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Global Insights, Local Applications: Irrigation Technologies and Agricultural Drought Mitigation in the Canadian Prairies

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Abstract: The Canadian Prairies face significant water scarcity challenges despite the country's abundant freshwater resources. This scarcity, driven by limited water availability and increasing agricultural demands, makes the region vulnerable to drought. As a major agricultural hub, droughts have led to economic losses and reduced crop productivity. This scoping review examines global drought response measures, focusing on irrigation technologies adaptable for Western Canada. Case studies from Australia, China, and the United States highlight advances in water use efficiency and irrigation technologies, including drip and subsurface drip irrigation (SDI), center-pivot irrigation (CPI), and drought-resistant crop varieties. Examples include Australia's prioritization of essential crops and improved irrigation infrastructure, China's adoption of water-saving rice varieties, and California's use of SDI for water conservation. Adopting these established irrigation techniques could enhance water use efficiency, support food security, and contribute to sustainable water management in the Canadian Prairies. This review underscores the value of integrating global practices to strengthen agricultural resilience in the region.

Keywords: Irrigation Technologies, Drought Mitigation, Canadian Prairies, Sustainable Agriculture.

1. Introduction

Despite being home to some of the world's most abundant freshwater resources, The Prairie region of Canada faces significant challenges related to water scarcity. This issue is primarily driven by limited water availability and increasing demand, especially from the agricultural sector, which is a major consumer of water resources [6]. While the Great Lakes serve as a critical source of both surface water and groundwater utilized for daily domestic water and agricultural activities, this resource is unevenly distributed across the country. The Prairie provinces—Alberta, Saskatchewan, and Manitoba—are particularly vulnerable due to their geographical distance from such large water bodies [7]. These provinces account for 80% of Canada's farmland and often experience significant fluctuations in rainfall. Such variability in precipitation leads to frequent droughts, which disrupt crop and pasture productivity, posing a persistent threat to the agricultural economy [1]. In Saskatchewan, where agriculture accounts for more than 56.3% of the province's water withdrawals, there is increasing pressure to adopt more efficient irrigation strategies. Population growth, economic

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development, and climate change are all contributing to rising water stress in the region. To address these challenges, the Saskatchewan Ministry of Agriculture has proposed a 400% increase in irrigated land to enhance food security and boost economic growth [5].

The impacts of these droughts are far-reaching. In the early 21st century, severe drought conditions resulted in considerable economic losses in the agricultural sector, affecting food security and livelihoods. Drought not only diminishes crop yields but also depletes water reserves that are vital for irrigation and livestock. Given the critical role agriculture plays in the Prairie economy, there is an urgent need for effective water management strategies that address the challenges of climate-induced water shortages. This scoping review seeks to explore global drought response strategies and irrigation technologies that could provide more sustainable water management practices in the Canadian Prairies. The review will focus on identifying effective irrigation methods that have been successfully implemented in other drought-prone regions and evaluating their potential application in Western Canada. Through a comprehensive analysis of global case studies, the review will answer three key questions: How do other regions address drought challenges in agriculture? What irrigation technologies have been proven effective in mitigating drought? How can these practices be adapted to the Canadian context, especially Western Canada? The ultimate goal of this review is to discover approaches that may enhance agricultural resilience to future droughts and ensure sustainable water use.

1.1. Drought handling approaches around the world

Affecting nearly half of the Earth's land area, droughts are a global phenomenon with severe consequences for major agricultural regions. The economic and social impacts of droughts are significant as they often lead to reduced crop yields, food shortages, and strained water resources [8]. One of the countries and regions facing these challenges is Australia, particularly in the Murray-Darling Basin, which relies heavily on irrigated agriculture. This region, home to the country's largest river system, has experienced dramatic reductions in crop production due to water shortages. Between 2002 and 2009, rice production in the Basin dropped by 99%, while cotton production fell by 84% [3]. These reductions not only harmed the economy but also severely impacted the livelihoods, as the farmers faced reduced income and declined food production. The drought's effects extended beyond just crop yields: falling reservoir water levels exacerbated the water shortages, further reducing the ability to irrigate crops [3]. In response, the Australian government and farmers implemented several strategies to mitigate the impact of drought on agriculture. One of the key measures was improving water use efficiency (WUE) through advancements in agricultural practices. These improvements were particularly effective in wheat production, where enhanced WUE helped reduce yield losses. In addition, water management policies in the Murray-Darling Basin prioritized essential crops over less critical ones, even though rice and cotton yields remained low. Farmers also expanded dryland farming to adapt to the reduced availability of irrigation water, helping to offset the impact of the drought [3].

In Asia, China faces similar drought challenges, particularly in its rice-producing regions. Rice accounts for nearly half of the country's freshwater consumption, making it especially vulnerable to water shortages. Each year, drought affects around 26.67 million hectares of farmland, leading to significant reductions in food production, estimated at 70-80 billion kilograms annually [2]. To combat these losses, China focused on developing water-saving and drought-resistant rice varieties. These improved varieties can maintain high yields under drought conditions while reducing water consumption by up to 50%. China's approach also includes integrating genetic and molecular techniques to further enhance drought tolerance and productivity in rice [2].

Both Australia and China's experiences underline the importance of developing drought-resistant crops and adopting advanced irrigation systems. These strategies not only increase agricultural

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resilience to drought but also ensure more sustainable water management. For Canada, particularly in the drought-prone Prairie region, adopting similar approaches could significantly mitigate the impacts of water scarcity on agriculture.

1.2. Irrigation technologies proven effective in mitigating drought

In drought-prone regions across the globe, efficient irrigation technologies have proven essential for conserving water and sustaining agricultural productivity. In California, for example, drip irrigation has become a widely used method, particularly for high-value crops like tomatoes, almonds, and cotton. This technique delivers water directly to the plants' roots, minimizing evaporation and maximizing water use efficiency [4]. Drip irrigation systems allow for precise control over water distribution, ensuring that only the necessary amount is applied, which is critical in regions with scarce water resources. A more advanced version of this method, subsurface drip irrigation (SDI), is becoming increasingly attractive, especially for perennial crops such as almonds and prunes. SDI delivers water below the soil surface, further reducing evaporation and allowing for the precise delivery of water, nutrients, and pesticides. This not only boosts crop yields and quality, but also minimizes water wastage and decreases weed growth, subsequently lowering the need for herbicides [4]. While drip irrigation, including SDI, excels in water use efficiency by delivering water directly to the plant roots and improving crop productivity, it can be costly to install and maintain, making it more suitable for high-value crops like almonds [4]. SDI has proven to be an effective technology for improving both water efficiency and crop productivity in water-scarce environments. Another notable irrigation technology is center-pivot irrigation (CPI), widely adopted in water-stressed areas like the Midwest United States. CPI consists of a rotating sprinkler system that evenly distributes water across large agricultural fields. This method is particularly beneficial for crops like corn and soybeans, which require consistent moisture. In regions like south-central Nebraska, CPI optimizes the timing and distribution of irrigation, improving overall yields by preventing water stress during critical growth periods [9]. While CPI is more cost-effective for large fields and is widely used for crops like corn and soybeans, it is less precise and can lead to higher water loss through evaporation [9]. Both SDI and CPI are critical for water-scarce environments, though they vary in efficiency and cost. However, adopting these technologies in Canada poses challenges for water resource management. With high agricultural water withdrawal and existing water deficiency, implementing technologies like drip irrigation, SDI, and CPI is critical for maintaining sustainable water use while supporting agricultural productivity in drought-affected areas.

1.3. Applying global irrigation technologies to STO and MTO in Western Canada

Agricultural and irrigation policies in the Canadian Prairie provinces face challenges in balancing productivity with environmental sustainability. Excessive nitrogen fertilizer use on crops like potatoes and corn increases nitrous oxide emission, contributing to eutrophication and climate change [16]. Improper irrigation management exacerbates this issue [10]. Researches show that National guidelines such as the IPCC Tier II protocol may be outdated that they overestimate emissions in the Prairies [10]. More region-specific data is needed to better manage irrigation and nitrogen fertilizer application, ensuring optimal yields while minimizing environmental impacts.

Alberta, with the largest irrigation system in Canada, primarily supports large irrigation districts using water from the Bow and Oldman Rivers in the southern region. The province is now shifting to policies prioritizing water conservation and sustainability [10]. In Alberta's Western Irrigation District, multi-time-step optimization (MTO) significantly improves water management across the season. It performs better than single-time-step optimization (STO), which focuses on individual periods [11]. MTO better balances water demand and reservoir storage, reducing the need for large

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infrastructure projects like the Bruce Lake reservoir [12]. Data shows that a 35% smaller reservoir expansion would meet irrigation demands while maintaining a low water deficit. STO, on the other hand, often depletes reservoirs too early, increasing the risk of crop failure especially in drought years [12]. Since STO makes decisions based on isolated time steps, MTO considers multiple steps simultaneously, achieving more efficient water allocation and minimizing shortages [11]. However, both methods have limitations. Global case studies offer valuable lessons for addressing the limitations of STO and MTO in Alberta's irrigation system. While STO focuses on isolated timeframes, leading to inefficiencies like premature reservoir depletion, MTO is more comprehensive but complex to implement. STO's short-term focus limits its effectiveness during prolonged droughts, whereas MTO, though more accurate and reliable, requires complex modeling and robust computational power, making it harder to implement in real-time scenarios [12].

These limitations can be partially complemented by innovations from international case studies [11]. For instance, water management strategies in Australia's Murray-Darling Basin prioritize essential crops and integrate adaptive water policies, which could supplement MTO by providing dynamic decision models. By balancing water allocation during extended droughts and ensuring critical crops receive water first, such strategies avoid STO's short-term risks and optimize MTO's multi-step approach [3]. This would reduce the likelihood of reservoir depletion during drought seasons. Furthermore, advanced irrigation technologies like subsurface drip irrigation (SDI), which have proven successful in managing perennial crops in California [4], can reduce water losses in Alberta's agriculture. SDI minimizes evaporation and delivers water directly to the root zone, cutting water waste in regions where STO models often fail to optimize long-term water efficiency. SDI can be combined together with CPI, where the flexibility of CPI supports large-scale crops and the precision of SDI conserves water for high-value, water-sensitive crops [4]. This hybrid strategy addresses STO's limitations by providing more stable water supplies during droughts.

Additionally, China's innovations in drought-resistant crop varieties offer a pathway for Alberta to reduce irrigation dependency for certain crops. If a drought-tolerant variety can be developed suited to local conditions, it can lower overall water demand during droughts. This strategy would reduce irrigation water needs and alleviate pressure on reservoir supplies, complement the MTO system by reducing the complexity of water allocation during prolonged droughts [2]. As Saskatchewan is planning to expand irrigation system and increase irrigation acreage by 400%, these global practices can be integrated with expansion efforts [5].

By adopting efficient irrigation technologies and crop management strategies from Australia and China, Saskatchewan's expansion can minimize environmental footprints and prioritize water conservation and sustainability. For example, combining SDI with optimized MTO systems would enable Saskatchewan to effectively manage water resources, even as irrigation demand rises [5]. Combining adaptive crop selection and innovative irrigation technologies from global case studies can significantly improve the efficiency and sustainability of Alberta's irrigation system, addressing the shortcomings of STO and MTO. These methods would not only mitigate water shortages but also enhance the long-term agricultural resilience of the Canadian Prairies.

2. Addressing drought by contributing to sustainable agriculture

The drought in Canadian Prairie region is related to not only water deficiency, but also rising energy costs, greenhouse gas emissions, biodiversity loss, and resource degradation [13]. Ecological factors significantly affect agriculture and water resource in various ways, highlighting the importance of agricultural sustainability. To address these issues, diversified planting, reducing external inputs, and using cover crops and perennials can improve the profitability, sustainability, and resilience of agricultural systems. These practices contribute to regional agricultural development and help to mitigate drought risks [13]. Additionally, using manure and green manure can reduce reliance on

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synthetic fertilizers and improve soil health, establishing more stable nutrient cycles and enhancing the long-term resilience and productivity of agricultural systems [13]. Drought-tolerant crops, such as quinoa, present a viable solution for cultivation in the arid regions of the Canadian Prairies. Quinoa is well-suited to these areas and they can regulate osmotic pressure by increasing soluble sugars, retaining moisture, and reducing oxidative damage under drought conditions [14]. Furthermore, quinoa is rich in protein, essential amino acids, dietary fiber, and minerals, making it a healthy food that boosts immunity, promotes digestion, and provides comprehensive nutrition [14]. Therefore, quinoa not only adapts well to drought-prone environments but also improves people's nutritional intake.

In addition to dealing with drought, sustainable land and water resource management also requires strengthening wetland conservation. Wetlands play a critical role in water resource sustainability and serve as vital habitats for waterfowl, but they are sensitive to climate and agricultural practices. Snowmelt is the primary water source for wetlands, but water depletes when evaporation in summer often exceeds precipitation. Monitoring wetland hydrology is essential in the context of climate and land-use changes, requiring regional and intensive monitoring methods to predict long-term trends and improve wetland management [15].

In summary, the Canadian Prairies face multiple environmental and agricultural challenges, including drought, rising energy costs, greenhouse gas emissions, and biodiversity loss. Diversified planting, reduced external inputs, and the introduction of drought-tolerant crops like quinoa can enhance agricultural sustainability and resilience while effectively addressing drought crises. Meanwhile, wetland conservation and monitoring are key to sustainable water resource management, ensuring long-term ecosystem health and stability. By integrating ecological farming practices, wetland conservation, and effective irrigation strategies, the Canadian Prairies can foster sustainable agricultural development while tackling future climate change.

3. Conclusion

In conclusion, the Canadian Prairies face numerous intertwined challenges, including drought, water scarcity, rising energy costs, and environmental degradation, all of which threaten the sustainability of its agricultural sector. This scoping review highlights the critical need for adopting innovative irrigation technologies and sustainable agricultural practices to enhance the region's resilience against these threats. Drawing on global case studies from Australia, China, and the United States, it is evident that advanced irrigation technologies such as drip irrigation, subsurface drip irrigation (SDI), and center-pivot irrigation (CPI) have proven effective in conserving water and maintaining agricultural productivity in drought-prone regions. These technologies, combined with region-specific policies, can significantly enhance water use efficiency and reduce the environmental footprint of agriculture in the Prairies. Moreover, integrating drought-resistant crop like quinoa, which can thrive under harsh conditions and offer considerable nutritional benefits, could play a crucial role in strengthening food security and reducing water demand in the region [14]. These crops, along with ecological practices such as crop diversification, green manure usage, and wetland conservation, can help establish more resilient farming systems while mitigating the impacts of climate change. This review also highlights the crucial role of adaptive water management strategies, such as multi-time-step optimization (MTO), in balancing water demand with reservoir storage. MTO reduces the necessity for large-scale infrastructure investments and offers a more flexible approach to water management during droughts. By incorporating global insights and customizing them to fit local conditions, the Canadian Prairie provinces can greatly enhance their ability to manage future droughts while promoting sustainable agricultural growth. The implementation of irrigation technologies, ecological farming practices, and flexible policies presents a well-rounded approach to create a resilient and sustainable agricultural system in the Canadian Prairies.

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References

[1] *Tadesse, T., Champagne, C., Wardlow, B. D., Hadwen, T. A., Brown, J. F., Demisse, G. B., Bayissa, Y. A., & Davidson, A. M. (2017). Building the vegetation drought response index for Canada (VegDRI-Canada) to monitor agricultural drought: First results. GIScience & Remote Sensing, 54(2), 230–257. https://doi.org/10.1080/15481603.2017.1286728*

[2] *Luo, L. J. (2010). Breeding for water-saving and drought-resistance rice (WDR) in China. Journal of Experimental Botany, 61(13), 3509–3517. https://doi.org/10.1093/jxb/erq185*

[3] *van Dijk, A. I., Beck, H. E., Crosbie, R. S., de Jeu, R. A., Liu, Y. Y., Podger, G. M., Timbal, B., & Viney, N. R. (2013). The millennium drought in Southeast Australia (2001–2009): Natural and human causes and implications for water resources, ecosystems, economy, and Society. Water Resources Research, 49(2), 1040–1057. https://doi.org/10.1002/wrcr.20123*

[4] *Ayars, J. E., Fulton, A., & Taylor, B. (2015). Subsurface drip irrigation in California—here to stay? Agricultural Water Management, 157, 39–47. https://doi.org/10.1016/j.agwat.2015.01.001*

[5] *Hassanzadeh, E., Elshorbagy, A., Wheater, H., & Gober, P. (2014). Managing water in complex systems: An integrated water resources model for Saskatchewan, Canada. Environmental Modelling & Software, 58, 12–26. https://doi.org/10.1016/j.envsoft.2014.03.015*

[6] *Sadler, B. (1990). Sustainable Development and Water Resource Management. Alternatives: Perspectives on Society, Technology and Environment, 17(3), 14–24. http://www.jstor.org/stable/45031205*

[7] *Hachborn, E., Berg, A., Levison, J., & Ambadan, J. T. (2017). Sensitivity of grace-derived estimates of groundwater-level changes in southern Ontario, Canada. Hydrogeology Journal, 25(8), 2391–2402. https://doi.org/10.1007/s10040-017-1612-2*

[8] *Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. Journal of Hydrology, 391(1–2), 202–216. https://doi.org/10.1016/j.jhydrol.2010.07.012*

[9] *Mausbach, J., Irmak, S., Kukal, M. S., Karnik, K., Sarangi, D., & Jhala, A. J. (2023). Evapotranspiration of Palmer Amaranth (Amaranthus palmeri) in maize, soybean, and fallow under subsurface drip and center-pivot irrigation systems. Weed Science, 72(1), 86–95. https://doi.org/10.1017/wsc.2023.57*

[10] *Gao, X., Tenuta, M., Nelson, A., Sparling, B., Tomasiewicz, D., Mohr, R. M., & Bizimungu, B. (2013). Effect of nitrogen fertilizer rate on nitrous oxide emission from irrigated potato on a clay loam soil in Manitoba, Canada. Canadian Journal of Soil Science, 93(1), 1–11. https://doi.org/10.4141/cjss2012-057*

[11] *Ilich, N. (2010). Improving real-time reservoir operation based on combining demand hedging and simple storage management rules. Journal of Hydroinformatics, 13(3), 533–544. https://doi.org/10.2166/hydro.2010.183*

[12] *Ilich, N., Davies, E. G., & Gharib, A. (2020). New modeling paradigms for assessing future irrigation storage requirements: A case study of the western irrigation district in Alberta. Canadian Water Resources Journal / Revue Canadienne Des Ressources Hydriques, 45(2), 172–185. https://doi.org/10.1080/07011784.2020.1737237*

[13] *Martens, J. R., Entz, M. H., & Wonneck, M. D. (2015). Review: Redesigning Canadian prairie cropping systems for profitability, sustainability, and resilience. Canadian Journal of Plant Science, 95(6), 1049–1072. https://doi.org/10.4141/cjps-2014-173*

[14] *Lin, P.-H., & Chao, Y.-Y. (2021). Different drought-tolerant mechanisms in quinoa (Chenopodium quinoa Willd.) and djulis (Chenopodium formosanum Koidz.) based on physiological analysis. Plants (Basel), 10(11), 2279. https://doi.org/10.3390/plants10112279*

[15] *Conly, F. M., & Van der Kamp, G. (2001). Monitoring the hydrology of Canadian prairie wetlands to detect the effects of climate change and land use changes. Environmental Monitoring and Assessment, 67(1–2), 195–215. https://doi.org/10.1023/A:1006486607040*

[16] *Sun, R., Kulshreshtha, S. N., Crézé, C. M., & Madramootoo, C. A. (2023). Enhancing environmental sustainability in eastern Canada's corn agroecosystem with controlled drainage and subsurface irrigation. Journal of Water and Climate Change, 14(6), 1900–1911. https://doi.org/10.2166/wcc.2023.509*