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Water-Smart Farming: Strategies, Technologies, and Practices for Smallholder Farmers in a Changing Climate

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Increases in human population and world temperatures, which have risen by 1.1°C in the last ten years, are already making it more difficult for agriculture to get water in areas where it is limited. The concept of "water-smart farming" was created to solve issues related to the accessibility, availability, and usage of agricultural water. In climate-smart agriculture, it supports aims and practices pertaining to agricultural water. It includes several water-saving techniques, tools, and technology for growing food sustainably, as well as cropping systems that adapt to changing climate conditions. The urgent problem of agricultural water competition can be lessened with the successful application of water-smart farming. Therefore, this review introduces the conceptual framework of water-smart farming and its main components or ideology. In situations when water is scarcer than land and other resources used in production, increasing crop water productivity is an important response strategy. A growing, wealthier, and more urbanized population places increasing demands on food, which can be met with improvements in agricultural water productivity. However, there is also a pressing need to achieve improvements in agricultural water management because of pressure to reallocate water from agriculture to cities and to increase the amount of water available for environmental purposes. Water clearly has a role in reducing poverty and promoting economic progress. The review also briefly shows the contribution of some of these best practices and adaptive technologies of water-smart cropping toward promoting water-saving methods used for crops and vegetables.

Keywords: Climate change; food security; greenhouse gas emission; water smart farming.

1. INTRODUCTION

For adequate living standard as in western and industrialized nation, a renewable water supply of at least 2000 m^3 per person per annum is necessary. If only 1000-2000 m^3 per person per annum is available, the country is 'water stressed', while the value comes below 500 m^3 per person per year, the country is called 'water scarce' (Kumar and Kar, 2013; Ahmad et al., 2009). “The demand for water will only rise due to the growing population and improving standards of living in competing industries such as agriculture, industry, and home use. In addition, an increasing amount of water will be needed for environmental issues like aquatic life, wildlife refuges, and leisure. Sustainable water management in agriculture is a major concern in India due to shifting global climate patterns and decreasing per capita availability of surface and ground water resources” (Ashoka et. Al., 2024; Kumar et al., 2023). Future agricultural water use in India will confront fierce competition for limited water resources due to growing water demand from other industries (Barker et al., 2007; Burzaco et al., 2013; Busari et al., 2015; Campbell et al., 2011; Comprehensive Assessment of Water Management in Agriculture, 2007; Craufurd & Wheeler, 2009). Therefore, the available water resources would be inadequate utilizable to meet the future water needs for all sectors unless the utilizable quantity is raised by all possible means and water is used more efficiently. Adoption of the suitable agro-techniques for cultivation of crop is need of hour to produce more crops with less water utilized so as to check the reduction of ground and surface water resources in India. Recognizing the importance of above fact, the country has developed water smart agriculture for achieve 'more productivity per drop water (Ercin & Hoekstra, 2014; Estavillo et al., 2002; FAO, 2014a; Gaihre et al., 2011; Gathala et al., 2013; Gill et al., 2005).

Efficient management of water resources is essential to guaranteeing fair distribution and maximum use (Godfray et al., 2010; Grace et al., 2012; Gupta et al., 2016; Hansen et al., 2007; Harvey & Pilgrim, 2011; Hertel & Rosch, 2010; Ignaciuk & Mason-D'Croz, 2014; Ingram et al., 2010). Fundamentally, this means utilizing every drop of water to maximize food production while minimizing losses, or, to put it more concisely, understanding the widely recognized definition of water usage efficiency, which is "the amount of carbon assimilated as biomass or grain produced per unit of water used by the crop" (Hoover et al., 2023). “A wide range of techniques are included in water-smart cropping solutions, such as the development of drought-tolerant maize varieties, cover crops, intercropping legumes with food crops, system rice intensification, alternate wetting and drying, and farmer-led reduced irrigation. It is imperative that these methods be widely used in conjunction with good agricultural practices. Smallholder farmers, who remain dominant in global agricultural landscape, must

be empowered to spearhead adaptation efforts of climate change" (Mushi et al., 2023; Ndhlovu and Mhlanga, 2023). "This empowerment necessitates agronomic management encompassing fertilization, cropping patterns, irrigation, and plant protection, along with addressing external factors that is input supply, post-harvest facilities and policy regulations" (Islam et al., 2022; Jasa et al., 2000; Keane et al., 2009; Kern & Johnson, 1993; Kijne et al., 2009; Komba & Muchapondwa, 2015; Kristjanson et al., 2012).

Over the past few decades, it has become clear that freshwater shortage is posing a danger to the sustainable development of human society due to a continually rising demand (Ladha et al., 2003; Larney et al., 1997; Lobell et al., 2008; Lobell et al., 2011; Marius, 2009; McCartney & Smakhtin, 2010; Mohammed & Tarpley, 2009). Water crises are the worldwide risk with the greatest potential impact, according to the World Economic Forum's most recent annual risk assessment (World Economic Forum, worldwide Risks 2015). "The primary causes of the rising worldwide demand for water include the growing world population, rising living standards, shifting consumption patterns, and the growth of irrigated agriculture" (Vörösmarty et al., 2000; Ercin and Hoekstra, 2014). There is enough freshwater available annually and globally to meet this need. However, there are significant seasonal and geographical changes in the demand and availability of water, which causes water scarcity in a number of regions of the world at certain periods of the year (Naresh, 2013; OECD, 2014; Paustian et al., 1997; Pathak, 2009; Pathak et al., 2012; Rhodes et al., 2014; Robert et al., 2009; Saharawat et al., 2012). The fundamental cause of global water shortage is the spatial and temporal mismatch between freshwater availability and demand (Savenije, 2000). This mismatch can be quantified physically or in terms of the consequences for society or the economy depending on the ability to adjust (Rijsberman, 2006; Wolfe and Brooks, 2003). This paper aims to address two topics: (i) the potential contribution of agricultural research to enhance the productivity of small farmers and their capacity to cope with and lessen the effects of climate change; and (ii) the most effective way to improve productivity under near-normal or slightly below-normal rainfall conditions using smaller-scale water management systems. and (iii) to describe how much improvements in water and land management, can increase productivity of water in the agriculture.

Water scarcity facing by people: When assessing water scarcity annually, one or a few months of extreme shortage won't be noticeable because they will average out with the other, less scarce months. We discover that 1.8 to 2.9 billion people—the range given by previous estimates—have been severely lacking in water for at least 4 to 6 months. Consequently, we demonstrate that quantifying the fluctuations in water shortage over the course of a year helps to illuminate the realities faced by The assumptions made about the degree of environmental flow requirements do not significantly affect the outcomes. With the present assumption of flow requirements environmental at 80% of natural runoff, we find 4.3 billion people living in areas with WS > 1.0 at least one month in a year. If we would assume flow of environmental requirements at 60% of natural runoff, this number would be still 4.0 billion. The results are also sensitive to uncertainties in blue water footprint and blue water availability (Silva-Olaya et al., 2013; Smith et al., 2007; Tirado & Cotter, 2010; West & Marland, 2002; Wolfe & Brooks, 2003; World Bank, 2008; World Bank, 2008b; Yao et al., 2009). We tested sensitivity of the estimated number of person facing severe water scarcity to change in blue water footprint and blue water availability. When we increase water availability worldwide estimates and for each month by 20%, number of people facing severe water scarcity during at least one month of year reduces by 2% (from 4.0 to 3.9 billion). Reducing water availability by 20% gives 4.1 billion. Changing water foot prints in the ±20% range results in the number of people facing severe water scarcity to be between 3.9 and 4.1 billion as well. Changing water availability in the ±50% range yields 3.8 to 4.3 billion people facing severe water scarcity during at least part of the year, whereas changing water footprints in the ±50% range yields 3.6 to 4.2 billion people. Due to a significant temporal mismatch between water availability and demand, sensitivity is low: Generally speaking, availability is higher than demand, or the reverse is true. Changes in one or the other can only cause the situation to shift from one level of shortage to another when the demand and availability of water are of equal size.

The future of food production and water-smart agriculture: Global food systems differ greatly, as do the ways in which various consumers obtain food. The majority of the world's poorest rural communities still depend heavily on locally grown food and poorly linked

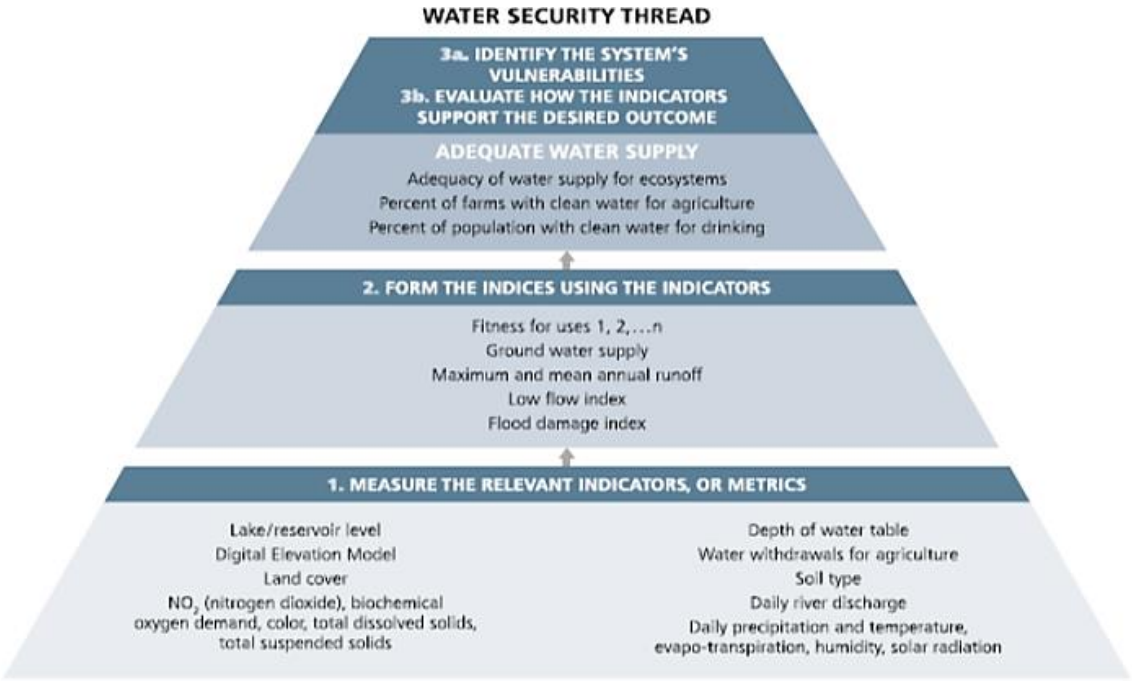

Fig. 1. Water security thread from Vital Signs. The pyramid of the water security thread depicts the integration of metrics (1) that build the desired indices (2) with the outcomes of interest (3a and 3b). Adapted with permission from the Vital Signs programme (S Barbour, personal communication, 2014)

local economies to survive and make a living. Barrett (2007). Cross-country econometric data provided by the World Bank (2008a) demonstrates that investments in agriculture, where smallholder farmers are involved as managers and laborers, have double the impact on reducing poverty as investments in any other sector. The difficulty lies in reducing these emissions without jeopardizing the security of food and livelihood, especially for the impoverished rural population. Hence, research on climate change, agriculture, and food systems is especially needed to address extremely local contexts while also paying the necessary attention to larger institutional mechanisms for disseminating solutions, creating common future visions, and negotiating disparate roles and responsibilities. All of this will require a sincere dedication to fostering collaboration, building capacity, and resolving societal disparities.

Regional effects of climate change are probably going to be significant and uneven, with some areas benefiting from a changed environment and others suffering negative effects. In most important places (such as subtropical and tropical areas), food production is generally expected to drop; but, when technology is more readily available and proper adaptive modifications are made, agriculture in industrialized countries may actually gain. Parvatha, (2014). Accordingly, it is predicted that crop productivity will rise marginally at mid-to high-latitudes for local mean temperature increases of up to 1-3°C, depending on the crop, and then decline in some places after that. Crop productivity is predicted to decline at lower latitudes, particularly in seasonally dry and tropical areas, with even modest local temperature rises (1-2°C), which would raise the risk of hunger OECD (2015). Warmer weather expected to bring longer growing seasons in northern areas, and plants every places were give benefit from carbon fertilization Vuren et al. (2008).

Farm-scale Management Practices to Improve Productivity: Enhancing water production is crucial to lessening the demand on water supplies. Even with an assumed increase in water productivity from 1,800 m3 to 1,200 m3 per ton of grain produced, there would still be a significant increase in water demand to fulfill the MDG by 2015. According to Jacob et al., (2009), the projected increased water requirements, including for increases in water productivity, range from 1,850 m3 y-1 in 2015 to over 3,000 m3 y-1 in 2030 and 2050. When we also take

into account the obligation to allocate water resources for purposes other than agricultural output, this extra requirement poses an enormous difficulty. As per Thornton and Lipper, (2013), agriculture alone contributes 30-40% of anthropogenic GHG emissions. Three-quarters of agricultural in developing countries, GHG emissions occur and this share may increase above 80% by 2050. Livestock dung and fertilized agricultural soils are the sources of direct emissions. IPCC (2014) states that indirect emissions are caused by fertilizer leaching and runoff, changes in land use, and the use of fossil fuels for transportation, mechanization, and the manufacturing of agrochemicals and fertilizers. Changes in conventional land use and natural vegetation, such as deforestation and soil degradation, account for the majority of indirect emissions. Another traditional land use strategy that involves constantly disturbing the land is intensive tillage. Due to soil erosion and SOM breakdown, this method raises CO2 emission Yibekal et al., (2013).

Reduction of Greenhouse Gases by adopting conservation agriculture: Positive changes under agronomic practices like manuring, tillage, and irrigation can help reduce the release of greenhouse gases into atmosphere Table 1. Adoption of controlled irrigation and zero tillage can reduce the evolution of N_2O and CO_2. Reduction in burning crop residues reduces the generation of CO_2, CH_4 and N_2O to the significant extent. Saving on diesel by judicious use of water pumps and reduced tillage can have play major role. Changing to zero tillage would save 98 litres diesel per hectare Naresh et al., 2013. With each litre of diesel generating 2.62 kg, about 3.21 Mt CO_2 $annum^{-1}$ (about 0.80 MMTCE) can be reduced through zero-tillage in 12 million ha under rice-wheat cropping systems in Indo-Genetic Plains alone. Intermittent irrigation and drainage will be further reducing CH_4 emission from paddies by 28% to 30% as per findings at Pantnagar and IARI (Delhi). Enhancing plant uptake and decreasing N2O emission can be achieved by applying nitrogenous fertilizers deeply rather than topically and by substituting calcium nitrate or urea for ammonium sulphate. Through changes in soil parameters (such as soil porosity, soil temperature, and soil moisture, among others), tillage and crop residue retention have a significant impact on CH4 and N2O emission [Yao et al., 2009]. According to certain studies, switching from conventional tillage (CT) to no-till (NT) can drastically cut emissions of CH4 and N2O (Estavillo et al., 2002). According to Wang et al. (1998), the primary variations in the CH4 production zone were caused by the tillage methods' disturbance of the soil at different depths. Consequently, depending on the tillage technique used, the CH4 production zone may change. Regina et al., 2007 revealed that CH_4 oxidation rate were higher when there were fewer micro-pores or more macro-pores in the soil.

Table 1. Carbon dioxide emissions over a 19-day period after tilling wheat residue with different Method

Tillage method	Cumulative CO_2 Loss (t/ha)
Moldboard plough	9.21
Disk harrow	3.79
Chisel plough	3.59
No- tillage	1.91

Source: Reicosky, 1998

Agricultural technology for changing climate resilience and mitigation: Investing in agricultural water management systems is just one way to lessen sensitivity to mild changes in rainfall; other alternatives include diversification and breeding for drought stress. The majority of crop germplasm development aimed in subtropical regions is concentrated on increasing tolerance to stressors like drought. There is also debate over whether increasing yields during dry spells must come at the expense of yields during seasons with adequate rainfall, even if the production of drought-resistant germplasm is generally well-established and supported in comparison to some of the more recent developments in climate risk management. Diversifying one's sources of income can help one become more resilient to the unpredictable nature of the climate if the diversified portfolio does not significantly reduce average income and (a) there is no significant correlation between the various income sources and seasonal rainfall. Diverse rural economies, combinations of farm and non-farm businesses within the household, and cultivars with staggered phenology at the field scale are examples of opportunities for diversification. Additionally, these studies can be used to customize the creation of germplasm for small-scale water management practices like conservation agriculture and for cultivar combinations that are more resilient to dry spells than individual cultivars (Brown and Hansen 2008).

Climate variability and the frequency, severity, spatial extent, length, and timing of extreme

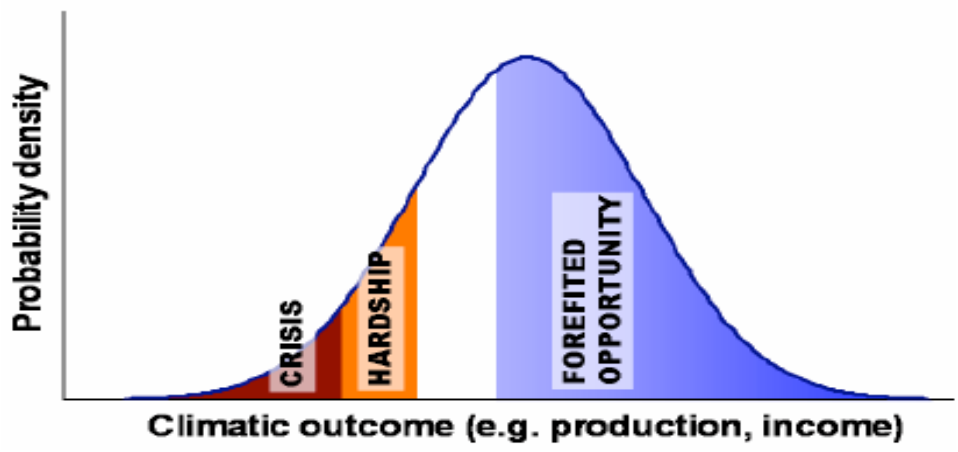

Fig. 2. Idealized representation of the impact of climatic risk associated with different portions of distribution of some climate sensitive outcome.

weather and climate events are inextricably linked to climate change (IPCC, 2012). Extreme weather and climate fluctuation can also have an impact on yield quality. It has been demonstrated that the protein content of wheat grain is sensitive to variations in rainfall and temperature variability (Porter & Semenov, 2005); in particular, large temperature extremes during grain filling can impact the protein content of wheat grain (Hurkman et al., 2009). “More fundamental alterations may arise in circumstances where climate unpredictability and variations are greater, especially if crucial thresholds for rainfall and/or temperature are crossed. Changes in nature and timing of growing season may be inducing smallholders to grow shorter duration and/or more heat and drought tolerant varieties and crops” (Gornall et al., 2010).

Climate risks management: "Reducing water-related risks posed by high rainfall variability rather than coping with an absolute lack of water" is the fundamental problem in subtropical India, where a large portion of the remaining hunger and poverty are concentrated (AWMA, 2007). However, the most promising avenues for enhancing agricultural water management provide little control. To address the residual risk that water control alone cannot minimize, a comprehensive approach to investing in pro-poor agricultural water management necessitates concurrent investment in other climate risk management measures.

Agricultural climate risk management entails:

- Systematic use of climate knowledge and climate information in strategic planning and adaptive decision-making;
- Climate informed technologies and management strategies that decline vulnerability to climate-variability;
- Climate informed policy and market based interventions that transfer risk from vulnerable of rural populations.

Climate risk management must be address in full range of variability, balancing protection against impacts of the climatic extremes such as floods and droughts with effort to capitalize on the opportunities arising from average and favorable climatic-seasons (roughly 2/3 of the area toward right, Fig. 2).

2. CONCLUSION

To sum up, this review has clarified a thorough framework for improving agricultural water management and developing water-smart cropping systems that are sustainable. Several important conclusions have been highlighted by us during the investigation. As a natural approach to agriculture's adaptation to climate change, we have highlighted the critical role that water-smart cropping plays and highlighted how it can protect water supplies for coming generations. We have emphasized the variety of water-saving methods, technical advancements, and climate-responsive food cropping systems that make up the foundation of water-smart farming. Together, these tactics support the production of food in a sustainable manner. Furthermore, when it comes to water, adaption solutions that rely on energy to provide water are in opposition to mitigation. Consequently, increase greenhouse gas emissions. In order to ensure that short-term activities in a particular area do not increase vulnerability to climate

change in the long run, short-term plans to address food insecurity, provide access to water resources, or encourage economic growth must be placed in the context of future climate change. National, regional, and international policy harmonization of climate change, agricultural, and food security is required. Therefore, a variety of tactics should be used to adapt, such as increasing the use of water and soil conservation techniques, crop diversification, planting dates that are adjusted, crop diversification, and a shift from farm to non-farm activities. Nonetheless, the review study suggests that these safeguards should be reinforced.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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