

Water-smart farming: review of strategies, technologies, and practices for smallholders Farming Areas in a changing climate

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 more scarce 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

INTRODUCTION

For adequate living standard as in western and industrialized nations, a renewable water supply of at least 2000 m³ per person per annum is necessary. If only 1000-2000 m³ per person per annum is available, the country is 'water stressed', while the value comes below 500 m³ per person per year, the country is called 'water scarce' (Kumar and Kar, 2013). 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. Future agricultural water use in India will confront fierce competition for limited water resources due to growing water demand from other industries. Therefore, the available water resources would be inadequate 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.

Efficient management of water resources is essential to guaranteeing fair distribution and maximum use. 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). These 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).

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. 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; Erzin 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. 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. 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 footprints in the $\pm 20\%$ 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 $\pm 50\%$ 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 $\pm 50\%$ 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.

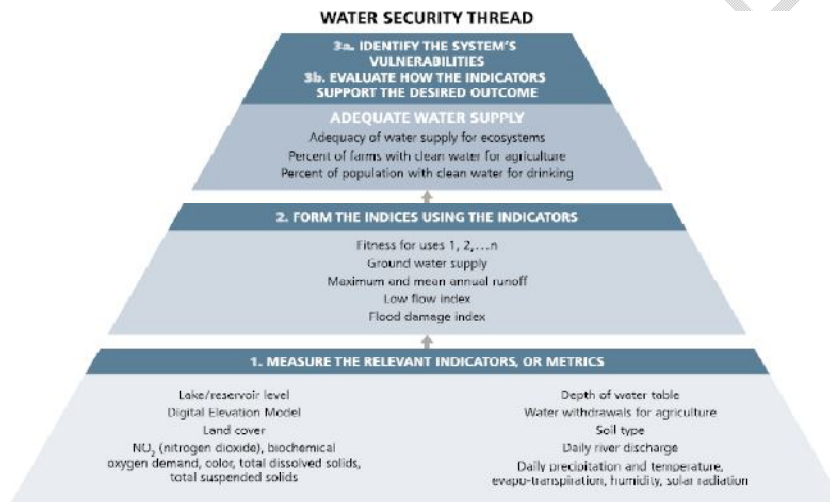


Fig. 1: Water security thread from Vital Signs. The pyramid of the water security thread depicts the integration of metrics (1) that build the desired indices (2) with the outcomes of interest (3a and 3b). Adapted with permission from the Vital Signs programme (S Barbour, personal communication, 2014).

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 local economies to survive and make a living. Barrett (2007). Cross-country econometric data provided by the World Bank (2008) 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 everywhere will 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 Yibeka *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. Adoption of controlled irrigation and zero tillage can reduce the evolution of N₂O and CO₂. Reduction in burning crop residues reduces the generation of CO₂, CH₄ and N₂O 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 CO₂ annum⁻¹ (about 0.80 MMTCE) can be reduced through zero-tillage in 12 million ha under rice-wheat cropping systems in Indo-Gangetic Plains alone. Intermittent irrigation and drainage will be

further reduce CH₄ 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 CH₄ 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 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 (Gornall *et al.*, 2010). 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.

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, Figure 2).

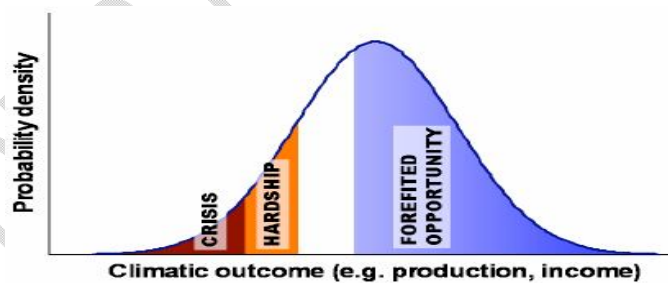


Fig. 2. Idealized representation of the impact of climatic risk associated with different portions of distribution of some climate sensitive outcome.

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, adaptation 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.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

- Ahmad, S., Li, C., Dai, G., Zhan, M., Wang, J., Pan, S., Cao, C. 2009. Greenhouse gas emission from direct seeding paddy field under different rice tillage systems in central China. *Soil Till. Res.* 106, 54–61.
- Barker T, Bashmakov I, Bernstein L, Bogner JE, Bosch PR, Dave R, Davidson OR, Fisher BS, Gupta S, Halsnæs K *et al.* 2007. Technical summary. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.
- Barrett CB. 2008. Smallholder market participation: concepts and evidence from eastern and southern Africa. *Food Policy* 2008; 33:299-317.
- Brown, C. and Hansen, J.W. 2008. Agricultural Water Management and Climate Risk. Report to the Bill and Melinda Gates Foundation. IRRI Tech. Rep. No. 08-01. International Research Institute for Climate and Society, Palisades, New York, USA. 19 pp.
- Burzaco, J. P.; Smith, D. R. and Vyn, T. J. 2013. Nitrous oxide emissions in mid west US maize production vary widely with band injected N fertilizer rates, timing and nitrapyrin presence. *Environ. Res. Lett.* 8 015014
- Busari, A.M.; Kukal, S.S.; Kaur, A.; Bhatt, R. and Dulazi, A. A. 2015. Conservation tillage impacts on soil, crop and the environment. *Int. Soil Water Conserv Res.* 3:119-129.
- Campbell, B.; Mann, W.; Meléndez-Ortiz, R.; Streck, C.; Tennigkeit, T. 2011. Agriculture and Climate Change. A Scoping Report. *Meridian Institute, Washington, DC*
- Comprehensive Assessment of Water Management in Agriculture. 2007. Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture Earth scan and International Water Management Institute, London and Colombo.
- Craufurd, P.Q. and Wheeler, T.R. 2009. Climate change and the flowering time of annual crops. *J Exp Bot.*, 60, 2529–2539.
- Ercin, A.E. and Hoekstra, A.Y. 2014. Water footprint scenarios for 2050: A global analysis. *Environ. Int.* 64, 71–82.
- Estavillo JM, Merino P, Pinto M, Yamulki S, Gebauer G. 2002. Short term effect of ploughing a permanent pasture on N₂O production from nitrification and denitrification. *Plant Soil* 239:253–265.
- FAO (2014a) Agriculture's greenhouse gas emissions on the rise. [<http://www.fao.org/news/story/en/item/216137/icode/>] Assessed on: Feb 25, 2016.
- Gaihe, Y. K.; Tirol-Padre, A.; Wassmann, R.; Aquino, E.; Pangga, G. V. and Cruz, P. C. S. 2011. Spatial and temporal variations in methane fluxes from irrigated lowland rice fields Philippine. *Agric. Sci.* 94 335–42.

- Gathala, M.K., Kumar, V., Sharma, P.C., Saharawat, Y.S., Jat, H.S., Singh, M., Kumar, A., Jat, M.L., Humphrey, E., Sharma, D.K., Sharma, S., Ladha, J.K., 2013. Optimizing intensive cereal-based cropping systems addressing current and future drivers of agricultural change in the northwestern Indo-Gangetic Plains of India. *Agr. Ecosyst. Environ.* 177, 85–97.
- Gill, M. S.; Samra, J.S.; Singh, Gurbachan. 2005. Integrated farming system for realizing high productivity under shallow water-table conditions. Research bulletins, Department of Agronomy, PAU, Ludhiana, pp. 1-29.
- Godfray H C J, Beddington J R, Crute I R, Haddad L, Lawrence L, Muir J F, Pretty J, Robinson S, Thomas S M and Toulmin C. 2010 Food security: the challenge of feeding 9 billion people *Science* 327 812–8
- Gornall, J.; Betts, R. and Burke, E. 2010. Implications of climate change for agricultural productivity in the early twenty-first century. *Philosophical Transaction of the Royal Society B*, 365: 2973-2989.
- Grace, P.R., Antle, J., Ogle, S., Paustian, K. and Basso, B. 2012. Soil carbon sequestration rates and associated economic costs for farming systems of the IGP. *Agr. Ecosyst. Environ.* 146, 137–146.
- Gupta, Dipak Kumar; Bhatia, A.; Kumar, A.; Das, T.K.; Jain, N.; Tomar, R.; Malyan, S. K.; Fagodiya, R.K.; Dubey, R. and Pathak, H. 2016. Mitigation of greenhouse gas emission from rice–wheat system of the Indo-Gangetic plains: Through tillage, irrigation and fertilizer Management. *Agri. Ecosyst. Environ.* 230: 1–9
- Hansen, J.W., Baethgen, W., Osgood, D., Ceccato, P., Ngugi, R.K. 2007. Innovations in climate risk management: protecting and building rural livelihoods in a variable and changing climate. *J Semi-Arid Tropical Agri Res* 4.
- Harvey M. and Pilgrim S. 2011. The new competition for land: food, energy, and climate change. *Food Policy* 2011, 36: S40-S51.
- Hertel, T.W. and Rosch, S. D. 2010. Climate change, agriculture, and poverty. *Appl Econ Perspect Policy* 32:355-385
- Hoover, D. L., Abendroth, L. J., Browning, D. M., Saha, A., Snyder, K., Wagle, P., et al. (2023). Indicators of water use efficiency across diverse agroecosystems and spatiotemporal scales. *Sci. Total Environ.* 864:160992. doi: 10.1016/j.scitotenv.2022.160992
- Hurkman, W.J.; Vensel, W.H.; Tanaka, C.K.; Whitehead, L. and Altenbach, S.B. 2009. Effect of high temperature on albumin and globulin accumulation in the endosperm proteome of the developing wheat grain. *J Cereal Sci.*, 49, 12–23
- Ignaciuk, A. and Mason-D'Croz, D. 2014. Modelling Adaptation to Climate Change in Agriculture. OECD Food, Agriculture and Fisheries Papers 70: 58.
- Ingram J, Ericksen P, Liverman D (Eds): Food Security and Global Environmental Change. London, UK: Earthscan; 2010.
- IPCC (Intergovernmental Panel for Climate Change). 2007a. Climate Change 2007: The Fourth Assessment Report. Impacts, Adaptation and Vulnerability.
- IPCC. 2014. AR5 WGIII. Geneva. [<http://www.ipcc.ch/report/ar5/>]
- Islam, M. S., Bell, R. W., Miah, M. M., and Alam, M. J. (2022). Unbalanced fertilizer use in the eastern Gangetic plain: the influence of government recommendations, fertilizer type, farm size and cropping patterns. *PLoS One* 17:e0272146. doi: 10.1371/journal.pone.0272146
- Jacob Kijne, Jennie Barron, Holger Hoff, Johan Rockström, Louise Karlberg, John Gowing, Suhas P. Wani and Dennis Wichelns. 2009. Opportunities to increase water productivity in agriculture with special reference to Africa and South Asia. A report prepared by Stockholm Environment Institute, for the Swedish, *Ministry of Environment* presentation at CSD 16, New York 14 May 2009
- Jasa, P., D. Shelton, and J. Siemens. 2000. Tillage system selection and equipment considerations. *Conservation Tillage Systems and Management*. Midwest Plan Service. 2000.
- Keane, J.; Page, S.; Kergna, A. and Kennan, J. 2009. Climate Change and Developing Country Agriculture: An Overview of Expected Impacts, Adaptation and Mitigation Challenges, and Funding Requirements.
- Kern, J.S. and M.G. Johnson. 1993. Conservation tillage impacts on national soil and atmospheric carbon levels. *Soil Sci. Soc. Amer. J.* 57:200-210.
- Komba, C., and Muchapondwa, E. 2015. Adaptation to Climate Change by Smallholder Farmers in Tanzania. Environment for Development. Discussion Paper Series.
- Kristjanson, P., Neufeldt, H., Gassner, A., Mango, J., Kyazze, F.B., Desta, S., Sayula, G., Thiede, B., Förch, W., Thornton, P. K. and Coe, R. 2012. Are food-insecure smallholder

- households making changes in their farming practices? Evidence from East Africa. *Food Security*, September 2012, 4 (3): 381-397.
- Ladha, J.K.; Pathak, H.; Padre A.T.; Dawe, D. and Gupta R.K. 2003. Productivity trends in intensive rice-wheat cropping systems in Asia. In Ladha J K (eds) .Improving the productivity and sustainability of rice-wheat systems: issues and impacts. ASA Special Publication No.65. Madison, Wis., USA, pp. 45-76.
 - Larney, F.J., Bremer, E., Janzen, H.H., Johnston, A.M. and Lindwall, C.W.1997.Changes in total, mineralizable and light fraction soil organic matter with cropping and tillage intensities in semiarid southern Alberta, Canada. *Soil Till. Res.*, 42(4): 229-240.
 - Lobell, D.B.; Beanziger, M.; Magorokosho, C. and Vivek, B. 2011. Nonlinear heat effects on African maize as evidenced by historical yield trials. *Nature Climate Change* 1, 42–45.
 - Lobell, D.B.; Burke, M.B.; Tebaldi, C.; Mastrandrea, M.D.; Falcon, W.P.; Rosamond, L. Naylo. 2008. Prioritizing climate change adaptation needs for food security in 2030. *Journal of Science* 319: 607-610.
 - Marius, K. 2009. Climate Risks and Development Projects Assessment Report for a Community-Level Project in Guduru, Oromiya, Ethiopia.
 - McCartney, M. and Smakhtin, V. 2010. Water Storage in an era of climate change: Addressing the challenge of increasing rainfall variability. International Water Management Institute (IWMI). Colombo, Sri Lanka.
 - Mohammed, A.R. and Tarpley, L. 2009. High night time temperatures affect rice productivity through altered pollen germination and spikelet fertility. *Agri Forest Meteorol.* 149, 999–1008.
 - Mushi, G. E., Serugendo, G. D. M., and Burgi, P. Y. (2023). Data management system for sustainable agriculture among smallholder farmers in Tanzania: Research-in progress. *Inf. Technol. Dev.* 2023, 1–24. doi: 10.1080/02681102.2023.2215528
 - Naresh R.K. 2013. Rice residues: from waste to wealth through environment friendly and innovative management solutions, its effects on soil properties and crop productivity. *Int. J. LifeSc. Bt & Pharm. Res.* 2 (1):133-141.
 - Naresh, R.K.; Singh, S.P.; Tomar, S.S. and Purushottam. 2013. Role of Conservation agriculture for enhancing productivity, sustainability of Rice-wheat systems in climate change scenario of North West India. *Int. J. Res. Biomedicine Biotech*, 3 (1): 21-29.
 - Ndhlovu, E., and Mhlanga, D. (2023). “Smart technologies, climate change, and smallholder farmer production in Zimbabwe” in *The fourth industrial revolution in Africa: Exploring the development implications of smart Technologies in Africa.* eds. D. Mhlanga and E. Ndhlovu (Cham: Springer Nature Switzerland), 293–309.
 - OECD (2015). Agriculture and Climate Change. Trade and Agriculture Directorate. [<http://www.oecd.org/tad/sustainable-agriculture/agriculture-and-climate-change.htm>]
 - OECD (Organization for Economic Co-operation and Development). 2014. Climate change, water and agriculture: Towards resilient agricultural and water systems.
 - Parvatha, P. R. 2014. Climate Resilient Agriculture for Ensuring Food Security. *Springer*. pp: 1-15.
 - Pathak, H., 2009. Greenhouse gas mitigation in rice-wheat system with resource con-serving technologies. In: Fourth World Congress on Conservation Agriculture, February 4-7, 2009, New Delhi, India, pp. 373–377.
 - Pathak, H., Sankhyan, S., Dubey, D.S., Bhatia, A. and Jain, N. 2012. Dry direct-seeding of rice for mitigating greenhouse gas emission: field experimentation and simulation. *Paddy Water Environ.* 11 (1–4), 593–601.
 - Paustian, K., Collins, H.P. and Paul, E.A. 1997. Management controls on soil carbon. In: *Soil Organic Matter in Temperate Agro ecosystems: Long-Term Experiments in North America*, Paul, E.A., Paustian, K., Elliott, E.A. and Cole, C.V. (eds). CRC Press, Boca Raton, pp.15-49.
 - Regina K, Pihlatie M, Esala M, Alakukku L. 2007. Methane fluxes on boreal arable soils. *Agric Ecosyst Environ* 119: 346–352
 - Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.L. Douglas and P.E. Rasmunssen. 1995. Soil organic matter changes resulting from tillage and biomass production, *J. Soil Water Conserv.* 50: 253–261.
 - Rhodes, E.R.; Jalloh, A. and Diouf, A. 2014. Review of research and policies for climate change adaptation in the agriculture sector in West Africa. Working Paper 090.
 - Rijsberman, F.R. 2006. Water scarcity: Fact or fiction? *Agric. Water Manage.* 80, 5–22.
 - Robert, J.; Adrian, M. and Anne, O. 2009. High Sequestration, Low Emission, Food Secure Farming. *Organic Agriculture - a Guide to Climate Change & Food Security*, IFOAM.

- Saharawat, Y.S., Ladha J.K., Pathak H., Gathala M., Neelam Chaudhary and Jat M. L. 2012. Simulation of resource-conserving technologies on productivity, income and greenhouse gas GHG emission in rice-wheat system. *J. Soil Sci. Environ. Manage.*, 3 (1):9-22
- Savenije, H.H.G. 2000. Water scarcity indicators; the deception of the numbers. *Phys. Chem. Earth B* 25, 199–204.
- Silva-Olaya, A. M.; Cerri, C. E. P.; N. L. S. Jr.; Dias, C. T. S. and Cerri, C. C. 2013. Carbon dioxide emissions under different soil tillage systems in mechanically harvested sugarcane. *Environ. Res. Lett.* 8 015014
- Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko .2007a. Climate Change 2007: Mitigation. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds.). Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, USA.
- Thornton P, Lipper L. 2013. How does climate change alter agricultural strategies to support food security? Background paper for the conference "Food Security Futures: Research Priorities for the 21st Century", 11-12 April 2013, Dublin.
- Tirado, R. and Cotter, J. 2010. Ecological Farming: Drought-resistant Agriculture. Greenpeace Research Laboratories, University of Exeter, United Kingdom.
- Vörösmarty, C.J.; Green, P.; J. Salisbury, J. and R. B. Lammers, R.B. 2000. Global water resources: Vulnerability from climate change and population growth. *Science* 289: 284–288
- Wang M, Li J, Zhen X. 1998. Methane Emission and Mechanisms of Methane Production, Oxidation, Transportation in the Rice Fields. *Sci Atmos Sin* 22: 600–612.
- West, T.O. and Marland, G. 2002. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. *Agric. Ecosyst. Environ.* 91(1-3): 217-232.
- Wolfe, S. and D. B. Brooks, D.B. 2003. Water scarcity: An alternative view and its implications for policy and capacity building. *Nat. Resour. Forum* 27, 99–107.
- World Bank. 2008a, World Bank data on agricultural value added as a share of GDP in 2008.
- World Bank. 2008b. Agriculture for development policy brief: adaptation and mitigation of climate change in agriculture: World Development Report 2008.
- World Bank. 2008. World Development Report 2008: Agriculture for Development. Washington DC, USA:
- World Economic Forum, Global Risks 2015, 10th Edition (World Economic Forum, Geneva, Switzerland, 2015
- Yao Z, Zheng X, Xie B, Mei B, Wang R. 2009. Tillage and crop residue management significantly affects N-trace gas emissions during the non-rice season of a subtropical rice-wheat rotation. *Soil Biol Biochem* 41: 2131–2140.
- Yibekal, A.T.; Chanyalew, S.A. and Getachew, S.E. 2013. Understanding the process of adaptation to climate change by small-holder farmers: The cases of east Hararghe Zone, Ethiopia A springer open *J Agric Food Eco.*