Climate resilience and economic viability of climate-smart agriculture technologies: Evidence from Bangladesh

Introduction

Climate change is one of the most critical global challenges faced by countries across the globe. The 6th Assessment Report of Intergovernmental Panel on Climate Change (IPCC) has mentioned that climate change is widespread, rapid, and intensifying (IPCC, 2021). Climate change has reduced food security and has affected water security due to global warming, changes in precipitation patterns, increase in frequency of extreme climate events, making it challenging to meet the Sustainable Development Goals (SDGs). The impacts of climate change are affecting economic livelihoods of the people, thereby causing social and economic impacts across the national boundaries (IPCC, 2023). It has also reaffirmed by IPCC that climate change poses risks to agricultural activities also (IPCC, 2021). (Porter, et al., 2014) anticipated negative impacts of climate change on crop yields in different parts which included 60% reduction in maize yield, 50% reduction in sorghum yield, 35% reduction in rice yield, 20% reduction in wheat yield, and 13% reduction in barley yield. Moreover, rain – fed crops are going to face a decrease of almost 50% in their yield (Okolie et al., 2023). Climate change affects four key dimensions of food security: food availability, food accessibility, food utilization, and food systems stability (Rao, Sharma, & Raghuraman, 2017). Hence, climate change poses drastic impacts on agricultural productivity as well as food security across the globe. Therefore, to reduce further negative impacts of climate change on agriculture, it is imperative to develop mitigation and adaptation strategies. Climate-smart agriculture (CSA) is one such strategy that aims to provide adaptation, mitigation, and resilience to agriculture and farmers. Hence, adoption of CSA technologies and scaling-up of these practices is of utmost importance.

CSA can be defined as an approach of changing and reorienting agricultural development under the new realms of climate change (Lipper, et al., 2014). Food and Agricultural Organization (FAO) of the United Nations has defined CSA as “agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/removes GHGs (mitigation) where possible, and enhances achievement of national food security and development goals.” CSA cannot be applied universally as it consists of components integrated into the local environment, including on-farm and off-farm actions. It encompasses technologies, policies, institutions, and investments tailored to meet local needs. According to the FAO, CSA aims at sustainable intensification and rural development goals which if achieved would contribute to millennium development goals (MDGs) of reducing hunger and improved environment management. CSA is a holistic concept including environmental (water and energy) as well as social (gender) and economic issues. CSA constitutes of three main pillars – productivity, adaptability, and mitigation (FAO, 2013). CSA aims to sustainably increase crop yields and income of the farmers without having a negative impact on the environment. The concept of CSA focusses on sustainable intensification. It is necessary to maintain productivity and our ability to adapt to climate change. Hence, identifying synergies and weighing costs and benefits based on farmer's experiences is essential to develop context – specific, socially applicable, and viable options.

South Asia is the world's most vulnerable region to the impacts of climate change. This region is still primarily dependent on agriculture with most of its population dependent on agriculture for their livelihoods, but at a high risk of climate vulnerability. It is highlighted that in the absence of adaptation measures to climate change, South Asia can lose 1.8% of its GDP by 2050 and 8.8% by 2100 (Ahmed & Suphachalasai, 2014). The average economic losses are projected to be 9.4% for Bangladesh, 6.6% for Bhutan, 8.7% for India, 12.6% for Maldives, 9.9% for Nepal, and 6.5% for Sri Lanka (ADB, 2014). Given this background, IFAD developed and approved the Consortium for Scaling-Up Climate Smart Agriculture in South Asia (C-SUCSeS) with the objective of promoting sustainable and resilient agricultural intensification in South Asia with a focus on small-holder farmers. In this brief, we will be focusing on Bangladesh to discuss the profitability and economic viability of the selected CSA technologies in terms of fuel efficiency, water efficiency, crop productivity, and income of the farmers. The findings and recommendations are coupled with secondary literature and primary surveys with the farmers, BARI scientists, and extension agents.

Risk and vulnerability of Bangladesh to climate change

Agriculture is the mainstay of the Bangladesh economy, contributing around 11.6% of the country's GDP in 2021 (BBS B., 2022). Around 70% of the land is dedicated to growing crops in the country with around 50% of its population employed in this sector. Bangladesh is the most densely populated country in the world which along with rapid urbanization and industrialization put constant pressure on the arable land. Sustainable food and livelihood security is needed in Bangladesh as the population density continues to expand. Agricultural and rural communities are highly vulnerable to climate change and increasing threats of cyclones, floods, and droughts. Climate-related hazards give rise to dangerous risks to communities causing disproportional damage and disrupting the lives and livelihoods of millions of people. Bangladesh is the 7^{th} most vulnerable country to climate change in the world between 2000 – 2019 (Eckstein, Kunzel, & Schafer, 2021). Extreme weather events (salinity intrusion, floods, and cyclones) are expected to intensify in frequency and intensity in the country. Climate change brings droughts and floods making the land unsuitable for agriculture production (Saha, et al., 2019). The cyclones of 2007 and 2009 caused a loss of around 2 million metric tons of rice, expected to feed about 10 million people (Ali & Meisner, 2017). A study conducted by Bangladesh Soil Resource Development Institute (SRDI) found that out of 8.1 million hectares of arable land in the country, 1.02 million hectares lie in 19 coastal districts which are severely affected by salinity (SRDI, 2021). The arable land in the country has reduced drastically from 0.11 ha/capita in 1980 to 0.05 ha/capita in 2014 (World Bank, 2016a). Around 99% of the farms in the country are small and fragmented, with average landholding size of less than 1 hectare (BBS, 2016 and 2015). Climate change poses a risk to growth and human development. It is also projected that $1/3^{rd}$ of agricultural GDP will be lost due to climate variability and extreme events by 2050 and cropland will shrink by 18% in southern parts of the country and 6.5% nationally by 2040 (World Bank, 2022). Under these circumstances, by 2050, it is estimated that production of rice, wheat, pulses, rapeseed, vegetables, and other crops will reduce by 8%, 32%, 8.8%, 6.3%, 5.3%, and 3.3%, respectively (World Bank, 2022). All this will indirectly lead to a rise in poverty levels in the country. CSA is one of the most effective methods to promote adaptation and resilience in the agriculture sector. Additionally, scaling-up of these technologies is vital for the benefits to be reaped by all the sections of society. CSA practices and technologies have been adopted by the farmers in the country, but scaling-up is limited. C-SUCSeS project aims at upscaling the adoption of CSA technologies by prioritizing three techniques. The technologies adopted by the country for elevation are bed planting, zero-tillage, and strip tillage.

Economic viability of CSA technologies in the country

Strip tillage (ST) is a conservation system which uses minimum tillage. It combines the benefits of conventional tillage, soil drying and warming, and no tillage, soil protection by distributing the portion of soil that contains the seed row. The advantages of using ST are decline in wind and water erosion, improvement in water infiltration, retainment of soil moisture, decrease in sedimentation, appreciation in water quality, and boost in soil fertility (Sergieieva, 2021) (Masa, 2023). A study in Bangladesh by Hossain et. al. (2021) showed that mechanized seeding of mustard and mungbean in strip planting with 50% residue mulching resulted in 62% higher profit in comparison to the broadcasted conventional tillage without residue. The ST method reduced the cost of land preparation by 68%, thereby leading to a decline in labour and fuel requirements of 30%. Figure 1 and Figure 2 portray the fuel efficiency and income gains in strip planting in comparison to the conventional planting methods. We observe 51% saving in fuel consumption in strip planting as compared to conventional planting. Moreover, income gain of 12-14% is reported for the farmers cultivating potato by ST as compared to conventional tillage.

The key challenges faced in scaling the adoption of ST are lack of awareness of the technology, expensive machines and inability to afford them, lack of training and skills to operate the machines, inertia and risk associated with adoption of the practice, and perceiving wastage of land because of excessive spacing between the rows and limited benefit in terms of crop yield as there is a lag of 2-3 years till the profits become apparent to the farmers. Some of the policy solutions to upscale the practice are raising awareness and capacity building through training camps, advertisements and field demonstrations; increasing accessibility of the machines at the village level through custom hiring centers, extension agents and LSPs; enabling easy credit and financial services for small-holder farmers.

Figure 1: Fuel saving in bed panting and strip planting

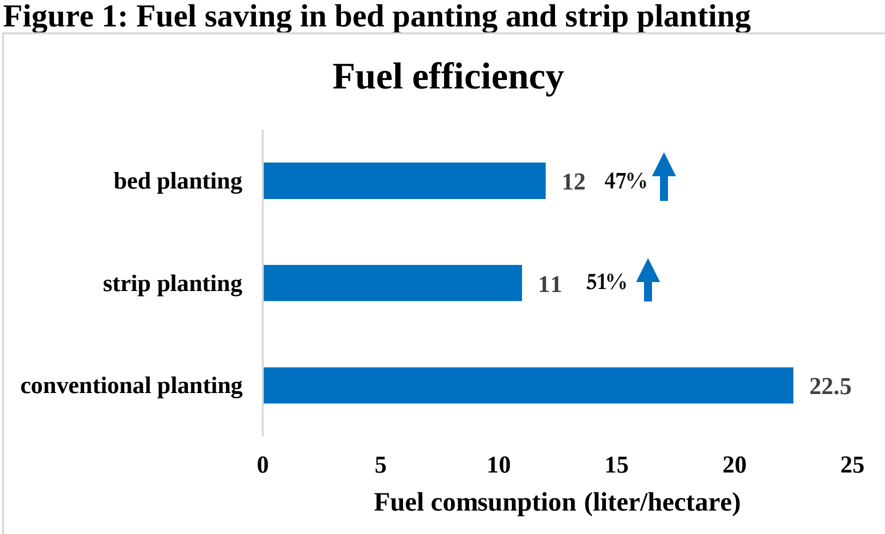
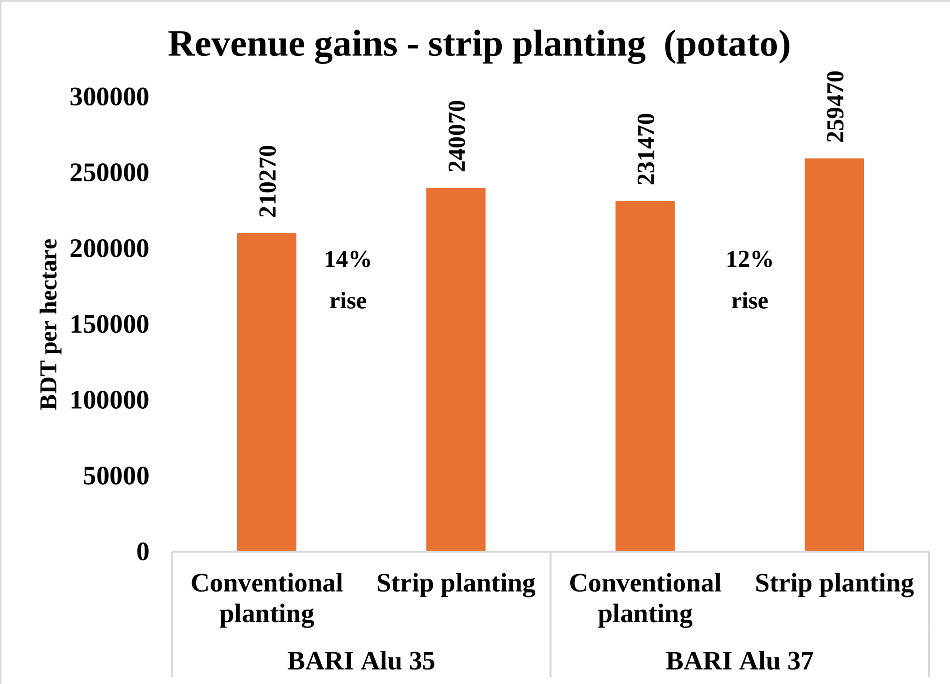


Figure 2: Net income gains in strip planting



Bed planting, commonly known as broad bed furrow (BBF) method is a new way of conserving water for dry land farming (Talokar, Gabhane, & Umale, 2017). The BBF landform management system effectively reduces the velocity of runoff and sediment losses and therefore increases infiltration. The furrows help in draining out the excess water from the plots during the period of heavy rainfall and hence minimizes losses from waterlogging to the crop. The general function of BBF system is to control erosion and to conserve soil moisture in the soil during the rainy days. BBF system also acts as a drainage channel during heavy rainfall days. The main advantages of using BBF method are improvement in crop yield, reduction in amount of labour required, cost – effective, increases water use efficiency, and helps to control the weeds (Talokar, Gabhane, & Umale, 2017) (Verma, Parmanand, & Tamrakar, 2017) (Borde, Rajput, & Umale, 2022) (Hassan, Hussain, & Akbar, 2005). Miah et al. (2015) conducted a study in Bangladesh to understand the status of using raised bed technology at farm level, assess the status of adoption of the technique at the farm level, factors affecting adoption and non – adoption, and evaluate farmer's perception on the impact of raised beds on input use and farmer's income. More than 82% of the farmers reported an increase in their incomes due to technology. Most of the farmers reported that raised bed technology reduced the use of seed (94.4%), fertilizer (73.3%), and irrigation water (61%).

Figure 3 displays the water efficiency, Figure 4 portrays the rise in crop yield, and Figure 5 shows the income gains for farmers adopting bed planting method in comparison to the conventional method in cultivation of mustard, wheat, and maize crops. Mustard reports a saving of 18% in irrigation, leading to a 15% rise in crop yield, and a 40% increase in farmer's income. Similarly, 23% saving of irrigation water was reported for wheat cultivation with a 20% rise in crop yield and 46% increase in farmer's income. Lastly, maize cultivation reported a 14% saving in irrigation resources with a 15% increase in crop productivity and 89% rise in income of the farmers.

The main constraints in scaling-up the adoption of bed planting practice are lack of availability and accessibility to the bed planters, poor ergonomics of the machines, inadequate availability of the machines during the sowing period, lack of credit facilities, and lack of trained and skilled manpower to operate the machines. Some policy prescriptions for increasing the adoption are enhancing availability and accessibility to the machines through LSPs and extension agents; facilitating easy credit options for the farmers to acquire bed planter machines; raising awareness and knowledge about the practice through training programs, advertisements, field demonstrations etc.; and restructuring the ergonomics of the machine to make it user friendly.

Figure 3: Water efficiency in bed planting

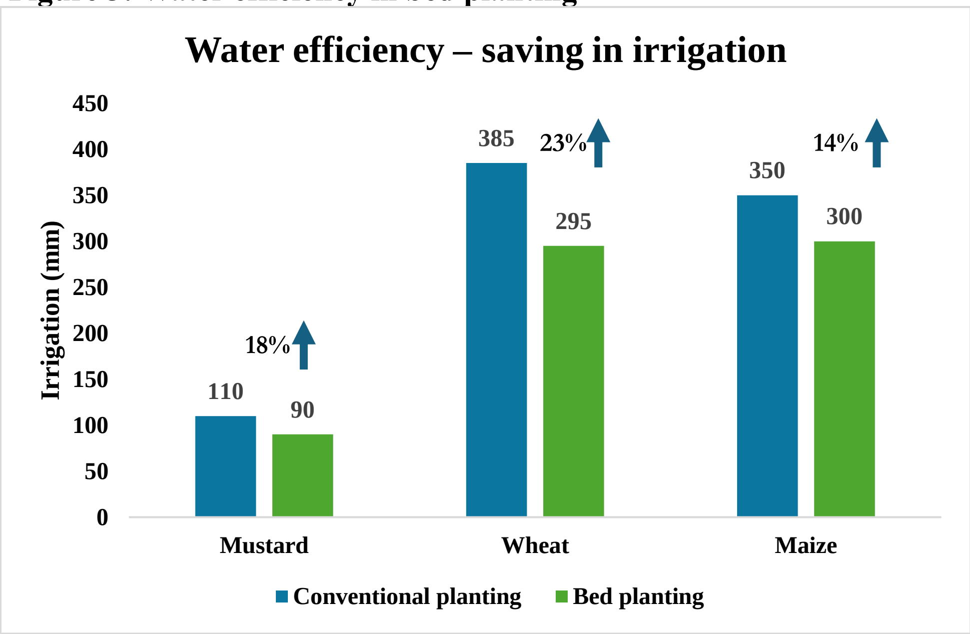


Figure 4: Crop productivity under bed planting

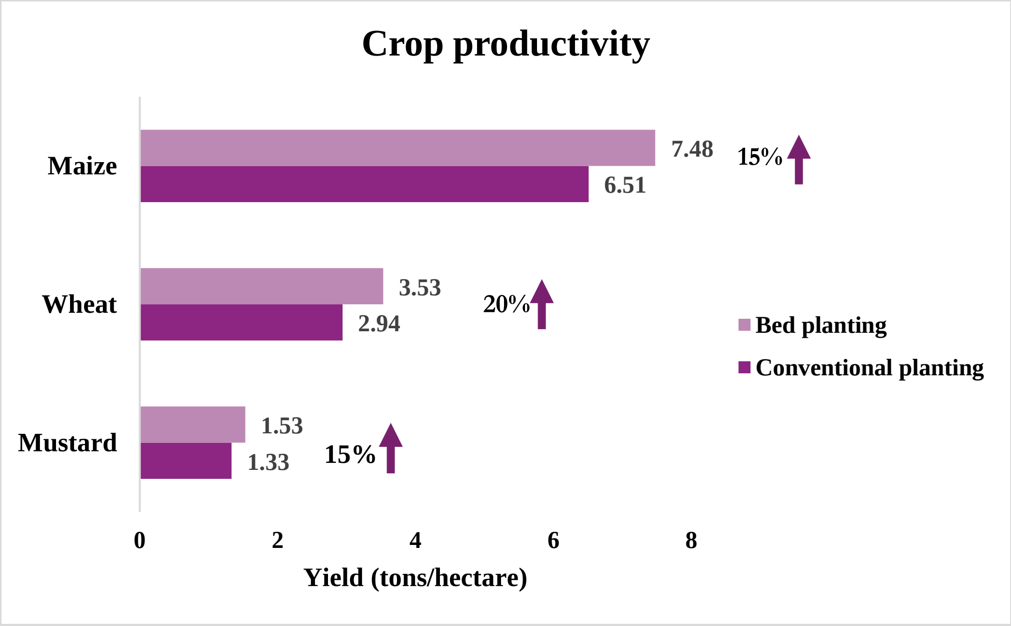
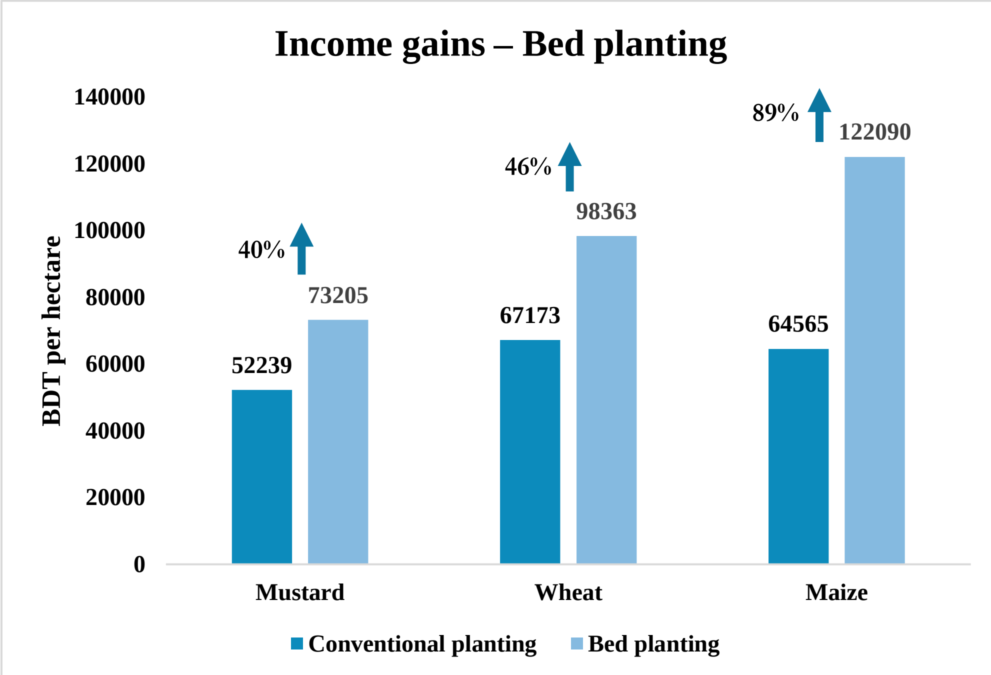


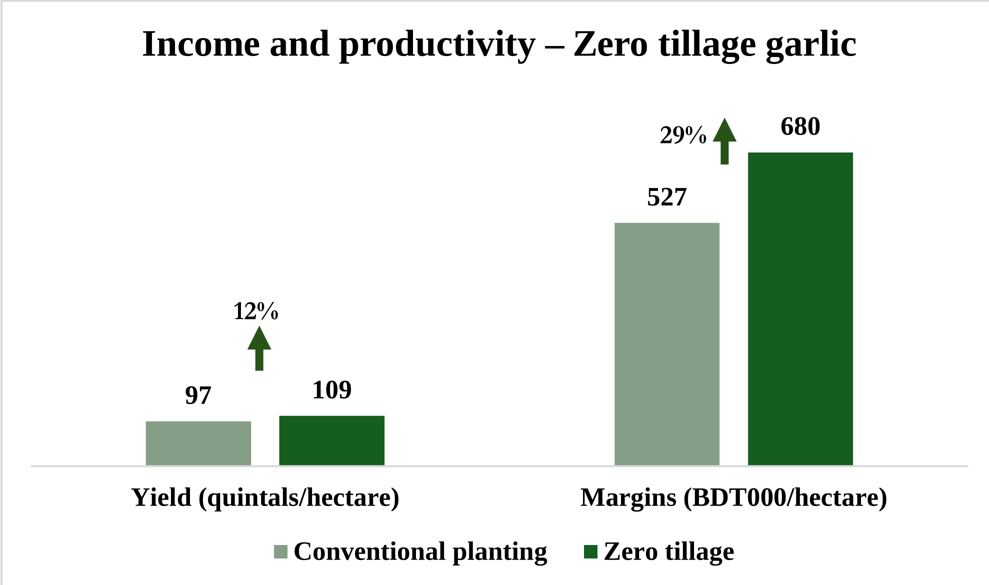
Figure 5: Income gains in bed planting



Zero tillage (ZT) refers to the cultivable land on which no tillage is applied between the harvest and sowing seasons of the crop. It is a style of cultivation in which the crop is sown directly into the soil. ZT decreases the amount of soil erosion that tilling causes in certain types of soil, like sandy and dry soils on hilly terrain. This method is gaining importance due to the rise in incidence of stubble burning. It has been well stated that ZT is a sustainable agriculture technique and helps to mitigate the adverse effects of climate change on environmental resilience (Hassan, et al., 2022). This system reduces production cost of the farmers significantly as compared to the conventional system (De Vita, Di Paolo, Fecondo, Di Fonzo, & Pisante, 2007) (Erenstein, Farooq, Malik, & Sharif, 2008). ZT system also saves irrigation time, irrigation water, and increases water productivity (Yerli, Sahin, Ors, & Kiziloglu, 2023) (Erenstein, Farooq, Malik, & Sharif, 2008) (Hassan, et al., 2022). Studies conducted by Bangladesh Agricultural University (BAU) to test the growth characteristics of garlic under ZT and tillage condition showed that ZT system had significant impact on the growth, yield, and bulb yield of the crop (Rahman, Hossain, Rahman, Rahim, & Islam, 2020) (Kabir, Rahim, & Majumder, 2011). Figure 6 shows the income and productivity gains under zero tillage in garlic production. The crop yield increased by 12% from 97 quintals/hectare under the conventional method to 109 quintals/hectare under the zero-tillage system. On the other hand, income gains are reported to rise by 29%.

Some of the challenges faced in zero-tillage are lack of awareness about the practice, non-availability of the ZT machines, depth of seedlings, and hesitant to shift to modern method of cultivation due to anticipation of low crop yields. Few policy solutions in scaling-up of ZT are increasing awareness about the method using advertisements, training camps, field demonstrations etc,; increasing accessibility to the machines through extension agents, LSPs and custom hiring centers; capacity building and training of the farmers through workshops and field days; and providing easy credit and financing options to the small and marginal farmers.

Figure 6: Income and crop productivity under zero tillage garlic



Bangladesh has been proactive and proficient in climate change adaptation by the Constitution in its 15th amendment of article 18A (Protection and Improvement of the Environment and Biodiversity). The country has made landmark achievements in this field by the formulation of National Adaptation Programme for Action (NAPA, 2005), Bangladesh Climate Change Strategy and Action Plan (BCCSAP, 2009), Bangladesh Delta Plan 2100, Mujib Climate Prosperity Plan 2030, National Environmental Policy (2018), food security and CSA, and may others. The latest accomplishment in building adaptation against climate change has been the release of National Adaptation Plan of Bangladesh (2023-2050). A key adaptation strategy of NAP is to promote extension of CSA methods to make agriculture climate-resilient and foster food and livelihood security. In this study, we present an in-depth analysis of the economic and environmental viability of the three prioritized CSA technologies in the country. Moreover, we also highlight the challenges faced in scaling-up these technologies and provide some policy solutions to overcome them.

Bibliography

ADB. (2014). *Assessing the costs of climate change and adaptation in South Asia.* Asian Development Bank.

Ahmed, M., & Suphachalasai, S. (2014). *Assessing the costs of climate change and adaptation in South Asia.* Asian Development Bank.

Ali, Y. M., & Meisner, C. (2017). *Climate-smart agriculture in Bangladesh.*

BBS. (2016 and 2015). Yearbook of agricultural statistics. Dhaka: Bangladesh Bureau of Statistics, Ministry of Planning, Government of Bangladesh.

BBS, B. (2022). Gross Domestic Product (GDP) of Bangladesh 2021-22. Bangladesh: Government of People's Republic of Bangladesh.

Borde, S. A., Rajput, U. U., & Umale, S. M. (2022). Performance of groundnut under broad bed furrow method in Buldana district of Maharashtra. *Asian Journal of Agricultural Extension, Economics & Sociology, 40*(7), 30-34.

De Vita, P., Di Paolo, E., Fecondo, G., Di Fonzo, N., & Pisante, M. (2007). No-tillage and conventional tillage effects on durum wheat yield, gram quality and moisture content in Southern Italy. *Soil and Tillage Research, 92*(1-2), 69-78.

Eckstein, D., Kunzel, V., & Schafer, L. (2021). Who suffers most from extreme weather events? Weather related loss events in 2019 and 2000 - 2019. *Global Climate Risk Index 2021*. Germanwatch e.V.

Erenstein, O., Farooq, U., Malik, R. K., & Sharif, M. (2008). On-farm impacts of zero tillage wheat in South Asia's rice-wheat systems. *Field Crop Research, 105*, 240-252.

FAO. (2013). *Sourcebook on climate-smart agriuclture, forestry and fisheries.* Food and Agriculture Organization of the United Nations.

Hassan, I., Hussain, Z., & Akbar, G. (2005). Effect of permanent raised beds on water producitivity for irrigated maize-wheat cropping system. *Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico,* (pp. 59-65).

Hassan, W., Li, Y., Saba, T., Jabbi, F., Wang, B., Cai, A., & Wu, J. (2022). Improved and sustainable agroecosystem, food security and environmental resilience through zero tillage with emphasis on soils of temperate and subtropical climate regions: A review. *International Soil and Water Conservation Research, 10*(3), 530-545.

IPCC. (2021). *Climate Change 2021: The Physical Science Basis.* Cambridge University Press.

IPCC. (2023). *Sections. In: Climate Change 2023. Synthesis Report. Contribution of working groups I,II and III to the sixth assessment report of Intergovernmental Panel of Climate Change.* Geneva: IPCC.

Kabir, M. A., Rahim, M. A., & Majumder, D. A. (2011). Effect of organic manure on the growth and yield of garlic under zero-tillage condition. *Journal of Agroforestry and Environment, 5*(1), 139-142.

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., . . . Torguebiau, E. F. (2014). Climate-smart agriculture for food security. *Nature Climate Change, 4*, 1068-1072.

Masa, M. R. (2023). Strip cropping purpose, types and advantages. agraryo. Retrieved from https://agraryo.com/agriculture/strip-cropping-purpose-types-and-advantages/

Nelson, G. C., Rosegrant, M. W., Koo, J., Robertson, R., Sulser, T., & Zhu, T. (2009). *Climate change: Impact on agriculture and costs of adaptation.* International Food Policy Research Institute.

Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, S. M., Iqbal, M. M., . . . Travasso, M. I. (2014). Foos security and food production systems. *Methods*, 485-533.

Raghuveer, M., Charan, G. S., Kumar, P. Y., Kumar, M. S., Ramadevi, A., Poshadri, A., & Mamatha, K. (2022). Impact of frontline demonstrations of broad bed furrow (BBF) on yield and economics of soybean under rainfed conditions of northern Telanga zone, India. *Ecology, Environment and Conservation, 28*(2), 702-706.

Rahman, M. M., Hossain, M. M., Rahman, M. H., Rahim, M. A., & Islam, M. T. (2020). Growth and yield performance of garlic varieties under zero-tillage and tillage system. *International Journal of Horticulture Science, 26*, 46-54.

Rao, R. K., Sharma, P. K., & Raghuraman, M. (2017). Impact of climate change on food security. *Indian Journal of Agriculture and Allied Sciences, 3*(2), 29-40.

Saha, M. K., Biswas, A. A., Md. Faisal, Meandad, J., Ahmed, R., Prokash, J., & Sakib, M. F. (2019). Factors affecting to adoption of climate-smart agriculture practices by coastal farmers' in Bangladesh. *American Journal of Environment and Sustainable Development, 4*(4), 113-121.

Sergieieva, K. (2021). Strip cropping fields in agriculture: Why & how to use. EOS Data Analytics. Retrieved from https://eos.com/blog/strip-cropping/

SRDI. (2021). Soil Resource Development Institute. Dhaka, Bangladesh.

Talokar, N. P., Gabhane, A. T., & Umale, S. M. (2017). Enhancing productivity of groundnut by use of PDKV BBF planter cum inter row cultivator in Buldana district of Maharashtra. *Internal Journal of Agriculture, Innovtaions and Research, 5*(5), 754-757.

Verma, P. D., Parmanand, & Tamrakar, S. K. (2017). Effect of broad bed furrow method for rainfed soybean cultivation at Baldabazar district of Chattisgarh. *International Journal of Agricultural Engineering, 10*(2), 297-301.

World Bank. (2016a). World Development Indicators. Bangladesh: World Bank.

World Bank. (2022). Bangladesh - Country climate and development report. The World Bank Group.

Yerli, C., Sahin, U., Ors, S., & Kiziloglu, F. M. (2023). Improvement of water and crop productivity of silage maize by irrigation with different levels of recycled wastewater under conventional and zero tillage conditions. *Agricultural Water Management, 277*, 108100.