Agricultural Water Management 299 (2024) 108838

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Water conservation and saving technologies for irrigation. A structured literature review of econometric studies on the determinants of adoption

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ARTICLE INFO

Handling Editor - Dr. B.E. Clothier

Keywords:
WCSTs adoption
Structured Literature Review
Irrigation technology
Water conservation
Innovation in agriculture

ABSTRACT

Water Conservation and Saving Technologies (WCSTs) can contribute to reduce the pressure on water resources from agricultural activities. A significant strand of literature on agricultural and innovation economics has explored the main drivers behind the adoption of WCSTs in agriculture, but due to the shortage of data most studies are based on survey analyses focusing on a specific case study. Therefore, results cannot be easily generalised. In this paper, we used a structured literature review (SRL) approach to systematise the original studies already published on the WCSTs adoption. Focusing on the econometric analysis used to estimate the main drivers of WCSTs adoption, our analysis started from an initial selection of 1027 studies, then after excluding book chapters, book, conference chapters and after checking abstracts and key-words we arrived to a final selection of 36 papers which have been deeply scrutinized with a structured analysis of their contents. Several findings have emerged from the analysis. The drivers of WCSTs adoption are various and heterogenous. We synthetized the main determinants into different categories: a) farm characteristics (land size, the presence of extension services, capital assets and internal organization within the farm; b) farmer characteristics (age, level of education, income); c) institutional environment (social networks, previous information on the technology, membership to farmer organizations, public fundings, access to credit, cost of water, access to groundwater, water constraint); d) geographic and climate characteristics (soil quality, drought, aridity).

1. Introduction

Water will be a crucial resource for sustaining the food systems in the next future due to an increasing global population (Alexandratos and Bruinsma, 2012). Moreover, the climatic variability involving more frequent, extreme, and adverse climate conditions may exacerbate water shortages and affect crop productions globally (Fischer et al., 2007). Agriculture is the economic sector which affects, the most, water resources being responsible for almost 70% of global freshwater withdrawals whose primary use is for intensive irrigation of crops which is characterized by low levels of efficiency (Pérez-Blanco et al., 2020).

So far, the research effort has been made to analyse how to increase water efficiency. Sustainable water management may indeed be pursued through various strategies such as reducing water demand, increasing water availability and improving water efficiency use[1] (Alcon et al., 2011). A recent strategy to increase water efficiency use consists in the adoption of water conservation and saving technologies (WCSTs) that may significantly contribute to reducing the impact of agricultural activity on water resources in a context of water scarcity and water endowment variability (Expósito and Berbel, 2019; Pérez-Blanco et al., 2020). WCSTs such as drip irrigation, sprinklers, low pressure micro-sprinkling, and sub-irrigation can optimize the application of water directly to plant roots, reducing water stress through a high frequency water application which decreases the difference between evapotranspiration and the plant extraction of water mitigating drought effects through continuous but reduced, water applications (Frenken

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[1] As underlined by Knox et al. (2012), the concept of efficient water use differs for scientists, regulators and farmers. For farmers, water efficiency is more related to the maximization of input economic productivity and not to water-saving practices as for scientists and regulators, except in the case of inadequate allocated resources.

https://doi.org/10.1016/j.agwat.2024.108838
Received 31 December 2022; Received in revised form 28 December 2023; Accepted 21 April 2024
Available online 23 May 2024

and Gillet, 2012; Pereira et al., 2002; Schuck et al., 2005). In terms of water efficiency use, the adoption of WCSTs compared to gravity irrigation (such as furrow and flooding) systems may reduce water losses increasing the rate of water consumed by plants (Taylor and Zilberman, 2017; Wheeler et al., 2010).

As a comprehensive survey of the relevant published works in water efficiency use is still missing, we aim to provide a structured literature review (SLR) of the empirical studies using econometric methods on only WCSTs adoption developed in the literature. Our contribution is designed to present a critical overview of the main determinants of irrigation technology adoption. The focus of the SLR is only on quantitative studies based on econometric methods. First, we collect several empirical papers on WCSTs adoption for sustainable irrigation. The focus is on the choice of farmers for implementing agricultural innovation. Farmers indeed decide to adopt a new technology considering their future expectations and productive needs, but their decisions are also influenced by many other factors, such as institutions, external information, weather, climate, and local conditions, as well as all interactions with the other farmers, that can directly or indirectly affect their perceptions on the future outcome of adoption.

Second, we provide the main findings obtained by applying the SRL approach to the more relevant empirical studies on irrigation technology innovation adoption i.e., WCSTs. In these recent years, an important literature has emerged on WCSTs drivers of adoption focusing principally on socio-economic and geographical factors influencing the adoption of this technology by farmers. These studies employed mainly econometric methodologies providing important empirical evidence on the main drivers of WCSTs adoption. This can be important in terms of efficient technology diffusion policies to incentivize water conservation techniques in the agricultural production. But, due to water data limitations, most of the empirical analysis are based on single sub-regional case studies from heterogenous areas with very case-related implications limiting the relevant information for policy makers or researchers.

However, the importance for the policy debate of the implementation of WCSTs is due to the fact that this new irrigation technology may ameliorate water productivity in terms of gross value added per cubic meter of water used which can indicate the capability to produce more value with less water (Expósito and Berbel, 2019). Nevertheless, it is worth to note that to gain in terms of water efficiency and related economic benefits from such innovative technologies, a high and widespread level of knowledge and technological experiences should be developed by farmers to adopt new irrigation technologies (Levidow et al., 2014).

The paper is developed as follows. In Section 2, the main theoretical background on technology adoption is introduced, while in Section 3, the review method on the empirical studies is explained. The results of the review are shown in Section 4 and discussed in Section 5. Finally, the paper ends with some concluding remarks.

2. WCSTs adoption for sustainable irrigation: theoretical background

The adoption of technologies in agriculture is a complex and dynamic decision process that in literature has been strictly linked to the expected utility theory framework (Stoneman and Battisti, 2010). According to this theory, farmers choose the level of productive inputs used (e.g. fertilizers, pesticides, energy and water) based on their expected future values. At the same time, they consider all the factors which may influence their expected utility such as a mix of profits, yields, labour use and risks (Feder et al., 1985; Fleischer et al., 2011). In doing so, they decide whether to adopt a specific innovation (linked to farming input use) if and only if the expected utility (higher return or lower risk) from the adoption is higher than the non-adoption state (Foster and Rosenzweig, 2010). The adoption decision of the farmer may be influenced by many factors linked directly to the technology to be adopted (e.g. level of the baseline technology, information availability, complexity of the new technology and adaptation costs, expected returns, variability in yields with the new technology, comparability of the new technology with other methods) and several actors (e.g. institutions, scientists, extension service, other farmers) which may affect the innovation adoption influencing the perception of risk and uncertainty (Geroski, 2000; Rogers, 1971; Stoneman, 2013; Turral et al., 2010). Other aspects influencing the adoption of a technological innovation in agriculture such as the level of education and the age of the farmer may influence the perception of risk or the propensity toward changes. The wealth of the farmer, the access to financial assets either from internal or external sources, or the availability of insurance schemes, may increase the capacity to bear risks and the chance of adopting a new technology.

Moreover, a growing literature shows that behavioural and social aspects are also relevant factors in influencing adoption decision in agriculture (Burton, 2004; Crudeli et al., 2022; Streletskaya et al., 2020). Those can be identified in: individual learning and learning from other peers (i.e., learning spillovers), social networks (e.g., imitation, knowledge sharing), social norms, phycological aspects, personal values and beliefs.

Since the 1960s, the literature on technology adoption in agriculture has reported on the factors influencing the decision to implement innovations (Jaffe et al., 2002), noting that the technology adoption and diffusion literature has focused on the agricultural determinants of innovation adoption, such as agroecological constraints, farmers' characteristics, soil features, seed supply constraints, risk preferences, or traditional values (Arslan et al., 2014; Koundouri et al., 2006). This topic has started to gain interest, especially in the works on developing countries (among others Feder et al., 1985; Neupane et al., 2002; Sheikh et al., 2003; Bandiera and Rasul 2006), where the main focus has been on the causes that determine the success or failure of agricultural innovations such as improved fertilizers, ploughing techniques, and pest control (Baidu-Forson, 1999; Feder and Umali, 1993; Somda et al., 2002).

A stream of the empirical literature relying on econometric methods has focused on irrigation technology adoption (Taylor and Zilberman, 2017). Among the seminal works, we may recall the analyses of Caswell and Zilberman (1985), Shresta and Gopalakrishnan (1993), and Green et al. (1996), which focus mainly on farm production features (such as crop type, field size, expected yields), geographical aspects (such as type of soil, slope) and water resource characteristics (such as water sources, water price and irrigated land size). Subsequently, Skaggs (2001), Moreno and Sunding (2005), Schuck et al. (2005) and Foltz (2003) introduce farmers' characteristics such as age, education, years of experience, in-farm and off-farm income, expectations of water availability, access to information and extension services. More recently, other studies have enlarged the initial framework by adding further interesting factors such as electricity costs (Namara et al., 2007; Singh et al., 2015; Wheeler et al., 2010), farming production risks (Koundouri et al., 2006), social factors—being part of farmers' organizations, the imitation of adopting WCSTs by other colleagues, social networks, etc.—(Alcon et al., 2011; Genius et al., 2014; Hunecke et al., 2017; Salazar and Rand, 2016) and mechanization levels within farms. The variables of financial aspects (Alcon et al., 2011), governmental incentives (Huang et al., 2017) and water use metering (Hunecke et al., 2017) have also been considered. All these abovementioned studies substantially agree in confirming that the main determinants of adoption are socioeconomic, technical, geographical, and productive factors, even though the results are sometimes contradictory.

Finally, further studies have focused on climatic variables influencing WCSTs adoption choice. Among the indicators used to capture these climate effects, we may recall evapotranspiration, rainfall, temperature (Huang et al., 2017; Negri and Brooks, 1990), frost-free days (Moreno and Sunding, 2005; Negri and Brooks, 1990) and drought aridity events (Genius et al., 2014; Knapp and Huang, 2017; Koundouri et al., 2006; Schuck et al., 2005). Moreover, Frisvold and Deva (2013) and Knapp and Huang (2017), which focus on climate and irrigation technology adoption, introduce climatic variables considering both different time spans and the variations and intensities of climatic events.

A classification in macro-categories of irrigation technology adoption drivers can be done following Neupane et al. (2002), Foltz (2003), Sheikh et al. (2003), Boahene et al. (1999) and Wisdom et al. (2014). Those authors provided various classification of irrigation technologies determinants which can be synthetized into main five classes of adoption drivers. Adoption drivers can be divided into observable or unobservable as they can be explicit or implicit and subjective with respect to the farmer's actions. Fig. 1 illustrates the five classes of characteristics which are:

1. *Farm organisational characteristics*, current practice adopted, demographic factors, past experiences, tendency to be innovators, land tenure, family size, type of crop, connections (direct or indirect) with experts and innovation developers, norms and values, culture, size, and structure of the farm.
2. *Farmer personal characteristics*, which influence absorptive capacity, awareness, knowledge, skills, competence, social position gender, age, education, experience, income, external activity, risk perceived and expected returns.
3. *Institutional environment*, which depends on governmental regulations, incentives from the governments, social norms and social networks, credit availability.
4. *Geographic and Climate characteristics,* which depend on seasonal temperature, rainfall, evapotranspiration, aridity, soil type, soil quality, source of water used, altitude and slope.
5. *Innovation characteristics*, which depend on complexity, price, relative advantage, observability, cost-efficacy, feasibility, ease in the implementation, compatibility with existing practice, facilitating procedures (training courses), fitting with local norms and values and intrinsic risks.

3. Literature review on WCSTs adoption empirical studies

3.1. Method employed for the literature review

In this paper we applied a SLR approach (Dumay and Cai, 2014; Massaro et al., 2015; Mishra et al., 2017; Secundo et al., 2020): the method facilitates identifying the main trends, findings, and gaps in WCSTs adoption studies since their first appearance in the scientific debate. The SLR method analyses the body of academic literature to develop critical insights and reflections as a basis for understanding research question and knowledge gaps (Massaro et al., 2016; Mishra et al., 2017; Petticrew, 2001). The main difference from other literature review methods (rapid review, research synthesis, or systematic review) is that the SLR approach is not 'just comprehensive' but has specific questions to be answered with stringent inclusion criteria.

Following Massaro et al. (2015) and Secundo et al. (2020), to perform a robust SLR the analysis must be as much transparent and replicable as possible following some rigorous steps. Firstly, the review protocol must declare the review question, the analytical methods, the coding framework, the type of studies to analyse, and how these studies will be appraised and synthesized. Massaro et al. (2016) stress the importance of setting a research protocol to give a logical and structured form to the approach of the analysis and appropriate research questions to start the analysis. In our study, we identified four main research questions which are:

RQ1. How has the WCSTs adoption literature evolved along time?

RQ2. What are the main determinants of adoptions identified in the literature?

RQ3. What are the implications for policy makers and practitioners?

RQ4. What are the potential research implications for further development of the literature?

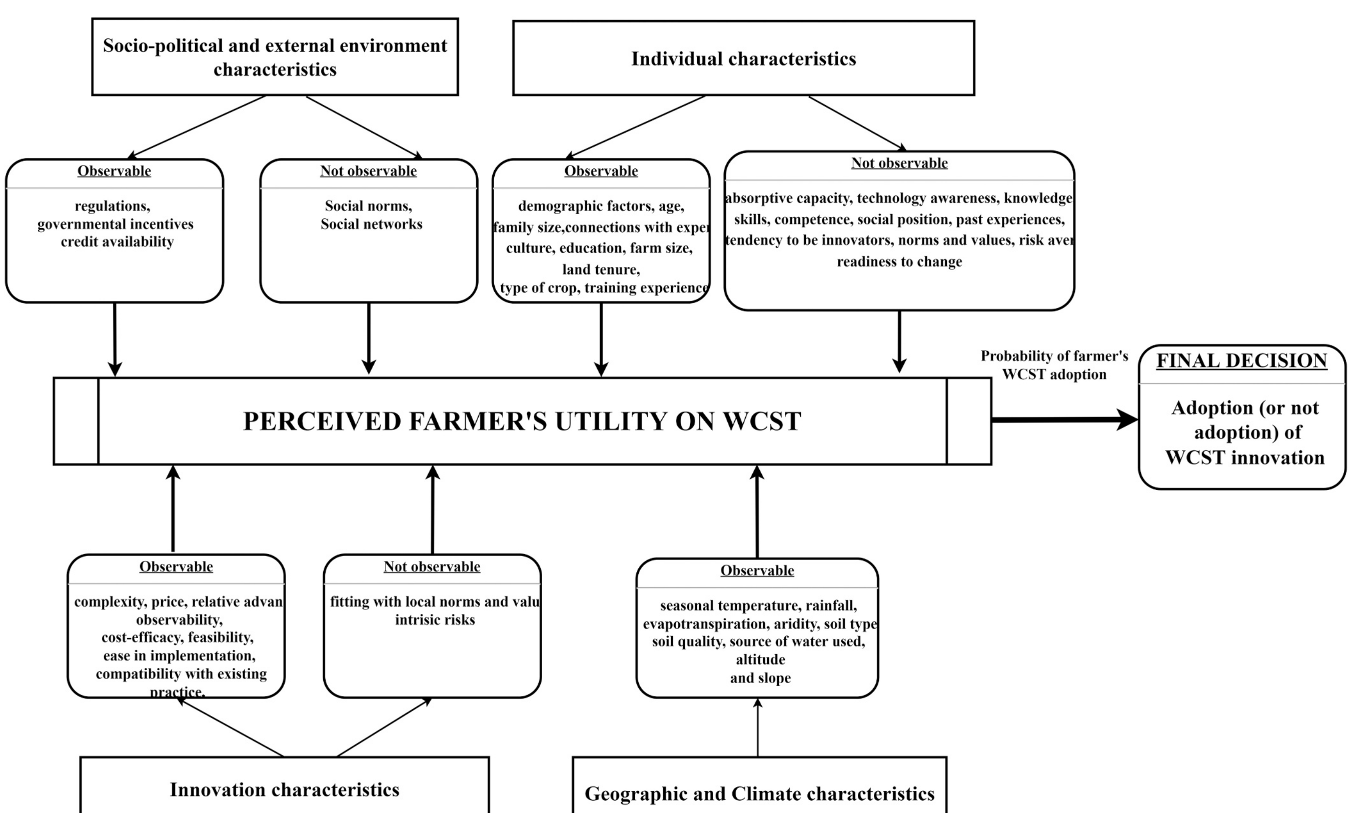

Fig. 1. Observable and unobservable characteristics which influence the farmer's decision of WCSTs adoption. Source: Authors' own elaboration.

RQ1 refers to the current state of the art of the literature, considering the temporal evolution and geographical distribution of the main empirical works on the adoption of WCSTs determinants, their method, and empirical approaches. RQ2 focuses on the main findings in the literature, in our case, as it seems, most of the published research describes single case studies, so it will be necessary to supplement the findings. RQ3 refers to the potential implications for policy makers and practitioners in relations to the main evidence provided in the literature on the WCSTs adoption determinants. RQ4 refers to the research gaps and potential development that emerge from the analysis of the body of literature on the field.

In the second stage, once research questions are stated, the SLR analysis follows Mishra et al. (2017)' suggestions, namely: a) the selection of a scientific paper database, b) the collection of papers selected on the basis of specific keywords, c) the elimination of duplicates and non-peer reviewed literature (e.g., book chapters), d) the selection of papers, and, finally, f) the analysis of the findings and research issues.

We have chosen the Scopus database because this database has the widest coverage of scientific papers on the web (Mishra et al., 2017; Secundo et al., 2020; Waltman, 2016). Our review has narrowed WCSTs technologies to drip, micro, sprinkler, or sub-irrigation systems, all of which increase the water efficiency use. We have excluded others water conservation techniques (e.g., mulching, rainfall storage). This choice was made for the sake of precision in our analysis as suggested by Massaro (2016) and Petticrew (2001) who recommend focusing on specific targeted topics from the beginning.

As far as methodologies are concerned, we have selected empirical works that use econometric methods either at the micro (using farm or farmers as statistical units) or 'meso' level (based on aggregated territorial area such as county, province, states). This selection allows the inclusion of research published in the fields of economics, environment, agronomy, and hydrology.

The focus on econometric methods implies that papers relying on simple descriptive statistical analysis of surveys or using qualitative methods of analysis (e.g., semi-structured interviews, observant participation, deep interviews) have been excluded as well as studies based on mathematical programming methods that do not use observed empirical data.

The coding framework of analysis has considered the following categories:

- Time distribution of publication,
- Geographical distribution of publications,
- Journal distribution of publications,
- Empirical methods adopted in the studies selected,
- Main findings of the publication in terms of determinants of WCSTs adoption.
- A critical analysis of the main determinants of WCSTs adoption identified in the literature review.

The working database of selected papers is build by selecting a series of search strings as "Water" AND "Conservation" OR "Saving" AND "Technology" AND "Adoption". As first result, we obtained 1027 papers from which 329 non-peer-reviewed papers (i.e., books chapters, conference papers, reports) were excluded. After a revision of keywords and abstracts, another group of 585 works have been excluded. The remaining 113 papers underwent a thorough review that resulted in a further exclusion of 77 papers as they were not focused on WCSTs in the strict sense of the term defined above, leaving to our final sample of 36 papers for content analysis. In Fig. 2, it is depicted the methods followed for the selection of papers. This final sample of papers has been used for a deep analysis on several aspects. Firstly, general information on the paper in terms of time of publication, area of study, irrigation technology considered and methodological approach have been analyzed. Then, the papers selected for the SLR have been deeply scrutinized to check and classify the main findings in order to compare and provide a systematic description of the empirical evidence found in the econometric literature on WCSTs adoption.

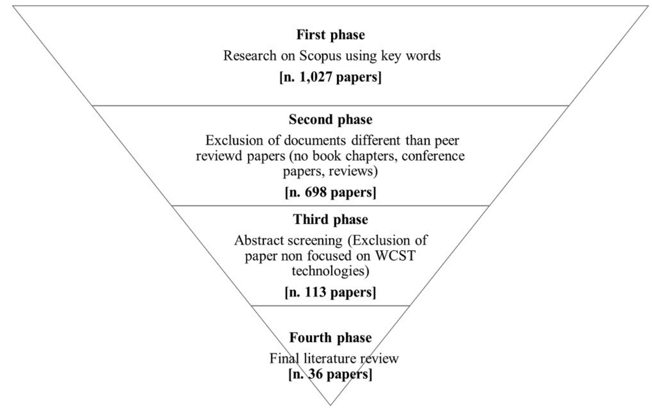

Fig. 2. Description of the phases of the paper selection for the SLR. Source: Authors' elaboration.

4. Main findings of the SLR

This section provides the main results from the SLR approach answering RQ1 in sub-Section 4.1 and RQ2 in sub-Section 4.2. Then main implications for policy makers and practitioners are discussed in sub-section 4.3, whereas further development of research is discussed in sub-Section 4.4.

4.1. Descriptive results

4.1.1. Geographical, time and journal distribution of the publications

Most papers considered in the SLR approach focus on specific sub-regional areas (i.e., counties, provinces, and regions) and only some have been developed at the national level. Most of the area covered suffered for droughts and structural water scarcity. The country with the highest number of studies is the United States of America (17), followed by China (6), and Chile, Greece, and India (2), other countries such as Spain, Israel and Gaza, Bulgaria, Tunisia, Canada, and Iran have only one study. Fig. 3 shows the geographical distribution of the papers considered in this study.

This highlights as the main geographical areas covered by the literature on WCSTs adoption were focused principally in high and middle income countries, whereas no studies were developed in low-middle income and developing countries. This might depend on the fact that the development of WCSTs in those countries is not widespread, while other types of water saving strategies not covered by our SLR are in place (e.g., rainfall storage, water saving traditional practices). Anyway, this seems to be a gap in the literature which could be filled with further studies since WCSTs may impressively help the improvement of agricultural productivity in developing countries.

Fig. 4 shows the evolution of papers starting from the year 1985 with the seminal paper of Caswell and Zilberman (1985). We must wait until 1990 to see other two significant studies, while numerous publications started to flourish in 2000's with an average of two papers per year with a slight increase of papers per year in the second decades of the new century. Even though, no more than three papers per year have been published on WCSTs determinants adoption since the first appearance of this topic in the literature. This highlights that, even if the econometric literature on WCSTs adoption started more than 30 years ago, the abundancy of publications is still low and this may depend on the difficulty in finding data on irrigation technology adoption as data on water and irrigation are very scarce.

Regarding journals of publications, the topic is of interest of many areas: agronomy, hydrology, water, and development studies. The major

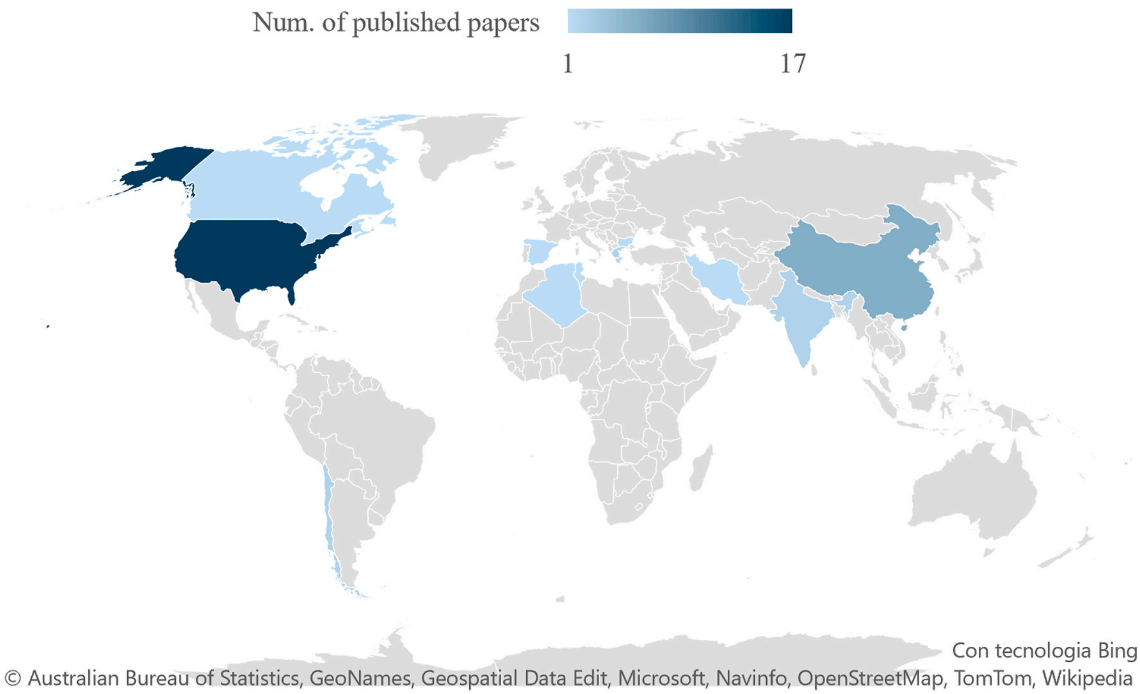

Fig. 3. Geographical distribution of the papers. Source: Authors' elaborations.

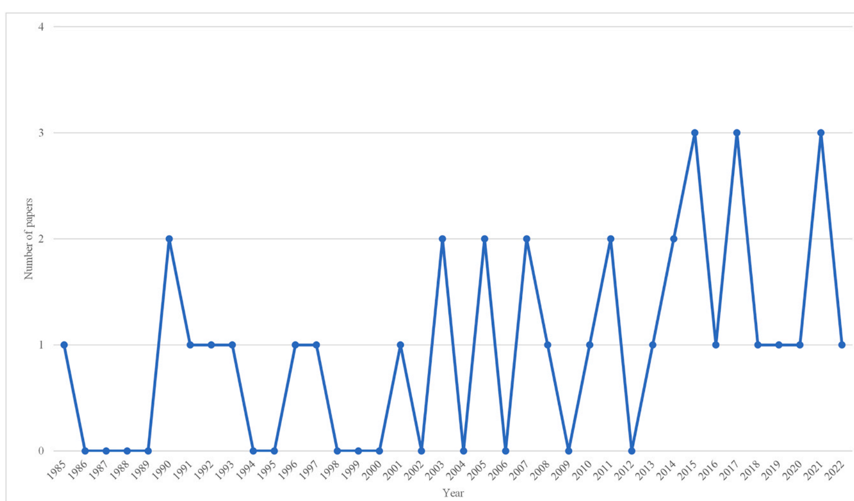

Fig. 4. Evolution of the papers along time. Source: Authors' elaborations.

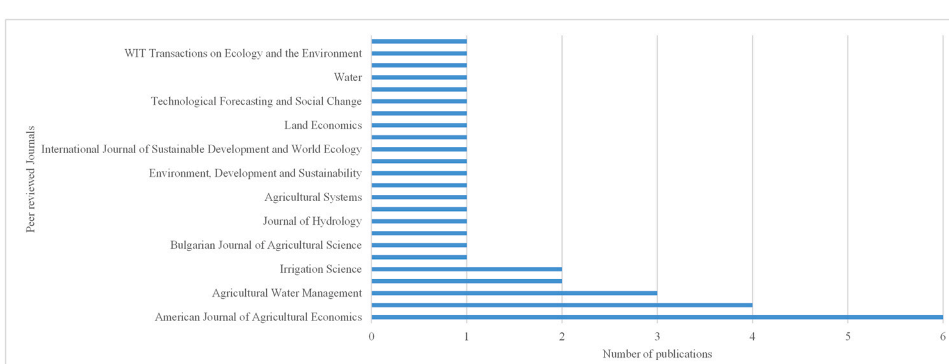

Fig. 5. Papers' distribution in terms of journals. Source: Authors' elaborations.

number of publications is hosted in American Journal of Agricultural Economics (6) and Agricultural Water Management (4), both in the domain of agricultural economics (see Fig. 5).

4.1.2. Empirical strategy adopted

The dominant empirical strategy applied is the cross-sectional analysis based on ad-hoc surveys confirming the scarcity of secondary data availability on irrigation. Another common aspect found is the low numerosity of observations used in the econometric analysis with only ten papers which present a high number of observation (thousands), whereas the vast majority of papers analyzed in the SLR relies on classical survey-samples between 150 and 500 observations (Fig. 6).

The most common econometric model used was logit (16) followed by probit (8) and multinomial logit (6) models. These methodologies aim to estimate the likelihood of the adoption of a specific technology over the set of alternative available choices. Most likely, the higher use of logit compared to probit, which are similar in the results, is justified by the use of the logistic function in the theoretical model of technology diffusion such as those explained in Rogers (1971) or Geroski (2000) which may had increased the use of logit model for econometric modelling.

Those methods imply a vision of adoption/non adoption state without focusing on other aspects such as diffusion which implies an analysis on the intensity of adoption. Until now, very few studies have used nested binary models, fractional methods or tobit models to analyse the intensity of adoption in terms of irrigated land under a specific technology, also considering other studies of innovation adoption in agriculture outside the WCSTs realm (Arslan et al., 2014; Pokhrel et al., 2018). The SLR method has also extrapolated papers that use other econometric methods such as the Heckman model, duration analysis, partial least squares, triple hurdle model and multinomial probit. In Fig. 7, the econometric methods employed in our SLR selected 36 papers are shown. The cross-sectional strategy is the most spread among the papers considered in the SLR analysis with thirty studies relying on cross-section analysis, whereas only seven papers employed panel data analysis using datasets with multiple years. This principally depends on the structural lack of data in agricultural water studies that constrain researchers to the use of own-produced surveys or local studies based on data availability from water authorities or other parties. This partially limits the research in terms of the time coverage in which the adoption of WCSTs can occur (which cannot be in only one specific year) and in terms of potential biases due to unobserved heterogeneities that may affect the reliability of the estimated coefficients due to endogeneity biases. Considering this, none of the studies using cross-section analysis employed specific empirical strategy to reduce bias from unobserved factors such as instrumental variables. Few studies, with a more economic focus, have included some controls to partially reduce bias due to unobserved heterogeneity, such as spatial dummies or other controls mimicking a fixed effects strategy. Fig. 7 shows the empirical strategy adopted by the studies analysed in the SLR approach.

None of the papers focus on a specific crop in the research design, but some studies included various crops as determinants of WCSTs adoption (citrus, vineyard, olive trees, chili peppers, wheat, alfalfa, hay, pasture, potatoes, rice, soybean, cotton, and maize). Nevertheless, generally the results show that the crop variable does not determine the choice of adopting WCSTs.

4.1.3. Type of irrigation technologies

In terms of irrigation technologies, many papers included in the SLR considered WCSTs in their analysis both jointly or separately. The studies considered presented a marked focus on drip and sprinkler systems, which were analyzed as irrigation systems in 11 and 16 papers respectively, micro-sprinkler technologies were studied in two papers, whereas sub-irrigation systems were only included in the analysis once.

Nine papers jointly considered the technologies as a single general class of WCSTs, whereas four papers did not mention specifically which type of technologies they referred to in their analysis, merely mentioning that the technologies under scrutiny were WCSTs. Fig. 8 shows the type of irrigation systems analyzed in the SLR.

4.1.4. Key-words co-occurrence network

We employed the VoS viewer software (van Eck and Waltman, 2022) to analyse the co-occurrence networks of the keywords included in the paper analysed in the SRL analysis. Although the interconnections between topics are modest (no more than 8 papers have a keywords co-occurrence more than two items) we can draw some general findings, for descriptive purposes only, of the main topics considered by scholars when studying WCSTs adoption (Fig. 9). The main topic treated is obviously the concept of adoption and the type of irrigation systems used. However, other characteristics arise such as conservation, water scarcity, technology adoption, climate, and social learning.

The co-occurrence network highlights that most studies refer to water conservation aspects only in water scarcity circumstances, especially in the presence of adverse climatic conditions. Another cluster of the network shows the connection among technology adoption, social learning, and extension services underling the importance of social aspects and learning activities in the studies of WCSTs adoption.

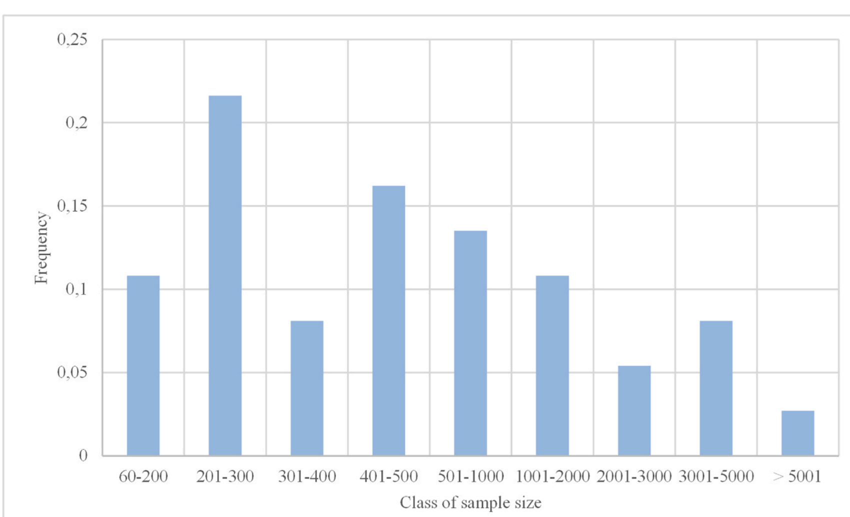

Fig. 6. Frequency of sample size by classes. Source: Authors' elaborations.

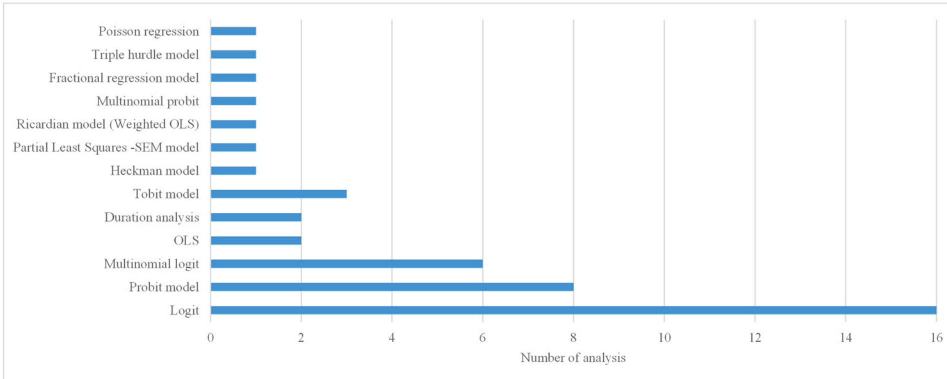

Fig. 7. Method of analysis used for WCSTs determinants of adoption. Source: Authors' elaborations.

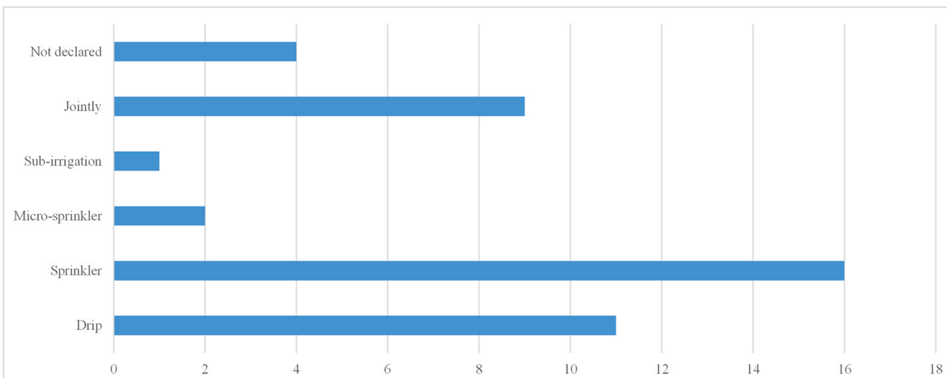

Fig. 8. Irrigation technologies considered in the papers selected for the SLR. Source: Authors' elaborations.

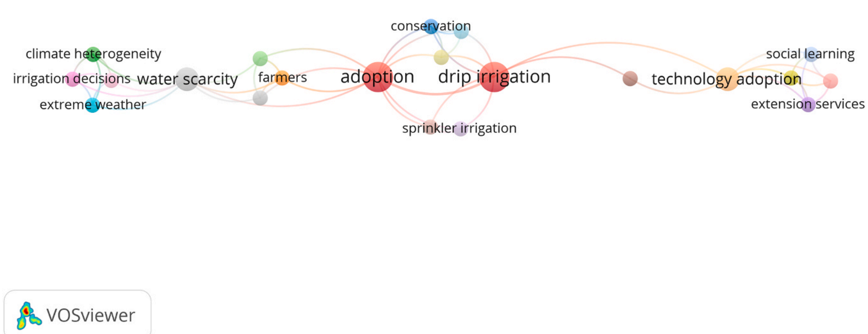

Fig. 9. Co-occurrence network of key-words in the papers selected for the SLR analysis. Source: VoS (van Eck and Waltman, 2022).

4.2. *WCSTs determinants of adoption*

In the following subsections we have summarised the main results of the SLR following the classification by macro-categories already described in Section 2. Only statistically significant drivers of the WCSTs are commented on, while non-significant factors were not considered. In the papers analyzed in the SLR, we decided not to consider relevant the results related to a specific variable that showed statistically significant but contradictory effects (e.g. negative in one model and positive in another model) without any evident or specified justification by the authors or related to specific factors (e.g. different types of irrigation technologies).

4.2.1. *Farm organisational characteristics*

In this category, the drivers with a positive correlation with WCSTs adoption are a) land size, b) cost and labour intensity, c) productive (crop) orientation, d) land tenure (e.g. area owned or rented), e) size of irrigated area f) price of the main crop, g) yield level, h) organisational aspects (i.e. absorption capacity, capital assets and internal labour organization), and i) contact with extension services. In Fig. 10, the drivers of WCSTs adoption related to the farm's characteristics are shown. Based on paper results, the type of correlation, i.e., positive, or negative, with the probability of WCSTs adoption is represented.

These results can provide important explanations since farm drivers of WCSTs adoption can be identified. Land size was found to be an important factor of adoption in 11 studies and it is rational since WCSTs implementation can be linked to economy of scale due to high costs of irrigation and control of water distribution when the cultivated areas are large (Dinar et al., 1992; Green and Sunding, 1997; Mi et al., 2021; Mohammadzadeh et al., 2014; Schuck et al., 2005; Shrestha and Gopalakrishnan, 1993; Singh et al., 2015; Wang et al., 2021; Yuan et al., 2021; Zhang et al., 2019). In this specific context three authors (Cremades et al., 2015; Quintana-Ashwell et al., 2020; Yu et al., 2008) focused on irrigated area finding it as an incremental factors of WCSTs

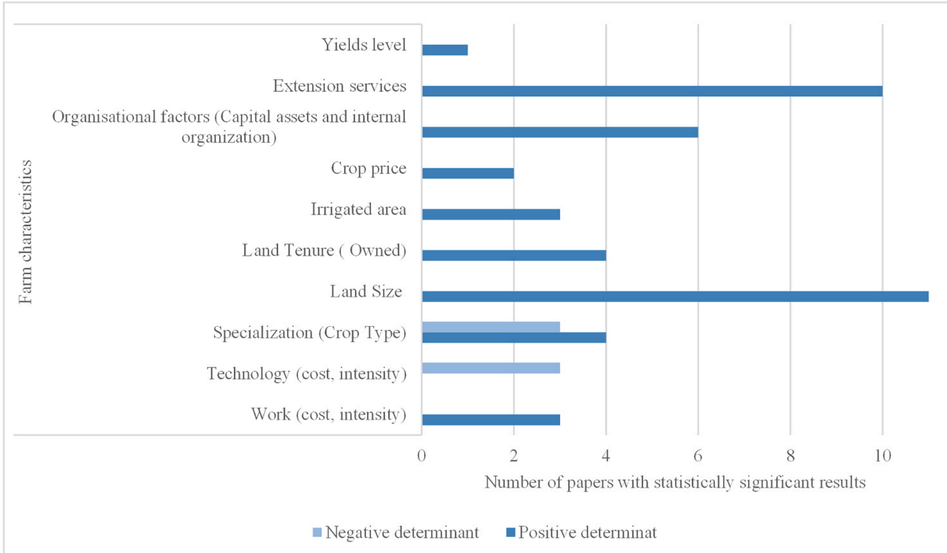

Fig. 10. Drivers of WCSTs adoption linked to farm characteristics divided between negative and positive determinants statistically significant in relation to the number of published articles (x-axis). Source: Authors' elaboration.

adoption indicating that high levels of irrigated areas may stimulate higher levels of irrigation through WCSTs.

A second aspect to consider related to farm characteristics is the connection with extension services and training. This aspect was found to be an incremental factor of WCSTs adoption in 10 papers (Alcon et al., 2011; Cremades et al., 2015; Genius et al., 2014; Koundouri et al., 2006; Salazar and Rand, 2016; Wang et al., 2021; Yu et al., 2008; Yuan et al., 2021; Zhang et al., 2019). This underlines the importance of external support in providing technical information and practical training linked to WCSTs to increase the overall level of adoption.

The third element identified as a key driver of WCSTs adoption within farm characteristics is the level of internal organization found to be relevant in six papers (Cremades et al., 2015; Dinar et al., 1992; Mi et al., 2021; Salazar and Rand, 2016; Wang et al., 2021; Yuan et al., 2021). This driver is grouping various aspects of farm organization as capital assets, farm labour division and familiar labour contribution within the farm. This evidence suggests that organisational factors and capital assets within the farm are critical factors in increasing the adoption of WCSTs.

Land tenure has been identified as an incremental factor of WCSTs adoption in 4 papers (Pokhrel et al., 2018; Salazar and Rand, 2016; Schuck et al., 2005; Shrestha and Gopalakrishnan, 1993) and this confirms that higher WCSTs adoption depend also on whether the farmer has property rights on the land irrigated and this might be linked to the return on the investments in WCSTs implementation. This aspect is apparently not linked to a specific crop or irrigation technology, since the four authors who noted it studied heterogeneous cases: Salazar and Rand (2016) investigated potato cultivation using micro-sprinkler, sprinkler and drip irrigation jointly, Pokhrel et al. (2018) studied drip irrigation in cotton plantations, Schuck et al.(2005) studied sprinkler adoption applied to various crops and Shrestha and Gopalakirishnan (1993) studied the adoption of drip irrigation in sugar cane cultivations.

Other incremental factors of WCSTs adoption found in literature have been the level of work intensity spent in the farm (Belaidi et al., 2022; Frisvold and Deva, 2013; Negri and Brooks, 1990), the price of crops (Dinar et al., 1992; Schaible et al., 1991) and level of yields (Pokhrel et al., 2018).

On the contrary, crop specialization and technology absorbing capacity in terms of technology cost for the technology implementation present a negative correlation with WCSTs adoption. If the latter is straightforward to interpret, since high technology implementation costs are identified as a negative driver of technological implementation in the general innovation adoption literature (Foster and Rosenzweig, 2010), the former is more puzzling.

Green et al. (1996), Moreno and Sunding (2005), Wheeler et al. (2010), Alcon et al. (2011) found crop specialization of farms to be a positive driver of WCSTs adoption, whereas Michailidis et al. (2011), Zhang et al. (2019) and Quintana-Ashwell et al. (2020) found a negative effect. They all have analyzed various crops without focusing on a specific one and this might explain why the effect of this variable was found to be heterogeneous. Furthermore, two of them considered WCSTs as a group of technologies without investigating them separately and this might have hidden some characteristics of each technology in terms of crop specialization.

4.2.2. *Farmer personal characteristics*

Considering farmers' personal characteristics, papers in our review identified as main factors influencing adoption: gender, age, education, experience, income, external activity, risk perceived, expected returns, and social status (see Fig. 11). Most papers (14) found that education is an incremental driver by the majority of papers (14) indicating a positive correlation of increasing level of education with WCTS adoption (Belaidi et al., 2022; Genius et al., 2014; Koundouri et al., 2006; Mi et al., 2021; Michailidis et al., 2011; Mohammadzadeh et al., 2014; Quintana-Ashwell et al., 2020; Salazar and Rand, 2016; Schuck et al., 2005; Singh et al., 2015; Wang et al., 2021; Yu et al., 2008; Yuan et al., 2021; Zhang et al., 2019). This result is straightforward since higher level of education may improve general knowledge, technical skills, problem solving capabilities, all factors reducing the perception of risk when adopting new technologies.

Age was found to have a negative correlation with WCSTs adoption in nine studies (i.e. younger farmers are more likely to adopt WCSTs) (Alcon et al., 2011; Belaidi et al., 2022; Cremades et al., 2015; Genius et al., 2014; Green and Sunding, 1997; Koundouri et al., 2006; Michailidis et al., 2011; Pokhrel et al., 2018; Zhang et al., 2019), but only in one paper the correlation was found to be positive (i.e. younger farmers are less likely to adopt WCSTs) (Singh et al., 2015). This also can indicate that younger farmers are more prone to technological changes since they might perceive less risk than older farmers. In general, this is confirmed by other studies on the adoption of innovations that are not strictly focused on agriculture (Foster and Rosenzweig, 2010). The paper of Singh et al. (2015) in which was found an opposite effect of age did not

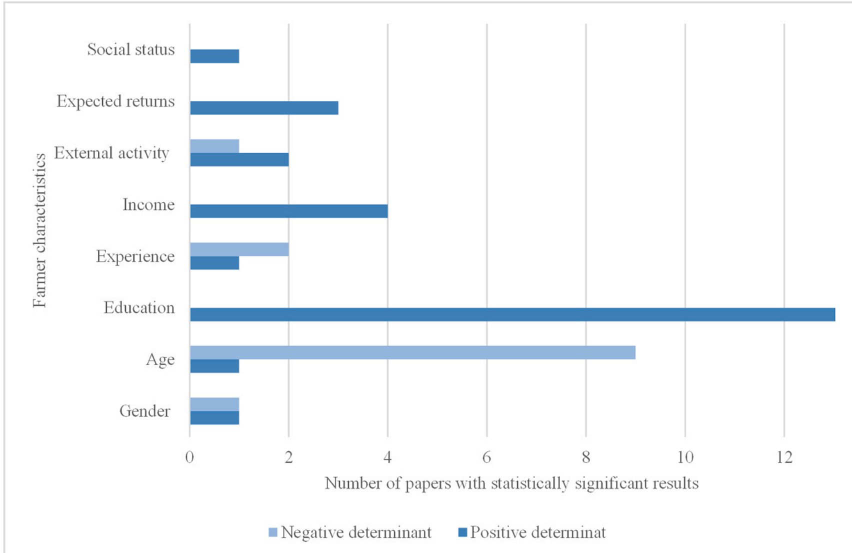

Fig. 11. Drivers of WCSTs adoption linked to the farmer's characteristic divided between negative and positive determinants statistically significant in relation to the number of published articles (x-axis). Source: Authors' elaboration.

explicit what type of irrigation technology was under investigation referring to a general "micro-irrigation systems", therefore technological aspect cannot be investigated in finding this contrasting result with the rest of the papers analyzed in the SRL. This is also confirmed by authors who used farmers'experience as a variable instead of age (Olen et al., 2016; Quintana-Ashwell et al., 2020), finding that variable being negatively correlated with WCSTs adoption.

Income level was found to be positively correlated with WCSTs adoption in four articles (Michailidis et al., 2011; Quintana-Ashwell et al., 2020; Singh et al., 2015; Yu et al., 2008). This factor is also an expected incremental driver of adoption, already found in the general literature on innovation adoption (Foster and Rosenzweig, 2010) and can be explained by the fact that higher income levels may allow farmers to bear higher levels of risk when adopting new technologies with unknown outcomes in terms of yields effects.

Expected returns produced by the technology adoption was found to be an incremental driver of WCSTs adoption by three studies (Koundouri et al., 2006; Mishra et al., 2017; Shrestha and Gopalakrishnan, 1993), whereas external activities (off-farm jobs) was found two times as positive drivers of adoption (Wang et al., 2021; Yuan et al., 2021) (external activity was found to be negative in Singh et al. 2015).

Gender showed a mixed result with one paper indicating a negative correlation with being male (Cremades et al., 2015), whereas another one indicating positive correlation with being male, suggesting some kind of barriers for female farmers (Salazar and Rand, 2016). To be mentioned, among the factors related related to the farmers' characteristics, the social status of the head of the household was found to be an incremental factor of WCSTs adoption in the study of Namara et al. (2007) focused on the Indian regions; this is probably related to the hierarchical society of the case study.

4.2.3. Institutional environment

Social networks and the adoption by other farmers were found to be a relevant positive driver of WCSTs adoption in seven studies (Genius et al., 2014; Hunecke et al., 2017; Salazar and Rand, 2016; Shrestha and Gopalakrishnan, 1993; Wang et al., 2021; Yuan et al., 2021; Zhang et al., 2019). This highlights the importance that imitation process among peers can influence the level of technology diffusion in a specific location and additionally positively increase the decision of new adoptions. This has been widely confirmed in the literature on innovation diffusion and studies on technology adoption, and in the case of the WCSTs, social networks also appear to be a valid driver of adoption. Only the study of Mi et al. (2021) found that social networks have a negative effects on WCSTs adoption without finding a potential explanation to this.

Also membership to associations, unions, cooperatives, or water programs was identified in five studies as a relevant driver of WCSTs adoption (Quintana-Ashwell et al., 2020; Salazar and Rand, 2016; Wheeler et al., 2010; Yuan et al., 2021; Zhang et al., 2019). This result may justify the fact that membership in an agricultural (or other) organisation may increase the chances of adoption of WCSTs, by increasing the ease of exchange of relevant information on technology, imitation among members or creating the right environment to find training and practical activities related to new technologies to reduce farmers' risk aversion.

Previous information and knowledge available to the farmer was also found as an important social factor driving WCSTs adoption in five studies (Foltz, 2003; Mohammadzadeh et al., 2014; Wang et al., 2021; Yuan et al., 2021; Zhang et al., 2019), while on field training appeared to be relevant only in the paper of Zhang et al. (2019). Even in these cases, the incremental effect of these variables on WCSTs adoption is linked to the reduction in uncertainty and risk borne by the farmer prior to the adoption decision.

Another important relevant driver influencing WCSTs adoption is covered by financial variables. The papers analyzed in the SLR identified a positive impact of three main drivers: debt level, public fundings (incentives), and access to credit. The most relevant financial driver of adoption is public funding which was identified as a positive determinant of adoption in four cases (Cremades et al., 2015; Mi et al., 2021; Yu et al., 2008; Zhang et al., 2019). Access to credit was found to be a positive driver of WCSTs adoption in three papers (Alcon et al., 2011; Belaidi et al., 2022; Salazar and Rand, 2016), while low levels of debts was found to be a positive driver of adoption only in one study (Foltz, 2003). The relevance of financial drivers in WCSTs adoption can be important in terms of policy indications in fact, sustaining access to credit both from the private and public sector may potentially increase the adoption and diffusion of WCSTs. This may be especially important when farmers alone cannot bear the cost of the 'transition' toward more sustainable technologies as the case of developing countries or where the agricultural sector is structurally under capitalized.

Social and financial aspects influencing the probability of WCSTs adoption are shown in Table 1.

Table 1
Drivers of WCSTs adoption linked to social and financial aspects. Source: Authors' elaboration.

	Social Aspects				Financial characteristics		
	Social networks (adoption by other farmers, imitation)	Previous information	Training	Membership (association, union, cooperatives, water programs)	Low debts	Public fundings (incentives)	Access to credit
Positive	7	5	1	5	1	4	3
Negative	1	0	0	0	0	0	0

Regarding water supply characteristics, they are summarized in Fig. 12. The cost of water in terms of price or pumping cost was found to be a positive driver of WCSTs adoption in ten papers (Caswell and Zilberman, 1985; Dinar et al., 1992; Dinar and Yaron, 1990; Frisvold and Deva, 2013; Green et al., 1996; Green and Sunding, 1997; Negri and Brooks, 1990; Olen et al., 2016; Wang et al., 2021; Yuan et al., 2021). This finding was highly expected since the direct cost of water may strongly influence farmers' adoption decisions.

The cost of energy and electricity was found positively correlated with WCSTs adoption in two cases (Quintana-Ashwell et al., 2020; Wheeler et al., 2010). This suggests that energy costs when using traditional irrigation techniques (e.g., furrow or flooding) may be linked to higher energy costs (e.g., pumping water) which may increase farmers interests toward WCSTs which may also allow energy costs savings.

Water scarcity (volume constraints and groundwater access limitations) was identified by six studies as another relevant factor that may positively influence WCSTs adoption (Belaidi et al., 2022; Cremades et al., 2015; Olen et al., 2016; Quintana-Ashwell et al., 2020; Yu et al., 2008; Zhang et al., 2019). This result was highly expected and it is completely rational since lower level of water access may increase the needs for efficiency in resource scarce usage influencing positively the propensity toward the adoption of WCSTs. In contrast, access to surface water was found to be negatively correlated with adoption, as examined in the Negri and Brooks (1990) and Olen et al. (2016) studies (both considered sprinkler irrigation), which is consistent with the findings for groundwater indicating that access to superficial water may be a factor reducing WCSTs adoption. This may be explained by the higher cost of groundwater resources compared to surface water supply which when accessible may reduce the needs for efficient use of water resource.

Water institutional aspects (i.e., water quota, water rights or extraction fees) showed ambiguous results. Three papers assessed those aspects as positive (Cremades et al., 2015; Foltz, 2003; Hunecke et al., 2017), while two identified these elements as negative adoption drivers (Dinar and Yaron, 1990; Olen et al., 2016) (in the negative case the authors hypothesized that quota was related to seniority water rights). Anyway, no clear pattern in these puzzling results are evident.

Finally, reliable water source (perceived) and water quality have a positive influence with respect to adoption respectively in one paper (Dinar and Yaron, 1990; Quintana-Ashwell et al., 2020).

4.2.4. Geographic and climate characteristics

As regards geographic aspects, the main driver of adoption are proximity to strategic centres as markets, extension services, and towns for both selling products or collecting inputs (e.g. information, knowledge, fertilizers), acclivity (sloped area), soil quality (e.g., salinity, erosion, and permeability) and soil type (e.g., soil sandy, soil mixed, and soil clay).

Soil quality was found to be a positive factor influencing WCSTs adoption in six papers (Cremades et al., 2015; Dinar et al., 1992; Dinar and Yaron, 1990; Frisvold and Deva, 2013; Green and Sunding, 1997; Mendelsohn and Dinar, 2003). Soil type and acclivity were found to be positively correlated with WCSTs adoption in three papers respectively (Green and Sunding, 1997; Koundouri et al., 2006; Mendelsohn and Dinar, 2003; Moreno and Sunding, 2005; Negri and Brooks, 1990), but both factors present a negative impact on WCSTs adoption in one (Cremades et al., 2015) and two papers respectively (Dinar et al., 1992; Shrestha and Gopalakrishnan, 1993) as the SLR analysis shows. Both results do not depend on the type of technology considered nor the type of crop, since all the studies which evidenced these aspects have analyzed heterogenous classes of both.

Geographical proximity to market, extension services, input markets, and towns were found to be positive factors of adoption in two studies (Cremades et al., 2015; Genius et al., 2014). All the geographical aspects influencing the adoption of WCSTs are shown in Fig. 13.

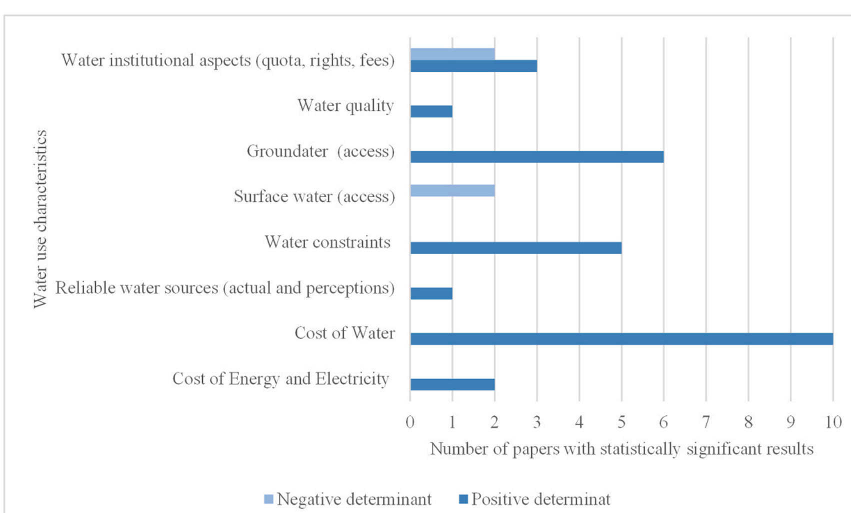

Fig. 12. Drivers of WCSTs adoption linked to water characteristics divided between negative and positive determinants statistically significant in relation to the number of published articles (x-axis). Source: Authors' elaboration.

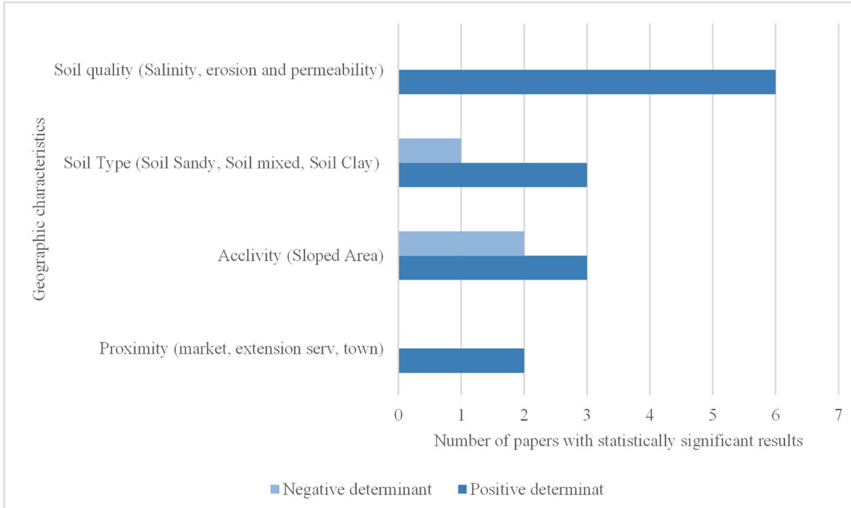

Fig. 13. Drivers of WCSTs adoption linked to geographic characteristics divided between negative and positive determinants statistically significant in relation to the number of published articles (x-axis). Source: Authors' elaboration.

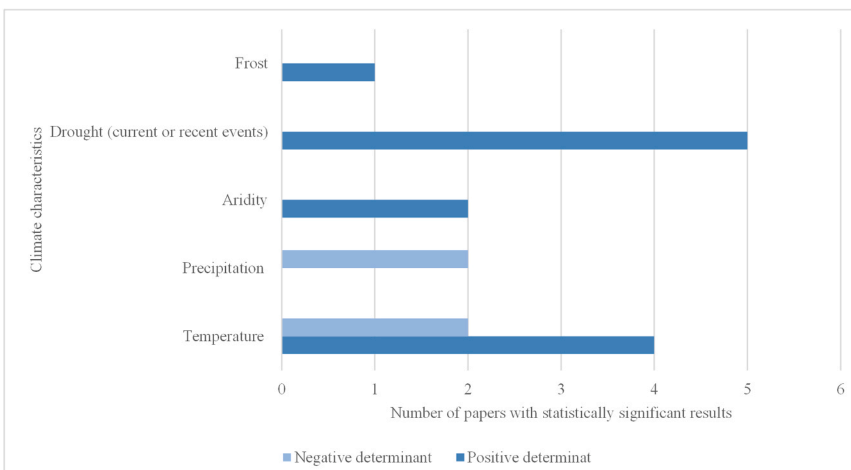

Fig. 14. Drivers of WCSTs adoption linked to climatic characteristics. Source: Authors' elaboration.

Among the climatic factors influencing WCSTs adoption, Fig. 14 shows that drought events (current or recent events) were found positively correlated with the probability of WCSTs adoption in five studies (Huang et al., 2017; Knapp and Huang, 2017; Olen et al., 2016; Schuck et al., 2005; Zhang et al., 2019), indicating that droughts seem to be the most relevant climatic event in farmers' adoption strategies. Temperatures was found to be an important positive driver of adoption in four studies (Dinar and Yaron, 1990; Knapp and Huang, 2017; Mendelsohn and Dinar, 2003; Olen et al., 2016), while it was identified as a negative factor in only two studies (Frisvold and Deva, 2013; Huang et al., 2017). Aridity was identified as a positive driver of adoption in two studies (Genius et al., 2014; Koundouri et al., 2006), while frost was considered to be positively correlated with WCSTs adoption in one paper (Olen et al., 2016). Precipitations was found to be negatively correlated with WCSTs adoption in two papers (Huang et al., 2017; Negri et al., 2005).

All results related to climate variables were highly expected and straightforward, except for those related to temperature, which showed negative effects on WCSTs adoption. Both studies by Frisvold and Deva (2013) and Huang et al. (2017) focused on sprinkler irrigation systems and justified these results in terms of high evaporation levels related to high temperatures that may reduce the irrigation efficiency of this type of technology which is a plausible explanation. On the other hand, the other four studies indicate that rising temperatures are increasing the propensity of farmers towards WCSTs adoption, such as higher drought events and aridity levels. In this case those authors analysed different type of irrigation technologies (i.e., sprinkler and drip) not identifying differences among them. As expected, increasing levels of precipitation reduce the willingness to adopt WCSTs.

Table 2 depict the papers considered in our SLR analysis regarding authors, year of publication, study area, country, type of data used, econometric method employed, number of observations, type of crop analysed, variables considered in the study, main findings in terms of WCST determinants of adoption, and journal in which the paper was published.

Table 2
List of papers used for the SRL on WCST. Source: Authors' elaboration.

	Authors	Year	Area	Country	Method	Observations	Irrigation Technology	Crop	Variable used	Main findings	Journal
1	Caswell and Zilberman	(1985)	San Joaquim Valley (California)	United States	Multinomial logit	-	Sprinkler, Drip	Perennial crops	Water costs, Water source, Type of crop.	WCSTs adoption differ among counties, Water source do affect WCSTs adoption, WCSTs adoption is directly related to water price, WCSTs adoption change among crops.	American Journal of Agricultural Economics
2	Negri and Brooks	(1990)	Various states	United States	Logit model	5.145	Sprinkler	Variuos	Cost of water, Price of labour, Irrigated area, Water source (groundwater, surface), Frost free days, Rainfall, Growing degree days, Soil slope, Land productivity, Type of soil (sand, clay).	Water price and cost of labour influence the adoption of WCSTs, Access to surface water decrease the WCSTs, Soil typology (sand) increase WCSTs adoption, Rainfall decrease WCSTs adoption since crop water requirement is less and irrigation is supplemental, Longer growing seasons reduce likelihood of WCSTs adoption.	Journal of Agricultural and Resource Economics
3	Dinar and Yaron	(1990)	Various regions	Israel and Gaza	OLS	209	Sprinkler, Micro-sprinkler, Drip	Citrus	Water quality, Water allotment, Cost of water, Soil salinity, Soil type, Rootstock, Land size, Average Yields, Organizational type of farm, Farmer experience.	Land quality and temperatures increase WCSTs adoption, Water quality and price influence WCSTs adoption, Water allotment and farm area decrease adoption.	Journal of Agricultural and Resource Economics
4	Schaible et al.	(1991)	Various states	United States	Logit model	-	Sprinkler	Various	Locational and crop dummies, Crop prices, Electrical costs.	Locational (heterogenous) factors play important role in WCSTs adoption, Crop prices are significantly important only for some crops in adoption decisions.	Journal of Agricultural and Resource Economics
5	Dinar et al.	(1992)	San Joaquim Valley (California)	United States	Logit and Tobit	571	Sprinkler	Various	Water table depth, Water quality, Water quota, Water price, Weather conditions (Temp and Rain), Farm organization, Water source, Crop Price.	Water cost increase WCSTs adoption, Crop price increase adoption, Farm organization incrase WCSTs adoption (constant presence of irrigators), Large areas, slope and poor soils increase adoption.	Environmental and Resource Economics
6	Shrestha and Gopalakirishnan	(1993)	Hawaii	United States	Probit model	450	Drip	Sugar cane	Perceived yield different using WCSTs, Difference in expected water use, Field size, Time, Type of soil, Crop type, Average temperature, Slope.	Expected revenue and passing of time have a positive influence on WCSTs, Field size influences directly WCSTs adoption, physical property of soil influence WCSTs, Flatness of land influence of non-WCSTs adoption.	Economic Development and Cultural Change
7	Green et al.	(1996)	San Joaquim Valley (California)	United States	Multinomial logit	1.493	Sprinkler, Micro-sprinkler, Drip	Variuos	Water price, Use of surface water, Soil type, Field size, Type of crop.	The choice of irrigation technology highly depends on the type of cultivated crop, Water price influence probability of WCSTs adoption, slope influence positively WCSTs adoption.	American Journal of Agricultural Economics

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Table 2 (*continued*)

	Authors	Year	Area	Country	Method	Observations	Irrigation Technology	Crop	Variable used	Main findings	Journal
8	Green and Sunding	(1997)	California Central valley	United States	Logit model	271 and 419	Micro-sprinkler, Drip (jointly)	Citrus and Vineyard	Price of water, Soil permeability, Field slope, Field size, Water source.	Soil permeability and field slope increase adoption, Water price influence positively adoption only for citrus.	Journal of Agricultural and Resource Economics
9	Skaggs	(2001)	New Mexico	United States	Logit model	60	Drip	Chili peppers	Age, Education, Farm size, Land tenure, Contact with extension personel, Off-farm job, Net farm income, future vision on water availability.	Older farmers have less propensity to adopt WCSTs, Farm size increase probability of WCSTs adoption, positive vision increase probability of WCSTs adoption.	Agricultural Water Management
10	Foltz	(2003)	Cap Bon	Tunisia	Probit model		Drip	Various	Water cost, Degree of salinity, Education, Information on WCSTs, Financial debts, Farm size, Diversity of crops, Land under direct work.	Salinity is not important in WCSTs adoption, whereas it is water price, previous information on WCSTs and level of low financial debts.	Economic Development and Cultural Change
11	Mendelsohn and Dinar	(2003)	Various states	United States	Ricardian model (Weighted OLS)	2863	Sprinkler, Drip	Various	Aggregated irrigated land under gravity or WCSTs as interactions with climatic and geographical variables.	Sandy and saline soils, Hot temperatures increase the adoption of drip irrigation systems (rainfall is positive at a declining rate), Sprinklers are adopted where water is more abundant and temperature are cooler and lower with high altitude, Gravity systems increase in flat areas and with higher temperatures but not with less rainfall.	Land Economics
12	Schuck et al.	(2005)	Colorado	United States	Logit model (binomial and multinomial)	231	Sprinkler	Various	Farm size, Irrigated land, Land tenure, Education, Type of crop, On-farm income, Drought event.	Land tenure,education and farm size affect the type of WCSTs; A recent drought event increase WCSTs adoption.	Water Resources Development
13	Moreno and Sunding	(2005)	Kern County (California)	United States	Logit model (Nested logit)	2.300	Sprinkler, Drip	Various	Soil type, Slope, Field size, Water price, Surface water, Frost-Free days.	Soil permeability influence positively adoption of WCSTs, Slope increase probability of adoption of drip, Experience and specialization influence choice of irrigation system, high elasticity of WCSTs adoption to price.	American Journal of Agricultural Economics
14	Namara et al.	(2007)	Gujarat and Maharashtra regions	India	Logit model	448	Sprinkler, Micro-sprinkler, Drip (jointly)	Various	Family size, Age, Education, Social status, Depth of well Access to water, Access to electricity for pumping, Crop type, Poverty index.	WCSTs are never adopted singolarly, but in combination with other irrigation systems. Social status is one of the main important aspect as access to water and electricity, other factors do not influence the likelihood of WCSTs adoption.	Irrigation Science
15	Koundouri et al.	(2006)	Crete Island	Greece	Probit model	265	Sprinkler	Various	Age, Education, Aridity index, Debts, Extension visits, Access to information, Off-farm income, Family farming, Soil characteristics, Profit (four moments).	Perceived risk has a prominent role in decision of WCSTs adoption and it is strictly linked to high aridity and sandy soils, Educational and Informational aspects (both access and extension visits) increase	American Journal of Agricultural Economics

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Table 2 (*continued*)

	Authors	Year	Area	Country	Method	Observations	Irrigation Technology	Crop	Variable used	Main findings	Journal
										WCSTs adoption whereas Ageing decrease it, high Expected profits affect is positively related to WCSTs adoption.	
16	Yu et al.	(2008)	Various regions	China	Tobit model	1760	Sprinkler, Drip, Sub-irrigation (jointly)	Various	Groundwater, Inadequacy of surface water, Inadequacy of groundwater, Extension services, Subsidies, Demonstrations, Cropped area, Soil type. At village level: Irrigated area, Net income, Non-agricultural employement rate, Education, Distance between village to country government.	Groundwater and Inadequacy of groundwater, Extension services, Subsidies, Cropped area they all influence positively WCSTs adoption. At village level: Irrigated area, Net income, and Education influence positively the likelihood of WCSTs adoption.	Ecological Economy
17	Wheeler et al.	(2010)	Alberta	Canada	Probit model	300	Sprinkler	Various	Farm tenure, Age, Parenthood, Education, Off-farm income, Energy source for irrigation, Being member of an Irrigation District.	Lower off-farm income, higher level of elettricity as source of irrigation energy, being a member of an Irrigation District and cultivation of high value crop increase the WCSTs.	WIT Transactions on Ecology and the Environment
18	Alcon et al.	(2011)	Campo de Cartagena	Spain	Duration analysis	360	Drip	Various	Age, Education, Farm size, Crop type, Member of a Cooperative, Water Price, Access to credit, Groundwater, Contact with extension services, On-farm income, Water availability.	Younger farmers are more open to WCSTs, Credit access increase WCSTs adoption, Fruits have higher probability of using WCSTs, Information availability from extension personel influence WCSTs.	Technological Forecasting and Social Change
19	Michailidis et al.	(2011)	Western Macedonian Region	Bulgaria	Logit model	400	Sprinkler	Various	Age, Type of cultivation (cereals), Distance from urban place, Education, Altitude, Number of workers,Experience, Farm size, Income, Cost of adoption, Gender, Water insufficiency.	Age, Type of cultivation (cereals) and Cost of adoption decrease the likelihood of WCSTs adoption. Education, Income and Water insufficiency increase the probability of WCSTs adoption.	Bulgarian Journal of Agricultural Science
20	Frisvold and Deva	(2013)	Various states	United States	OLS	68	Sprinkler	Variuos	Water pumping cost, Farm dimension, Temperature (avg in growing season), Number of days below 0 °C, Soil erosion, Hired labour growth rate.	Water pumping and labour costs increase adoption of WCSTs, Increase in temperature reduce WCSTs (authors worked on areas interpreting this result as a matter of non-adataptation in warmer areas), Soil erosion increase adoption of WCSTs.	Journal of Natural Resources Policy Research
21	Mohammadzadeh et al.	(2014)	Urmia lake	Iran	Logit model and ordinal logistic model	136	Drip	Apple	Knowledge of WCSTs, Education, Experience, Income, Mechanization level, Type of crop, Land tenure, Extension service, Land size.	Knowledge of WCSTs and Education are the main determinants of adoption, Land size and contact with extension personal are also factor influencing WCSTs adoption.	Journal of agricultural science technology
22	Genius et al.	(2014)	Crete Island	Greece	Duration analysis	265	Sprinkler, Drip (jointly)	Olive trees	Age, Education, Land size, Tree density, Installation cost, Irrigation water price, Olive oil price, Profits moments, Aridity index, Altitude, Soil type, Stock	The presence of other peers adopting the technology influence positively the adoption through social pressures, learning by doing	American Journal of Agricultural Economics

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Table 2 (*continued*)

	Authors	Year	Area	Country	Method	Observations	Irrigation Technology	Crop	Variable used	Main findings	Journal
									of adopters, Stock of peers, Extension service, Distance from extension outlet and peers.	and imitation. The effect of extension services and geographical proximity are also relevant in technology adoptuon. Age and education influence adoption, Installation costs do not affect adoption. Aridity levels and profit risks increase adoption.	
23	Singh et al.	(2015)	Dahod district (Gujarat)	India	Logit model	700	-	Various	Family size, Age, Education, Social status, Depth of well Water source, Access to electricity for pumping, Crop type, Diversity of income.	Education, Age, Total income and Total area are relevant for WCSTs adoption.	International Journal of Sustainable Development and World Ecology
24	Olen et al.	(2016)	Various states	United States	Logit model (binomial and multinomial) for different crops.	457, 591, 376 and 526	Sprinkler	Wheat, Alfalfa, Hay, Pasture	Water supply institutions, Water scarcity, Climate and land characteristics, Demographic factors.	Water rights seniority (institutional) and surface water availability influence negatively WCSTs adoption, Well depth and water cost increase WCSTs adoption. Drought, Frost and temperature increase the adoption of WCSTs but with heterogeneities among crops. Younger and less experienced farmers have higher probability of WCSTs adoption.	American Journal of Agricultural Economics
25	Cremades et al.	(2015)	Various regions	China	Logit model	4172	Sprinkler, Drip, Sub-irrigation (jointly)	Various	Financial subsidies, Extension service, Years without reliable water supply, Groundwater use, Irrigated area, Distance to township, Precipitation, Irrigation fee, Proportion of households adopting WCSTs, Gender, Age, Education, Off-farm work, Household's assets, Cropped area, Type and quality of soil, House-plot distance.	Financial subsidies, Extension service, Irrigation fee, Irrigated area, Groundwater use, Household's assets, House-plot distance all influence WCSTs adoption positively, whereas Precipitation,Gender and Age influence negatively WCSTs adoption. Saline plot and medium quality plot increase likelihood of WCSTs adoption, Clay and Loam soils decrease WCSTs adoption.	Earth System Dynamic
26	Salazar and Rand	(2016)	All regions	Chile	Probit model with sample selection and Multinomial probit	7.274	Sprinkler, Micro-sprinkler, Drip (jointly)	Potato	Age, Gender, In-Farm income, Capital invested, Access to credit, Land Tenure, Participation in agricultural organizations, Extension services, Percentage of eroded soil, Number of WCSTs adopters in the community.	Education, Capital, Credit, Owned land and Extension services are positively associated with WCSTs adoption. Number of other WCSTs adopters and participation to agricultural groups are important for decision.	Latin American Economic Review
27	Huang et al.	(2017)	Arkansas	United States	Logit model (binomial and multinomial)	1.191	Sprinkler	Rice, Soybean, Cotton, Maize	Years of experience, Farm size, Crop diversity, Land tenure, Soil type, Water costs, Dept of wells, Irrigated land, Governmental programs, Mean daily	Higher temperature reduce the likelihood of using sprinklers. Total precipitations do not predict the choice between sprinkler and gravity systems.	Journal of Agricultural and Applied Economics

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Table 2 (*continued*)

	Authors	Year	Area	Country	Method	Observations	Irrigation Technology	Crop	Variable used	Main findings	Journal
									temperature, Variation of temperature, Total precipitation, Variation of precipitation, Palmer drought index.	Large variations of total precipitations reduce the adoption of sprinklers. High frequency of droughts increase likelihood of WCSTs adoption.	
28	Knapp and Huang	(2017)	Arkansas, Mississippi, Louisiana	United States	FE OLS regression	4.521	Sprinkler	Variuos	see Huang et al. (2017) adding moving average(MA) of climatic variables.	Mean daily temperature are important for choosing sprinkler. The same is for long drought periods. Climatic variables are significant in choosing WCSTs considering either MA from 5 to 30 years back of variation.	Journal of Hydrology
29	Hunecke et al.	(2017)	O'Higgins and Maule Regions	Chile	Partial Least Squares -SEM model	452	Sprinkler, Drip (jointly)	Vineyards	Water requirement measurement instruments, Formal and Informal networks, Trust in water communities.	Trust in water institutions play an important role in choosing irrigation technology, Formal and infomal networks strongly influence adoption of WCSTs.	Agricultural Systems
30	Pokhrel et al.	(2018)	Various states	United States	Probit model and multivariate fractional regression model	1.812	Drip	Cotton	Age, Education, Land tenure, Income, Use of computer, Yields, Cover crop.	Yield level and Land tenure infuence WCSTs adoption. Education reduce the probability of adoption. Older farmers have higher probability of adopting non-WCSTs.	Water
31	Zhang et al.	(2019)	Beijing	China	Logit model	490	Sprinkler, Micro-sprinkler, Drip, Sub-irrigation (jointly)	Variuos	Age, Education, Farming experience, Farm size, On-farm demonstration, Cooperative and water association membership, Training, Distance to market, Use of Groundwater, Information access, Adoption costs, Drought potential, Neighobour adopting, Subsidies.	Education, Farm size, On-farm demonstration, Cooperative membership, Training, Groundwater, Access to information, water use associations, drought-prone area, neighboring farmers, and subsidies increase the likelihood of WCSTs adoption. Age, production specialization, and cost have a negative effect on famers' adoption of WCSTs.	Agricultural Water Management
32	Quintana-Ashwell	(2020)	Delta region of Mississippi	United States	Probit model	148	Sprinkler, Drip (jointly)	Various	Irrigated area, Groundwater use, Type of crop(Rice), Experience, Education, Perception of Groundwater problems, Conservation program participation, Pumping costs.	Irrigated area, Groundwater use, Perception of Groundwater problems, Conservation program participation, Education and Income influence positively the likelihood of WCSTs adoption. Farming experience, Pumping costs and type of crop influence negatively the likelihood of WCSTs adoption.	Agronomy
33	Mi et al.	(2021)	Xinjiang	China	Triple hurdle model	715	-	Cotton	Land size, Number of plot, Distance from town, Production equipments, Communication tools, Household head age, Education, Health level, Labour, Income, Cooperative membership, Local government	Field size and Education increase likelihood of WCSTs adoption, Production equipments and number of workers reduce WCSTs adoption, Rent-in increase WCSTs adoption while rent-out	Agricultural Water Management

(*continued on next page*)

Table 2 (*continued*)

	Authors	Year	Area	Country	Method	Observations	Irrigation Technology	Crop	Variable used	Main findings	Journal
									membership, Subsidy, Neighbour adoption, Experience, Training, Transfer factors (rent-in, rent-out).	does the opposite. Subsidies and WCSTs adoption of neighbours have a negative effect on WCSTs likelihood of adoption.	
34	Wang et al.	(2021)	North China Plain Hebei province	China	Heckman model	261	-	Wheat, Maize	Gender, Age, Education, Number of workers, Family labor, Extension services, Farm size, Number of plots, Soil quality, Off-farm work, Cooperative membership, Relatives working in government, Water scarcity index, Irrigation costs, Information quality, Labor-saving potential, Capital-saving potential.	Education, Extension services, Farm size, Off-farm work, Relatives in the governmental structures, Water scarcity, Irrigation costs, Information quality, Labor and Capital saving capacity are all positively influencing WCSTs adoption.	Environment, Development and Sustainability
35	Yuan et al.	(2021)	North China Plain Hebei province	China	Probit model	267	Sub-irrigation	Various	Age, Gender, Family labor, Extension service, Farm size, Number of plots, Soil quality, Off-farm work, Cooperative membership, Relatives in the government, Water scarcity index, Irrigation cost, Information quality, Labor and Capital saving potential.	Education, Extension services, Farm size, Off-farm work, Cooperative membership, Relatives in the governmental structures, Water scarcity, Irrigation costs, Information quality, Labor saving capacity are all positively influencing WCSTs adoption.	Irrigation Science
36	Belaidi et al.	(2022)	Mitidja plain	Algeria	Logit model, Tobit model and Poisson model	136	-	Various	Farm size, On-farm diversification, Labor force, Credit access, Investment on WCSTs, Age, Education level, Information source, Organization membership, Public subsidies, Drilled wells ratio.	Investment, Age and Drilled wells ratio are negative determinants of adoption (all the models). Information sources and public subsidies are negative correlated with adoption for the logit, tobit and poisson model. Credit access, Labor force and Education is positive for the logit and poisson model. Organization membership is negatively correlated with WCSTs adoption only for the poisson model.	New Medit

5. Discussion

5.1. Drivers of WCSTs adoption

The works analysed in this SLR, over the years, have shown a diversification of the aspects analysed as drivers of WCST adoption. Early studies focused mainly on agronomic and production aspects, while in recent decades other factors of analysis such as social and institutional aspects have been added. The SLR indicates that the factors that can influence the adoption of WCSTs are diverse and not only linked to productive aspects suggesting that the process of technology adoption is far to be only a 'rational' choice as simple profit maximiser agents.

The findings of the SRL analysis highlighted the vast heterogeneity of factors which can potentially influence WCSTs adoption. In terms of farm characteristics, the most important seems to be the access to extension services and land size, which can positively affect the likelihood of adoption. Although for the latter factor, some scholars have found some evidence of negative effects on WCSTs adoption. This could be related to the fact that as land size increases, the net marginal benefits of WCSTs adoption decreases, as for large areas irrigated with WCSTs, the marginal cost may increase substantially or the effectiveness of pivot sprinkler systems that require large farms and may enter in competition with drip irrigation systems that are more flexible and can be adapted to smaller and irregular shaped farms. A prospective extension of the literature could be to investigate the potential non-linearities of land size on WCSTs adoption by adding quadratic terms in the explanatory variables.

Another important driver identified in the SLR is the contact of farmers with extension services which, through training activities, demonstrations, knowledge transfers can reduce farmers' risk perception on new technologies. In terms of policies, extension services may play an important role as drivers of WCSTs diffusion, thus policy makers could increase the effectiveness of WCSTs adoption policies incentivizing farmers through an informal educational process to improve farmers' agricultural productivity and build their capacities for future development.

Other farm characteristics that positively influence the adoption of WCSTs are organisational factors (we have considered in this category all aspects related to capital goods and internal organization, e.g. structured division of labour and planning activities) and the availability of labour both in terms of intensity and low costs compared to other production factors. Therefore, farm structure and assets are crucial for WCSTs adoption, considering this, policy makers may operate in this direction by improving the managerial skills of farmers. Also capital assets of farm are a crucial driver of adoption and this could be stimulated directly through public funds or indirectly by stimulating the access to financial credit. A special type of asset is land ownership which was found to be another aspect that positively influences WCSTs adoption.

Finally, crop price and yields were unexpectedly found to be statistically correlated with a high level of WCSTs adoption in only a residual number of publications (two - Dinar and Yaron, (1990), Schaible et al., (1991) and one papers Pokhrel et al. (2018) - respectively). Crop specialisation, captured by including specific dummies in the econometric models, provided little evidence, as there is no clear correlation with WCSTs adoption - four papers show a positive correlation (Alcon et al., 2011; Green et al., 1996; Moreno and Sunding, 2005; Wheeler et al., 2010), while three show a negative correlation (Michailidis et al., 2011; Quintana-Ashwell et al., 2020; Zhang et al., 2019) - depending on the peculiarities of the crop studied in each different case. All of those factors should be furtherly explored in future studies to improve the actual knowledge in the literature.

In terms of farmer characteristics, the factor that most influences WCSTs adoption is education, in fact in thirteen papers increasing education level showed statically significant positive effects on WCSTs adoption. Therefore, investments in education are effective policies to increase WCSTs adoption. Another relevant aspect is the age of the farmer, which shows a negative correlation with WCSTs adoption, indicating that younger farmers have a greater propensity to invest in these technologies. These results are relevant in terms of policy suggestions, as the better educated and younger farmers may be the early adopters of the new irrigation technologies and increase their diffusion through other social factors, as also highlighted by the SLR results (Rogers, 1971).

As expected, farmer income and expected returns on investment were also found to be positively correlated with WCSTs adoption. External activities, defined as non-full-time work, were found to be positively correlated with WCSTs adoption in two cases (Wang et al., 2021; Yuan et al., 2021), while they were found to be negatively correlated in one case (Singh et al., 2015), giving no definite picture of how they might influence innovation adoption. In this case differences are not attributable to different irrigation technology adopted since in the three papers only in the work of Yuan et al. (2021) the technology analyzed is specified (sub-irrigation).

The social aspects were found to be relevant in the literature, indicating that these aspects can be an important driver of adoption and can be used by policy makers as a lever to diffuse innovation. The most important influencing element is social networks, found to be a driver of WCSTs adoption in seven studies (Genius et al., 2014; Hunecke et al., 2017; Salazar and Rand, 2016; Shrestha and Gopalakrishnan, 1993; Wang et al., 2021; Yuan et al., 2021; Zhang et al., 2019), which can increase the adoption of new irrigation technologies through imitation processes that reduce innovation risk (Feder, 1982; Feder et al., 1985; Stoneman and Battisti, 2010). This aspect have been extensively studied in the literature on innovation adoption and it should be further extended also in the literature focusing on WCSTs adoption. In terms of policies social networks can be a crucial factors to increase irrigation technology diffusion and this might be sustained through public support to bottom-up activities of farmers and mutual change of knowledge and association between farmers. Moreover, membership in farmers' associations (e.g., associations, unions, cooperatives) has been found in the literature as a factor influencing WCSTs adoption in five studies (Quintana-Ashwell et al., 2020; Salazar and Rand, 2016; Wheeler et al., 2010; Yuan et al., 2021; Zhang et al., 2019).

Another important factor for WCSTs adoption is prior knowledge and information on WCSTs, which is in line with the findings on extension services, while training activities were found to positively influence WCSTs adoption in only one case (Zhang et al., 2019). These last two findings are relevant in terms of innovation policies that can target specific organized farmer groups (e.g., associations) with information and knowledge transfers to amplify the potential level of adoption among members.

Access to credit and public funding were found to be factors in WCSTs adoption in relatively few publications, in fact they were found to be positively correlated with adoption in only three (Alcon et al., 2011; Belaidi et al., 2022, 2022; Salazar and Rand, 2016) and four cases (Cremades et al., 2015; Mi et al., 2021; Yu et al., 2008; Zhang et al., 2019) respectively. This highlights the importance of financial resources for undertaking the adoption of new irrigation technologies, therefore increasing the access to credit may boost the diffusion of WCSTs.

The most important geographical factors positively influencing the adoption of WCSTs are soil quality, which, as expected, increases the likelihood of adoption. In contrast, there is no clear picture for the other geographic characteristics (acclivity, soil type and proximity), as they were found to be statistically significantly correlated with WCSTs adoption with both positive and negative effects. There are not clear evidences on the effects of specific irrigation technologies in this results. The cost of water seems to be the most important aspect in influencing WCSTs adoption among water characteristics. This was expected and confirms that increasing water costs increase the level of WCSTs adoption. Water constraints (e.g., limited access to water) are another aspect that positively influences WCSTs adoption. As expected, access to groundwater increases WCSTs use, while conversely access to surface water reduces the likelihood of WCSTs adoption. This may highlight that groundwater, as a more expensive and less reliable source of water (e.g., energy cost, quality variability, potential depletion), increases farmers' investment in WCSTs, while access to surface water may influence the use of less water-efficient traditional irrigation methods (e.g., furrow or flood irrigation).

In terms of climatic and weather, the most prominent driver of WCSTs adoption has been identified in the literature as drought experiences (current or past) and aridity. Temperature was found to be positively correlated in four papers (Dinar and Yaron, 1990; Knapp and Huang, 2017; Mendelsohn and Dinar, 2003; Olen et al., 2016), but two studies indicate temperature as a negative determinant of WCSTs adoption (Frisvold and Deva, 2013; Huang et al., 2017), which might depend on: a) conditions of the case study and irrigation system considered (i.e. sprinklers reduce their efficiency with high level of evaporation which can occur at high temperatures), b) difficulties in capturing this element with the econometric approaches employed in those studies, c) the level of aridity is a combination of precipitation and temperature, but both indicators (not only temperature) are necessary to characterize a location (Frisvold and Deva, 2013; Knapp and Huang, 2017). As expected, the level of precipitations negatively affects WCSTs adoption.

It should be noted that econometric analyses for WCSTs adoption are a very strong tool for interpreting farmers' adaptation strategies to various constraining factors, but may be limited by data availability. Furthermore, while econometric methods are good tools for explaining correlations and causality, they are not very good at predicting technology adoption or diffusion in the presence of data scarcity. An alternative method, in the absence of observational data, could be the use of mathematical programming, which can provide information on farmers' adaptation strategies to various constraints such as water limitation, climatic adversity, and land availability. Although these methods can be very useful for policy design, they are based on strong assumptions (e.g. complete rationality, profit maximisation, complete information) that are many times far from reality. Econometrics in this case can help to consider the adoption process in a more systemic view, taking into account all potential aspects that may influence adoption decisions. In any case, these two main methods widely used in agricultural economics can be balanced or used together to find different answers or to provide more in-depth knowledge of WCSTs adoption processes.

5.2. Further development of research on WCSTs adoption

Although the econometric literature on the WCSTs originated in the late 1980s, it has not grown significantly over time and this may be mainly due to the limited level of available data on irrigation water. The lack of data is a common situation in many countries, confirmed by the fact that most analyses considered in this review, with just a few exceptions, rely on one-year case studies based on surveys of specific productive agricultural areas. One of the main aspects of interest outlined by this review is that data limitations on irrigation technology and water use in agriculture restricted the analysis of this literature to specific case studies and the use of cross-sectional analysis based on small sample size.

The use of cross-sectional data confines the analysis to the explanation of why a farmer chooses to adopt new technology in the period considered. The use of cross-sectional strategies is most of the time driven by data constraints which may force the analyst to collect data through survey methods limiting the spectrum of the variety of observation to specific and homogeneous agricultural areas with low diversity of farms on various aspects: production, socio-economic conditions, climate and geographic factors and water endowments. Moreover, this approach may reduce the reliability of theoretical dynamic models that focus mainly on farmers' dynamic processes for choosing technology adoption on different dates or for excluding time-related elements such as learning by doing, observation and information collection, productive strategy changes, macroeconomic events and the individual heterogeneity of farmers (Koundouri et al., 2006). A panel data model can improve substantially the results of the analysis controlling for a dynamic pattern either endogenous or exogenous reducing the effect of time-specific events and unobserved individual effects problems providing more robust and consistent estimates (Greene, 2018). This is especially important if adoption farmers' decisions refer to past events, such as climate events or weather variables, or social factors influenced by the passing of time, such as imitation, word of mouth information and other peer effects. Only seven studies have used panel data and applied either continuous, fractional, multichoice or binary dependent variable models (Alcon et al., 2011; Huang et al., 2017; Knapp and Huang, 2017; Koundouri et al., 2006; Moreno and Sunding, 2005; Shrestha and Gopalakrishnan, 1993; Wheeler et al., 2010). Access to panel data could increase if there was active collaboration in research activities with farmers' associations and water management institutions to increase the implementation of measurement tools and data collection strategies.

The principal method used is a binary choice model, with probit and logit models, these models can capture the probability of adoption of the WCSTs innovation. Other extensively used methods based on multichoice dependent variable applying multinomial logit models. These methodologies are run to understand the probability of adoption of a specific technology over a set of several technologies available. But the main limitation of those methods is that they cannot capture the intensity of adoption in terms of how much WCSTs are used, which can be useful also for analysis related to technology diffusion processes (Stoneman and Battisti, 2010). Some studies focused on different type of innovation adoption as Arslan et al. (2014) used nested binary models, fractional methods, or Tobit models in order to study the intensity of adoption in terms of land under a specific technology, but those are still a residual part of the paper published (considering the wider literature on technology adoption in agriculture). The majority of the studies focused on WCSTs still focus on binary models, most of the time without differentiating between new adopters or already WCSTs users as most of the time cross-sectional studies do not allow to discern this aspect.

In terms of modelling, non-linearities in the covariates are not considered especially for aspects in which decreasing marginal rate of impacts on the probability of WCSTs adoption may occur, such as land, irrigated areas, the adopter's age and weather variables. Some potential determinants which may influence WCSTs adoption are not fully considered as drivers of adoption decision such as differences between family farms and business-oriented farms, insurance costs, proxies of risk propensities and sustainable productive approaches such as agroecological or organic farming. Those factors may be considered in future analyses as potential factors influencing adoption of sustainable irrigation technologies.

Most of the studies analysed in the SLR approach have been conducted in areas with important water scarcity problems, such as Israel, Greece, Spain, India, Chile, the Southwest USA, and China, but only focusing on specific regions without embracing supra-regional or national studies. Studies at the national level may improve the external validity of WCSTs adoption analysis allowing also for better inferential statements useful for policy makers. Further research may investigate determinants of adoption using national case studies to improve the external validity of the findings of WCSTs adoption literature. It should point out again that the SLR evidenced the complete absence of developing countries among the areas covered by econometric analysis on WCSTs adoption in the literature analyzed in this SLR. Further studies should focus on middle-low income and poor countries where the gains in terms of productivity may be strategic for agricultural development in the global south (e.g., Sub-Saharan Africa).

WCSTs adoption literature in its almost forty years of history had focused on various factors influencing farmers' adoption strategies such as cost-saving considerations, spatial distance, water price, the use of groundwater, institutional aspects, soil properties, local aspects and technical (crop choices) and informational factors as crucial in the process of farmers' decision of WCSTs adoption (Caswell and Zilberman, 1985; Green et al., 1996; Moreno and Sunding, 2005; Shrestha and Gopalakrishnan, 1993). This has been confirmed by other scholars with little differences due to the methods applied and different case studies (Alcon et al., 2011; Schuck et al., 2005; Wheeler et al., 2010). Only Skaggs (2001) considered farmers' expectation on the future perception of his/her economic performances as well as on water rights (farmers believe to lose the right of consuming water if they use fewer irrigation systems). However, statistical evidence is against the importance of these perceptions in the WCSTs adoption process. Very few studies tried to disagree with the mainstream, addressing some specific issues of the irrigation problem. For instance, focusing on risk aversion of farmers in adopting WCSTs as in Kounduri et al. (2006) or social capital as in Hunecke et al. (2017) highlighting the main role of the trust in water institutions, social norms and social networks (both formal and informal).

Farmers' adoption choices include the best adaptation strategies for climate change. Deciding to adopt new technology is mainly related to expectations about future outcomes on weather and climate, as well as their own perceptions and the information received from others. Therefore, by considering different scenarios of climate change, a farmer may gain the maximum benefits in terms of irrigation considering all the water constraints and natural risks. Just few studies in the literature have introduced climatic variables to analyse their effect on WCSTs adoption such as Negri and Brooks (1990) (evapotranspiration, rainfall, temperature in the growing season and frost-free days), Negri et al. (2005) (maximum temperature and high intensity or low intensity of precipitations), Genius et al. (2014) (aridity index) and Olen et al. (2016) (droughts, heats, and frost events as proxies of extreme climate conditions). But all of them relied on annual averages without considering past events or seasonal heterogeneities, which may be important in building up the "climate experience" of farmers in shaping their irrigation strategies. Only Frisvold and Deva (2013), used a long span of period (from 5 to 40 years) of seasonal mean temperature and the number of months below a threshold temperature of the long period mean as well as a measure of soil erosion due to excessive precipitations. Whereas, Knapp and Huang (2017) focused on climate variables using a different set of time period (5, 10, 20 and 30 years) for calculating the classical mean variables and their coefficient of variation (CV) influencing WCSTs adoption (mean temperature and total precipitations in the growing season) and adding indexes for severe droughts (Palmer index) and intense rainfall. Seasonal weather and past climatic events may be furtherly analysed in next research as potential determinants of WCSTs adoption to extend the actual literature on WCSTs adoption.

One element that has not attracted the attention of scholars is the specific characteristics of the WCSTs innovation as a factor influencing the adoption decision. But these practical aspects are crucial in defining the farm's absorptive capacity towards a new technology and thus will guide farmers' decision on technology adoption and diffusion. The characteristics of innovation have been neglected in the existing literature (none of the papers analysed in the SLR analysis treated this topic) and this may be mainly due to the difficulty of measuring and observing these aspects. Further studies could consider this topic as a new element of investigation to test the effects of innovation characteristics on WCSTs adoption decisions.

Another element which can be furtherly proposed in next studies is the use of counterfactual analysis to provide some causal evidence in terms of drivers and determinants of adoption. In none of the papers analysed in the SLR approach this aspect has been considered.

5.3. Other implications for policy makers and practitioners

The findings of the SLR analysis underlined the heterogeneity of situations and local aspects which may affect the adoption and diffusion of WCSTs among farmers. In fact, even if several factors influencing WCSTs adoption are common among the different case studies, some aspects remain case specific highlighting the importance of tailored and ad-hoc policies case by case.

In many cases, papers on WCSTs adoption and diffusion do not neither mention the potential drawbacks of WCSTs diffusion, but principally focusing on just the beneficial aspects using only a micro perspective ignoring most of the time hydrological component at basin scale or macro-scale effects of massive WCSTs diffusion.

Water conservation and saving techniques go beyond the classic motto 'more crop per drop' that FAO and other development agencies established as a strategy to increase food production when the water resources are limited (Giordano et al., 2021). Water saving has been demonstrated to have many positive outcomes such as increased resources productivity (e.g., land, water, and labour), higher efficiency in the use of fertilizer with a reduction in the diffuse pollution impact, improved labour quality enabling attractiveness of farming for young entrepreneurs.

On the other hand, relying on just WCSTs implementation as water conservation policy may present some 'side-effects' as increased energy consumption and increased water consumption at the water-basin level (i.e. 'rebound effect') (Berkhout et al., 2000; Sorrell and Dimitropoulos, 2008). More precisely, irrigation is closely related to the energy consumption increase (Espinosa-Tasón et al., 2020) that may be palliated by increasing the use of renewables, mainly solar photovoltaic systems (Hilarydoss, 2021). But the main potential drawback of WCSTs is the possibility of a rebound effect consisting in an overall increased water consumption after efficiency improvement that has been observed worldwide (Pérez-Blanco et al., 2020; Perry et al., 2017). Some authors pointed out that the inevitable rebound effect occurring after massive introduction of WCSTs may be limited if proper governance is implemented (Berbel and Javier, 2021) such as managing water return flow reduction (that are appropriated by the administration), controlling area expansion under WCSTs, and implementing policies aimed at increase water costs. There is evidence in the literature of an avoided rebound effect at the regional scale when appropriate policies are considered to mitigate the negative impacts of the massive spread of WCSTs (Zhou et al., 2021).

Improving water use efficiency is a policy measure with several well-demonstrated positive effects (water quality, resource productivity, and quality of labour) and some potential negative, though avoidable, effects (energy consumption and potential rebound). Policy makers should aim to maximize the positive and minimize and prevent the negative effects of WCSTs. Once the proper measures and countermeasures have been adopted, and WCSTs have been selected as a measure to tackle water scarcity, policy makers should consider the determinants for the adoption of innovation by farmers.

In the EU, the convenience of setting efficiency targets for stressed basins is outlined in 'Blueprint' (EC, 2012) as a tool to achieve Water Framework Directive objectives. Available evidence on the impact of water use efficiency improvements is diverse (ECA, 2021). Nevertheless, some EU countries (e.g., Spain, and Italy) with water scarce regions promote WCSTs as an important measure within agricultural and environmental policy.

Other countries have also promoted adoption of WCSTs by farmers, with mixed results and a heated debate in Australia. Wheeler et al. (2020) argue two justifications for subsidising WCSTs irrigation infrastructure: improved water quality and increased agricultural productivity; in contrast, arguments against the use of WSCTs in the Australian experience include: higher costs, lack of transparency, reduced return flows, rebound effect (as most farmers have increased irrigated areas) and reduced resilience (increased permanent crops) among other negative effects.

In the US, States and federal agencies subsidize farmers for WCSTs adoption and irrigation districts infrastructure (Burt, 2013). There has also been an academic debate on the rebound effect of WCSTs like the one mentioned for Australia. China has promoted water-saving irrigation at the regional level with significant abstraction decreases at the farm level but reported increased water consumption at the regional level explained by the crop intensification (perennials and higher demanding crops) (Wang et al., 2020). Similar policies have been promoted and observed in Canada even though the adoption rate by farmers is low and enhanced by the relevance of social networks (Wang et al., 2016).

Worldwide experience in the promotion of WCSTs suggests that farmers' response to subsidies is positive although the WCSTs adoption is heterogeneous depending on personal characteristics of the farmer and the farm environment. At the policy level, the promotion of WCSTs results in a complex impact on agricultural production, farmer welfare, water quality and water resource exploitation. Therefore a mix of different policies is needed to compensate the potential negative effect of WCSTs mass diffusion while allowing the beneficial effects of irrigation innovation adoption on farm productivity and agricultural income.

6. Conclusions

To ensure food security in a context of increasing water use and demand and growing climatic variability, more crop per drop is required. This can be achieved by improving agronomic practices, using improved seeds and investing in WCSTs. This study has developed an extended SLR analysis exploring the determinants of WCSTs adoption by analysing 40 years of available literature. This analysis has drawn a critical overview of the empirical works dealing with these issues.

The results show how there exist many factors that may affect the adoption of irrigation technologies as WCSTs. Our analysis has shown that many dimensional aspects influence the likelihood of farmers adoption of WCSTs and that there are convergence in the results found in the literature regarding both farmer characteristics (age, education, financial state), farm characteristics (size), socioeconomic environment (extension services, country level of development, subsidies) institutions (quotas, waster cost) or natural environment (scarcity, precipitation, drought). Although our results are based on case studies and small surveys, highlights that the adoption of more sustainable irrigation methods should be considered in a multidimensional way. Therefore, the implementation of tailored water policies, based on the relevant determinants of WCSTs adoption, should be stimulated by considering spatial diversity and improving water savings without negatively impacting on agricultural production.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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