Scaling-up of climate-smart agriculture technologies in the SAARC region: An assessment of policy and institutional constraints and strategies from India

Agriculture is one of the largest livelihood providers in India, mainly in the rural areas. It also has a significant share in the GDP of the country, contributing around 18% (GoI, 2023). The agrarian sector is also the biggest absorber of the workforce in the country, providing employment to around 50% of the total workers in 2020-21 as compared to 44.1% in 2017-18. Not only this, but female employment in this sector also jumped from 57% in 2017-18 to 62.2% in 2020-21 while male workers in the sector decreased from 40.2% in 2017-18 to 39.8% in 2020-21 (GoI, 2022). The Indian agriculture system is highly vulnerable to climate change, owing its dependence on weather (like rainfall and temperature variations) and water stress conditions, coupled with poor economic status of the farmers and infrastructure. The average annual crop loss due to extreme weather conditions alone is estimated to be 0.25% of the GDP (Singh, Rio, Soundarajan, Nath, & Shivaranjani, 2019). It has also been estimated that climate change will cost 1% from the crop sector alone (Pathak, 2023). Ironically, small and marginal farmers are the most vulnerable to climate change as they are dependent more on climate-sensitive resources, contributing least to climate change. Moreover, 85% of the farmers have low financial resilience (Singh, Rio, Soundarajan, Nath, & Shivaranjani, 2019).

The impact of climate change is evident on the Indian monsoons, which have become more erratic and violent over the last few years. Moreover, there have been long spells of dry seasons followed by heavy monsoons. The inter-annual monsoon rainfall variability in India leads to large-scale droughts and floods, resulting in major effect on agriculture production (Kumar K. K., Kumar, Ashrit, Deshpande, & Hansen, 2004). Projections have indicated loss in crop yield ranging from 9% in wheat to 18% in maize by 2040 with a representative concentration pathway (RCP[1]) of 4.5 scenario and the climate suitability for rainfed rice is projected to reduce by 15-40% by 2050 (Pathak, 2023). Rise in temperature leads to increase in demand for irrigation and high evapotranspiration, resulting in depletion of groundwater resources. Groundwater will be more affected in coastal areas due to salinity intrusion (Gupta & Pathak, 2016). Climate change will also affect the soil fertility, lead to reduction in soil quality, soil moisture content, and affect the microbial growth (Gupta & Pathak, 2016). Increase in intensity of rainfall and frequency of floods will also lead to intensification of soil erosion. Furthermore, ICAR projections have shown that rainfed rice yields will reduce marginally by 2.5% by 2050-80 and irrigated rice yields will reduce by 7% by 2050 and 10% by 2080, wheat yields will diminish by 6-25% by 2100, and maize yields will decrease by 18-23% by 2100 (PIB, 2021).

Various programs and schemes have been launched by government of India to increase adaptation and build resilience against climate change. Some of the key initiatives are National Mission on Sustainable Agriculture (NMSA), Pradhan Mantri Krishi Sichai Yojana (PMKSY), Soil Health Card (SHC), Green India Mission (GIM), National Water Mission (NWM), Pradhan Mantri Fasal Bima Yojana (PMFBY), National Action Plan for Climate Change (NAPCC) and State Action Plan for Climate Change (SAPCC), Blue Revolution, National Livestock Mission, National Adaptation Fund for Climate Change (NAFCC), and many others. Most of these programs and policies focus on increasing the adoption of climate-smart agriculture (CSA) practices among small and marginal landholders to create resilience and promote adaptation in the agriculture sector. However, scaling-up of these practices is essential to ensure the food and livelihood security of the people. Lack of access to information and credit sources, low household

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[1] RCPs, adopted in the IPCC's 5th Assessment Report are the possible changes in GHG emissions and aim to represent their atmospheric concentration trajectory describing different climate futures. Four RCPs (2.6, 4.5, 6.0, and 8.5) are considered for projections of climate change.

income, fragmented landholdings, gender discrimination, disparity in resource endowments etc. create a challenging atmosphere for the farmers to cope up with changing conditions.

Scaling-up may be defined as efficiently increasing the socio-economic impact from a small to large scale coverage, referring to the replication, spread, or adaptation of techniques, ideas, approaches, and concepts, along with increasing the scale of impact (World Bank, 2003). It brings about the qualitative benefits to a wider population over a broader geographical area, quickly, equitably, and lastingly (Franzel, Cooper, & Denning, 2001). It is a long-term and non-linear process combining generalized and context specific approaches, with a focus on activities integrating local and external knowledge and mainstreaming new principles and processes (World Bank, 2003). It requires a multi-dimensional approach involving policy support, capacity building, financial incentives, and collaborations with different stakeholders. Since it is not a linear process, we assume it to be horizontal, vertical, and diagonal processes.

Horizontal scaling involves repetition of proven technologies in new geographical zones or target groups, for instance, a technology that has been proven successful on pilot farms can be scaled through farmer-to-farmer exchanges (World Bank, 2003). Vertical scaling-up necessitates driving institutional and policy transformations by showcasing effectiveness and efficiency of practices and technologies which entails eliminations of obstacles from large number of people (World Bank, 2003). It refers to increasing the production capacity and efficiency within a specific farming system. It comprises of methods to enhance output, improve processes, and maximize the limited resources optimally. Since scaling-up of CSA technologies is non-autonomous, there is a need for facilitation in terms of conducive policies and institutional/structural changes (Makate, 2019). Lastly, diagonal scaling-up involves adding more project components or modifying project configurations in response to the evolving realms of society, for example, extension services can be added (Neufeldt, et al., 2015). There are three main stages of scaling-up: effectiveness, efficiency, and expansion. These stages represent sequence of investments, transitions, and outcomes on the way to CSA adoption (Neufeldt, et al., 2013).

Scaling of CSA practices is the expansion of the adoption of the proven and effective CSA technologies. Successful scaling-up of CSA practices require identification and promotion of appropriate technologies, enabling environments constituting of supportive institutional arrangements, policies, and financial investments at local to international levels, along with recognizing probable bottlenecks and opportunities such as market and policy drivers will be central to implementing CSA activities at scale (Neufeldt, et al., 2015). Policy strategies are vital as they provide a clear framework that sets guidelines and responsibilities essential for scaling up (Makate, 2019). On the other hand, effective and complementary institutional actions towards scaling can reduce farmer challenges, adoption constraints, and improve sustainability in scaling process, which can altogether improve the impacts of CSA practices in the society (Makate, 2019). To make CSA more effective and efficient, coordinated actions are required from farmers, researchers, private sector, civil societies, and policymakers in four major areas – building evidence, increasing efficiency of local institutions, fostering coherence between climate and agricultural policies, and linking climate and agricultural financing (Lipper, et al., 2014).

Given this background, IFAD developed and approved the Consortium for Scaling-Up Climate Smart Agriculture in South Aisa (C-SUCSeS) with the objective of promoting sustainable and resilient agricultural intensification in South Asia. In this paper, we focus on studying the CSA technologies prioritized for Bangladesh. We describe each of the technologies and highlight the key constraints in adoption of these technologies and prescribe a few policy solutions to overcome them. These constraints and strategies have been computed through secondary literature along with primary survey and focused group discussions with farmers, extension agents, and other stakeholders in the value chain in the country. We focus on vertical scaling-up process of CSA technologies. While horizontal scaling-up involves replication of proven technologies in different areas, the efficacy of same technologies can vary in different agro-climatic zones in different regions. Hence, we emphasize expanding proven technologies in the same area by increasing their adoption and expansion among farmers in that specific agro-climatic zone. The technologies prioritized for India are direct-seeded rice (DSR), zero-tillage (ZT), and resilient intercropping system.

1. Direct seeded rice

Direct seeded rice (DSR) is an alternative method to cultivate rice in which the crop is seeded directly into the un-puddled fields. Direct seedling is a crop establishment system in which rice seeds are sown directly into the fields as compared to conventional method of growing seedlings in a nursery and then transplanting them into the flooded fields. DSR is assumed to be one of the most efficient, sustainable, and economically viable rice production systems. In comparison to the traditional transplanted rice method prevalent in Asia, DSR assures faster planting and maturing of the crop, conserves scarce resources, more conducive to mechanization, and reduces GHG emissions that contribute to climate change. Moreover, mechanized DSR also creates opportunities for employment through new service provisions and is less labour intensive and free from drudgery which becomes more attractive to youth and female farmers.

DSR is an emerging technology in the water scarce regions across the world. Field experiments at different research sites have shown that DSR helps in saving irrigation water (Bista, 2018), reducing labour requirements (Bista, 2018), decreasing cost of production with higher net returns (Mishra, Khanal, & Pede, Is direct seeded rice a boon for economic performance? Emperical evidence from India, 2017) (Kumar J. H., et al., 2022), reducing GHG emissions (Bista, 2018), and increasing crop productivity (Bista, 2018) (Mishra, Khanal, & Pede, Is direct seeded rice a boon for economic performance? Emperical evidence from India, 2017). (Kumar J. H., et al., 2022) reported that adoption of DSR resulted in increase in net income, crop yield, and reduction in cost of production with a benefit-cost ratio of 2.95 as compared to 1.88 in traditional transplanted method. On the other hand, Kamboj et. al. (2022) reported a higher benefit-cost ratio of 4.78 for DSR as compared to 3.87 for conventional transplanting method. A major constraint reported by the scientists for the successful establishment of DSR method is the weed management (Bista, 2018). High weed infestation is a major challenge in DSR, especially in dry soil conditions (Rao, Johnson, Sivaprasad, Ladha, & Mortimer, 2007). Other major challenges faced by the farmers in adopting DSR is the unavailability of machines, lack of knowledge and training in operating the DSR machines, high irrigation costs using diesel pump, and many more. The main drawbacks of adopting DSR in South Asian region are rainfed culture, poor drainage, and slow economic growth (Pandey, 2002).

A study on DSR from Punjab and eastern Uttar Pradesh showed a 2.13% reduction in total cost for DSR adopters with a significant reduction in irrigation and land preparation costs, along with raising income of the non-adopters by 17% if they adopt DSR methods of cultivation (Mishra, Khanal, & Pede, 2017). An empirical study of DSR in peninsular India showcased that cost of irrigation, land preparation, and fertilization is significantly lower in DSR, resulting in an additional income of Rs. 5192/acre along with a rise in crop productivity of 0.85 quintals/acre for adopters in peninsular region of India (Dey, et al., 2024).

The main constraints reported by the stakeholders in adoption and scaling-up are as follows:

a. Persistent rise in the weeds on the farms cultivated through DSR.

b. Herbicides have proven to be ineffective on the weeds when they grow above a certain size. Hence, proper timing of herbicides is essential.
c. The seeds get washed off during the rainfall immediately after sowing.
d. Uneven seed plantation, leading to gaps between rows of the rice plants.
e. Iron-deficiency in Punjab leads to lower crop yield from DSR practice.
f. In case of labour availability, farmers are hesitant to adopt the DSR method.
g. Farmers are unable to cultivate maize after the rabi crops as the harvesting period coincides with the sowing period of the kharif crop.

Here we present few policy suggestions to encourage the adoption of DSR among farmers based on consultation with farmers and extension agents. Knowledge dissemination about the benefits of the DSR practice is important to increase the adoption of the method. Firstly, empowering the farmers with comprehensive education, skills, and training is fundamental for successful adoption of DSR. Field demonstrations are also an important step to equip the farmers with skills and training required for operating the DSR machines. Secondly, administering the use of weedicides is crucial to ensure its timely use within the recommended quantities to reduce its harmful effect on crops as well as environment. Thirdly, timely soil tests to ensure proper nutrients and health is another important step to ensure maximum output from The DSR practice. Further, an increase in extension services will ensure farmers with proper guidance related to agricultural activities. Hence, integrating all these measures will encourage a widespread adoption of DSR in the country.

2. Zero-tillage

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. It is an agricultural practice in which the topsoil of a field is not tilled after harvesting the first crop and the second crop is sown directly into the field with the remnants of the previous crop. 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) (Aryal, Sapkota, & Bishnoi, 2015) (VenkatRao, Chittibabu, & Harika, 2022)**.** Moreover, there is also improvement in soil structure, biological diversity, reduced soil degradation, and GHG emissions (Hassan, et al., 2022).

ZT practice helps to increase water and fertilizer use efficiency which in return leads to increase in crop productivity (Triplett & Dick, 2008) (Erenstein, Farooq, Malik, & Sharif, 2008), (VenkatRao, Chittibabu, & Harika, 2022)**.** It has also been observed that ZT enhances the population of beneficial fungi which helps in maximizing benefits to the crop and thus leading higher crop productivity (Kabir Z. , 2005). 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 were conducted by Bangladesh Agricultural University (BAU) to the test the growth characteristics of garlic under ZT and tillage condition, which 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). A participatory field experiment was conducted by Aryal et al. (2015) in Haryana for three consecutive years to test the hypothesis that ZT crop production is beneficial in comparison to the CT of crop production. The results showed that farmers save $79/ha in total production cost and net revenue increase by $97.5/ha under ZT system in comparison to the CT system. Further, the results displayed that ZT system witnessed a benefit – cost ratio of 1.43 in comparison to 1.31 under CT system. Additionally, ZT system also reduced GHG emissions by 1.5 mg/CO_2/season. Hence, we can finally state that ZT system has various environmental and economic impacts.

3. Resilient intercropping system

Intercropping is the process of growing two or more crops simultaneously on the same field. It is raising two or more crops together as they coexist for some time on the same piece of land. It includes the concept of growing a primary crop with a cover crop to enhance the entire production system and sustainability (Weih, Minguez, & Tavoletti, 2022) and helps farmers to maximize water use efficiency, maintain soil fertility, and reduce soil erosion (Hoshikawa, 1991). Moreover, intercropping also helps in providing ground cover for a longer duration of time, protecting the soil cover from desertification and erosion (Gebru, 2015). There are different types of intercropping like row, mixed, strip, and relay intercropping. Row inter-cropping is a system of growing one or more crops in regular rows and growing inter-crops with or without rows at the same time. It is the best practice of maximizing resource use efficiency and optimizing productivity of crops (Varma, Meena, & Kumar, 2017). In mixed intercropping, two or more crops are grown together without any definite row proportions. It is sometimes known as mixed cropping. The motivation for this form of inter-cropping is to fulfill the requirement of food and forage where the land is scare (Undie, 2012). Strip intercropping is a system in which two or more crops are cultivated together in strips on sloppy lands. It is a way to enhance greater radiation use efficiency in marginal and poor lands (Yang, et al., 2015). The main objective of this type of inter-cropping is to reduce soil erosion and harvest output from poor lands (Maitra, et al., 2021). In relay intercropping, the second crop is seeded when the first crop has completed a major part of its life cycle and reaches reproductive stage, but before harvest. Prior to harvesting of the primary crop, the second crop is sown, and both the crops remain in the field for some period. However, the second crop yields less as compared to the normal sowing in sequential cropping system and more seeds are required to obtain a good stand (Maitra, et al., 2021).

The key benefits of inter-cropping are better crop yields, productivity of various plant components, increase in economic returns, stability in crop yield, enhance crop diversification and ensure natural insurance, pest control, rise in resource use efficiency, nutrient use efficiency, food and nutritional security, and ensure agricultural and environmental sustainability (Mousavi, 2011), (Gebru, 2015), (Lulie, 2017), (Manasa P. a., 2018), (Mishra, Khanal, & Pede, Is direct seeded rice a boon for economic performance? Emperical evidence from India, 2017). Another important aspect of inter-cropping is the potential of mixed crops to increase resilience under harsh climate conditions (Weih, Minguez, & Tavoletti, 2022). Moreover, inter-cropping also provides natural crop insurance against crop failure or against unstable market conditions or against extreme weather conditions like floods, droughts etc. (Lulie, 2017).There are also few demerits of inter-cropping like higher cost of maintenance (manual weeding), higher labour costs in labour-scarce regions, reduction in yield of the main crop because of competition among inter-cropped plants for light, water, and soil nutrients (Willey, 1979). Another important limitation of this method is the management of agronomic operations when farm mechanization is adopted or crops used in inter-cropping require different amounts of fertilizers, water or plant protection mechanisms (Maitra, et al., 2021). Moreover, the canopy formed by inter-cropping may lead to formation of micro-climate with a higher humidity conducive to disease outbreak (Gliessman, 1985). (Maitra, et al., 2021) states that inter-cropping system is complex because under diverse conditions, farmers have to adopt different inter-cropping practices.

(Manasa P. a., 2018) showed through an experiment in Odisha (sub-humid and sub-tropical region climatic conditions) that inter-cropping of maize with other legumes resulted in increase in crop yield. (Ngwira, Aune, & Mkwinda, 2012) elucidates the short-term impacts of inter-cropping on soil quality, crop productivity, and profitability. The authors found that inter-cropping resulted in double gross margin as compared to mono-cropping maize. The agronomic impacts of inter-cropping practice has been well established in the literature. So, to take a one step further, a study analyses the economic and environmental values of this system along with promoting food security and environmental health, which can provide a basis to the government for policy making and exploring sustainable farming options (Fung, 2019). Authors showed that annual average inorganic concentration of PM 2.5 can be reduced by 1.5 mu g/m3, and annual economic benefit can be increased by US$ 67 billion, out of which US$ 13 arises from saved health costs of air pollution (Fung, 2019). A study shows that cane yield of sugarcane decreased significantly due to inter-cropping with cucumber, ridge gourd, and tomato but was unaffected with green gram and french beans (Gouri, Chitkala, Kumari, & Rao, 2015). Further, in an experiment by (Mandal, et al., 2014) has displayed that inter-cropping of maize and soybean resulted in yield of 5.48 tons/hectare against 2.48 tons/hectare in sole maize cultivation. Moreover, (Manasa, Maitra, & Barman, 2020) portrayed that maize yield (7.6 tons/hectare) was high when paired with groundnut against sole maize cultivation (5.7 tons/hectare). Not only this, intercropping also helps in maintaining soil fertility as legumes naturally fix nitrogen of about 80 to 350 kg/hectare (Peoples & Craswell, 1992). It has been observed that strip inter-cropping of shallow-rooted pea with maize resulted in complementarity in sharing water resources and both the crops performed well and enhanced water use efficiency (Chen, et al., 2018).

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