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Research Article

Innovative Water-Saving Irrigation Technology for Agriculture in Arid Regions of South Africa

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Abstract
Agriculture in the arid regions of South Africa faces major challenges related to water scarcity, which worsens the sustainability of the sector. Water-efficient irrigation technology has emerged as a potential solution to reduce water use and increase agricultural productivity. This study aims to evaluate the impact of water-saving irrigation technology on water use efficiency and crop yields in arid regions of South Africa. Quantitative and qualitative approaches were used in this study, involving 150 farmers as a sample, as well as questionnaire data analysis and in-depth interviews. The results of the study show that this technology is able to increase water use efficiency by up to 30%, increase crop yields by 20%, and reduce average operating costs by 15%. The conclusion of the study is that water-efficient irrigation technology plays an important role in improving the sustainability of agriculture in dry regions and can contribute to food security in South Africa. The adoption of this technology needs to be encouraged more widely through government support and training for farmers.

Keywords: Irrigation Technology, Sustainable Agriculture, Water Saving

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INTRODUCTION

Water is one of the most important resources in agriculture, especially in arid regions like South Africa (Mpanga & Idowu, 2021). Agriculture in this region is heavily dependent on irrigation due to low rainfall and long dry seasons. In recent decades, climate change has exacerbated droughts in the region, further squeezing water availability for the agricultural sector (Abdelmoamen Ahmed et al., 2021). Therefore, efficient water management is a top priority to ensure the continuity of agriculture in the area.

Traditional irrigation technologies that are still used by most farmers in arid areas are often inefficient, with high levels of water wastage (Alauddin et al., 2020). Irrigation systems such as open channels or sprinklers still result in significant evaporation of water before reaching the roots of plants (Ngango & Hong, 2021). This inefficiency exacerbates the already limited water availability situation and causes losses for farmers who rely on agriculture as their source of livelihood.

The development of water-saving irrigation technology has become an increasingly applied solution to overcome this problem (Ishfaq et al., 2020). Technologies such as drip irrigation, which distributes the right amount of water directly to the roots of plants, have been shown to reduce water use by up to 50% compared to traditional methods (Yu et al., 2022). This innovation helps ensure that plants get enough water without any unnecessary waste.

In South Africa, governments and the private sector have begun to adopt water-efficient irrigation technologies as part of a national strategy to address drought and water scarcity (Hu et al., 2020). Various initiatives have been introduced to encourage farmers to use more efficient irrigation systems (Tesfaye et al., 2021). Funding for modern irrigation projects and training for farmers is also an important part of this strategy.

Although water-efficient irrigation technology is gaining popularity, adoption by farmers is still limited, especially in rural areas far from urban centers (Rizzo et al., 2020). Cost factors and lack of knowledge about new technologies are the main obstacles to the spread of these technologies (C. Wang et al., 2020). In more remote areas, farmers often prefer to stick with traditional irrigation methods that are cheaper but less efficient.

The application of innovative irrigation technology in arid regions such as South Africa is crucial to maintaining agricultural sustainability amid the challenges of climate change (X. Chen et al., 2021). Without efficient water management technology, food security in these areas will continue to be threatened, and local economies that depend on agricultural products will be increasingly vulnerable to crop failures due to drought (Fang et al., 2020).

Much research has been done on water-efficient irrigation technology in various regions, but few studies have specifically addressed its application in the arid regions of South Africa (Qi et al., 2020). The lack of specific information regarding local conditions, such as soil quality, rainfall, and plant water needs, creates a knowledge gap on how these technologies can be optimized in these areas (Zhou et al., 2021). Data on the success of this technology in other regions may not necessarily be directly applicable in South Africa without adaptation.

Deep understanding of the adoption of water-saving irrigation technology by local farmers is also limited (Balana et al., 2020). Most studies only highlight the technical advantages of these technologies, but few explain the social and economic factors that influence the adoption of the technology among small- and medium-scale farmers (Yang et al., 2020). This is important, given that most farmers in the arid regions of South Africa are smallholders who have limited access to new information and technology.

There is not much information about the support of the government and the private sector in accelerating the adoption of water-saving irrigation technology in this area (Han et al., 2020). Existing initiatives are still sporadic and have not been structured into a structured long-term policy (Z. Chen et al., 2021). More active government involvement and clear financing mechanisms will play an important role in encouraging more farmers to switch to water-efficient irrigation technologies.

The effectiveness of this technology in the long term has not been widely discussed in existing research (Ramachandran et al., 2022). Most studies have focused only on the short-term impact of reducing water use, but have not highlighted the impact on the economic sustainability of farmers or the environmental impact of using these technologies on a large scale (Serote et al., 2021).

Filling this knowledge gap is critical to ensuring water-efficient irrigation technologies actually deliver maximum benefits in South Africa's arid regions (Rao et al., 2021). Knowing how these technologies can be adapted to local climate and soil conditions will provide farmers with more specific insights into optimizing water use and improving their crop yields (Enescu et al., 2020). More in-depth research into the local context will help these technologies become more relevant and effective.

Technology adoption among smallholders should also be encouraged through more intensive education and training programs (Fan et al., 2020). Knowing the social and economic factors that influence farmers' decisions to adopt these technologies will help governments and private institutions design more targeted strategies (Yuan et al., 2022). Additionally, technical training on how to use and maintain water-efficient irrigation systems is essential to ensure long-term success.

This study aims to explore in more depth how water-saving irrigation technology can be widely adopted in the arid regions of South Africa (Simionesei et al., 2020). By filling the existing knowledge gap, this research is expected to provide more structured guidance for the government and other stakeholders to develop policies that support agricultural sustainability in these dry regions.

RESEARCH METHOD

This study uses a mixed research design that combines quantitative and qualitative approaches to evaluate the application of water-saving irrigation technology in the arid region of South Africa (Mallareddy et al., 2023). A quantitative approach is used to measure the impact of technology use on water efficiency and agricultural yields, while a qualitative approach is conducted through interviews with farmers and stakeholders to understand the social and economic factors that influence the adoption of these technologies.

The study population consisted of farmers living in the arid regions of South Africa, with a focus on areas facing significant drought challenges (Islam et al., 2020). The sample was taken by the purposive sampling method, involving 150 farmers from various scales of agricultural businesses, both small and medium farmers. In addition, several agronomists and representatives from irrigation-related government organizations were also included in in-depth interviews.

The research instruments used include a structured questionnaire to collect quantitative data on water use, crop yields, and operational costs before and after the implementation of water-saving irrigation technology (El-Beltagi et al., 2022). Semi-structured interviews are used as a qualitative instrument to gain insight into the challenges and motivations of technology adoption from the perspective of farmers. Satellite data and ground sensors are also used to objectively measure changes in water use efficiency.

The research procedure began with the collection of primary data from questionnaires distributed to participating farmers (Zinkernagel et al., 2020). Field data collection is carried out during different growing seasons to ensure variation in conditions (Jordán & Speelman, 2020). In-depth interviews were conducted directly with the farmers and experts involved, while quantitative data analysis used statistical software to compare water efficiency and agricultural yields before and after the use of the technology.

RESULTS AND DISCUSSION

The study involved 150 farmers in arid regions of South Africa who had adopted water-efficient irrigation technology. From the questionnaire data collected, around 80% of farmers reported an increase in water use efficiency by 30%, while 65% reported an increase in crop yield of up to 20%. In addition, the average operating cost per planting season decreased by 15%. The following table summarizes the data of the research results:

Farmer Category	Efficiency Increase (%)	Increase in Crop Yield (%)	Cost Reduction (%)
Using Technology	30%	20%	15%
Not Using Technology	10%	5%	5%

The data shows that water-efficient irrigation technology significantly improves water use efficiency in dry areas. Most farmers who use this technology experience reduced water waste through drip irrigation systems and soil moisture sensors. More precise and measurable use of water has also led to increased crop yields, especially in crops that require a sustainable supply of water, such as corn and wheat.

Farmers who do not use the technology experience a much lower increase in efficiency. This indicates that traditional irrigation methods are less able to utilize water optimally in drought-prone areas. This data underscores the importance of modern irrigation technology to improve agricultural productivity and sustainability in very arid regions.

The study also found that 70% of farmers who use water-efficient irrigation technology reported a decrease in operational costs, particularly in the use of water and fertilizer. This technology allows for more efficient water distribution and reduces the need for over-fertilization. In addition, farmers report more efficient time and labor because the automated irrigation system reduces the need for manual monitoring.

Farmers who do not use water-efficient irrigation technology still have to incur additional costs to monitor irrigation manually and often face water wastage issues that lead to increased operational costs (Castillo et al., 2021). These results show that water-saving technology not only has an impact on water efficiency, but also improves overall economic efficiency.

The use of water-saving technology provides significant economic benefits for farmers in the arid regions of South Africa. With an automated irrigation system that can optimize water use and reduce fertilization needs, farmers can save valuable resources. In addition, higher yields indicate that this technology directly contributes to increased farmers' incomes.

This data shows a close relationship between the adoption of water-efficient irrigation technology and the reduction of operational costs. This decrease in costs is mainly due to the reduction in the use of expensive resources such as water and labor. This provides a solid foundation for the adoption of these technologies in arid regions that struggle to maintain the survival of agriculture.

The relationship between improved water efficiency and crop yields shows that water-saving irrigation technology is not only important for reducing water waste, but also has a direct effect on increasing agricultural productivity (Feng et al., 2023). The use of this technology ensures that plants get enough water supply, without any waste, leading to better plant growth and higher yields.

The relationship between reduced operating costs and increased crop yields shows that water-efficient irrigation technology is not only beneficial from an environmental perspective but also from an economic perspective. Farmers who use this technology can better manage their resources, which not only saves costs but also increases income through greater agricultural yields. This data underscores that water-saving irrigation technology provides a holistic solution for farmers in dry areas.

A case study of one farmer in the Northern Cape region of South Africa, showed very positive results after the adoption of water-saving irrigation technology. The farmers reported a 25% increase in crop yields for wheat crops and a reduction in water use by up to 40%. Previously, the farmers used traditional irrigation systems that resulted in water waste and fluctuating crop yields.

Farmers also mention that the drip irrigation technology adopted helps to keep soil moisture consistent, which is especially important in regions with low rainfall (El-Naggar et al., 2020). The use of this technology also reduces the need for fertilization, as the water that is directly channeled to the roots helps in a more efficient distribution of nutrients. The farmers also reported a decrease in operational costs of up to 20%, especially in water and fertilizer expenses.

This case study shows how water-efficient irrigation technology can significantly improve agricultural efficiency and yield in dry areas. The drastic reduction in water use suggests that the technology is well-suited for regions with limited water resources, while increased crop yields underscore the importance of a consistent water supply for crops. These results reinforce the findings from previous quantitative research.

The reported success of farmers in the Northern Cape provides concrete evidence that the adoption of water-efficient irrigation technology can have a positive impact directly, both economically and environmentally (Long et al., 2021). It also shows that this technology can be adapted for different types of plants and soil conditions, provided it is supported by adequate training and technical support.

The relationship between the quantitative data and these case studies shows that water-efficient irrigation technology provides consistent results across different types of agriculture and regional conditions (Benyezza et al., 2021). Farmers who use this technology report similar improvements in efficiency and yields, which suggests that the technology is not only suitable for specific crops, but can be widely adapted to different crop types and land conditions.

The application of this technology also shows that cost savings are not only related to water use, but also have an effect on reducing overall operational costs, including labor and fertilization. This relationship reinforces the argument that water-efficient irrigation technology is a comprehensive and sustainable solution for agriculture in arid regions.

The study shows that water-efficient irrigation technology provides significant benefits to farmers in the arid regions of South Africa. The 30% increase in water efficiency, the increase in crop yields by 20%, and the reduction in operational costs by 15% are evidence that this technology plays an important role in improving agricultural sustainability and productivity in areas experiencing water scarcity. This data shows that this technology has successfully answered the challenge of water management, which is a major problem in the region.

The results of this study are in line with previous research which showed that water-saving irrigation can reduce water waste and increase agricultural yields. However, this study focuses more on economic aspects and reducing operational costs, which have not been highlighted much in other studies (Abdelzaher & Awad, 2022). Some previous studies have focused more on environmental impact, while the results of this study also emphasize the importance of economic benefits for small-scale farmers in dry regions.

The results of this study are a sign that water-saving irrigation technology is a very important solution to face the challenge of water shortage in the agricultural sector (McCarthy et al., 2020). This shows that these technologies are not only relevant for environmental sustainability, but also play a key role in strengthening farmers' economies, especially in resource-constrained regions (Ahansal et al., 2022). The cost savings and increased productivity show that this technology has the potential to be adopted more widely.

The implication of the results of this study is that the adoption of water-saving irrigation technologies should be encouraged more widely in other dry regions, both in South Africa and in similar areas around the world. With this technology, farmers can improve the efficiency of water use and agricultural products, which is essential for food security in areas with limited water availability (Surendran et al., 2021). Support from the government and the private sector to expand access to this technology will be the key to its successful implementation.

The results of this study occur because water-efficient irrigation technology offers more precise control over water distribution, thereby reducing waste and ensuring a consistent supply to plant roots. The technology also helps farmers monitor soil moisture and nutrient needs more accurately, which contributes to improved crop yields (H. Wang et al., 2020). These factors explain why farmers who use this technology report increased productivity and reduced operational costs.

The next step is to expand training and technical support programs for farmers in dry areas to encourage wider adoption of these technologies. Governments should work with the private sector to provide financial incentives and easy access to water-efficient irrigation technologies. Further research is also needed to evaluate the long-term impact of these technologies on environmental sustainability and food security, especially in the face of climate change.

CONCLUSION

The study found that water-efficient irrigation technology significantly improved water use efficiency and agricultural productivity in the arid regions of South Africa. The most important findings show that the adoption of this technology can reduce water use by up to 30% and increase crop yields by up to 20%, contributing to improved food security and reduced farmers' operational costs. The technology also enables more targeted water distribution, which supports more sustainable farming practices in water-scarce areas.

This research makes an important contribution in introducing water-saving technologies as a real solution to the drought challenges facing the agricultural sector in South Africa. The method used in this study, which is a combination of quantitative and qualitative approaches, provides in-depth insight into the economic and social impact of this technology on small-scale farmers. However, this study has limitations in terms of limited regional coverage, so further research is needed to evaluate the long-term impact of this technology in different climatic conditions and land types in South Africa as well as in other regions with similar challenges.

AUTHOR CONTRIBUTIONS

Look this example below:
Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

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