholder maize farmers, finding that improved seed varieties, fertilizer use, and soil and water conservation practices, have a positive impact on maize yields and farm income. However, the authors note that the impact of sustainable intensification practices varies depending on the level of rainfall and unobserved heterogeneity, since the impact is higher under high rainfall conditions and for households with higher levels of education and access to credit.

Geffersa et al. (2022) also scrutinize the impact of improved maize adoption on farm household welfare in rural Ethiopia, and the likelihood of adoption. Paper's findings suggest that households that adopted improved maize varieties have higher income and are less likely to experience food shortages compared to households that did not adopt it. In addition, the study shows that the impact of improved maize adoption on income is larger for households with better access to credit, land, and extension services. The same factors (extension services, availability of credit, and market access) also affect the likelihood to adopt improved maize.

For the same country, Ethiopia, but concerning different technologies, namely climate-smart agricultural (CSA) technologies, Habtewold (2021) suggests that CSA technology adopters are 14% less likely to be in multidimensional poverty compared to non-adopters. By relying on household survey data, the authors find that the poverty-reducing impact of CSA technology adoption is highest among female-headed households and households with low initial levels of asset ownership. This suggests that CSA technologies have the potential to reduce gender and asset-based inequalities. Similar results can be found in Tesfaye et al. (2021), who confirms that innovation adopters in Ethiopia have significantly higher household income and expenditure compared to non-adopters. They also find that the innovation has a significant and positive impact on reducing the poverty incidence, depth, and severity. The study identifies several pathways through which technology adoption leads to poverty reduction, including increased productivity and income from agricultural activities, improved natural resource management, enhanced access to market opportunities, and increased resilience to climate shocks and stresses.

Antonelli et al. (2022) analyse instead the role of diversification of crop and of income-generating activities in rural adaptation to climate variability and change in Uganda[8]. The authors use panel data collected from smallholder farmers over four years (2012-2015) and show that crop diversification has a positive and significant effect on household income, with each additional crop increasing income by about 6%. However, the diversification of income-generating activities does not have a significant impact on household income. Instead, diversification of both crop and income-generating activities have a positive and significant effect on household food security and poverty reduction, with each additional crop (income source) reducing the likelihood of food insecurity (of being poor) by about 5% (6%). The authors conclude that promoting crop diversification can be an effective strategy for improving household income, food security, and reducing poverty in rural areas of Uganda. However, policies that encourage the diversification of income-generating activities may not have significant effects on household welfare, depending on the specific context and characteristics of households, that must therefore be considered when designing policies to promote diversification for rural adaptation.

Still more recently, Kamara et al. (2022) analyse the impact of adopting improved soybean varieties on productivity and revenue among male and female-headed households in Nigeria by using a survey of 1,010 soybean farmers. The authors find that adoption of improved soybean varieties has a significant and positive impact on productivity and revenue among both male and female-headed households. However, the magnitude of the impact is higher for male-headed households, indicating

[8] A substantial body of research in development economics has made significant strides in advocating for income diversification as a strategy to manage climate change-related risks. This trend is exemplified in studies such as Loison (2016). The rationale behind this approach is that the growing exposure to adverse climate risks can be alleviated by assembling a diverse portfolio of income-generating activities, thereby reducing the expected losses. In this context, rural households are inclined to diversify their income streams, often branching out into commerce, manufacturing, or other non-crop production activities, as noted by Antonelli et al. (2022). Consequently, for farmers who rely primarily, or even exclusively, on a combination of rural assets including land, crops, livestock, and low-skilled family labor for income and sustenance, the decision to diversify their activities within such a volatile and weather-dependent environment becomes a crucial one.

a gender differential impact. The study identifies several factors that influence the adoption of improved soybean varieties, including access to credit, extension services, and market opportunities. The original contribution of the paper mainly consists in evidencing the importance of promoting gender equity in agricultural development programs and suggests that strategies that address the specific needs and constraints of female farmers could be effective in promoting their adoption of improved soybean varieties and improving their productivity and income.

Martey et al. (2022) assess the impact of *Striga*-resistant maize varieties and fertilizer use on maize yield and income in Ghana. The study used a panel data set of 600 maize farmers across three regions in Ghana for the 2016 and 2018 cropping seasons, showing that the adoption of such maize varieties and fertilizer use had a positive and significant impact on maize yield (with a 28% to 48% increase) and income (that increases by a minimum of 36% and a maximum of 60%). These findings emphasise the potential benefits of using integrated soil fertility management practices to address the challenges of soil degradation and low crop productivity in sub-Saharan Africa.

Finally, Oduniyi et al. (2022) examine the welfare impact of adopting conservation agriculture (CA) practices on smallholder maize farmers, based on a survey of 400 smallholder maize farmers in the KwaZulu-Natal province of South Africa. The study finds that smallholder maize farmers who adopted CA practices had on average 32% higher maize yields and 24% higher net farm income than non-adopters. Additionally, CA adoption led to improved food security and higher household consumption expenditure. The authors also acknowledge that access to credit and extension services are important drivers of CA adoption among smallholder maize farmers.

4. The ProSmallAgriMed project

ProSmallAgriMed (Promoting soil fertility, yield and income in smallholder agriculture of semiarid and arid Mediterranean regions by management of beneficial soil microbiota, conservation agriculture and intercropping) is a project part of the *Partnership for Research and Innovation in the Mediterranean Area* (*PRIMA*) Joint Programme. *PRIMA's* purpose is to generate creative solutions for enhancing the efficiency and sustainability of food productions and water quality/availability, in order to foster inclusive well-being and socioeconomic growth in the Mediterranean Region and contribute to the EU's climate change adaptation goals.[9] In particular, the project is strictly related to the "Section 2 Call 2020 - Thematic Area 2 - Farming systems: Redesign agro-livelihood systems to guarantee resilience", which addresses fundamental aspects of sustainable intensification by implementing conservation agriculture systems, supporting the effective use of water, and boosting cultivated biodiversity in space and time, with relevant implications for natural and agriculture-associated biodiversity in both water-limited and non-water-limited socio-agro-ecosystems.

Strictly following the proposed masterplan, the *ProSmallAgriMed* project "aims to promote the rational use of beneficial soil microbiota and to improve small farmer agronomic practices to enhance the productivity of inter-cropped perennial (cactus pear) and short-term species (field crops and vegetables)", as well as "to promote synergistic cooperation between farmers and the value chain" (Era Learn, 2020). The project's results are likely to increase the farmers' chances of improving yield, yield stability, profit, and profit stability both within and between cropping seasons, by protecting soil from diminished fertility and erosion, as well as enhancing both functional and total biodiversity. In particular, "the optimization of such practices in water-limited environments will contribute to food security by (1) enhancing carbon sequestration and ensuring soil fertility; (2) expanding land coverage in space and time, thus supporting soil conservation and water use efficiency; (3) improving yields for consumption as food, feed, or industrial transformation; (4) increasing the nutritional quality of crop products; and (5) guaranteeing water and soil quality by decreasing chemical inputs. Such goals will be pursued by stimulating smallholder associations by increasing their expert

[9] See https://www.era-learn.eu/network-information/networks/prima.

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knowledge and ability to interact each other and with various actors of the value chain, and by modulating new agronomic practices to be tested in real-life field conditions" (Era Learn, 2020).

The project stems from the need to promote the ability of small-scale farmers in arid and semi-arid Mediterranean areas to scale up the value chain with cropping systems that can combine sustainability and resilience. These fundamental objectives are being pursued also by studying the economics of their implementation and fostering the planting of beneficial microorganism production systems that can be reused on site or even used in other contexts. In fact, microorganisms from arid environments could play a crucial role in boosting yields in Mediterranean countries in the light of climate change. Conservation soil management also plays a key role in the project, since increasing the amount in organic matter while reducing or eliminating tillage will promote the soil's water holding capacity and reduce evaporation losses. This is critical for both boosting yield and profit in arid and semi-arid environments, as well as in relatively humid environments (such as Northern-Central Italy, Southern France, and some Spanish areas). By integrating new biotechnologies, mixed *inocula* formulations containing AMF (*arbuscular mycorrhizal fungi*) and PGPB (*plant growth-promoting bacteria*) with intercropping practices, the project sets out to ensure soil fertility, reducing carbon emissions, expanding land cover in space and time, with beneficial effects on soil conservation and water use efficiency.

For the project, a consortium of 11 units from five different countries (Algeria, France, Italy, Morocco and Tunisia) was created, including members of different kinds, namely academies, research institutions, enterprises and associations. The consortium composition is aimed at guaranteeing that basic and applied knowledge, instruction and training, technological transfer, dissemination, socio-economic benefits will be provided. In addition, the different geographical provenience will allow to test the proposed methodology under different environmental conditions. The economic evaluation of the benefits of the innovative technologies will be made by comparing production costs as well as expected revenues of traditional and new methods. This requires collecting information about the socio-economic conditions of farmers from the different countries involved in the projects, the technical data concerning current and innovative production technologies as well as the macroeconomic and environmental conditions in which the farmers operate. Causal inference methodologies require retrieving data referred to a time span covering both the pre-adoption and the post-adoption periods, which requires establishing a solid cooperation with farmer and the local cooperatives supporting them.

The process of know-how transfers from Europe to North African countries in the improvement of crop water efficiency and in the development and production of beneficial microbial *inocula* is intended to provide farmers with a competitive edge and result in high-quality goods. This transfer will also encourage the creation of start-ups in the Maghreb that specialize in the manufacturing of tailored, high-added-value *inocula* based on indigenous beneficial soil bacteria. The project's findings, in addition to potentially giving a model for the sustainable cultivation of various crops in both water-limited and non-water-limited socio-agro-ecosystems, are meant to increase the food and by-product production per unit area and time, to support the ecological and agro-ecological conditions of semiarid and arid areas (by means of a rationalization in the employment of chemical inputs, a reduction of soil erosion and water loss, and an increased resilience to climate change), to improve the socio-economic conditions of both farmers and countries hosting new enterprises, as well as the absorptive capacity of local smallholder farmers.

5. Conclusions

There is a vast empirical literature in agricultural economics analysing the impact of innovative technologies in agriculture and the factor influencing the likelihood of adopting it. Despite the recent rise in contributions focusing on the welfare and economic growth consequences of agricultural innovation in sub-Saharan countries, scholars agree that rigorous empirical analysis is needed to address the potential endogeneity of technology adoption and the complex nature of household welfare, since the evidence on the subject remains limited and inconclusive.

This paper responds to this appeal by offering a review of the most recent articles on the subjects and an overview of the *ProSmallAgriMed* PRIMA project, whose goals relate to the improvement of the socio-economic conditions of both farmers and countries adopting the technological innovation developed through the project itself. The project aims at providing a large-scale model for the use of beneficial microbiota and intercropping systems in the cultivation of intercropped perennial (cactus-pear) and short-term (field crops and winter-grown vegetables) species in semiarid and arid Mediterranean regions. By explicitly including, among its goals, the economic evaluation of benefits stemming from the innovative technologies developed through the project, *ProSmallAgriMed* aspires to offer both a state-of-the-art and an agenda for opening up avenues of research on the advantages, including the economic ones, of innovation in the production of crops in water-limited agro-ecosystems. As highlighted by the scientific literature on the impact of innovation in agricultural methodologies, the results of the project may inform policies that protect small farmers by supporting research for the development of appropriate technologies, improving farmers' access to credit and markets and promoting the development of rural infrastructure. Given the multifaceted nature of household welfare and potential endogeneity of technology adoption, more empirical research needs to be done to understand the impact of technology adoption on agricultural productivity, income, and poverty reduction.

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