Bangladesh Agricultural Research Institute
Gazipur, Bangladesh

Climate-Smart Agriculture Technologies and Practices in Bangladesh

Consortium for Scaling-up Climate Smart Agriculture in South Asia (C-SUCSeS) Project
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SAARC Agriculture Centre (SAC)

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This book 'Climate-Smart Agriculture Technologies and Practices in Bangladesh' contains the climate-smart agriculture (CSA) technologies and practices of Bangladesh produced as an output of the inventory of CSA technologies conducted by the National Focal Point of C-SUCSeS project of Bangladesh and the associates working under the Bangladesh Agricultural Research Institute (BARI). The CSA technologies and practices in this publication are those of the authors gathered from various sources and do not imply any opinion whatsoever on the part of SAC.

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Foreword

Bangladesh stands as one of the world's most climate-vulnerable nations, with its agriculture sector particularly exposed to climate change impacts. The country's agricultural framework hinges on subsistence production, predominantly steered by small and marginalized farmers reliant on rice-centric cropping systems.

To fortify production and ensure food security, research concentrates heavily on non-rice crops, especially high-value varieties like pulses, oilseeds, vegetables, and fruits. The Bangladesh Agricultural Research Institute (BARI), a multi-crop research body, spearheads the development of high-yield strains encompassing cereals beyond rice, pulses, oilseeds, root crops, spices, and an array of fruits and vegetables. This aligns with their drive for food self-sufficiency.

Our commitment lies in delivering location-specific, climate-smart technologies, synchronized with the Sustainable Development Goals (SDGs). The On-farm Research Division (OFRD) at BARI holds the reins of validating and disseminating BARI-bred varieties and technologies across farmers' fields throughout the nation. This division plays a pivotal role in climate change adaptation and mitigation research.

Climate-smart agriculture (CSA) emerges as the strategy to bolster agriculture's resilience to climate change. CSA can significantly contribute to food security and broader developmental aspirations amidst changing climate dynamics and mounting food demands. CSA practices can enhance productivity sustainably, bolster resilience, and mitigate greenhouse gas emissions. Many CSA practices have already been adopted by farmers across Bangladesh, yielding a notable positive impact on the national agricultural system. However, these beneficial CSA technologies often lack recognition and documentation.

In this context, the commendable endeavor by BARI and other National Agricultural Research Systems (NARS) scientists to compile a repository of viable CSA technologies is highly commendable.

I have confidence that this CSA inventory report will prove invaluable to researchers, DAE personnel, policymakers, development partners, and farmers in Bangladesh. Furthermore, I anticipate this report will serve as a reference within the international research community.

Dr. Debasish Sarker

CSO & Head
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Preface

Bangladesh, a country marked by diverse agro-ecological conditions encompassing soil and climate variations, seeks to harness Climate-Smart Agriculture (CSA) to enhance its agricultural production systems in the face of shifting climates. Despite the generation and limited adoption of promising CSA technologies by local farmers, comprehensive documentation of these technologies remains lacking.

In response, the On-farm Research Division (OFRD) at the Bangladesh Agricultural Research Institute (BARI) has undertaken the commendable task of cataloging the existing CSA technologies in Bangladesh. This effort is carried out under the project titled "Consortium for Scaling-up Climate Smart Agriculture in South Asia (C-SUCSeS)."

Within this report, an inventory presents a compilation of existing and prospective CSA technologies across the nation. The report delves into the key attributes of these CSA technologies, highlighting their benefits and applicability within the institute's purview.

It is my anticipation and belief that this report will stand as a comprehensive repository on the status of CSA technologies in Bangladesh, serving as a touchstone for future reference.

I extend heartfelt gratitude to the SAARC Agriculture Centre, IFPRI, and IFAD for their financial support in spearheading the preparation of this CSA inventory report. My admiration goes to the dedicated scientists involved in this project, whose remarkable contributions have brought this report to fruition. A special acknowledgment is also extended to the cooperative farmers for their invaluable assistance. Lastly, I recognize the relentless efforts and wisdom of the scientists who have labored to complete this substantial work.

Dr. Md. Mazharul Anwar
National Focal Point (C-SUCSeS Project)

Acknowledgment

This publication is the result of a collaborative endeavor involving the South Asian Association for Regional Cooperation (SAARC) Agriculture Centre (SAC), the International Food Policy Research Institute (IFPRI), and the International Fund for Agricultural Development (IFAD), titled "Consortium for Scaling-up Climate Smart Agriculture in South Asia (C-SUCSeS)." The project's focal point for Bangladesh is Dr. Md. Mazharul Anwar, Chief Scientific Officer at the On-Farm Research Division of the Bangladesh Agricultural Research Institute (BARI), responsible for coordinating all project activities.

Among the project's activities is the development of an inventory of Climate-Smart Agriculture (CSA) technologies, aiming to scale up technically feasible and gender-sensitive solutions for smallholders in specific farming systems. Consequently, our focus has been to identify and document existing CSA technologies in Bangladesh, making them accessible to relevant stakeholders like the Department of Agricultural Extension (DAE) and end-users, namely farmers.

We extend profound gratitude to all National Agricultural Research System (NARS) institutes for generously sharing their generated CSA technologies. Without their unwavering contributions, this publication would not have come to fruition, both in terms of collaborative discussions and the provision of valuable information regarding their CSA innovations.

Our heartfelt appreciation goes to the International Fund for Agricultural Development (IFAD) for their financial support, which has made the publication of this inventory report possible. We also express our gratitude for the guidance and support provided by the C-SUCSeS project management unit of SAC, from inception to the finalization of this CSA inventory report.

Lastly, we offer special recognition to the scientists of OFRD, BARI, whose dedication and hard work have been instrumental in the preparation, compilation, and editing of this comprehensive inventory report.

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Acronyms

AEZ	Agro-ecological Zones
AWD	Alternate Wetting and Drying
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
BINA	Bangladesh Institute of Nuclear Agriculture
BRRI	Bangladesh Rice Research Institute
BSFB	Brinjal Fruit and Shoot Borer
BSRI	Bangladesh Sugarcrops Research Institute
BW	Bacterial Wilt
CLS	Cercospora Leaf Spot
CRI	Crown Root Initiation
CSA	Climate Smart Agriculture
DAE	Days After Emergence
DAP	Days After Plantation
DAT	Days After Transplanting
DAS	Days After Sowing
FRG	Fertilizer Recommendation Guide
GDP	Gross Domestic Product
HYV	High Yielding Variety
IPM	Integrated Pest Management
Kg	Kilogram
MP	Muriate of Potash
NARS	National Agricultural Research System
NGO	Non-Government Organizations
PI	Panicle Initiation
PLRV	Potato Leaf Roll Virus
PRSV	Papaya Ring Spot Virus
PTOS	Power Tiller Operated Seeder
SAARC	South Asian Association for Regional Cooperation
STP	Spaced Transplantation
t/ha	Ton/hectare
TSP	Triple Super Phosphate
WRC	Wheat Research Centre
YLCV	Yellow Leaf Curl Virus
YVMV	Yellow Vein Mosaic Virus

1. Introduction

Bangladesh, the eighth most populous nation worldwide, is home to 169.4 million people in an expanse spanning 148,460 square kilometers (57,321 sq miles, 14.85 million hectares). Within this context, agriculture takes center stage, being a crucial source of livelihood, employment, and GDP contribution. The sector employs over 40% of the nation's workforce and constitutes 11.6% of GDP. Notably, the crop sub-sector alone contributes 7.25% (World Bank, 2022). The nation's efforts have borne fruit, achieving self-sufficiency in essentials like rice, fruits, fish, meat, and eggs, vital for feeding its populace. Remarkably, rice production has surged over threefold, from 12 million tons (M t) in the late 1970s to 37.6 M t in 2021 (BBS, 2022). This shift has steered Bangladesh from food scarcity to self-sufficiency (Bokhtiar & Samsuzzaman 2023), a transformation catalyzed by agricultural policy reforms and technological breakthroughs. The cropping intensity, standing at 198% in 2020, reflects significant growth from 180% in 2010 and 177% in 2000. Key crops encompass rice, wheat, maize, potato, jute, sugarcane, pulses, and vegetables. Complementing crop farming, livestock, and fisheries also constitute pivotal facets of Bangladesh's agricultural landscape.

Bangladesh's strides in agriculture have profoundly impacted poverty reduction and food security. However, these gains face potential erosion due to numerous challenges. Cultivable land has diminished from a peak of 9.44 million ha in 2000 to 8.77 million ha in 2020, even as the population swells by 2 million yearly (https://www.worlddata.info/asia/bangladesh/index.php). Climate vulnerability looms large, manifesting in sea level rise, salinity, drought, and floods. Across the nation, five fragile ecosystems—Barind, Char, Coastal, Haor, and Hill ecosystems—experience notably low cropping intensity and crop productivity (Bokhtiar et al., 2023).

Climate change exerts profound influence over agriculture and the adoption of climate-smart technologies. The impacts are multifaceted, encompassing extreme weather events (droughts, floods, salinity, heatwaves), shifts in crop growing conditions (alterations in growing season timing and duration), soil fertility degradation (intensified by high temperatures and submergence), pest and disease outbreaks (driven by changing pest and disease distribution), and water scarcity (stemming from erratic rainfall patterns and flood-related water waste).

Climate-smart Agriculture (CSA) represents a farming approach designed to tackle the challenges that climate change presents to food production, all while fostering sustainable agriculture and rural progress. This approach recognizes the necessity of bolstering food output to sustain a growing populace, concurrently curbing greenhouse gas emissions, and heightening resilience against climate change impacts. The core tenets of Climate-smart Agriculture encompass:

I. **Sustainable enhancement of agricultural productivity and incomes:** This involves optimizing production efficiency and augmenting yields via novel technologies, as well as better management of natural resources like water and soil.

II. **Cultivating resilience against climate change impacts:** This entails fortifying farming systems to withstand the repercussions of shifting weather patterns and other climate-associated risks.

III. **Mitigation and/or reduce of greenhouse gas emissions:** This centers on diminishing emissions arising from agricultural activities, such as fertilizer usage, and augmenting carbon storage within the soil.

Presently, Bangladesh boasts 61 available CSA technologies. These technologies and practices are actively applied to endorse sustainable agricultural production and elevate resilience against climate change repercussions. Notable CSA technologies encompass:

i. **Precision agriculture (GPS and remote sensing):** Utilizing GPS and remote sensing to enhance farming accuracy.

ii. **Climate-resilient crop varieties:** Incorporating varieties that endure challenging conditions such as salinity, drought, submergence, cold, and shorter growth cycles.

iii. **Improved water management systems:** Optimizing water usage and efficiency, in addition to conservation-oriented practices.

iv. **Conservation agriculture:** Embracing practices like reduced tillage, cover cropping, and legume-based crop rotations.

v. **Enhanced livestock management:** Enhancing livestock efficiency, curbing emissions, and enhancing animal health.

vi. **Year-round aquaculture:** Providing a consistent source of protein-rich food for Bangladesh throughout the year.

These CSA technologies embody a proactive stance in facing the complexities of climate change while concurrently bolstering agricultural sustainability and securing food production.

2. Purpose of CSA Inventory

The CSA inventory report assembles a diverse array of CSA technologies that are either already released or actively being researched across various fields. Through this inventory, the most effective CSA technologies and practices tailored for smallholder and women farmers can be pinpointed. These selected solutions will subsequently be expanded through national policies and programs.

The inventory report proves invaluable to national and international donors, policymakers, researchers, extension personnel, NGOs, and other stakeholders. It aids in making well-informed investment decisions and establishing priorities for the upscaling of CSA technologies.

Thus, the primary objective of the CSA inventory is to seamlessly integrate strategies for climate change adaptation and mitigation. This integration serves the overarching goal of guaranteeing food, nutrition, and livelihood security.

3. Methodology of CSA Inventory

Various National Agricultural Research Institutes, Agricultural Universities, Consultative Group of International Agricultural Research (CGIAR) Centers, and other development partners have collectively developed numerous climate-smart agricultural (CSA) technologies in Bangladesh. These CSA technologies were identified through a combination of secondary sources (literature reviews) and primary sources (workshops and meetings).

Literature Review

An exhaustive literature review, encompassing both published and unpublished grey literature, was conducted to unearth proven and emerging CSA technologies suitable for Bangladesh.

Central Workshop

A pivotal central consultation workshop was orchestrated at the Bangladesh Agricultural Research Institute in Gazipur. This gathering brought together scientists from pertinent NARS institutes, personnel from the Department of Agricultural Extension (DAE), and BARC personnel (see Annexure 1). During this event, research organizations presented their portfolio of CSA technologies developed to date. Subsequently, the most pertinent CSA technologies were selected, and tailored to specific regions.

Regional Workshops

Furthermore, a series of regional workshops were convened to pinpoint CSA technologies suited to specific geographic areas. In these workshops, scientists from NARS institutes, DAE personnel affiliated with the designated regions, and forward-thinking farmers were invited as the participants. These gatherings resulted in presentations of their CSA technologies (see Annexure 1 and Annexure 2). Following comprehensive discussions, a subset of CSA technologies was chosen for each region.

Meetings

Several meetings, both physical and virtual, were conducted with scientists to deliberate on CSA technologies. During these sessions, the focus was on identifying pertinent CSA technologies that matched specific locations (see Annexure 3).

4. Concept and Pillars of CSA

Climate Smart Agriculture (CSA) encompasses practices aimed at enhancing crop productivity and bolstering land resilience against the backdrop of climate change impacts. This practice involves the fusion of sustainable farming techniques tailored to address the specific climate challenges encountered by distinct agricultural communities, culminating in what can be termed as "climate-smart agriculture," a facet akin to sustainable farming practices. The initial stride entails a meticulous evaluation of precise climate risks. For instance, a farm grappling with prolonged water scarcity necessitates disparate strategies from those required by one facing recurrent inundation. Diverse tools are available to assess climate risk and ecosystem vulnerability, guiding the selection of suitable crops for specific environments.

According to the FAO (2010), Climate Smart Agriculture (CSA) delineates an approach for augmenting productivity, adaptation, and resilience to climate change, while concurrently curbing or eliminating greenhouse gas (GHG) emissions.

CSA is upheld by three foundational pillars:

- **Sustainable Enhancement of Food Security:** Achieved by elevating agricultural productivity and incomes.
- **Enhanced Resilience and Adaptation:** Ensuring farms are equipped to weather the challenges posed by climate change.
- **Greenhouse Gas Emission Mitigation:** Creating avenues to reduce emissions in comparison to projected trends, wherever feasible.

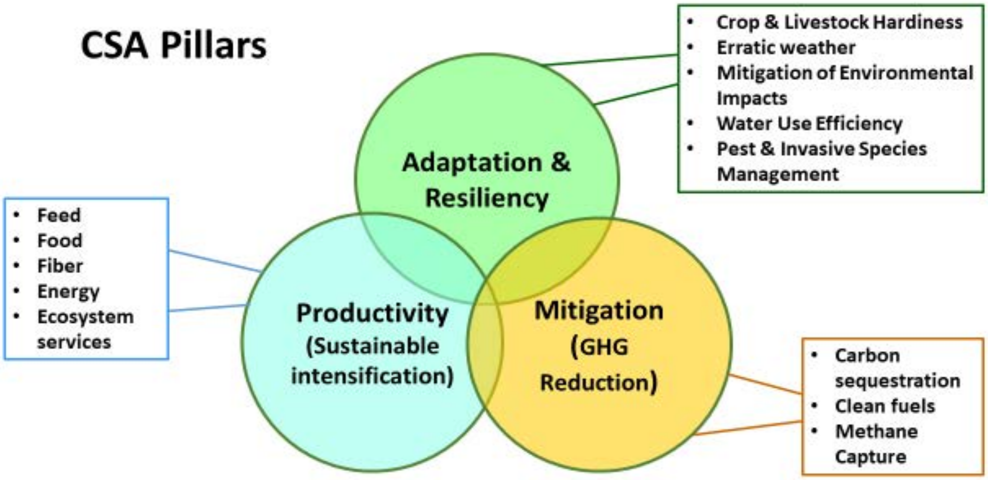

Fig. 1 *Three pillars of climate-smart agriculture*

(Source: FAO, 2013)

5. Brief Description of Individual Technology

Currently, the nation boasts a total of 61 available CSA technologies and practices. These technologies and practices can be classified into six distinct categories (Aggarwal et al. 2013) based on different dimensions and level of climate-smartness, namely Weather-smart, Carbon-smart, Water-smart, Nutrient-smart, Energy-smart, and Knowledge-smart. For a comprehensive overview, Table 1 displays the entire roster of 61 CSA technologies and practices, delineating their respective categories and priority standings.

Table 1 Climate Smart Agricultural technologies and their categories

Name of CSA Technologies and Practices	Categories of CSA technologies	Priority ranking* (High-H, Medium-M, Low-L)
1. Saline-tolerant rice	Weather-smart, Knowledge-smart	H
2. Saline-tolerant potato	Weather-smart, Knowledge-smart	M
3. Saline-tolerant mustard	Weather-smart, Knowledge-smart	M
4. Heat-tolerant wheat	Weather-smart, Knowledge-smart	M
5. Heat-tolerant maize	Weather-smart, Knowledge-smart	M
6. Heat-tolerant sweet potato	Weather-smart, Knowledge-smart	M
7. Heat-tolerant grass pea and lentil	Weather-smart, Knowledge-smart	M

8. Heat-tolerant barley	Weather-smart, Knowledge-smart	M
9. Heat-tolerant foxtail millet	Weather-smart, Nutrient-smart	M
10. Heat-tolerant proso millet	Weather-smart, Nutrient-smart	M
11. Heat-tolerant groundnut	Weather-smart, Nutrient-smart	M
12. Drought-tolerant rice	Weather-smart, Knowledge-smart	M
13. Short duration T. Aman rice	Weather-smart, Knowledge-smart	M
14. Late blight-resistant potato	Knowledge-smart	H
15. Disease-resistant sugarcane	Weather-smart, Knowledge-smart	L
16. Biochar application	Nutrient-smart, Carbon-smart	H
17. Zero tillage garlic cultivation	Carbon-smart, Energy-smart, knowledge-smart	H
18. Inclusion of mustard in the single cropping pattern	Knowledge-smart	M
19. Double transplanting of T. *Aman* rice	Knowledge-smart	M
20. Less irrigation requiring cropping pattern	Water-smart	M
21. Levee management in T. Aman rice season	Water-smart	L
22. Growing vegetables with low-land rice	Knowledge-smart	M
23. Dibbling method of planting in zero-tilled wetland	Knowledge-smart	M
24. Relay cropping of cowpea/ grass pea in T. Aman rice for coastal areas	Knowledge-smart	M
25. Maize seedling transplanting system	Knowledge-smart	M
26. Floating agriculture system	Weather-smart, Knowledge-smart	M
27. Sorjan farming in coastal saline soil	Weather-smart, Knowledge-smart	M
28. Furrow and ridge cropping for coastal saline areas	Weather-smart, Knowledge-smart	M
29. Pyramid cropping for coastal saline areas	Weather-smart, Knowledge-smart	M
30. Maize-kenaf cropping system in haor areas	Knowledge-smart, Water-smart	M
31. Silicon-enriched rice husk ash management in wheat	Nutrient-smart, Knowledge-smart	M
32. Liming	Carbon-smart, Nutrient-smart, and Knowledge-smart	M
33. Integrated nutrient management	Carbon-smart, Nutrient-smart, and Knowledge-smart	H
34. Black gram production technology in haor areas	Weather-smart, Knowledge-smart	M
35. Mulching in watermelon field	Water-smart, Knowledge-smart	M
36. Mixed/Intercropping	Carbon-smart, Knowledge-smart	H
37. Integrated rice –fish-vegetables system	Weather-smart, Knowledge-smart	M

38. Spaced transplanting (STP) for sugarcane	Weather-smart, Knowledge-smart	L
39. Litchi-based agroforestry system	Carbon-smart	H
40. Integrated pest management of cucurbit fruit fly	Knowledge-smart	M
41. Integrated pest management of mango/guava fruit fly	Knowledge-smart	M
42. Management of litchi fruit borer	Knowledge-smart	M
43. Management of banana leaf and fruit beetle	Knowledge-smart	M
44. Bio-rational management of varroa mite in honeybee colony	Weather-smart, Knowledge-smart	L
45. Bio-rational management of *Spodoptera litura* in vegetables and aroid	Knowledge-smart	M
46. Integrated management of powdery mildew and root-knot diseases of cucurbits	Knowledge-smart	L
47. Integrated viral disease management of vegetable crops	Knowledge-smart	M
48. Integrated management of bacterial wilt disease of brinjal, tomato, and potato	Knowledge-smart	M
49. Biological control of sugarcane stem borer	Weather-smart, Knowledge-smart	L
50. Rainwater Harvest	Weather-smart, Knowledge-smart	M
51. Alternate Wetting and Drying (AWD) technology	Water-smart, Weather-smart, and Knowledge-smart	H
52. Solar-powered irrigation	Energy-smart	M
53. Alternate furrow irrigation technology	Water-smart, Weather-smart, and Knowledge-smart	M
54. Drip irrigation/fertigation technology	Water-smart, Weather-smart, and Knowledge-smart	H
55. Conjunctive use of fresh and saline water in coastal areas	Water-smart, Weather-smart	M
56. Surface drainage technique	Knowledge-smart	H
57. Non-puddled mechanical rice seedling transplanter	Energy-smart	H
58. Raised bed planter	Carbon-smart, Energy-smart, Knowledge-smart	H
59. Laser land leveling	Water-smart, Knowledge-smart	M
60. Reduced tillage machinery for sugarcane cultivation	Energy-smart, Weather-smart	M
61. Strip planting system	All six categories	H

*Priority ranking of the CSA technologies were done based on the farmers' preferences and willingness-to-pay for the respective technology.

The details of all these listed technologies are stated below.

A. Climate Resilient Crop Varieties

A growing emphasis is placed on an extensive array of crop production practices that can be deemed 'climate-smart,' as viewed through both adaptation and mitigation lenses. Notably, crop-based measures, such as drought-tolerant and short-duration varieties, wield the potential to significantly curtail the perils of yield decline or crop loss (Roy et al., 2014) (Refer to Table 2). Predominantly, salinity, drought, and heat constitute major abiotic stresses that exert a detrimental impact on crop productivity, consequently impinging upon food security. This challenge is exacerbated particularly in light of climate change occurrences and their escalating consequences.

Table 2 Stress-tolerant crop varieties

Types of stress-tolerant varieties	**Crop varieties**
Salinity-tolerant rice varieties	BRRI dhan47, 53, 54, 55, 61, 67, 73, 78, 97 & 99 Bina dhan- 8 & 10
Drought-tolerant rice varieties	BRRI dhan56, 57, 66 & 71
Short duration or early maturing T. Aman rice	BRRI dhan76, 77 & 87
Submergence-tolerant rice varieties	BRRI dhan51, 52 & 79 (T. Aman) BRRI dhan78 (T. Aman Saline condition) Binadhan-11, 12 & 23 (T. Aman)
Cold-tolerant rice varieties	BRRI dhan18, 36, 55 & 69 (Boro)
Heat-tolerant crop varieties	BARI Gom-33, BWMRI Gom-1, 2 BARI Barley-1, 2, 3, 4, 5 & 6 BARI hybrid maize-12, 13 & 16 BARI Alu-72 & 73; BARI Mistialu-8 BARI Khesari-3, BARI Masur-8; BARI Chinabadam-10 BARI Kaon-1, 2 & 3; BARI Cheena-1
Salt tolerant other crops	BARI Sarisha-11 & 16; BARI Alu-72, 73 & 78 BARI Sweet potato-6 & 7; BARI Til-4; BARI Masur-1; BARI Tomato-14; BARI Gom-25; BARI Barley-7 Binagom1; Binachinabadam-6, 7, 8 & 9; Binatil1 Binasoyabean-2 & 6; BJRI Deshi Pat-10
Late blight disease-resistant potato	BARI Alu-77, 90 & 91
Red rot and Smut disease-resistant sugarcane	Isd 39, Isd 40, BSRI Akh 41, BSRI Akh 43, BSRI Akh 44, BSRI Akh 45 and BSRI Akh 46.

(1) Saline-tolerant rice

Approximately 1.1 million hectares of arable land in Bangladesh's coastal regions confront varying degrees of salinity, with 75% classified as slightly to moderately saline (<12 dS/m). In this context, rice (*Oryza sativa*) varieties developed by BRRI (BRRI dhan47, 67, 97 & 99) and BINA (BINA dhan 8 & 10) have demonstrated successful cultivation potential during the Boro (dry) season (Nayak et al., 2022). It is noteworthy that salinity levels and their extent are progressively escalating due to the effects of climate change.

This technology occupies a dual role within the CSA framework, being part of both the weather-smart and knowledge-smart categories. The rice varieties mentioned yield between 5 to 6 tons per hectare. This approach is specifically applicable to rice production in the coastal districts of Bangladesh, spanning Satkhira, Khulna, Bagerhat, Borguna, Jhalokathi, Patuakhali, Bhola, and Noakhali, among others. Moreover, it's well-suited for smallholder farmers.

BRRI dhan97 *BINA dhan8*

Fig. 2 *Saline-tolerant rice varieties*

The untapped potential of fallow land in the late Rabi to Kharif-I seasons in saline areas can be harnessed for the cultivation of these salt-tolerant rice varieties from BRRI and BINA.

Nonetheless, scaling up this technology faces challenges such as the availability of irrigation water and quality seeds. It's noteworthy that farmers who've adopted the cultivation of saline-tolerant rice varieties have reaped higher yields and increased income.

For broader extension, this technology is recommended throughout the entirety of the coastal regions in the country. Achieving this entails a collective endeavor involving researchers, extension workers, and farmers collaborating within robust seed supply chains, thereby facilitating widespread adoption.

(2) Saline-tolerant potato

Potato (*Solanum tuberosum*) stands as a significant staple in Bangladesh, following rice and wheat. The country achieved a substantial potato production of 11 million tons in 2022, ranking as the third-largest producer in Asia after China and India. Of this, around 0.8 million tons were exported to Malaysia, Nepal, and Sri Lanka. The cultivation of potatoes is widespread across Bangladesh. However, in coastal regions, the combined effects of rising sea levels and frequent severe storms result in saltwater intrusion into soil and groundwater, rendering crop growth, including potatoes, challenging.

To address this issue, the Bangladesh Agricultural Research Institute (BARI) has introduced salt-tolerant potato varieties, BARI Alu-72 and BARI Alu-78, which also exhibit resilience to heat stress and drought (Rahman et al., 2021). These varieties boast an average yield potential of 22 tons per hectare, containing 18.4% dry matter. With an oval-shaped medium-large-sized tuber, shallow eye depth, red skin, and yellow flesh, these varieties have been developed with the environment-smart and knowledge-smart CSA classifications in mind.

Barren land within saline-prone regions could be transformed through the cultivation of BARI Alu-72 and BARI Alu-78, thereby enhancing cropping intensity and farmers' income. These crop varieties thrive during the rabi (winter) season in the southern districts of the country, situated within the saline belt. Notably suitable for smallholder farmers, the crops mature between 70 to 90 days, allowing flexibility in planting and harvesting, all while adapting seamlessly to saline environments with minimal disease or insect complications.

However, these relatively novel varieties have not gained significant traction among coastal farmers. The limited availability of quality seeds further constrains their expansion within the region. To address this, implementing more pilot production initiatives with these varieties in saline-prone zones through a participatory approach involving farmers could amplify their popularity.

Fig. 3 *Saline-tolerant potato varieties*

The cultivation of salt-tolerant potato varieties has notably elevated yields and income for farmers. This technology is recommended for large-scale adoption within saline-prone potato cultivation regions.

(3) Saline-tolerant mustard

Mustard (*Brassica* spp.) thrives in soils with moderate salinity levels. In the coastal regions of Bangladesh grappling with significant soil salinity challenges, farmers have strategically managed mustard cultivation. Their methods encompass the utilization of salt-tolerant varieties and the enhancement of irrigation and drainage systems. Notably, BARI has introduced two mustard varieties, BARI sharisha-16 and BARI sharisha-19, tailor-made for salt-affected coastal regions. Moreover, BARI sharisha-16 also boasts drought tolerance.

Fig. 4 *Saline-tolerant mustard varieties*

Distinguished by its yellow flowers, resistance to Alternaria disease, and an oil content of 40-42%, BARI sharisha-16 yields between 2 to 2.5 tons per hectare. This technology slots aptly within the environment-smart and knowledge-smart CSA categories. The crop's cultivation takes place during the rabi season post the T. Aman rice harvest. This approach enhances cropping intensity, consequently amplifying profitability for farmers.

Due to their recent development, the adoption rate of BARI sharisha-16 and BARI sharisha-19 remains gradual. Moreover, the timely availability and provision of quality seeds pose challenges to their expansion in the designated areas.

With a maturation period of 90 to 100 days, this crop offers flexibility in planting and harvesting. It also experiences minimal pest and disease infestations. Particularly suitable for smallholder farmers in the southern districts of Bangladesh, the BARI sharisha-16 mustard variety excels in both saline and heat tolerance.

Farmers reaping better yields and income through the cultivation of this variety highlight its potential. This technology is highly recommended for large-scale adoption throughout the coastal regions of the country.

(4) Heat-tolerant wheat

Wheat (*Triticum aestivum*) stands as a major cereal crop in Bangladesh, second only to rice. A key factor contributing to low wheat yields is the prevailing temperature during the flowering stage, which commonly used varieties struggle to withstand, leading to empty or unhealthy grains. Notably, the Bangladesh Wheat and Maize Research Institute (BWMRI) has pioneered the development of heat (and salt) tolerant wheat varieties, namely BARI Gom-33, BWMRI Gom-1 & 2, showcasing robust adaptation to heat stress (Bokhtiar et al., 2023). With a yield potential ranging from 4 to 5 tons per hectare, these varieties offer a promising solution.

Fig. 5 *Heat-tolerant wheat varieties*

This technology is fittingly categorized within the weather-smart and knowledge-smart aspects of CSA. Fallow land within drought-prone regions during the rabi (winter) season can be rejuvenated with the cultivation of BARI Gom-33, BWMRI Gom-1, and BWMRI Gom-2, ushering in heightened cropping intensity and augmented farmer income. As newly introduced varieties, their popularity among farmers is still burgeoning. The Department of Agricultural Extension (DAE) plays a pivotal role in disseminating and fostering farmers' adoption.

Particularly well-suited for drought-prone regions like the High Barind Tract (AEZ 26), these varieties resonate with smallholder and women farmers, effectively supporting successful wheat cultivation. Therefore, the cultivation of heat-tolerant wheat varieties not only bolsters wheat production but also elevates farmer income. This technology is strongly endorsed for broader implementation countrywide, particularly within drought-prone zones.

(5) Heat-tolerant maize

Maize (*Zea mays*), ranked as the third most significant cereal crop in Bangladesh, boasts a remarkable adaptability to the nation's climate and soil variations. It is particularly suited for fallow lands, river islands (chars), Chittagong Hill Tracks (CHT), and areas susceptible to drought and salinity. Given the escalating demand for maize in the feed market, its cultivation has become increasingly profitable. Although the current production fulfills only 70% of the demand, the remainder is fulfilled through imports. Noteworthy developments by BARI and BWMRI have resulted in the creation of heat-tolerant maize varieties, including BARI hybrid maize-13 & 16.

Marked by short, oval-shaped, medium-large cobs with shallow eye depth, red skin, and yellow flesh, these maize varieties showcase a grain yield potential ranging from 9 to 11 tons per hectare. This technology seamlessly aligns with the weather-smart and knowledge-smart CSA categories. It's encouraging to witness growing farmer enthusiasm for this technology, supported by coordinated efforts from the DAE and various NGOs striving for its comprehensive dissemination.

BARI Hybrid Maize-13

BARI Hybrid Maize-16

02/05/2017

Fig. 6 *Heat-tolerant maize varieties*

Fallow land within drought-prone regions offers fertile ground for the cultivation of BARI hybrid maize-13 and BARI hybrid maize-16, an approach poised to elevate cropping intensity (CI) and bolster farmers' income. This technology caters well to smallholder farmers.

Encouragingly, farmers are actively encouraged to embrace the large-scale cultivation of BARI hybrid maize-13 & 16 during the rabi season (winter) within drought or heat-stressed locales.

(6) Heat-tolerant sweet potato

Sweet potatoes (*Ipomoea batatas*) thrive in well-drained sandy loam soil; however, akin to many crops, they confront vulnerabilities posed by climate change, spanning elevated temperatures, drought, and extreme weather events. To tackle these climatic hurdles, BARI researchers have pioneered a novel sweet potato variety, BARI mistialu-8, distinguished by its heightened resilience to climate change impacts, notably heat, and drought tolerance. With a maturation window spanning 3 to 5 months, it facilitates sequential harvesting, thereby ensuring consistent food availability—an indispensable facet of food security.

This variety of sweet potato features red skin coupled with yellow flesh, showcasing a robust yield potential ranging from 40 to 45 tons per hectare.

***Fig.** 7 Heat-tolerant sweet potato variety*

In alignment with the CSA framework, this technology seamlessly falls within the weather-smart and knowledge-smart categories. Fallow land within drought-prone domains can be harnessed for the cultivation of BARI mistialu-8, effectively augmenting cropping intensity while concurrently addressing nutritional needs.

The prevailing lack of awareness among farmers regarding this sweet potato variety is notable, underscoring the pivotal role the Department of Agricultural Extension (DAE) can play.

Noteworthy advantages encompass the potential for supplemental income when cultivated between two rice cycles, alongside its remarkable adaptability to unfavorable environments, marked by minimal disease or insect issues. Additionally, its cultivation necessitates minimal fertilizer input (Motsa et al., 2015). This technology is apt for smallholder farmers situated within drought-prone and char areas.

Farmers, benefitting from augmented yields and income through the cultivation of heat-tolerant sweet potatoes, firmly underscore its viability. Consequently, this technology is enthusiastically endorsed for expansive cultivation nationwide.

(7) Heat-tolerant grass pea and lentil

Grass pea (*Lathyrus sativus* L.) stands as a robust, cold-weather adapted legume with seeds serving both as nourishment and animal fodder. In the realm of pulse crops, lentil takes the lead with the most substantial area (142,510 ha) and production (175,384 MT), alongside earning the highest consumer preference and total consumption ranking (BBS, 2019). BARI has made strides in fostering heat-tolerant variants of these pulses, notably BARI khesari-3 and BARI masur-8, heralding heat-tolerant grass pea and lentil varieties, respectively.

With a maturation period of 120-125 days, BARI khesari-3 yields an average of 1.8-2.0 tons per hectare. Meanwhile, BARI masur-8, a lentil variety enriched with Zn, boasts a yield potential ranging from 2.0 to 2.3 tons per hectare.

Categorized within the CSA framework, both pulse varieties align with the weather-smart and nutrient-smart domains.

Grass pea (khesari) finds its niche as a reliable crop alongside Aman rice, and also as a standalone cultivation. In drought-prone domains, post-T. Aman rice harvest, the land can be judiciously allocated for the cultivation of BARI khesari-3 and BARI masur-8, thereby elevating cropping intensity while simultaneously catering to nutritional (protein) demands.

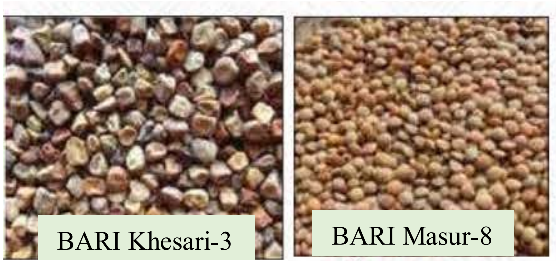

Fig. 8 *Heat-tolerant grass pea and lentil varieties.*

Although these nascent varieties are yet to achieve widespread popularity among farmers, their traction is steadily growing. Low fertilizer inputs are a distinctive attribute of both crops, as their leguminous nature facilitates atmospheric nitrogen fixation in the soil. Their cultivation predominantly occurs during the rabi (winter) season.

Resonating particularly well with smallholder farmers within drought-prone areas, these crop varieties effectively marry favorable yields with minimized production costs, fostering commendable income. As such, a clarion recommendation emerges for the large-scale cultivation of these heat-tolerant pulse varieties across the country.

(8) Heat-tolerant barley

Barley (*Hordeum vulgare* L.) is a minor cereal crop in Bangladesh, and its normal yield is affected by heat stress and saltwater intrusion. To address this issue, researchers at BARI have developed heat and salt-tolerant barley varieties, including BARI barley-6, BARI barley-7, BARI barley-8, and BARI barley-9. These varieties can withstand both heat and salt stress while also possessing qualities such as early maturity, high biomass production, and good fodder quality. This makes them suitable for both food and feed purposes. There is also literature supporting successful barley cultivation in rain-fed areas (Kilic et al., 2010).

These barley varieties are characterized by their six-rowed hull-less grains, brown-colored bold seeds, and a 13.4% fiber content. They are resistant to heat and salt, with a yield potential of 2-3 tons per hectare. This technology can be categorized as both weather-smart and knowledge-smart under CSA technologies.

Fig. 9 *Heat-tolerant barley*

Utilizing fallow lands during the rabi (winter) season in drought-prone char areas for barley cultivation can increase cropping intensity and farmers' income. This technology is particularly suitable for smallholder farmers. However, it's important to note that this new barley variety is not yet widely adopted by farmers, so raising awareness through training and demonstration trials is necessary.

In conclusion, cultivating heat-tolerant barley in drought-prone areas of Bangladesh can significantly enhance farmers' income and livelihoods at a reasonable cost. The performance of this variety has been tested and evaluated in various regions of the country, demonstrating promising results in terms of yield and resilience to the impact of climate change. Therefore, the large-scale cultivation of heat-tolerant barley varieties is recommended, especially in drought-prone areas.

(9) Heat-tolerant foxtail millet

Foxtail millet (*Setaria italica*) is a lesser-known cereal crop in Bangladesh, particularly in regions where water is scarce. Like many other crops, foxtail millet faces challenges from climate change, including rising temperatures and drought. To tackle these issues, scientists at BARI have developed heat-tolerant varieties of foxtail millet, namely BARI Kaon-1, BARI Kaon-2, and BARI Kaon-3, which can thrive in high-temperature and drought conditions. These varieties have a shorter growth cycle to mature earlier and avoid heat stress during critical growth stages. They also exhibit improved root and shoot growth, enabling them to access water and nutrients from deeper soil layers.

***Fig. 10** Heat-tolerant foxtail millet*

These heat-tolerant foxtail millet varieties have distinct characteristics: brown-colored bold grains, containing 13.4% fiber, and resistance to heat and salt stress. Their yield potential is 2-3 tons per hectare. This technology falls into the categories of weather-smart and nutrient-smart CSA technologies.

Utilizing fallow land in drought-prone and char areas during the rabi (winter) season for cultivating BARI Kaon-1, BARI Kaon-2, and BARI Kaon-3 can be beneficial. Their cultivation is well-suited for char land in drought and saline-prone regions, requiring minimal fertilizer inputs. This technology is particularly suitable for smallholder farmers.

Despite the promising attributes of these varieties, they are not yet widely adopted by farmers. Thus, spreading awareness about the technology through training and field demonstrations is crucial. Additionally, ensuring the availability of high-quality certified seeds is a limitation that needs to be addressed.

Cultivating heat-tolerant foxtail millet in drought-prone areas has the potential to significantly improve the income and livelihoods of farmers. Therefore, it is recommended for widespread adoption among farmers throughout the country.

(10) Heat-tolerant proso millet

Proso millet (*Panicum miliaceum* L.) is a winter cereal crop primarily grown in arid and semi-arid regions in Asia and South Asia. These regions often face terminal drought stress during the grain-filling period. According to Kilic et al. (2010), proso millet's early maturity and its ability to withstand terminal drought stress make it a suitable crop, especially in areas with limited irrigation resources. However, the absence of high-yielding and heat-stress-tolerant cultivars has resulted in low yields for this crop. To address this issue, researchers at BARI have developed a heat-tolerant proso millet variety called BARI Cheena-1. This variety exhibits adaptability to high temperatures, a significant abiotic factor affecting proso millet production under changing climate conditions.

***Fig. 11** Heat-tolerant proso millet*

BARI Cheena-1 is characterized by brown-colored bold seeds, containing 13.74% fiber, and resistance to heat and salt stress. It has the potential to yield 2-3 tons per hectare. In the context of CSA, this technology falls into the categories of weather-smart and nutrient-smart.

Utilizing fallow land in drought-prone areas after the T. Aman rice harvest for cultivating BARI Cheena-1 is a viable option. However, as it is a new variety, it has not gained widespread popularity among farmers. Dissemination of this technology would be facilitated through the participation of the Department of Agricultural Extension (DAE).

BARI Cheena-1 is particularly well-suited for smallholder farmers in char land with low soil fertility in saline and drought-prone areas of the country. Its adoption could lead to increased cropping intensity and higher income for farmers. Therefore, this environmentally friendly and straightforward technology warrants the attention of the DAE for broader dissemination throughout the country.

(11) Heat-tolerant groundnut

***Fig. 12** Heat-tolerant groundnut*

Groundnut (*Arachis hypogaea* L.), also known as peanut, holds significant importance as an oil crop in Bangladesh. Traditionally, it is consumed as fried 'badam.' The soil and climate conditions in Bangladesh are well-suited for groundnut cultivation, particularly in sandy soils and riverbeds (Nath and Alam, 2002). Groundnut can thrive in soils with low salt content and can withstand heat stress. In response to the challenges posed by climate change, BARIhas developed the heat-tolerant peanut variety known as BARI Chinabadam-10. These varieties exhibit adaptability to high temperatures, which is a major abiotic factor affecting groundnut production in the face of climate change.

BARI Chinabadam-10 has distinctive morphological characteristics, including brown skin with bold seeds, and it is tolerant to both heat and drought. Its yield potential ranges from 2.0 to 2.5 tons per hectare. In the context of CSA, this groundnut variety falls into the weather and nutrient-smart categories.

Utilizing fallow land, particularly in drought-prone char areas, for cultivating BARI Chinabadam-10 during the rabi (winter) season can increase cropping intensity and help meet the oil demand. The oilcake produced from this variety can also serve as valuable animal feed.

Currently, BARI Chinabadam-10 is not widely adopted among farmers, which poses a challenge to its dissemination. However, promoting the technology and raising awareness among farmers can address this issue.

Groundnut is a climate-resilient oilseed crop well-suited for cultivation in char areas of Bangladesh. It exhibits high adaptability to adverse conditions and experiences minimal disease or insect-related problems. Therefore, cultivating Chinabadam-10, the heat-tolerant groundnut variety, has the potential to enhance farmers' income and livelihoods in char and other relevant areas. This variety could be disseminated throughout Bangladesh, with a particular focus on char lands where it is most suitable.

(12) Drought-tolerant rice

In South Asia, rice productivity faces significant challenges due to factors such as rising temperatures, unpredictable rainfall, fluctuating water availability, and various biotic and abiotic stresses, including drought (Ahmed et al., 2016). Science-based solutions, such as utilizing stress-tolerant rice varieties in conjunction with sound agronomic practices, have the potential to double crop yields (Nayak et al., 2022). Bangladesh is among the countries most affected by climate change, and the cultivation of stress-tolerant rice varieties holds great promise in this context. Undoubtedly, the adoption of drought-tolerant rice varieties can play a crucial role in ensuring an adequate food grain supply and enhancing the well-being of the population. Over the last 15 years, BRRI has developed five promising drought-tolerant rice varieties (BRRI dhan 56, 57, 66, 71, & 83), with yields ranging from 5 to 6 tons per hectare.

Fig. 13 *Drought-tolerant rice varieties*

In terms of CSA categories, this technology aligns with the weather and knowledge-smart categories.

Bringing fallow land in drought-prone areas under the cultivation of these drought-tolerant rice varieties can significantly increase cropping intensity and, consequently, farmers' income.

This technology is well-suited for smallholder farmers. However, its expansion faces limitations due to restricted access to CSA technologies resulting from a lack of awareness and limited availability of these varieties.

Therefore, it is strongly recommended to promote the widespread cultivation of these drought-tolerant rice varieties by raising awareness among farmers and ensuring the supply of high-quality labeled seeds through both public and private extension and distribution networks. This proactive approach can contribute to enhancing food security and improving the livelihoods of farmers in Bangladesh.

(13) Short duration T. Aman rice

In Bangladesh, approximately 1.0 million hectares of coastal lands are dedicated to mono-cropping of T. aman rice, and they face various challenges such as soil salinity, waterlogging, and climate vulnerability. The traditional T. Aman rice variety, grown exclusively in the wet season and maturing in the last week of December to January, makes it unprofitable to cultivate Rabi crops afterward. However, the introduction of early maturing T. Aman rice varieties presents an opportunity to advance the maturity date of T. Aman rice, enabling early and timely sowing of Rabi crops.

This technology was introduced by the IWM Division of BRRI (Bangladesh Rice Research Institute).

Fig. 14 Short duration transplanted aman rice varieties

Key features of the technology:

- ✓ Introduction of modern rice varieties developed by BRRI, including BRRI dhan87, BRRI dhan76, and BRRI dhan77, which mature earlier and yield better than local varieties.
- ✓ Early maturing varieties facilitate more profitable and timelier establishment of Rabi crops.

Benefits of the technology:

- ✓ Modern rice varieties mature 15-25 days earlier than traditional varieties.
- ✓ Modern varieties provide a yield advantage of 0.5-1.0 ton per hectare over local varieties.
- ✓ Enables early and timely establishment of Rabi crops, increasing overall agricultural productivity.

It's important to note that block cultivation is required to prevent infestations from rats and birds, which can be considered a limitation of this technology.

Suitability of the technology:

- ✓ Geographical area: Coastal regions of Bangladesh.
- ✓ Cropping pattern/Season: Suitable for both Aman/Kharif and Rabi seasons.
- ✓ Agro-ecosystem: Ideal for the coastal agricultural system.

These modern rice varieties are gaining popularity among coastal farmers and are particularly suitable for smallholder farmers, including women. This technology not only helps improve agricultural productivity but also contributes to the economic well-being of farmers in coastal areas by facilitating the cultivation of additional Rabi crops.

(14) Late blight-resistant potato

Potatoes grow well in well-drained sandy loam soils and require a moderate amount of water. They exhibit adaptability to a wide range of climates, from tropical to temperate. However, potatoes are susceptible to 'late blight' disease, exacerbated by the effects of climate change. To address this challenge, scientists at BARI have developed potato varieties that are tolerant to 'late blight' disease. These varieties include BARI Alu-46, 53, 77, 90, and 91 (TCRC, 2012).

These late blight-resistant potato varieties possess some fundamental characteristics. They are typically round to oval with a flat shape, medium to large-sized, and come in light yellow/red colored tubers with deep eye depth and cream flesh color. Their yield ranges between 30 and 40 tons per hectare, with a dry matter content of 19%.

In the context of CSA, this technology falls under the weather and knowledge-smart categories. It is environmentally friendly, eliminating the need for pesticide sprays, which not only benefits the environment but also reduces production costs.

Potatoes are a highly popular vegetable crop, and this technology is well-suited for smallholder farmers. However, the limited popularity of these varieties among farmers is primarily due to a lack of awareness and the availability of high-quality seeds.

Cultivating late blight-resistant potatoes can lead to a 25 percent reduction in fungicide costs alone, resulting in cost savings for farmers. Additionally, the use of these varieties is expected to enhance farmers' income while promoting environmental sustainability. Therefore, this technology is highly recommended for large-scale adoption in most potato-growing areas, including Munshiganj, Bogura, Rangpur, and Dinajpur, contributing to improved agricultural practices and outcomes in these regions.

Fig. 15 *Late blight-resistant potato varieties*

(15) Disease-resistant sugarcane varieties

Sugarcane is a crucial commercial crop cultivated worldwide, primarily in tropical and sub-tropical regions. Despite advances in plant biology, disease resistance in crop plants remains a challenging problem to address.

This technology has been developed by the Bangladesh Sugarcrops Research Institute (BSRI), as mentioned in the BSRI Annual Report of 2021. BSRI has introduced several sugarcane varieties that are resistant to red rot, a fungal disease caused by *Colletotrichum falcatum*, characterized by interrupted red and white patches within the cane and a sour alcoholic odor when the cane is split open. These red rot-resistant varieties include Isd 37, Isd 39, Isd 40, BSRI Akh 41, BSRI Akh 43, BSRI Akh 44, BSRI Akh 45, BSRI Akh 46, and BSRI Akh 48.

Additionally, most of these varieties also exhibit resistance to smut diseases, including Isd 39, Isd 40, BSRI Akh 41, BSRI Akh 43, BSRI Akh 44, BSRI Akh 45, and BSRI Akh 46. Sugarcane smut, caused by *Sporisorium scitamineum*, can significantly reduce both cane quantity and quality.

This technology aligns with the weather-smart category of CSA technologies. However, it is important to note that the treatment of seed canes with moist hot air treatment (MHAT) should be performed annually to control these seed-borne diseases, which is a limitation.

Fig. 16 *BSRI developed disease-resistant sugarcane varieties*

This technology is suitable for medium to highland cultivation of sugarcane in plain land, coastal, and hill ecosystems. The major benefits of this technology are twofold: it minimizes the need for fungicide use, reduces production costs, and has no adverse effects on the environment. By using disease-resistant sugarcane varieties, farmers can promote sustainable and cost-effective sugarcane production while minimizing the environmental impact.

B. Climate Resilient Soil and Crop Management Technologies

Healthy soil is essential for successful crop production in various ecosystems, both favorable and unfavorable. Key aspects of healthy soil include:

I. **Comprehensive Soil Cover by Vegetation:** Ensuring that soil is covered by vegetation is crucial for maintaining its health.

II. **Minimizing Nutrient Loss through Leaching:** Efforts should be made to reduce the loss of soil nutrients through leaching.

III. **Reducing Rainwater Run-off and Soil Erosion:** Measures should be taken to minimize rainwater run-off and soil erosion, which can deplete the topsoil.

IV. **Preventing Contaminant Accumulation:** Soil should not accumulate contaminants that can harm crops or the environment.

According to FAO (2015), an estimated 320 kg of nutrients (N + P + K) per hectare are lost from the soil annually in Bangladesh. The country's diverse physiographic conditions, parent materials, lands, hydrology, and drainage conditions lead to a wide variety of soil types over short distances. Intensive cropping aimed at increasing food production has resulted in continuous soil fertility depletion, including organic matter loss, nutrient deficiencies, drainage issues, and waterlogging. Additionally, climate change effects, such as salinity, acidity, drought, and flooding, further impact soil properties, including salinity levels, organic matter decomposition, soil erosion, and greenhouse gas emissions.

Intercropping is considered more resilient than sole cropping, as it efficiently utilizes available resources and enhances productivity. An excellent example is cereal-legume intercropping, like maize and lentil, where legumes do not compete with cereals for nitrogen and can fix atmospheric nitrogen (N_2) in their roots. This approach can help address soil nutrient depletion.

BARI has developed 4-crop-based cropping patterns, including low-water-consuming crops like mustard-mungbean-T. Aus-T. Aman rice and lentil-mungbean-T. Aus-T. Aman rice. These patterns boost crop productivity and cropping intensity in rice-based systems. Seedling transplanting is an effective method for maize cultivation in haor areas. Integrated rice-fish-vegetable cultivation, particularly in southern districts like Khulna, Bagerhat, Satkhira, Borguna, and Patuakhali, is a promising CSA technology.

These climate-resilient soil and crop management technologies have the potential to improve agricultural sustainability, enhance productivity, and mitigate the adverse effects of climate change in Bangladesh.

The promising climate-resilient soil and crop management technologies and practices are described below.

(16) Biochar application

Biochar is a highly stable and long-lasting form of organic matter produced through pyrolysis. Using biochar as a soil amendment is a highly effective approach to enhance soil health and increase crop yields, as demonstrated by research (Sultana et al., 2011). Biochar contains valuable components that can significantly improve soil fertility and reduce soil acidity (Chan et al., 2008). Unlike direct incorporation of plant materials into the soil, which can decompose relatively quickly due to soil microorganisms, biochar is known to be recalcitrant and can persist in soils for hundreds of years (Chintala et al., 2013). This technology was developed by the BARI.

In terms of CSA categories, this technology aligns well with both carbon-smart and nutrient-smart categories.

Biochar technology is suitable for application across various agroecological zones in Bangladesh, particularly in medium to highland areas.

Although biochar is a relatively new technology in Bangladesh, its adaptability rate is currently at a minimum scale. However, it holds promise for smallholder farmers, offering higher productivity while maintaining soil fertility. Biochar production typically involves utilizing waste materials, a practice often managed by women, making it a woman-friendly technology.

***Fig. 17** Cabbage production by rice husk biochar application*

Key benefits of this technology include:

- Increasing productivity by 10-20% compared to chemical fertilizers (Jeffery et al., 2011).
- Reducing CO_2 emissions.
- Improving production efficiency.
- Sustaining soil fertility.

Given its capacity to enhance productivity and soil health, there is a need to focus on scaling up the adoption of biochar technology. The primary challenge lies in making biochar readily available and accessible to farmers at the grassroots level, ensuring that its benefits reach a wider farming community.

(17) Zero tillage garlic cultivation

Garlic (*Allium sativum*) is the second most important spice crop in Bangladesh after onions. The edible part of garlic is the underground modified stem, composed of individual cloves. Garlic cultivation requires a cool and humid climate for vegetative growth and a relatively dry period for bulb formation. In recent times, zero-tillage garlic cultivation has gained popularity in the lowland rice-growing regions of northern Bangladesh. In this method, garlic is sown directly into wet soil with rice straw used as mulch after the rice harvest.

Fig. 18 *Zero tillage garlic field*

Cultivating garlic under zero tillage in rice straw mulch is considered a climate-smart technology, offering an economical and effective means of increasing garlic productivity. Zero tillage involves minimal soil disturbance and was developed by the BARI in 2020. This method has proven to effectively utilize residual moisture and nutrients from previous crops.

The basic features of this technology (zero tillage garlic cultivation) include:

- Directly planting garlic cloves into untilled soil.
- Continuous sowing of single cloves in rows at a minimal distance.
- Germination of garlic seeds (cloves) with natural ambient moisture.
- Using mulch to cover the ground since no-tillage is performed.

In principle, this technology aligns with CSA categories such as carbon-smart, energy-smart, and knowledge-smart.

Key benefits of this technology include reduced production costs, lower labor demands, minimal soil disturbance, increased garlic bulb yield, soil carbon sequestration, and reduced greenhouse gas (GHG) emissions.

This technology is particularly suitable for smallholder farmers and is well-suited for cultivation in Chalan bil areas located in the Pabna, Natore, and Sirajganj districts. It presents an efficient and environmentally friendly approach to garlic cultivation in these regions, contributing to both increased productivity and sustainability.

Fig. 19 *Zero-tilled garlic with rice straw mulch.*

(18) Inclusion of mustard in the single cropping pattern in low-lying areas

Low-lying areas in Bangladesh cover approximately 2.43 million hectares (BBS, 2022) and are characterized by unfavorable ecosystems. These areas remain submerged in water for 4-5 months, typically from July to November, during which only a single crop of Boro rice is cultivated. However, there is potential to introduce a short-duration mustard crop (BARI Sarisha-14) before the Boro rice crop. Mustard seeds are typically surface-seeded in late October and harvested in mid-January (85-90 days after sowing), followed by the transplantation of Boro rice seedlings in late January to early February, with rice harvested in late April.

This technology was introduced by the BARI.

Key aspects of this technology include:

- ✓ Contributing to 0-40% higher productivity.
- ✓ Reducing significant emissions.
- ✓ Being cost-saving and environmentally friendly.
- ✓ Suitability for low-lying areas, especially in the beel areas of Bangladesh.
- ✓ A moderate adaptability rate for the technology.

Fig. 20 *Mustard cultivation in a low-lying area*

This technology is particularly suitable for smallholder farmers at a relatively lower cost and is considered women-friendly because post-harvest processing activities are primarily conducted by women.

Benefits of this technology include:

- ✓ Increasing productivity by 25-30% compared to sole Boro rice cultivation.
- ✓ Raising cropping intensity by 50%.

- ✓ Enhancing profitability by 15-20% compared to sole mustard cultivation.
- ✓ Improving land use efficiency.
- ✓ Offering cost savings and environmental benefits.

The primary enabling factor for scaling up this technology is its ability to deliver higher productivity. By incorporating short-duration mustard cultivation before Boro rice, farmers can achieve increased crop yields and enhanced profitability, making it an attractive approach for agricultural expansion in low-lying areas.

(19) Double transplanting of T. Aman rice

Double transplanting, also known as the *Bolon* system, is a unique method of crop establishment for rice in which farmers transplant T. Aman rice seedlings twice in the field to manage the risk of submergence by rain or floodwater. This indigenous technology involves two transplanting phases: first, seedlings are transplanted on a high piece of land with about 20-day-old seedlings and closer spacing. Then, when the seedlings reach approximately 55 days old and are tall enough, they are transferred to the main field once the risk of flooding is over.

The *Bolon* system was developed by farmers to address the challenges posed by submergence due to rain or floods. The BRRI introduced this technology.

Key features of this technology include:

- Contributing to higher rice productivity (15-20%).
- Reducing emissions (Azad & Hossain, 2006).
- Being nutrient and energy-efficient and environmentally friendly.
- Suitability for medium land areas in districts such as Bogura, Rangpur, and Dinajpur.
- A moderate adaptability rate for the technology.

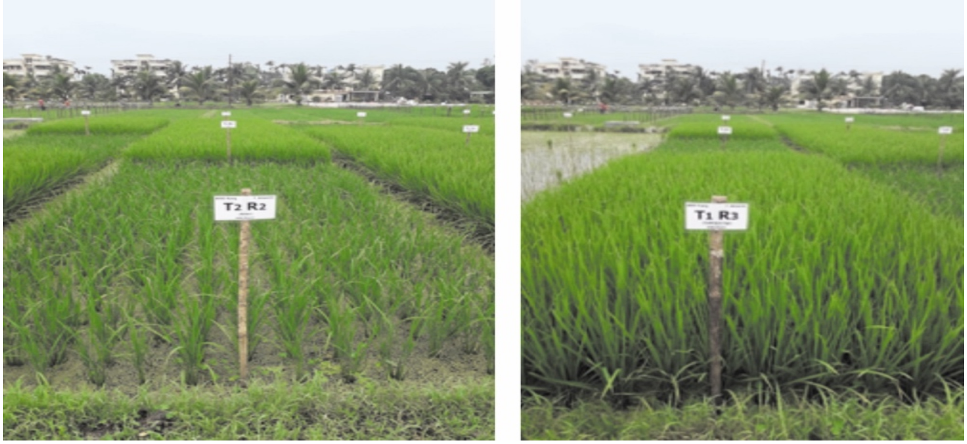

Fig. 21 *Double transplanted aman rice*

This technology is well-suited for smallholder farmers, offering higher productivity with a shorter field duration in the main field. It is also considered women-friendly, particularly in the tasks of uprooting seedlings and post-harvest operations.

Benefits of this technology encompass:

- Increasing productivity by 15-20% compared to late planting systems, which are common in many areas due to monsoon floods.
- Elevating cropping intensity.
- Enhancing profitability by 10-15% compared to late planting systems.
- Improving land use efficiency.
- Enhancing production efficiency.

The primary factor enabling the scaling up of this technology is its ability to deliver higher productivity. However, one of the main challenges associated with double transplanting is the higher labor cost involved in the process.

(20) Less irrigation requiring cropping pattern

The Irrigation and Water Management Division of the Bangladesh Rice Research Institute (BRRI) has developed and experimented with innovative cropping patterns involving T. Aman rice, Mustard, Potato, and Boro rice in comparison to the traditional T. Aman Rice-Fallow-Boro rice pattern in the Pabna and Rangpur regions during the 2018-19 and 2019-20 seasons.

These cropping patterns use specific rice and crop varieties, including BRRI dhan49, BARI Sarisha-14, BRRI dhan58 for T. Aman rice-Mustard-Boro rice; BRRI dhan49, BARI Alu-25, BRRI dhan58 for T. Aman Rice-Potato-Boro rice, and BRRI dhan49, BRRI dhan58 for T. Aman Rice-Fallow-Boro rice.

The introduction of a third crop (Rabi) in the T. Aman Rice-Fallow-Boro rice pattern delays the transplanting of Boro rice and exposes it to higher rainfall. Therefore, the T. Aman rice-Potato/Mustard-Boro rice cropping pattern is better suited for regions with higher rainfall, particularly during April and onwards, reducing the need for additional irrigation.

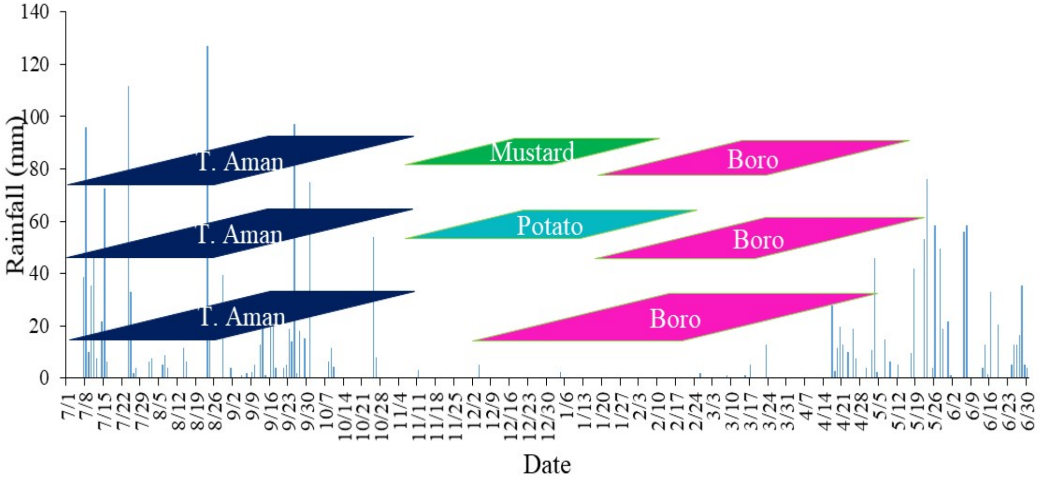

Fig. 22 *Total rainfall during the study period of T. Aman rice-mustard/potato-boro rice cropping pattern*

Key characteristics of this technology include:

i. Intensification of cropping patterns by accommodating an extra crop.
ii. Increasing system productivity.
iii. Saving irrigation water requirements.
iv. Saving energy used for water pumping.

In terms of its categorization, this technology aligns with Water-smart and Energy-smart categories.

Benefits of this technology include:

i. Saving 22-40% more irrigation water compared to the traditional T. Aman-Fallow-Boro rice pattern in the Rangpur and Pabna regions.
ii. Achieving 3-4 t ha-1 more rice equivalent yield (REY).

A potential limitation of this technology is the lack of judicious actions and proper planning for its improvement and dissemination.

The technology is suitable for implementation in Northern and North-Western Bangladesh, particularly in rice-based cropping systems following the T. Aman-Fallow-Boro pattern. It is well-suited for smallholder farmers and is also women-friendly, contributing to increased productivity and resource efficiency in these regions.

Table 3 Rice Equivalent Yield of different cropping patterns (CP1: T. Aman- Mustard-Boro, CP2: T. Aman-Potato-Boro, CP3: T. Aman-Fallow-Boro) at Rangpur during 2018-19

Cropping pattern	Mithapukur, Rangpur				Pirgonj, Rangpur			
	T. Aman	Rabi	Boro	Total REY	T. Aman	Rabi	Boro	Total REY
CP1	5.3	1.4	6.1	15.1b	5.3	1.24	7.37	16.2b
CP2	5.4	18.5	6.4	21.0a	5.3	16.7	7.37	21.0a
CP3	5.4		6.8	12.1c	5.0	-	8.07	13.1c
LSD(0.05)				2.6				1.57
CV(%)				9.7				6.0

(21) Levee management in T. Aman rice season

The practice of building high levees (*ail*) around fields during the T. Aman rice season to store rainwater is a common and simple technology employed by many farmers. This practice aids in facilitating puddling, transplantation, and crop growth. BRRI has upgraded this traditional practice to enhance its effectiveness (BRRI, 2022).

Key features of this technology include:

- Constructing levees with a height of 15 cm during the rainy season to store rainwater.
- Serving as a vital technology for mitigating terminal drought in regions where transplanted aman rice is grown and where there is limited access to irrigation and water storage facilities.

This technology is categorized as Water-smart within the framework of CSA.

Benefits of the technology include:

- The majority of rainfall (approximately 70-80%) occurs during the T. Aman rice season (Kharif-II), which spans from July to September.
- Rainwater can be conserved effectively through levee management.
- The technology aids in puddling, transplantation, overcoming short-term drought, and supporting normal crop growth.

However, it's worth noting that heavy rainfall may potentially damage the earthen levees.

This technology is suitable for implementation in T. Aman rice-growing areas throughout the country, primarily in rice-based cropping systems during the T. Aman rice season. It is especially beneficial for smallholder farmers as it reduces pumping costs, fuel consumption, and supports normal crop growth, ultimately leading to improved yields. Consequently, many rice growers already adopted this practice to enhance their agricultural operations.

(22) Growing vegetables with lowland rice

Growing vegetables alongside rice in lowland conditions during the monsoon season can significantly enhance vegetable production in Bangladesh. The IWM Division of BRRI has introduced a technology tailored for water-logged coastal areas to enable farmers to cultivate vegetables with T. Aman rice effectively.

Key features of this technology include:

- Utilizing plastic bags with diameters of 0.5-0.75 m filled with soil, compost, TSP (50 gm), MoP (30 gm), and mustard oil cake (1 kg). These bags are spaced 3m apart in the rice field.
- Positioning the bags at a height of about 0.3m above the highest flood level or tidal water level.
- Sowing vegetable seeds in poly bags in mid to late August, with seedlings transplanted in early September.
- Typically, vegetable harvesting begins in late October.

Fig. 23 *Growing vegetables in rice field*

This technology falls under the category of knowledge-smart technology within the framework of CSA.

Benefits of this technology include:

- Additional vegetable production for both household consumption and marketing.
- A significant increase in rice equivalent yield (REY) in the rice-vegetable system, which reaches 15-19 t ha^{-1} compared to sole rice fields (5-6 t ha^{-1}) (BRRI, 2023).
- While rice yield decreases by about 10%, the total system yield increases.

The technology is suitable for implementation in low-lying waterlogged areas, particularly in coastal regions of Bangladesh, during the Kharif II season. It is well-suited for smallholder farmers, including women, and has gained popularity among farmers in coastal areas. This approach not only boosts vegetable production but also contributes to enhanced food security and income generation.

(23) Dibbling method of planting in zero-tilled wetland

The Bangladesh Agricultural Research Institute (BARI) has developed technology for dibbling planting in zero-tilled wet soils in salt-affected coastal zones, which aids in ensuring timely/early sowing of Rabi crops. This technology offers several benefits and is categorized as Water-smart within the framework of CSA.

Key features of this technology include:

- Planting one or more seeds into a hole in a wet field, either by hand or using an implement.
- Growing Rabi crops under zero/minimum tillage after the T. Aman rice harvest, with the application of recommended nutrients, straw mulch, and 20% extra potassium.
- Using mulching materials like rice straw and compost to support crop establishment and growth.
- Planting at the recommended spacing when the soil is moist or slightly wet.
- Enabling timely establishment of Rabi crops through hand dibbling and straw mulch application under no-till systems in wet soils.

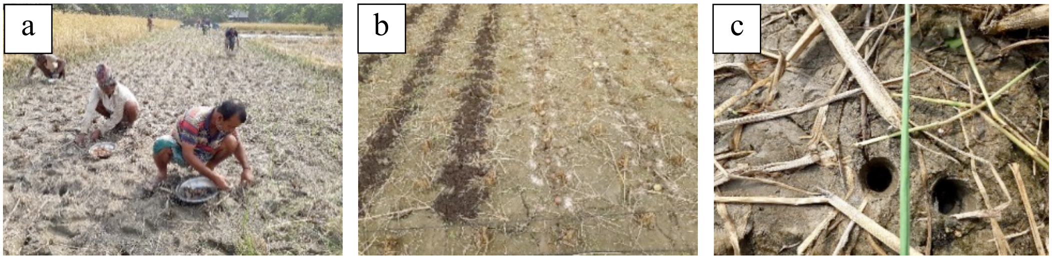

Fig. 24 *(a) Planting of potato seeds by dibbling in zero-tilled wet soil, (b) covering potato seeds with compost after planting, and (c) the depth of zero-tilled wet soil for planting potato seeds by dibbling*

Benefits of the technology:

- Facilitating conservative tillage practices and reducing the risk of soil erosion.
- Requiring fewer seeds and promoting uniform germination with good seedling vigor.
- Allowing for more than one crop per year in salt-affected areas, instead of the traditional one crop per year.
- Serving as a cost-effective method for potato cultivation in wet soil-based coastal regions.
- Minimizing the turnaround time after the T. Aman rice harvest.

However, there are some limitations to this technology:

- Uniform germination may not be achieved if seeds are not placed at a uniform depth.
- Dibbling is a labor-intensive and relatively expensive process compared to broadcasting.
- The cost may not be affordable for smallholder farmers.

This technology is well-suited for implementation in coastal zones, particularly for crops like potato, garlic, sunflower, and maize. It is highly compatible with the coastal ecosystem.

The adoption rate of dibble planting in wetlands of coastal regions has been increasing due to its technical and yield benefits. Widespread dissemination through training, demonstrations, and campaigns could further enhance its adaptability rate.

The technology is particularly suitable for smallholder farmers, especially for small-scale production. For large-scale production, it may require a higher investment. Additionally, it is a valuable technique to engage women farmers in planting potato seeds in wet soil using the dibbling technique.

The main challenges in upscaling this technology are farmers' limited knowledge of the method and technique of dibble planting in wet soil, as well as issues related to the availability and cost of rice straw or compost. Awareness and capacity-building efforts can help address these challenges and promote wider adoption of the technology.

For more information, success stories related to this technology have been published by the Australian Centre for International Agricultural Research (ACIAR), which can provide valuable insights and examples of its implementation.

https://www.aciar.gov.au/media-search/news/shared-salinity-intel-builds-farmer-resilience

https://www.aciar.gov.au/media-search/blogs/intensifying-cropping-south-bangladesh-and-west-bengal-india

(24) Relay cropping of cowpea/ grass pea in transplanted Aman rice

The relay cropping technology involving cowpea or grass pea is well-suited for specific areas with particular conditions, making it a valuable addition to the agricultural practices in those regions. Here are the key suitability factors and benefits of this technology:

Suitability Factors:

- Geographic Area: The technology is most suitable for areas where water drains out relatively early during the post-monsoon period and where soil salinity does not exceed 8 dS/m during the dry season.
- Cropping Pattern/Season: It is integrated into the T. Aman rice-based cropping system, typically during the post-monsoon season.
- Agro-Ecosystem: The technology is particularly suited for the coastal ecosystem (AEZ 13), which is characterized by specific conditions and challenges.

Key Benefits:

- Crop Integration: Cowpea or grass pea is grown in relay with T. Aman rice, allowing for the cultivation of multiple crops within a single growing season.
- Stubble Management: To facilitate the growth of cowpea or grass pea, rice should be harvested with tall stubbles (approximately 25 cm) to conserve soil moisture and provide adequate space for the leguminous crop.
- Increased Income: Relay cropping with cowpea or grass pea can significantly increase farmers' income. For example, the total net income from relay cropping is estimated to increase by about 88% and 336% when compared to growing high-yielding or local Aman rice alone, respectively.
- Soil Improvement: Leguminous crops like cowpea and grass pea enrich the soil with nitrogen through nitrogen fixation, which can benefit subsequent crops.

This technology was introduced by the BARI (Khan et al., 2013).

CSA Category: The technology is categorized as knowledge-smart within the framework of CSA. This categorization implies that it relies on knowledge-intensive practices and requires farmers to have a good understanding of the appropriate conditions and management techniques.

Fig. 25 *Relay cropping of cowpea in T. aman rice*

Popularity: Relay cropping with cowpea or grass pea has gained popularity in the coastal zones of Bangladesh, where it offers a promising approach to enhancing agricultural productivity and income.

Smallholder and Women-Friendly: The technology is well-suited for smallholder farmers, and women can actively engage in its implementation and management.

In summary, relay cropping with cowpea or grass pea in T. Aman rice fields is a valuable climate-smart agricultural practice in coastal areas of Bangladesh. It enhances crop diversification, increases income, and contributes to soil improvement while being well-suited for smallholder farmers and women. Farmers in these regions are increasingly adopting this technology to improve their livelihoods and agricultural sustainability.

(25) Maize transplanting system

The maize seedling transplanting system in the haor areas of Bangladesh offers several advantages in the context of climate change challenges and agricultural sustainability. Here are the key points regarding this technology:

Technology Overview:

- **Cropping Context:** The haor areas in northeastern Bangladesh face challenges due to flash floods and rising temperatures, affecting the cultivation of crops like boro rice.
- **Alternative Crop:** Maize is relatively heat-tolerant and can be a suitable alternative to boro rice in the haor areas.
- **Transplanting System:** The transplanting system involves transplanting maize seedlings, which provides benefits related to time-saving and early harvesting.

Fig. 26 *Transplanting maize seedlings from polybags*

Benefits of the Transplanting System:

1. **Time-Saving:** The transplanting system saves time in crop establishment compared to direct seeding.
2. **Flash Flood Mitigation:** Early harvesting of maize through transplanting can help avoid damage from flash floods, a significant challenge in the haor areas.
3. **Crop Rotation:** The system creates opportunities for subsequent crops, such as kenaf, in the haor area (OFRD, BARI, 2020).

Smart Agriculture Categories:

- **Weather-Smart:** This technology is considered weather-smart because it addresses challenges related to climate variability, including rising temperatures and flash floods.
- **Water-Smart:** It also falls under the water-smart category, likely due to its efficient use of available water resources.
- **Knowledge-Smart:** Farmers need to acquire knowledge about the transplanting system to implement it effectively, making it knowledge-intensive.

Cost Considerations: The transplanting system may incur additional costs compared to direct seeding, primarily due to the labor involved in transplanting seedlings.

Research and Adaptation: The Krishi Gobeshona Foundation of BARC and BARI have been involved in adapting and promoting this technology in the haor areas of Kishoreganj. Experimental results suggest that while transplanting maize seedlings may result in a slight yield penalty compared to direct seeding, it offers significant advantages in terms of field duration and flood avoidance (Ali et al., 2019).

In summary, the maize seedling transplanting system represents a valuable climate-smart agricultural practice in the haor areas of Bangladesh. It addresses challenges associated with flash floods and rising temperatures, allowing for early harvesting and crop diversification. While there may be additional costs involved, the benefits in terms of risk mitigation and crop opportunities make it a promising technology for these regions.

(26) Floating agriculture system

Floating agriculture, also known as hydroponic agriculture, is a unique and innovative agricultural practice used in parts of Bangladesh to grow crops in areas affected by flooding or waterlogging for extended periods. Here are some key points about floating agriculture:

Basic Characteristics:

- **Floating Platforms:** Local communities construct floating platforms or rafts using materials such as water hyacinth, algae, or other plant residues.
- **Crop Cultivation:** Crops, including diverse vegetables and spices, are cultivated on these floating platforms, allowing sustainable agriculture in waterlogged areas.
- **Sustainable Utilization:** This practice enables the sustainable use of agro-biodiversity, natural resources, and land. It combines fish farming in open water with crop cultivation on the floating beds.

- **Year-Round Production:** Floating agriculture allows crops to be grown almost year-round, utilizing the flooded areas during the monsoon season.
- **Environmental Benefits:** The decomposed floating bed materials are used as compost to improve soil fertility, reducing the need for chemical fertilizers. It also serves as an environmentally friendly way to increase arable land.

Geographical Expansion:

- **Traditional Practice:** Initially, this practice was common in non-saline coastal areas and wetland haor regions.
- **Expansion:** Over time, it has expanded to other regions, including southern areas such as Barisal, Gopalganj, and Pirojpur districts.
- **Local Names:** Different regions have adopted, modified, and given various names to this practice, such as *baira*, *boor*, *dhap*, *gathua*, *gatoni*, *geto*, *kandi*, and *vasoman chash*.

Fig. 27 *Cultivation of (a) Bitter gourd, (b) Bottle gourd and (c) Tomato in floating bed system*

Benefits:

- **Climate Resilience: Floating** agriculture is considered a climate-resilient crop production practice.
- **Income Generation:** It provides income opportunities for local communities by utilizing natural resources.
- **Soil Fertility:** Decomposed floating bed materials improve soil fertility, reducing the need for chemical fertilizers.
- **Food Security:** It **contributes** to food security and livelihoods, especially for vulnerable communities with limited land access.
- **Environmental Sustainability:** It is an environmentally sustainable method to increase arable land and supplement incomes.

Limitations:

- **Water Hyacinth Availability:** The availability of water hyacinth, a key material for constructing floating platforms, can be a limitation.
- **Knowledge Gap:** A lack of proper knowledge about this technology can hinder its adoption.
- **Initial Costs:** High initial costs for bed preparation may be a barrier.
- **Environmental Factors:** Waves and heavy rain can disperse floating farms, posing challenges.

Suitability:

- **Eco-System Areas:** Floating agriculture is suitable for waterlogged submerged eco-system areas.

In summary, floating agriculture is a valuable innovation that allows crop cultivation in areas prone to flooding and waterlogging. It offers multiple benefits, including climate resilience, income generation, and environmental sustainability. However, addressing challenges such as knowledge gaps and the availability of materials is essential for its widespread adoption and success.

(27) Sorjan system of farming

The *Sorjan* method is an indigenous agricultural technology introduced in Bangladesh, derived from the Indonesian term '*Soraju*' or '*Sorujan*' which means "double" or "pair." This innovative technique is designed for areas with high soil salinity and prolonged flooding, where traditional crop varieties struggle to yield satisfactory results. The key characteristics, benefits, and suitability of the *Sorjan* method are as follows:

Basic Characteristics:

- **Raised Subplots:** The land is divided into raised subplots, with soil taken from adjacent sites to create raised beds.
- **Concurrent Cultivation:** The raised beds are used for year-round cultivation of vegetables, quick-growing fruits, and other crops, while the sunken areas or canals are used for seasonal fish cultivation during the monsoon.
- **Water Management:** Canals or trenches surround the *Sorjan* to provide water and irrigation during the dry season.
- **Environmental Benefits:** Decomposed materials from the raised beds are used as organic fertilizer, improving soil fertility and reducing the need for chemical fertilizers.

Preparation of *Sorjan*:

- **Size and Layout:** The *Sorjan* model involves a piece of land typically 12 m long and 11 m wide, although it can be adjusted to local conditions.
- **Raised Beds:** Alternate rows and furrows are constructed to form raised beds, ensuring that the beds are high enough to prevent flooding.
- **Soil Placement:** Soil is placed on top of the raised beds, making them at least 1 m high.
- **Canal Construction:** A canal is built around the perimeter of the *Sorjan* to protect crops from animals.
- **Bed Slopes:** Slopes of the beds are leveled to ensure proper cultivation.

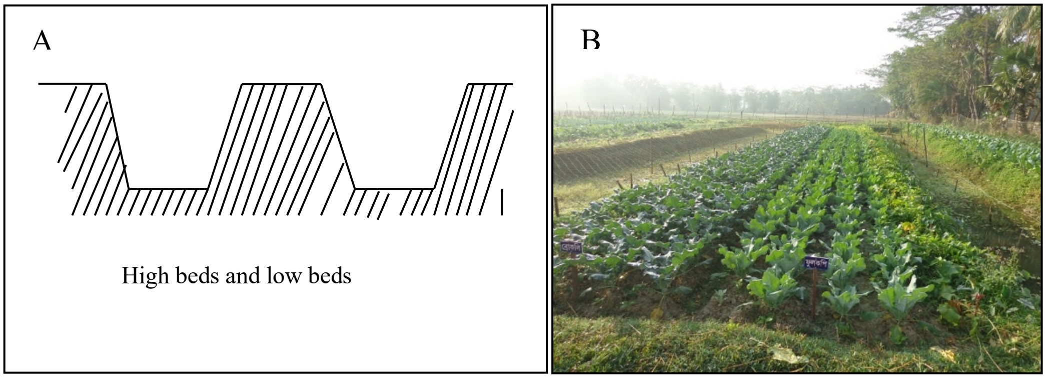

Fig. 28 *Schematic diagram of Sorjan (A) (Source:* Khan et al. 2013*), Crops grown in Sorjan (B)*

Crop Selection:

- The choice of crops depends on the size of the *Sorjan*, local preferences, and market demand.
- Year-round cultivation of vegetables, quick-growing fruits, and other suitable crops is common. Crops found most suitable and profitable in the region are listed below:

On top of a high bed:	**Crops:**
Vegetables	Eggplant, Chilli, Capsicum, Tomato, Spinach, Indian spinach, Cabbage, Cauliflower, Kholkhol, Amaranth, *Lalshak* (Red amaranth), Coriander, Okra, Carrot, Country bean, Yard long bean, Sweet gourd, Field pea, Kangkong
Fruits	Papaya, Lemons, Melons, Watermelon
On the rim & slopes of the high beds:	Bottle gourd, Ash gourd, Bitter gourd, Snake gourd, Ribbed gourd, Cucumber, Pointed gourd
Low bed	Fish and/or Duck

Fencing:

- Fencing may be needed to protect crops from animals, and materials such as old fishing nets or "Dhol Kalmi" (*Ipomoea fistulosa*) can be used.

Maintenance and Crop Management:

- *Sorjan* beds may require periodic repairs due to rainfall or tidal floods.
- Green manure (*dhaincha*) should be incorporated into the soil every three years to maintain soil fertility.
- Organic matter, such as cow dung, compost, or poultry litter, should be applied to the soil before planting crops.
- Chemical fertilizers are discouraged, while organic alternatives are encouraged.
- Integrated Pest Management (IPM) techniques and pheromone traps are used to control pests effectively.

Benefits and Success:

- *Sorjan* has demonstrated significant economic benefits. For example, it resulted in a net income of Tk. 121,227 from 0.55 ha of land in the first year, compared to Tk. 15,570 from a single crop of aman rice, representing a 678% increase in net income (Khan et al. 2013).
- It allows for year-round crop production, even in challenging soil and flooding conditions.
- *Sorjan* promotes sustainable agriculture and environmental practices, reducing reliance on chemical fertilizers.
- The *Sorjan* technique increases the overall farm income and can potentially lead to higher profits in subsequent years.

Suitability:

- *Sorjan* is suitable for areas with high soil salinity, prolonged flooding, and challenging environmental conditions.
- Sites near homesteads are preferred for easier maintenance.
- Land adjacent to rivers or canals should be avoided to prevent damage from tidal flooding.

In summary, the Sorjan method is a climate-smart and knowledge-smart agricultural technology developed by BARI. It offers a sustainable solution for crop cultivation in areas prone to soil salinity and flooding, leading to increased farm income and reduced environmental impact.

(28) Furrow and ridge cropping for coastal saline areas

The cropping technology for coastal saline areas, involving the use of alternate furrows and ridges to facilitate year-round cultivation of vegetables and non-rice crops in areas with late drainage and high soil salinity, is indeed a valuable addition to agricultural practices in challenging environments. Here are some key points condensing this technology:

Basic Characteristics:

- **Ridge and Furrow System:** The technology involves creating alternate ridges and furrows in fields with high soil salinity and late drainage, typically occurring from late December to January.
- **Ridge Size:** Ridges are typically 1 meter wide, with 1-meter furrows in between, resulting in a layout of 50 ridges, each 100 meters long per hectare.
- **Crop Pits:** Crop pits are prepared on top of the ridges at 2.5-meter intervals.
- **Trellis Support:** Trellises are used to support the crop and fruits, allowing for efficient vertical growth.

Crop Selection:

- Suitable crops for these ecosystems include cucurbits (e.g., cucumbers, melons, pumpkins), beans, and various leafy vegetables.
- These crops are preferred for their productivity and profitability compared to rice in such environments.

Fig. 29 *Furrow and ridge cropping (Source:* Khan et al. 2013*)*

Benefits:

- **Year-Round Cultivation:** The technology enables year-round cultivation of vegetables and non-rice crops, even in challenging soil and moisture conditions.
- **Productivity and Profitability:** Crops like cucurbits, beans, and leafy vegetables are more productive and profitable than rice in these ecosystems (Khan et al. 2013).
- **Climate-Smart:** The technology aligns with climate-smart agriculture by diversifying crop production and making efficient use of available resources.

Maintenance:

- Once constructed, the ridges can be used for crop production for up to five years.
- Regular maintenance and care of crops, including trellis support, are essential for successful cultivation.

Suitability:

- This technology is suitable for areas with late drainage (late December to January) and high soil salinity (EC exceeding 10 dS/m).
- Alternate furrows and ridges help create conditions conducive to growing vegetables and non-rice crops.

In summary, the use of alternate furrows and ridges is a climate-smart and knowledge-smart agricultural technology developed by the BARI. It addresses the challenges of late drainage and high soil salinity by allowing year-round cultivation of productive and profitable crops, such as cucurbits, beans, and leafy vegetables. This technology offers an environmentally sustainable solution for diversifying crop production in challenging agro-ecosystems.

(29) Pyramid cropping for coastal saline areas

The technology pyramid cropping for coastal saline areas, involving the use of pyramids made from a mixture of soil, weeds, and crop residues to grow vegetables in saline soil with stagnant water, is an innovative approach to address soil salinity challenges. Here are the key features of this technology:

Basic Characteristics:

- **Pyramid-like Structures:** Farmers create pyramid-like structures with a mixture of soil, weeds, and crop residues. These structures are elevated 12 to 18 inches above the water level.
- **Soil Moisture Control:** The pyramids help control soil moisture, preventing excess moisture during crop establishment and mitigating salt injury to crops during later growth stages.
- **Crop Selection:** This technology is primarily used for growing vegetables, particularly cucurbits (e.g., cucumbers, melons) and beans.
- **Two Culture Types:** There are two possible approaches: sole cropping of vegetables and relay cropping of vegetables with the aman rice crop.

Sole Cropping of Vegetables:

- After the harvest of the aman rice crop, pyramids are prepared at a distance of 2.5 meters by 2.0 meters.
- When the topsoil of the pyramid reaches the optimal moisture level for working with soil, pits are prepared within the pyramids, and vegetable seeds are sown.

Fig. 30 *Pyramid cropping (Source: Khan et al. 2013)*

- Proper manure and fertilizer application are essential for vegetable growth.

Relay Cropping of Vegetables with Aman Rice:

- Pyramids are created after final land preparation for T. aman rice, with wider spacing (2 meters between two rows) to minimize shading on rice crops.
- Aman rice is transplanted as usual.
- Vegetable seeds are sown on top of the pyramids, and they receive proper manures and fertilizers.
- Trellises are used to support vegetable plants in both sole and relay cropping systems.

Benefits:

- **Saline Soil Utilization:** The technology allows farmers to utilize saline soil (with an electrical conductivity, EC, ranging from 10 to 16 dS/m) that would otherwise be unsuitable for non-rice crops.

- **Vegetable Production:** Farmers can grow vegetables like cucurbits and beans, which can be profitable crops.
- **Soil Moisture Control:** The pyramids help manage soil moisture, reducing the risk of excess moisture during crop establishment.
- **Salt Injury Mitigation:** Salt injury to crops during later growth stages is mitigated by this approach.

Suitability:

- This technology is suitable for areas with saline soil conditions (EC ranging from 10 to 16 dS/m) and stagnant water at the end of the aman season.
- It is particularly well-suited for the cultivation of cucurbits and beans.
- The choice between sole cropping and relay cropping depends on farmer preferences and specific cropping systems.

In summary, the use of pyramid-like structures for vegetable cultivation in saline soil with stagnant water is a climate-smart and knowledge-smart agricultural technology developed by the BARI. It provides an innovative solution for utilizing challenging soil conditions and promotes the production of profitable vegetable crops, contributing to improved agricultural sustainability.

(30) Maize-kenaf cropping system in haor areas

The introduction of kenaf cultivation in the haor areas of Bangladesh as a cash crop after maize cultivation presents a valuable opportunity to enhance crop productivity, increase cropping intensity, and improve the economic well-being of haor communities. The average cropping intensity in haor areas is 104% whereas the national average is 195% (DAE, 2019) and the country is losing 0.49% of cultivable land every year for high population pressure and other purposes (Hasan et al., 2013). To ensure a secure life of increased population, the haor people need to increase cash crop production by increasing cropping intensity in haor areas. Here are the key features and benefits of this technology:

Basic Characteristics:

- **Crop Sequence:** After floodwaters recede (typically from the first week of October to the last week of October), farmers cultivate maize, with its harvest taking place from the second week of February to the end of February.
- **Kenaf Cultivation:** After maize harvesting, the fallow lands in haor areas are utilized for kenaf (*Hibiscus cannabinus*) cultivation, which is resistant to flash floods.
- **Potential of Kenaf:** Kenaf is a promising fiber crop with significant economic potential, including the ability to earn foreign currency for Bangladesh (Aktar et al., 2014; Sadekin et al., 2015). It has industrial uses due to its fiber content, medicinal value, and applications in the paper industry (Duke, 1983).
- **Benefits:** The inclusion of kenaf after maize cultivation offers several advantages, including labor-saving, water-saving, and time-saving benefits. It also contributes to increased soil fertility.

***Fig. 31** Maize-kenaf cropping in haor areas*

Suitability:

- The technology is suitable for all areas of the haor where floodwaters recede towards the end of October.
- It is particularly relevant to Agro-Ecological Zone-19 in Bangladesh.

Benefits of the Technology:

- **Simplicity:** The technology is simple and easy to adopt by haor farmers.
- **Environmentally Friendly:** Kenaf cultivation contributes to environmentally friendly fiber crop production.
- **Water Efficiency:** It requires less water for crop production, making efficient use of available resources.
- **Improved Nutrient Use Efficiency:** The inclusion of kenaf can enhance nutrient use efficiency in the soil.
- **Soil Health:** The technology improves soil health, potentially leading to long-term benefits for agricultural productivity.
- **Crop Yield and Productivity:** Kenaf cultivation increases crop yield, overall productivity, and cropping intensity in haor areas.
- **Economic Benefits:** Kenaf serves as a valuable cash crop, potentially improving the economic conditions of haor communities.

Cost and return:

Table 4 Cost and return analysis of improved pattern and farmers' existing pattern

Items	Improved pattern	Farmers pattern
Gross return (Tk/ha)	271833	153016
Total variable cost (Tk/ha)	165687	110424
Gross margin (Tk/ha)	106146	42592
MBCR	1.64	1.38

Overall, introducing kenaf cultivation in haor areas, especially after maize cultivation, represents a sustainable agricultural practice that aligns with climate-smart and knowledge-smart principles. It not only addresses the issue of fallow lands but also contributes to environmental conservation and economic development in these regions.

(31) Silicon-enriched rice husk ash management in wheat

Silicon-enriched rice husk ash is a valuable agricultural resource with proven benefits for crop growth and stress resistance. Researchers have documented its positive effects on various crops such as maize, wheat, carrot, and peas (Greger et al., 2018), demonstrating improved tolerance to both biotic and abiotic stresses, ultimately leading to higher yields (Vasanthi et al., 2014). Ahmad et al. (2016) showed that Si application to wheat grown under drought stress increased K^+ concentration in the shoots and grain, which helped to maintain water potential within the wheat plants, ultimately enhancing biomass production and grain yield. Despite not being considered an essential nutrient, silicon plays a crucial role in enhancing plant resilience against stressors, pests, and diseases.

The technology, developed by the On-Farm Research Division of BARI, Bangladesh, falls into multiple categories of CSA, including nutrient-smart, water-smart, and disease-smart.

Fig. 32 *Ash collection and application in a wheat field*

Suitability of the Technology:

- The technology is suitable for upland crops like wheat, maize, rice, lentils, mustard, creeper vegetables, etc., in various ecosystems, including high to medium-high land, plainland, Charland, drought-prone areas, and coastal regions of Bangladesh.
- Additionally, silicon-enriched rice husk ash can be used for producing high-quality seedlings of rice, tomatoes, onions, and other vegetables.

Adaptability and Impact:

- Field trials of the technology have been successfully conducted at farmers' fields across different regions of Bangladesh.
- Results have been showcased at Field Day events, engaging farmers, extension workers, and NGOs, leading to high levels of acceptance and adoption.
- Smallholder farmers, including women, have benefited from easy access to silicon-enriched rice husk ash, which can be collected from local rice mills.
- Integrating this technology with chemical fertilizers has the potential to reduce cultivation costs for small farmers.

Table 5 Performance of wheat under silicon-enriched rice husk ash management

Rice husk ask (t ha^{-1}) *	Relative water content (%) at mid mid-grain filling stage	Chlorophyll content (SPAD value) at mid-grain filling stage	Grain yield (t ha^{-1})	Economic return (gross margin (Tk. ha^{-1})	% increase in control	
					Grain yield	Economic Return
1.00	88.11	43.63	4.02	34855	11.67	30.76
1.25	92.26	46.43	4.34	41685	20.56	56.39
1.50	90.50	44.70	4.22	38955	17.22	46.15
Control	84.11	42.00	3.60	26655	-	

*A blanket dose of chemical fertilizers was used for all treatments.

Benefits of the Technology:

- Easy availability of rice husk ash from local rice mills.
- Simple application, with recommended rates of 1.25-1.50 t/ha during land preparation.
- Silicon enhances vascular systems, improving water and nutrient uptake in plants.
- Efficient water and nutrient uptake, especially under water-deficient conditions.
- Positive impacts on crop traits such as Relative Water Content, Chlorophyll content, grain spike, and 1000 grain weight in wheat.
- Increases in yield ranging from 10% to 20%, with significantly higher economic returns compared to omitting silicon.
- Suppression of leaf spot diseases in wheat.

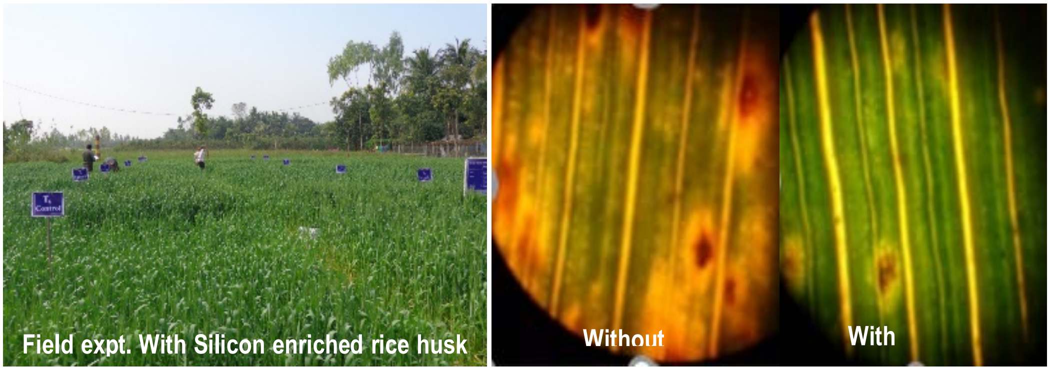

Fig. 33 *Field view of rice husk ash applied wheat field and wheat leaves of silicon applied field and field without silicon application*

Enabling Factors and Challenges:

- Awareness of the technology among farmers is currently limited. Farmer group formation, orientation, and results demonstration are essential for wider adoption.
- Collective measures for rice husk ash collection, preservation, and community-level application can promote adoption.
- Training, field days, workshops, and focus group discussions (FGDs) can contribute to the dissemination of the technology.

- Collaboration with industries that recognize the non-agricultural uses of silicon can lead to research and development opportunities.

Overall, silicon-enriched rice husk ash is a promising technology that can improve crop productivity, enhance resilience, and reduce production costs for farmers in Bangladesh. By raising awareness and facilitating its adoption, this technology has the potential to benefit a wider range of smallholder farmers and contribute to sustainable agriculture.

(32) Liming

The issue of acid soils poses significant challenges to soil fertility and crop productivity in Bangladesh, affecting approximately 4.6 million hectares of arable land (FRG-2018). Soil acidity can limit crop production by directly affecting plant growth and indirectly by influencing nutrient availability. Particularly, legumes are highly susceptible to soil acidity. It's worth noting that about 2.77 million hectares of land in Bangladesh are categorized as very strongly acidic (pH < 4.5), with an additional 3.64 million hectares classified as strongly acidic (pH 4.5-5.5). These acid soils can reduce soil productivity by up to 75% if left untreated, making up a significant portion of the country's arable land (Hasan et al., 2020).

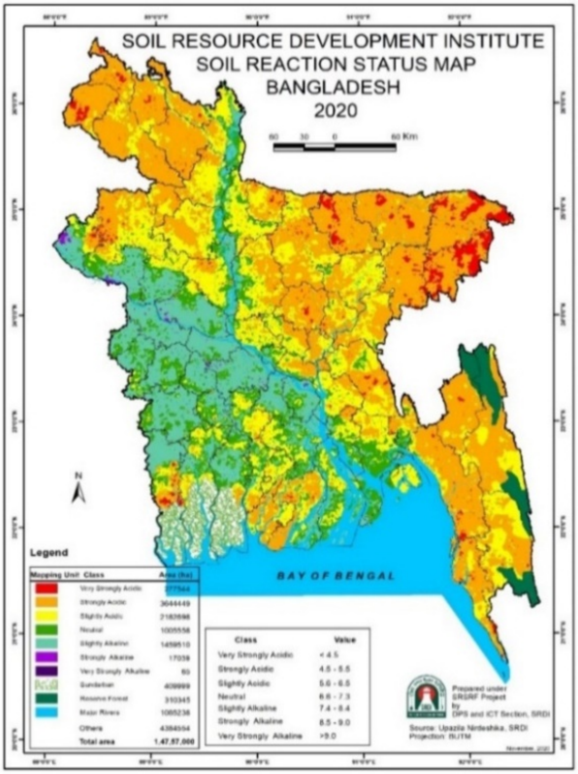

__Fig. 34__ Map of Bangladesh with soil reaction status

In Bangladesh, three main types of acid soils are found: acid basin clay, acid sulfate soil, and brown hill soil. Among the various methods to address soil acidity, liming stands out as the most cost-effective approach. The recommended lime application rate for all regions of the country is 1 ton/ha or 4 kg/decimal.

Key Points:

- **Technology Category:** Nutrient-smart and knowledge.
- **Effect of Liming:** Liming acid soils raises the pH level, mitigates the toxicity of elements like Fe, Al, and Mn, and enhances the availability of essential nutrients like N, P, Ca, and Mg. It also promotes microbial activities in the soil, contributing to improved soil health and increased crop productivity.

Liming Practices:

- Liming should be implemented in soils with a pH below or equal to 5.5.
- Application of lime in the High Barind Tract (AEZ 26), specifically in the Amnura soil series, has successfully elevated soil pH levels to pH 6.5 while enhancing soil health and crop yields.
- Liming is typically a one-time application and does not need to be repeated within three years.

Extension and Adoption:

- Extension efforts have been undertaken to promote lime technology in northwest Bangladesh, particularly in the Rajshahi and Rangpur divisions.
- Smallholder farmers in these areas are increasingly showing interest in adopting lime technology for managing acidic soils.
- The use of this technology (liming) is on the rise, indicating its acceptance and potential for wider adoption among farmers in Bangladesh.

In summary, liming acid soils is a vital agricultural practice in Bangladesh, addressing the challenges posed by soil acidity, enhancing soil health, and ultimately contributing to increased crop productivity. The growing interest and adoption of this technology among smallholder farmers highlight its effectiveness and relevance in the context of sustainable agriculture in the region.

(33) Integrated nutrient management

Integrated Nutrient Management (INM) involves the strategic combination of various nutrient sources, including mineral fertilizers, organic manure, crop residues, compost, green manure, and bio-fertilizers, tailored to local ecological conditions, land use systems, and the socio-economic circumstances of farmers. Rather than focusing on individual crops, INM considers the entire cropping pattern. It recognizes that using manure or fertilizers alone is insufficient to maintain soil fertility and crop yields sustainably; therefore, their integrated use is essential (FRG-2018).

The calculation of nutrient requirements in INM is represented by the formula A = B - C, where:

- **A** is the amount of nutrient needed from a fertilizer source.
- **B** is the total nutrient requirement for a specific crop.
- **C** is the nutrient supply obtained from manure application.

***Fig. 35** Integrated nutrient management in Wheat-Mungbean-T.aman rice cropping system*

Key Points:

- **Technology Development:** BARI has developed INM technology suitable for various cropping patterns.

Benefits of INM Technology:

- **Yield Increase:** INM technology typically leads to yield gains of 10-20%.
- **Nutrient Use Efficiency:** It enhances nutrient use efficiency, ensuring that nutrients are effectively utilized by crops.
- **Cost Reduction:** By optimizing nutrient management, it reduces the cost of fertilizers.
- **Environmental Benefits:** INM helps decrease nitrogen loss to the environment, reducing greenhouse gas (GHG) emissions by approximately 5-15% due to reduced nitrogen application.
- **Soil Health:** It contributes to improved soil health across physical, chemical, and biological aspects, especially when organic manure is integrated.

Adaptability and Challenges:

- **Suitable for Smallholders and Women:** The technology is well-suited for smallholder farmers and women in agriculture.
- **Adaptability Rate:** However, its adaptability rate is moderate. Several factors contribute to this, including the lack of subsidies for organic fertilizers, limited availability of manure sources like cow dung and compost, and insufficient awareness and attention from both government and non-governmental organizations (NGOs) for the large-scale adoption of INM technology.

In conclusion, INM technology holds significant promise for sustainable agriculture in Bangladesh. By optimizing nutrient management and minimizing environmental impacts, it can contribute to increased crop yields and soil health. However, addressing challenges such as the availability of organic fertilizers and raising awareness among farmers will be crucial for its wider adoption and impact.

(34) Black gram production technology in haor area

The haor areas in Bangladesh are characterized by unique agricultural ecosystems and face specific challenges, including lower cropping intensity compared to the national average. The land in haor areas often remains fallow for extended periods, presenting an opportunity for innovative cropping patterns. BARI has developed a technology involving the cultivation of short-duration black gram varieties during the fallow period before Boro rice planting. This practice can generate additional income and employment opportunities for haor farmers.

Key Points:

Cropping Intensity in Haor Areas: The cropping intensity in haor areas is approximately 104%, which is significantly lower than the national average of 195% (BBS, 2022).

Utilization of Fallow Period: Haor areas experience a fallow period of 80-90 days before Boro rice cultivation. This window of opportunity is leveraged for the cultivation of short-duration black gram varieties.

Cropping Practice: Given that the land remains moist during this period, black gram seeds can be directly sown on the surface without the need for extensive tillage.

Fig. 36 Black gram production in the Haor area of Kishoreganj

Cropping Pattern: The integration of black gram into the cropping pattern involves a sequence of Fallow-Boro rice-Fallow, providing farmers with an additional crop.

Categories of CSA Technology: This technology aligns with the weather-smart and knowledge-smart categories of CSA technology.

Suitability: The technology is suitable for all haor areas within Agro-Ecological Zone 19 where floodwaters recede by the end of October.

Benefits: The advantages of implementing this technology include simplicity, lower crop production costs, reduced irrigation requirements, increased crop yield, and higher cropping intensity in haor areas (Table 6).

Table 6 Cost and return of improved and existing patterns

Items	Improved pattern	Farmers practice
Gross return (Tk/ha)	194840	150600
Total variable cost (Tk/ha)	101775	83740
Gross margin (Tk/ha)	93065	66860
MBCR	2.50	-

Source: Mohiuddin 2022

The introduction of short-duration black gram varieties into the Fallow-Boro rice-Fallow cropping pattern represents a valuable innovation for haor farmers in Bangladesh. This practice not only optimizes land use during fallow periods but also contributes to increased crop yield and income generation. Furthermore, its alignment with weather-smart and knowledge-smart CSA categories demonstrates its potential to enhance the resilience and sustainability of agriculture in the haor areas.

(35) Mulching in watermelon field

In the southern region of Bangladesh, approximately 50% of medium-high lands remain fallow after the harvest of T. aman rice. To make efficient use of these fallow lands, BARI has developed a technology involving the cultivation of watermelon with the use of plastic mulching. This practice not only optimizes land utilization but also offers various advantages such as improved soil temperature and moisture regulation, weed control, and enhanced crop development.

Key Points:

Fallow Land Utilization: In the southern region, a significant portion of medium-high lands remains fallow after T. aman rice harvest. Watermelon cultivation is identified as a suitable option for utilizing these fallow lands.

Benefits of Mulching: Mulching, particularly with black or transparent plastic, offers multiple advantages. It regulates soil temperature and moisture, reduces weed growth, balances day-night soil temperature variations, decreases evaporation, and mitigates the effects of soil salinity.

Effect of Plastic Mulch: Plastic mulch, especially black and clear varieties, provides specific benefits. Black plastic warms the soil, leading to faster crop development and an early harvest by 1-3 weeks. It also reduces nutrient leaching and prevents fruit contact with the soil.

Technology Features: The basic features of this technology include the use of cut rolls of 4 mil plastic, typically 4 ft-wide sections to cover the length of the planting row. The edges of the plastic mulch are placed in shallow trenches and covered with soil to secure them. Plastic mulch is typically laid down in early May to warm the soil before the projected watermelon planting date.

Categories of CSA Technology: This technology falls under the water-smart and knowledge-smart categories of CSA technology.

Benefits: Implementing this technology leads to several advantages, including increased cropping intensity, reduced water requirements due to soil moisture and temperature conservation, yield improvements of 20-25% (Haque 2006), effective weed, pest, and salinity management, and overall sustainability and profitability of agricultural production.

***Fig. 37** Mulching in watermelon field*

Limitations: The limitations of this technology include the cost of plastic materials and the need for soil temperature monitoring when using plastic mulch to ensure optimal crop growth.

Applicability: This technology is suitable for high-value crop production, particularly for watermelon, squash, and cucumber, in coastal districts such as Khulna, Bagherhat, Satkhira, Borguna, and Patuakhali. It is designed for use by smallholder farmers.

The utilization of plastic mulching for watermelon cultivation on fallow lands in the southern region of Bangladesh represents an effective strategy for increasing agricultural productivity and optimizing land use. This technology's ability to conserve soil moisture, regulate temperature, and improve crop yield aligns with the principles of water-smart and knowledge-smart CSA technologies. It provides smallholder farmers with an opportunity to enhance the sustainability and profitability of their agricultural practices.

(36) Mixed/Intercropping

Intercropping, the practice of cultivating more than one crop simultaneously in a field, has gained recognition as a sustainable and land-use-efficient agricultural approach. This technique has proven to be more resilient than sole cropping, especially under adverse conditions. A notable example of intercropping is the Maize-Mungbean intercropping system developed by BARI. Intercropping offers several advantages, including improved weed control, optimized resource utilization, and enhanced water use efficiency. This practice aligns with the principles of carbon-smart and knowledge-smart CSA technologies.

Benefits of Intercropping: Intercropping is recognized for its land-use efficiency and resilience under varying conditions. It allows for the simultaneous cultivation of two crops, addressing challenges such as resource inefficiency, conflicting sowing times, and soil degradation. This practice, exemplified by the Maize-Mungbean intercropping, benefits from the differing growth patterns, phenology, and nutrient requirements of the combined crops. For instance, legume crops (Mungbean) do not compete with cereals for N and they fix N in their root from the atmosphere (Vesterager et al., 2008).

CSA Categories: The technology of mix or intercropping fits into the carbon-smart and knowledge-smart categories of CSA technologies. It enhances system productivity, compensates for yields of two crops, improves soil quality, increases net returns, achieves a land equivalent ratio, and helps control weed and pest infestation, thereby reducing the need for chemical pest control measures.

Environmental Benefits: Intercropping offers various environmental advantages, including improved soil, air, and water quality by reducing nutrient leaching, emissions, and eutrophication (Bandyopadhyay et al., 2016). It is especially appealing to smallholder farmers due to its potential to enhance land use efficiency, reduce fertilizer consumption, increase crop yields and nutrient accumulation, and promote biological activities.

Fig. 38 *Intercrop-ping of Bush bean with Sorghum*

Limitations: Challenges associated with intercropping include difficulties in mechanization and higher management requirements. Increased competition may arise for resources such as water, nutrients, and light.

Applicability: The technology of maize-mungbean intercropping is suitable for implementation throughout Bangladesh. It offers flexibility, profit maximization, risk reduction, soil conservation, and soil fertility improvement (Matusso et al., 2012). This approach is particularly advantageous for smallholder farmers and can contribute to increased production, income, soil health enhancement, and improved nutritional balance for communities.

Fig. 39 Intercropping of Black gram with maize (A), Intercropping of Brinjal with Spinach (B)

Crop Tolerance: Maize-mungbean intercropping stands out among grain legumes for its tolerance to harsh conditions, adaptability to unfavorable environments, and limited susceptibility to diseases and insect problems.

Resource Utilization: Intercropping optimally utilizes residual soil moisture from previous crops, reducing production costs per unit area. It presents an opportunity to enhance overall production, income, soil health, and human nutrition.

Intercropping, exemplified by the Maize-Mungbean intercropping system developed by BARI, represents a sustainable and efficient agricultural practice. This approach not only maximizes land utilization but also offers several environmental benefits and economic advantages. By adhering to the principles of carbon-smart and knowledge-smart CSA technologies, intercropping holds great promise for smallholder farmers in Bangladesh and contributes to improved agricultural productivity, resource efficiency, and resilience to changing conditions.

(37) Integrated rice-fish-vegetables system

The Gher system of farming, practiced in coastal areas, represents an integrated approach that combines agriculture, aquaculture, and horticulture. It encompasses the cultivation of rice, prawns, and various vegetables and fruits within the same ecosystem. This system maximizes land utilization and seasonality is crucial for its success. BARI has developed an integrated rice-fish-vegetables system for coastal areas, which enhances economic benefits compared to monoculture practices. This technology aligns with the principles of knowledge-smart and weather-smart CSA categories.

The Gher System: The Gher system is characterized by its multifaceted approach, integrating rice, prawn, and vegetable production. Rice and prawns are typically grown within the enclosure, while a variety of small-scale vegetables and fruits are cultivated on the dikes surrounding the enclosure. The success of this system depends on seasonality, as interactions between agriculture, aquaculture, and horticulture vary with the seasons.

Integrated Rice-Fish-Vegetables: BARI has introduced an integrated rice-fish-vegetables system in coastal areas. This approach involves cultivating agricultural and horticultural crops alongside fish in the gher. It offers farmers enhanced economic benefits compared to monoculture practices.

Fig. 40 *Integrated Rice-Fish-Vegetable production system*

CSA Categories: The integrated Rice-fish-vegetables cultivation technology falls under the knowledge-smart and weather-smart categories of CSA technologies. It boosts the productivity of the entire system, increases cropping intensity, and contributes to pest and weed control in paddy ecosystems.

Advantages: The technology offers several advantages, including increased overall system productivity, higher cropping intensity, and the ability of rice-fish farming to control pests and weeds in paddy fields. It promotes more sustainable land use.

Limitations: The technology's limitations include limited scope for commercial vegetable cultivation due to restricted production capacity. Additionally, it requires extra management practices compared to monoculture systems.

Applicability: Integrated rice-fish-vegetables cultivation is suitable for coastal districts such as Khulna, Bagherhat, Satkhira, Borguna, Patuakhali, and other coastal areas where the Gher system of fish farming is practiced.

Benefits with Evidence: This integrated approach yields a 20-25% increase in crop yields. Economic analyses have demonstrated the profitability and economic viability of integrated rice-prawn-vegetable farms compared to conventional rice farms. Integrated farms generate significantly higher gross revenues due to the combined production of rice, prawns, fish, and dike crops (primarily vegetables) from the same land. Freshwater prawns contribute a substantial share (27%) to gross revenue, while vegetable production on dikes accounts for 42% of total revenue (Alam et al., 2022a).

The Gher system of farming, particularly the integrated rice-fish-vegetables cultivation technology developed by BARI, represents a sustainable and economically advantageous approach for coastal areas. By optimizing land use and leveraging seasonality, this integrated system enhances overall productivity, cropping intensity, and pest control. It aligns with the principles of knowledge-smart and weather-smart CSA technologies, contributing to the resilience and profitability of agriculture in these regions.

(38) Spaced transplanting (STP) for sugarcane

The spaced transplanting (STP) technique has been developed to address challenges in sugarcane cultivation, particularly issues related to tillering synchronization and rapid seed multiplication. This technology was developed by the Bangladesh Sugarcrops Research Institute (BSRI, 2022) and has gained popularity not only in Bangladesh but also in neighboring countries. STP is recognized for its ability to increase the seed multiplication ratio from 1:10 to 1:40, making it an essential tool for sugarcane cultivation.

STP Technique: The STP technique is designed to overcome challenges such as unfavorable climatic conditions, late maturity, or delayed sugar mill openings, which can lead to yield gaps in sugarcane cultivation. It involves raising sugarcane settlings 1-2 months ahead of the planting time using one-eyed setts in bags or one/two-eyed setts on the soil bed. This approach allows for flexible planting times.

Soil bed settings　　Poly bag settings　　Main field

Fig. 41 *Spaced transplanted sugarcane cultivation*

Benefits of STP: The technology offers several advantages, including the ability to adjust the planting time to suit local conditions, ensuring an adequate supply of mother plants, promoting more tillering, reducing disease incidence, and ultimately leading to higher sugarcane yields.

Limitations: Some limitations of the technology include a relatively high initial input cost, a labor-intensive process, the need for technical knowledge, and the requirement for light irrigation after plantation.

CSA Categories: The STP technique aligns with the weather-smart and knowledge-smart categories of CSA. It leverages knowledge and timing to optimize sugarcane planting and maximize yields.

Applicability: This technology is suitable for both mill zone and non-mill zone areas, various cropping seasons, and diverse agro-ecosystems. Its adaptability and flexibility make it a valuable tool for sugarcane farmers facing varying conditions.

Seed Multiplication Ratio: One notable benefit of the STP technique is its significant increase in the seed multiplication ratio. It enhances the ratio from the traditional 1:10 to an impressive 1:40. This advancement contributes to the efficient multiplication of sugarcane seeds for wider cultivation.

The spaced transplanting (STP) technique developed by the Bangladesh Sugarcrops Research Institute (BSRI) represents a valuable innovation in sugarcane cultivation. By addressing timing and multiplication challenges, it enables sugarcane farmers to optimize planting, achieve higher yields, and multiply seeds efficiently. With its adaptability to various conditions and cropping seasons, STP plays a crucial role in enhancing sugarcane production and supporting the agricultural sector.

(39) Litchi based agroforestry system

The integration of vegetable crops into litchi-based agroforestry systems represents a significant innovation in agriculture, offering both higher productivity and increased income generation. This technology has been developed by the BARI and addresses the need for sustainable and profitable farming practices in regions with litchi orchards, such as Pabna, Rajshahi, and Dinajpur.

Agroforestry with Litchi Orchards: Litchi orchards are becoming increasingly popular in the Pabna area and other regions. In these orchards, farmers often grow perennial spice crops, which have a longer time frame for income generation. Additionally, some farmers practice haphazard vegetable cultivation under the fruit trees, while others do not engage in vegetable or spice cultivation within their orchards.

Technology Development: Scientists from the On-farm Research Division of BARI in Pabna have developed this technology to systematically grow vegetable crops within litchi-based agroforestry systems. The goal is to enhance productivity and income for farmers.

Fig. 42 Litchi-based agroforestry system with cabbage

Basic Features of the Technology: Farmers have the flexibility to choose suitable vegetable crops based on their preferences and agronomic feasibility. The technology recommends transplanting 30-day-old seedlings of vegetables like cabbage, cauliflower, or broccoli into litchi orchards with a spacing of 60 cm x 45 cm. Fertilizer application is adjusted according to the specific requirements of the selected vegetables.

CSA Category: This technology falls under the carbon-smart category of CSA. By integrating vegetable crops into the litchi orchards, the system contributes to sequestering CO_2, supporting climate change mitigation efforts.

Geographic Suitability: The technology is well-suited for regions with extensive litchi cultivation, including Pabna, Rajshahi, and Dinajpur. Orchards that are ten to eleven years old or older are particularly suitable for implementing this technology.

Benefits of the Technology: The integration of cauliflower and cabbage into litchi-based agroforestry systems has demonstrated substantial benefits. These systems have showcased 94% and 61% higher yields, respectively, compared to sole litchi cultivation (PCR, 2022; ARR, 2020). Additionally, cauliflower and cabbage grown within litchi-based agroforestry systems have generated 81% and 58% higher gross margins than sole litchi cultivation. Importantly, according to IPCC (2000), globally 630 million hectares of agroforestry could potentially sequester 2.15 megatons of CO_2 per year by 2040.

The practice of growing vegetable crops in litchi-based agroforestry systems, offers a promising approach to enhance agricultural productivity and income in regions with litchi orchards. By optimizing the use of available land and resources, farmers can diversify their income sources and contribute to sustainable and climate-smart agriculture. This technology has the potential to benefit both farmers and the environment, making it a valuable addition to agricultural practices in litchi-growing areas.

C. Climate resilient pest management

Pests (insects) and diseases pose a significant and ongoing threat to crop production in Bangladesh. These challenges are exacerbated by the emergence of new and invasive pests, which can have devastating effects on crops. Furthermore, climate change is recognized as a major factor contributing to the emergence and spread of these pests and diseases. The Fall armyworm, affecting maize crops, is one example of such a pest causing severe economic damage to crops across the country. Traditional chemical pesticides often struggle to effectively control these pests. However, ongoing research has led to the development of promising technologies, including Integrated Pest Management (IPM) and Integrated Disease Management (IDM), which are considered climate-smart approaches to address these challenges.

(40) Integrated pest management of cucurbit fruit fly

Pesticide poisoning and environmental damage are pervasive issues in Bangladesh, primarily due to excessive pesticide use. Addressing this problem requires educating farmers about the risks associated with pesticide overuse, emphasizing proper application techniques, and promoting the importance of taking necessary precautions (Ferdous et al., 2017). In response to these challenges, significant efforts have been made to develop an Integrated Pest Management (IPM) method specifically aimed at controlling fruit flies in cucurbit crops, such as *Bactrocera cucurbitae* (Ferdous et al., 2018). This innovative approach utilizes synthetic pheromone lures for sustainable, area-wide pest management in cucurbit cultivation. The goal is to reduce insect infestations, minimize pesticide usage, and establish safe control measures that result in chemical residue-free vegetables.

Key Points:

1. **Pesticide Challenges:** Bangladesh faces widespread issues related to pesticide poisoning and environmental harm, primarily due to the excessive use of these chemicals in agriculture.
2. **Education and Awareness:** Farmers need to be educated about the dangers of pesticide overuse and the critical role of correct application methods. Additionally, the importance of taking necessary precautions cannot be understated (Ferdous et al., 2017).
3. **IPM for Fruit Flies:** Efforts have been directed toward developing an Integrated Pest Management (IPM) approach for controlling fruit flies, particularly in cucurbit crops like *Bactrocera cucurbitae* (Ferdous et al., 2018).
4. **Pheromone Lures:** This innovative method utilizes synthetic pheromone lures to achieve sustainable, area-wide pest management in cucurbits. The primary objectives are to reduce insect infestations, minimize pesticide reliance, and establish safer control measures that lead to the production of vegetables free from chemical residues.
5. **Technology Origin:** BARI has been at the forefront of developing and promoting this technology (BARI, 2022).
6. **Technology Features:** Key features of this CSA technology include sanitation practices and the use of sex pheromones for mass trapping.

***Fig. 43** Sanitation and sex pheromone for mass trapping of cucurbit fruit fly in bitter gourd*

Benefits and Suitability:

- **Technology Category:** This CSA technology falls into the knowledge-smart category.

- **Benefits:** The advantages of this technology are manifold. It is highly effective, easy to implement, and cost-effective. Furthermore, there is no notable evidence of significant limitations associated with its use. Importantly, it poses no risk or adverse effects on the environment, making it an environmentally friendly solution.

- **Suitability:** This technology is versatile and suitable for application in both fragile (unfavorable) and favorable ecosystems, as well as for both summer and winter cropping seasons.

- **Evidence of Benefits:** The use of this technology has demonstrated its effectiveness in reducing the reliance on toxic chemical pesticides while simultaneously increasing farmers' income (Ferdous et al., 2018). It provides robust protection to cucurbit crops against fruit fly infestations, resulting in less than 5% infestation with 1.9 to 2.2 times less cost compared to pesticide-sprayed plots.

(41) Integrated pest management of mango/guava fruit fly

Mango, a vital commercial fruit in Bangladesh, faces a significant threat from the fruit fly, *Bactrocera dorsalis*, which is its major pest. Mango, being a native fruit, thrives naturally throughout the country under varying climatic conditions (Dominiak and Ekman, 2013). Adding to the challenge, the guava fruit fly, *B. correcta*, also poses a destructive menace in Bangladesh (Maung et al., 2021). To combat these pests, integrated pest management techniques have been developed, with a focus on controlling mango and guava fruit flies. These techniques encompass various strategies, including the Male Annihilation Technique (MAT), Bait Application Technique (BAT), biological control, fruit bagging, and field sanitation (Maung et al., 2021). In particular, the Male Annihilation Technique (MAT) targets adult fruit flies through the attraction of males using a blend of sex pheromones and insecticides, resulting in significant mortality among the target species (Maung et al., 2021).

Key Points:

1. **Mango Pest Challenge:** Mango, a prominent commercial fruit in Bangladesh, faces a significant threat from the *Bactrocera dorsalis* fruit fly, its primary pest.

***Fig. 44** Pheromone mass trapping of fruit fly in mango and guava*

2. **Destructive Guava Fly:** Adding to the complexity, the guava fruit fly, *B. correcta*, is also a destructive pest in Bangladesh, impacting guava production (Maung et al., 2021).
3. **Integrated Pest Management (IPM):** To address these pest challenges, integrated pest management techniques have been developed, emphasizing control strategies for mango and guava fruit flies. These techniques encompass various approaches, including MAT, BAT, biological control, fruit bagging, and field sanitation (Maung et al., 2021).
4. **Male Annihilation Technique (MAT):** MAT is a specialized technique targeting adult fruit flies by luring males with a combination of sex pheromones and insecticides, resulting in a substantial reduction in the target species' population (Maung et al., 2021).
5. **Technology Origin:** BARI has spearheaded the development of this technology.
6. **Technology Features:** A key feature of this CSA technology involves pheromone mass trapping, specifically employing methyl eugenol. This method has proven to be highly cost-effective for controlling oriental fruit flies in mango and guava production.

Benefits and Suitability:

- **Technology Category:** This CSA technology falls into the knowledge-smart category.
- **Benefits:** The primary advantage of this technology is its remarkable effectiveness, affordability, and ease of application for managing mango and guava fruit flies. Furthermore, there is no significant evidence of notable limitations associated with its implementation. Crucially, it is an environmentally friendly solution, posing no risks or adverse effects on the ecosystem.
- **Suitability:** This technology is versatile and suitable for application in mango-growing areas, such as Rajshahi, Naogaon, and Satkhira, as well as guava-growing regions, including Pirozpur, Jhalokathi, and other districts across Bangladesh.
- **Cropping Pattern/Season:** Applicable throughout the year.
- **Agro-ecosystem:** Suitable for both plainland and drought-prone ecosystems.
- **Evidence of Benefits:** Implementing this technology has demonstrated its potential to increase farmers' income by approximately 20% (Maung et al., 2021).

(42) Management of litchi fruit borer

Litchi cultivation in Bangladesh faces a significant challenge in the form of fruit and shoot borers, major pests that wreak havoc on this fruit crop. These pests pose a substantial economic threat to litchi growers, as infested fruits become unsuitable for the market. The damage caused by these borers typically occurs during the fruit's ripening stage, particularly in humid conditions. This infestation results in annual yield losses ranging from 30% to 52%, compelling farmers to resort to various insecticides in their attempts to mitigate these losses (Alam, 2011). Fortunately, an effective management strategy can help control the borer population and minimize economic losses for litchi growers.

Key Points:

1. **Litchi Pest Challenge:** Fruit and shoot borers are formidable pests in the cultivation of litchi, posing a significant challenge for growers in Bangladesh. The economic losses incurred due to infested fruits render them unmarketable.
2. **Annual Yield Loss:** These borers cause substantial annual yield losses, ranging from 30% to 52%, primarily during the fruit's ripening stage in humid conditions (Alam, 2011).
3. **Pesticide Use:** Grower's resort to the use of various insecticides to combat these pests.
4. **Effective Management:** An effective management schedule is essential to address this persistent issue.
5. **Technology Origin:** BARI has led the development of this technology (BARI, 2022).

***Fig. 45** Bagging of litchi fruits to manage litchi fruit borer*

6. **Technology Features:** The core feature of this CSA technology involves the practice of bagging litchi fruits with mosquito nets at the pea stage. This method has proven to be a highly effective means of managing fruit borers.

Benefits and Suitability:

- **Technology Category:** This CSA technology falls under the knowledge-smart category.
- **Benefits:** This technology stands out for being both eco-friendly and cost-effective in controlling litchi fruit borers. Importantly, it eliminates the need for toxic chemical insecticides.
- **Drawbacks:** While the technology itself has no significant drawbacks, its widespread adoption and dissemination require careful planning and concerted efforts.
- **Suitability:** This technology is exceptionally well-suited to litchi-growing regions, including Dinajpur, Rajshahi, and various other districts.
- **Evidence of Benefits:** Implementing this technology can result in a 25-30% increase in income for litchi growers, compared to the use of toxic chemical insecticides (Alam, 2011).

(43) Management of banana leaf and fruit beetle

Banana cultivation in Bangladesh faces a formidable seasonal challenge in the form of the Banana leaf and fruit scarring beetle, *Basilepta subcostata*. This notorious insect pest wreaks havoc during its active season. To effectively manage this pest, two main tools have emerged as highly efficient: bunch covering with polyethylene bags and the application of neem-based products. This innovative technology, which significantly enhances pest management in banana cultivation, has been developed by the Bangladesh Agricultural Research Institute (BARI, 2022).

1. **Banana Pest Challenge:** The Banana leaf and fruit scarring beetle, *Basilepta subcostata*, is a significant seasonal insect pest in Bangladesh, particularly affecting banana crops.
2. **Effective Pest Management:** To combat this pest effectively, two primary tools have emerged: bunch covering with polyethylene bags and the use of neem-based products.
3. **Technology Origin:** BARI has been at the forefront of developing and promoting this technology (BARI Annual Report, 2022).
4. **Technology Features:** The core features of this CSA technology include bunch covering with polyethylene bags, which must be implemented at the time of spathe initiation or before finger emergence. The required size of the polyethylene bag is 105 cm x 75 cm, with the bag's top end securely fixed to the peduncle, leaving the downside open. To ensure proper aeration, the polyethylene bag must contain 20-30 needle holes.

Fig. 46 *Polythene bagging of banana to manage banana leaf and fruit beetle*

Benefits and Suitability:

- **Technology Category:** This CSA technology falls under the knowledge-smart category.

- **Benefits:** The advantages of this technology are manifold. It is highly effective, cost-efficient, safe, and easy to implement for the management of Banana leaf and fruit scarring beetles. Importantly, it is environmentally safe and poses no health hazards.
- **No Environmental Risk:** The implementation of this technology carries no environmental risk or deleterious effects, making it a sustainable solution.
- **Suitability:** This technology is particularly suitable for the southern regions of Bangladesh, where the cropping season aligns with the rabi season. The technology thrives in plain land ecosystems.
- **Yield and Income Benefits:** Implementing this technology can result in a 15-20% increase in both yield and income compared to traditional practices involving the use of toxic chemical insecticides.

(44) Bio-rational management of varroa mite in honeybee colony

The concept of "bio-rational" extends to a broad spectrum of product types, sharing the common characteristics of being relatively non-toxic and causing minimal ecological disruption. This approach finds particular relevance in the management of V*arroa* mites in honeybee colonies. The Bangladesh Sugarcrop Research Institute (BSRI) has spearheaded the development of this technology, focusing on sustainable and eco-friendly varroa mite control (BSRI, 2019).

Key Features:

1. **Bio-rational Philosophy:** Bio-rational solutions encompass a diverse array of approaches and products. Their hallmark lies in their intrinsic low toxicity and limited adverse effects on the surrounding ecosystem.
2. **Varroa Mite Management:** The primary objective of this technology is the management of *Varroa* mites within honeybee colonies, a crucial facet of apiculture.
3. **Technology Origin:** The Bangladesh Sugarcrop Research Institute (BSRI) stands at the forefront of the development and promotion of this bio-rational approach.
4. **Technology Focus:** The core feature of this CSA (Climate-Smart Agriculture) technology is the utilization of sugar dust for the control of *Varroa* mites.

Applying sugar dust　　Sugar dust　　Dead varroa mite

Fig. 47 *Bio-rational management of Varroa mite in honey bee colony*

Benefits and Considerations:

- **Technology Categories:** This innovative approach aligns with both weather-smart and knowledge-smart categories of CSA technology.
- **Advantages:** Key benefits associated with this technology include cost-effectiveness, simplicity of application, and its environmentally friendly nature.
- **Limitations:** However, it's essential to acknowledge certain limitations, such as the relatively gradual action of the method. Furthermore, the honeybee colony must be in a robust state during sugar dust application.
- **Applicability:** This technology holds applicability across varroa mite-infested regions throughout the country.
- **Significant Advantage:** One of the standout features of this bio-rational technology is its cost-effectiveness, contributing significantly to its reputation as an eco-friendly solution. It harmoniously aligns economic and environmental interests in the realm of varroa mite control in honeybee colonies.

(45) Bio-rational management of Spodoptera litura in vegetables and aroid

The common cutworm, *Spodoptera litura*, stands as a significant pest menace, wielding its chewing mouthparts to wreak havoc on vital crops in Bangladesh. Among its favored victims are cabbage, as well as other vital vegetables such as tomatoes, aroids, and chili. Within the realm of pest management, the term "biorational" embraces a diverse range of products characterized by their inherent low toxicity and minimal ecological repercussions. Addressing this challenge, BARI has meticulously crafted a technology that harnesses biorational-based strategies to effectively combat *Spodoptera litura*, as documented in the BARI Annual Report of 2022.

Key Attributes:

1. **Pest Profile:** *Spodoptera litura*, renowned for its voracious appetite and crop devastation, poses a substantial threat to several essential vegetable crops in Bangladesh.
2. **Biorational Solution:** This technology draws its essence from biorational approaches, reflecting a broad spectrum of products known for their low toxicity and eco-friendly nature.
3. **Technology Provenance:** BARI leads the development and promotion of this innovative pest management approach.
4. **Technology Elements:** The foundational elements of this CSA technology encompass
    - Pheromone mass trapping with 2-3 bio-pesticide applications in cabbage.
    - Pheromone mass trapping with 2-3 bio-pesticide applications in tomatoes.
    - Sanitation, sex pheromone mass trapping with 2-3 bio-pesticide applications for aroids.
    - Employing pheromone traps with 2-3 bio-pesticide applications, initiated from the seedling stage of chili.

Fig. 48 *Pheromone mass trapping of Spodaptera litura in cabbage and tomato*

Benefits and Considerations:

- **Technology Category:** This technology finds its rightful place in the knowledge-smart category of CSA technology.
- **Advantages:** The multifaceted benefits of this technology are extensive. It boasts high effectiveness, environmental friendliness, ease of application, and cost-effectiveness in managing common cutworms, particularly *Spodoptera litura*, across a diverse array of vegetables and aroids.
- **Environmental Impact:** Regrettably, this technology carries certain environmental risks and potential deleterious effects.
- **Suitability:** Impressively, this technology is universally applicable, transcending the boundaries of fragile and non-fragile ecosystems throughout the country.
- **Evidence of Benefits:** The utilization of eco-friendly bio-pesticides exhibits substantial economic and yield benefits. For instance, in cabbage and cauliflower cultivation, it safeguards against 95-100% head infestations while reducing costs by 12-15% compared to insecticide-applied plots. In chili farming, bio-pesticide

applications increase healthy yields by 30-45%, with cost savings of 20-25%. Similarly, tomatoes witness enhanced yields of 25-35% and cost savings of 20-25%. Aroids enjoy a remarkable upswing with a 45-55% increase in healthy rhizome yields and 25-30% lower costs than insecticide-applied plots.

The adoption of eco-friendly bio-pesticides, as exemplified by this technology, emerges as a triumphant approach in the relentless battle against *Spodoptera litura* and similar threats. The evidence underscores not only its efficacy but also its potential for substantial cost savings. Moreover, its adaptability across various ecosystems heralds a promising future for sustainable pest management in Bangladeshi agriculture.

(46) Integrated management of powdery mildew and root-knot diseases of cucurbits

The insidious threat of powdery mildew looms large in the realm of cucurbit diseases. Characterized by the formation of white powdery spots on both upper and lower leaf surfaces, this malady rapidly evolves into sprawling blotches. What sets powdery mildew apart in the realm of cucurbit diseases is its uncanny ability to thrive at lower relative humidity (~50% RH) and leaf dryness, conditions conducive to the colonization, sporulation, and dispersal of pathogen spores. The temperature sweet spot for disease development falls between 20 and 27°C. Root diseases, too, cast their shadow on cucurbits, courtesy of soil-borne pathogenic fungi and root-knot nematodes residing in the rhizosphere. Yet, the plants muster their defenses, reinforcing cell walls, deploying pathogenesis-related proteins, and manufacturing antimicrobial molecules. Despite these efforts, the severity of powdery mildew and root-knot diseases often prevails. The imperative, therefore, is to embrace an integrated management approach for cucurbit diseases, (BARI, 2022).

Key Features:

1. **Holistic Approach:** This knowledge-smart CSA technology harmoniously addresses fungal and nematode diseases afflicting cucurbit crops.
2. **Crop Yield Enhancement:** By mitigating disease impacts, this technology bolsters crop yields, fostering agricultural stability, diversification, and resilience against powdery mildew and root knot diseases.

Fig. 49 *Powdery and downing mildew-infected sweet gourd leaves*

Technology Components: This integrated approach comprises several essential elements, including:

- Seed treatment with Provax @ 2.5 g/kg seed before sowing.
- Application of poultry refuge @ 6 kg/pit or 500 g neem oilcake before 15 days of seedling transplanting.
- Application of tricho-compost @ 2 kg/pit before 5 days of transplanting.
- Application of Furadan 5G @ 20 g/pit at the base of the plant during planting to control nematode disease.
- Application of Thiovit @ 2 g/L of water at 12-15 day intervals, repeated thrice.

Control **Treated** **Healthy**

Fig. 50 *Root knot nematode-infected cucurbits plant roots, treated and healthy roots*

Geographic Applicability: This technology finds relevance in several districts across Bangladesh, including Gazipur, Jamalpur, Mymensingh, Chattogram, Cumilla, Rajshahi, Bogura, Rangpur, Jashore, Patuakhali, and more, where cucurbit cultivation is prominent.

Benefits and Outcomes: The merits of this technology manifest in various ways:

1. **Chemical Reduction:** By supplementing organic pesticides and composts with an optimal dose of chemical fungicides and pesticides, this technology contributes to a reduction in chemical use.
2. **Yield Boost:** Crop yields witness a remarkable upswing, surging by 20-25%.
3. **Disease Mitigation:** The prevalence of powdery mildew and root-knot diseases dwindles significantly, attaining reductions of 75-85%.

In sum, the integrated management approach encapsulated by this technology not only mitigates the impact of cucurbit diseases but also promotes sustainable, resilient, and higher-yielding agricultural practices in Bangladesh.

(47) Integrated viral disease management of vegetable crops

Viruses pose a ubiquitous threat to vegetables, with cucumber mosaic virus (CMV), squash mosaic virus (SqMV), watermelon mosaic virus (WMV), pumpkin yellow mosaic virus (PYMV), and papaya ring spot virus (PRSV) ranking among the most common culprits. All but one, SqMV, rely on aphids for transmission, rendering identification based on symptoms alone a challenging endeavor. Timely diagnosis is pivotal in effectively managing these viral infections. To this end, the enzyme-linked immune sorbent test proves invaluable in discerning plant viruses (BARI, 2021).

Key Features:

1. **Disease Identification:** Recognizing and accurately identifying viral infections form the cornerstone of treatment. The symptoms often mimic other diseases or even nutrient deficiencies, underscoring the need for precise diagnosis.
2. **Early Detection:** Swift identification is crucial for implementing effective management strategies. Delayed response could result in substantial crop losses.
3. **Vector Control:** Rather than targeting the disease itself, controlling the vectors responsible for viral transmission takes precedence.
4. **Preventive Measures:** The first line of defense against viral diseases includes:
   - Utilizing virus-indexed healthy seeds and seedlings.
   - Opting for resistant cultivars to combat viral infections, with genetic resistance being the most efficient approach.
   - Practicing clean cultivation to minimize disease incidence.
   - Deploying parasitoids like Aphidius colemani and Binodoxys angelicae to manage aphid vectors.
   - Employing integrated tactics, such as netting of seed beds, polyethylene mulch, trap crops, and periodic applications of insecticides like imidacloprid, azadirachtin (neem-based insecticide), and soybean oil, spaced at 10-day intervals.
   - Implementing regular insecticide applications for effective vector control.

Fig. 51 *Integrated viral disease management of tomato, cabbage, and capsicum*

Technology Origin: This knowledge-smart CSA technology traces its roots to the Bangladesh Agricultural Research Institute, as detailed in the BARI Annual Report of 2021.

Geographic Applicability: This technology extends its relevance to all vegetable-growing regions across Bangladesh, encompassing areas like Rajshahi, Pabna, Jessore, Bogura, Magura, and other vegetable-centric districts.

Benefits and Outcomes: The merits of this technology are multifaceted:

1. **Disease Reduction:** Implementation of this technology can curtail virus disease incidence by 30-40%.

2. **Eco-Friendly:** An environmentally conscious approach, this technology aligns with sustainable agricultural practices.
3. **Profitability:** It offers the prospect of enhanced yields, potentially boosting crop production by 15-20%.

In summary, this knowledge-smart CSA technology equips vegetable growers in Bangladesh with the tools to combat the scourge of viral diseases effectively, promoting environmentally friendly, profitable, and resilient agricultural practices.

(48) Integrated management of bacterial wilt disease of brinjal, tomato, and potato

Bacterial wilt, attributed to the pathogen *Ralstonia solanacearum*, is a pervasive and devastating disease impacting Solanaceous crops, including potatoes, tobacco, pepper, tomatoes, and eggplants. This affliction poses a formidable threat to global crop yields and is known colloquially as "Green wilt" since the leaves of affected plants retain their green hue even as wilting symptoms manifest. To combat this pernicious disease, various physical, cultural, and chemical control measures have been employed. However, these strategies have proven inadequate in eradicating the disease due to the pathogen's broad host range, genetic diversity, and its ability to persist latently in soil and vegetation.

BARI has undertaken the development of a comprehensive technology package aimed at mitigating bacterial wilt, as detailed in the BARI Annual Report of 2021. This knowledge-smart CSA technology represents a critical advancement in disease management.

Key Features:

1. **Use of Disease-Free Seeds:** Initiating disease management at the seed stage with the utilization of disease-free seeds.
2. **Resistant Crop Varieties:** Cultivating disease-resistant varieties, such as BARI Begun-8.
3. **Residue Management:** Employing the practice of burning residual parts of infected plants to prevent disease spread.
4. **Irrigation Management:** Prudent irrigation management in the field.
5. **Crop Rotation:** Implementing crop rotation with non-host crops like rice to disrupt the disease cycle.
6. **Biological Control:** Application of the biological control agent pentaphage (lysate of the virulent strain of *Pseudomonas syringae*) under specific environmental conditions.
7. **Raised Bed Cultivation:** Raising planting beds and covering them with black polythene.

Fig. 52 *Bacterial wilt affected brinjal plants*

8. **Bio-Fungicides:** Application of bio-fungicides, including Bacillus subtilis and *Trichoderma harzianum*, during seedling transplanting.
9. **Bactericide Application:** Regular spraying of bactericides from the *Thiozole* group at specified intervals, beginning two months after seedling transplanting.

***Fig. 53** Bacterial wilt-infected potato and sweet gourd plants*

Geographic Applicability: This technology extends its benefits to vegetable-growing regions, including but not limited to Pabna, Rajshahi, Bogura, Jashore, and various other vegetable-centric districts.

Benefits and Outcomes: The advantages of this technology are threefold:

1. **Yield Enhancement:** Implementing this technology can result in impressive yields, reaching 50-60 tons per hectare, regardless of crop varieties.
2. **Yield Boost:** The technology contributes to an overall yield increase of 15-20%.
3. **Disease Mitigation:** It significantly reduces bacterial wilt disease incidence in brinjal crops by 75-80%, promoting a more resilient and productive agricultural system.

***Fig. 54** Healthy brinjal, tomato, and potato plants with integrated management of bacterial wilt*

In conclusion, this knowledge-smart CSA technology offers a holistic approach to addressing the formidable challenge of bacterial wilt in Solanaceous crops, promoting both eco-friendly practices and enhanced crop yields. However, it necessitates a degree of technical knowledge for proper implementation, which may pose challenges for some farmers. Nonetheless, its potential for mitigating disease and boosting yields underscores its importance in sustainable agriculture.

(49) Biological control of sugarcane stem borer

The concept of "biological control" encompasses a diverse array of product types characterized by their relative non-toxicity and minimal ecological side effects. In the context of agricultural pest management, biological control strategies have proven highly effective. In Bangladesh, these principles have been applied to address the challenge posed by the sugarcane stem borer, offering a sustainable and eco-friendly solution.

This biological control technology has been developed and refined by the Bangladesh Sugarcrop Research Institute (BSRI), as detailed in their Annual Report for the year 2021. By leveraging the natural enemy *Trichogramma* egg parasitoid, this approach effectively manages the sugarcane stem borer.

Key Features:

- ***Trichogramma* Egg Parasitoid:** The technology centers on the utilization of the *Trichogramma* egg parasitoid for controlling the sugarcane stem borer.
- **Strategic Release:** Freshly emerged *Trichogramma* parasitoids are released at a rate of 50,000 per week per hectare. This release occurs from the first week of May through the last week of September.

Fresh egg mass   Parasitized eggs   Releasing *Trichogramma*   Releasing *Trichogramma*

***Fig. 55** Biological control of stem borer*

Fit for CSA Categories: This technology seamlessly aligns with both weather-smart and knowledge-smart categories of CSA technology. It leverages ecological knowledge and adapts to varying environmental conditions.

Benefits and Outcomes: The adoption of this technology yields several significant benefits:

1. **Low Management Costs:** Implementing biological control is cost-effective compared to conventional chemical methods.
2. **Ease of Application:** The techniques involved are straightforward and easy for farmers to follow.
3. **Eco-Friendly:** By relying on a natural predator, this management approach minimizes harm to the environment and non-target organisms.

Limitations: While offering a sustainable solution, this technology does have certain limitations:

- **Knowledge-Based Rearing:** The rearing of biological agents, such as *Trichogramma* parasitoids, requires specific knowledge and expertise.
- **Frequent Release:** Regular and periodic release of *Trichogramma* parasitoids is necessary for its efficacy.
- **Environmental Dependency:** This method performs optimally under suitable environmental conditions.

Geographic Applicability: This technology exhibits broad applicability, suitable for adoption in all sugarcane-growing regions across Bangladesh.

In summary, the utilization of *Trichogramma* egg parasitoids for sugarcane stem borer management epitomizes a climate-smart and knowledge-smart approach. It offers an array of benefits, including cost-effectiveness and environmental friendliness, albeit with some knowledge and environmental dependency requirements. This technology represents a sustainable solution for sugarcane growers, contributing to the advancement of eco-friendly agricultural practices.

D. Climate Resilient Irrigation Management

In the face of escalating threats posed by climate change, the imperative to build resilience in our agricultural practices has never been more pressing. A critical aspect of this resilience lies in the adoption and enforcement of climate-smart water management practices. These practices must span from the individual farm level to comprehensive watershed management strategies. The current water utilization landscape in the country reveals an estimated ratio of green (rainfed) to blue (irrigation) water use at 2.5 (Amin, 2023). To bolster our capacity to withstand the challenges of climate change, it is paramount to augment this ratio. Achieving this necessitates the identification and implementation of robust, climate-resilient water management practices. Key Climate-Resilient Water Management Practices are: precision irrigation, reduced irrigation, point irrigation, water-dynamic crop rotation, conservation tillage, rainwater harvesting, infiltration and runoff management, virtual water transport, use of modern computing technologies, educating stakeholders, and use of renewable energy.

(50) Rainwater harvest

The High Barind Tract (HBT) stands as Bangladesh's most drought-prone region (Brammer, 1988). With vast non-irrigated expanses, the livelihoods of its residents are intricately tied to rainfed agriculture. In response to this challenge, a commendable initiative has taken root: rainwater harvesting. Farmers in the Barind area are digging various-sized ponds strategically, such as in homestead areas or adjacent to cropland. These ponds serve as reservoirs for monsoon rainwater, which can be employed to irrigate a variety of crops during the dry season. BARI has extensively researched and proposed a rainwater harvesting technology tailored to this context.

Key Features of the Technology:

***Fig. 56** Water harvest in a pond*

1. **Pond Dimensions:** A pond measuring 12 m x 12 m x 3 m, adequately sized to provide supplementary irrigation to approximately 1 ha of land during a drought period, is a pivotal component.
2. **Yield Savings:** This technology can significantly curtail yield reduction due to drought, ranging from 35% to 48%.
3. **Crop Flexibility:** If surplus water is available after meeting the needs of T. Aman rice, it can be efficiently utilized for cultivating low-water-demanding rabi crops like wheat, lentils, and more.
4. **Strategic Placement:** Ponds are strategically located at low elevations and corners of the land, optimizing rainwater collection.
5. **Collection Mechanism:** Rainwater is efficiently collected from the adjacent pond area using a well-designed drainage system.

Categorization of Technology: This innovative rainwater harvesting technology aligns with both weather-smart and knowledge-smart categories of CSA technologies.

Suitability and Adoption:

- The technology effectively addresses seasonal drought concerns during the T. Aman season, facilitating the cultivation of low-water-demand crops like leafy vegetables, potatoes, and lentils.
- Adoption of this technology among farmers is moderate, and it holds particular promise for smallholders due to its cost-effectiveness.
- Notably, this technology's application primarily focuses on cultivating vegetables and low-water-consuming crops, making it conducive to women's engagement in agricultural activities.

Benefits of the Technology:

1. **Availability of Dry Season Irrigation:** Rainwater harvesting ensures access to irrigation water during dry seasons, thus enhancing crop production reliability.
2. **Expanded Cropping Area:** It effectively increases the arable land area in water-limited environments.
3. **Yield Enhancement:** Across various crops, this technology offers yield gains ranging from 20% to 50%.
4. **Homestead Gardening:** The harvested water finds additional utility in homestead gardening, where it is predominantly managed by women.
5. **Cost-Efficient Irrigation:** It translates to reduced irrigation costs and heightened water use efficiency.

Constraints: A significant challenge lies in the consolidation and fragmentation of land holdings. In many cases, farmers are reluctant to allocate their land for pond excavation, posing a substantial constraint to the widespread adoption of this technology.

Rainwater harvesting technology is a beacon of hope in drought-prone regions like the High Barind Tract. Its ability to bolster crop production, expand arable land, and enhance water utilization efficiency underscores its significance. However, addressing land-sharing concerns and scaling up adoption are critical steps toward maximizing its potential impact.

(51) Alternate wetting and drying technology

Alternate Wetting and Drying (AWD) is an innovative water-saving technique designed to reduce irrigation water usage in rice fields. Unlike the conventional practice of continuously submerging rice fields, AWD involves applying irrigation water a few days after the ponded water has receded. The dry interval between wetting events can vary based on factors such as soil type, weather conditions, and the growth stage of the rice crop. This technology, jointly developed by the International Rice Research Institute (IRRI) and the Bangladesh Rice Research Institute, holds promise for sustainable rice cultivation.

Key Features of the Technology:

1. **Field Water Tube:** A 'field water tube' or 'pani pipe' serves as a monitoring tool for water depth in the field. When the water level inside the pani pipe drops below 15 cm from the soil surface, irrigation is applied to maintain a depth of about 5 cm of standing water.
2. **Ponding Period:** Typically, the rice field is initially ponded for 1-2 weeks after transplanting. AWD is then practiced for the remainder of the rice growing season, excluding the flowering stage, where a 5 cm water depth is maintained.

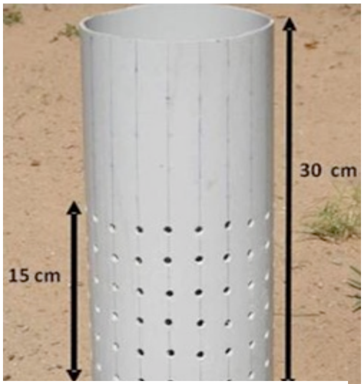

***Fig.** 57 AWD in the rice field*

Categorization of Technology: The AWD method aligns with the Water-smart, weather-smart, and knowledge-smart technology categories within the domain of CSA.

***Fig. 58** Water at 15 cm below the soil surface (A), Time to irrigate the field again (B)*

Benefits of the Technology:

- **Water Savings:** AWD can lead to substantial water savings, reducing the need for 4-6 irrigations (equivalent to 15-30% of total irrigation water) compared to continuous standing water.
- **Cost Reduction:** This technology lowers fuel requirements and irrigation costs by Tk. 2500-3000 per hectare, contributing to financial savings for farmers.
- **Sustainable Practices:** By reducing groundwater withdrawal and methane gas emissions by 25-30%, AWD promotes environmentally friendly and sustainable agricultural practices.
- **Yield Maintenance:** Importantly, AWD does not result in yield reductions and has additional benefits like promoting root anchorage, improving nutrient availability, and reducing plant lodging.

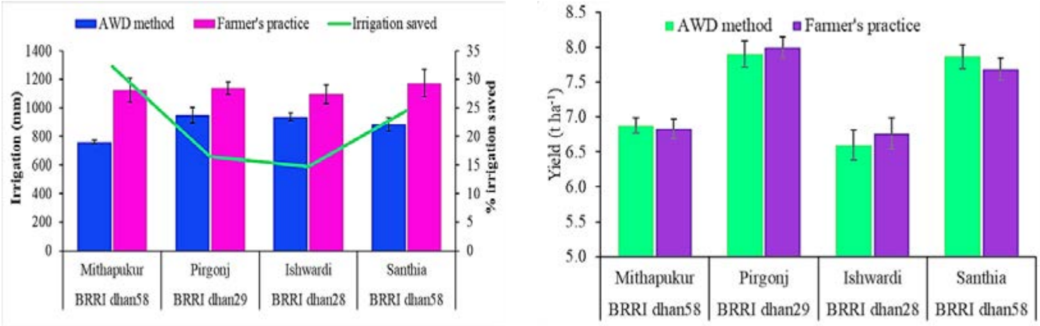

***Fig. 59** Irrigation saving and yield performance in AWD method over farmers' practice*

Limitations of the Technology:

- **Labor Demands:** AWD may require additional labor for tasks like weeding.
- **Nutrient Uptake:** The availability and uptake of certain nutrient elements, such as phosphorus, might be affected.
- **Research Needs:** Further research is needed, including advanced breeding materials and molecular investigations to optimize AWD's adaptability and impact (Price et al., 2013).

Suitability and Adoption:

- AWD is suitable for implementation throughout Bangladesh, except in saline areas during the boro season.
- It particularly benefits smallholder farmers and women, given its potential to reduce pumping costs, fuel consumption, and increase income per hectare.

Challenges:

- One major challenge is the distribution of financial benefits. Currently, service providers (pump owners) charge a flat rate based on the area, rather than the quantity or frequency of irrigation events. Policies and incentives need to be developed to encourage AWD adoption at the farm level.

Conclusion: Alternate Wetting and Drying (AWD) emerges as a promising water-saving technology for rice cultivation. Its ability to conserve water, reduce costs, and minimize environmental impacts make it an attractive option for sustainable agriculture. However, addressing labor requirements and fine-tuning nutrient management are essential steps in maximizing its potential benefits. Additionally, revisiting pricing models and government support policies can facilitate wider AWD adoption, furthering its positive impact on rice farming in Bangladesh.

(52) Solar powered irrigation

Solar-Powered Water Pumping and Electricity Generation is an innovative technology developed by the Bangladesh Rice Research Institute (BRRI, 2022). This technology harnesses solar energy to drive water pumps and generate electricity, offering multiple benefits for agricultural and domestic applications.

Key Features of the Technology:

1. **Solar Setup:** This technology employs a 410-watt solar power system consisting of 8 solar panels, coupled with a 3-kW inverter.
2. **Water Pumping:** It incorporates a 2.0 kW Low Lift Pump (LLP) capable of drawing surface water at a rate of 10-14 liters per second.
3. **Threshing Capability:** The solar panel system can also power a 1.5-2.0 kW open drum thresher, capable of threshing 250-350 kg of paddy per hour.
4. **Domestic Electricity:** Additionally, it generates sufficient electricity to meet the domestic needs of 3-4 rural households.

***Fig. 60** Portable solar pump irrigation system*

Categorization of Technology: Solar-Powered Water Pumping and Electricity Generation falls under the energy-smart category of CSA technology.

Benefits of the Technology:

- **Enhanced Irrigation:** This technology can facilitate irrigation of approximately 25 bighas of land during the Boro season, increasing agricultural productivity.

- **Reduced Emissions:** Since it relies on solar power, there is no need for traditional fuel sources, resulting in zero CO_2 emissions.

Limitations of the Technology:

- **Weather Dependency:** The operation of the pump may be restricted during foggy weather in the winter season.

Suitability and Adoption:

- The technology is suitable for deployment across all agroecological zones of Bangladesh, except for the Barind tract where the groundwater table is significantly deeper.
- It has garnered significant interest among smallholder farmers and holds great potential for wider adoption. Effective dissemination through channels like the Department of Agricultural Extension (DAE) can accelerate its adoption and benefits.

The Solar-Powered Water Pumping and Electricity Generation technology developed by BRRI presents a sustainable and environmentally friendly solution for agricultural and domestic energy needs. By harnessing solar energy, it not only enhances irrigation capabilities but also reduces carbon emissions, contributing to both agricultural productivity and environmental conservation. However, consideration of weather-dependent limitations and concerted efforts in dissemination are crucial to fully realize the benefits of this technology among smallholder farmers in Bangladesh.

(53) Alternate furrow irrigation technology

Alternate Furrow Irrigation (AFI) is an innovative irrigation technique designed to enhance water use efficiency in dryland crop cultivation. Developed by the BARI (Sarker et al., 2020), this technology offers a promising solution to address water scarcity and optimize irrigation practices.

Key Features of the Technology:

1. **Irrigation Method:** AFI involves the application of irrigation water in alternate furrows, leaving the in-between furrows dry during each irrigation event.
2. **Selective Root Watering:** With each irrigation, water is applied to only one side of the root system, allowing the other side to dry.
3. **Sequential Irrigation:** In subsequent irrigation cycles, water is directed to the alternate furrows that were kept dry during the previous round.
4. **Irrigation Frequency:** AFI typically follows a 10-day interval or is timed based on different crop growth stages.

Categorization of Technology: Alternate Furrow Irrigation (AFI) falls within the Water-smart and Energy-smart categories of CSA technology.

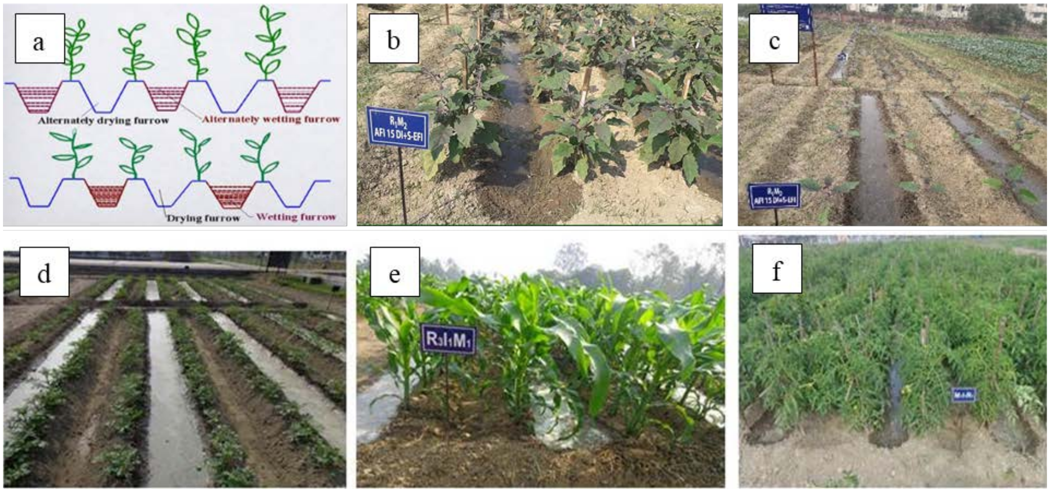

Fig. 61 *Diagram/photo shows (a) AFI technique, (b & c) AFI for brinjal, (d) potato, (e) maize, and (f) tomato*

Benefits of the Technology:

- **Water Savings:** AFI significantly reduces irrigation water usage, resulting in water savings of approximately 25-30%. This contributes to efficient water resource management.
- **Enhanced Water Use Efficiency (WUE):** By selectively watering the root system and optimizing irrigation, AFI improves WUE compared to other irrigation techniques.

Limitations of the Technology:

- **Soil Suitability:** AFI is most suitable for sandy loam to loamy soils and may not be effective on sandy soils.
- **Crop Applicability:** This technology is primarily applicable to row crops and may not be suitable for all crop types.

Suitability and Adoption:

- AFI is particularly well-suited for drought-prone areas, especially in the northern regions of Bangladesh, such as the Barind Tract.
- Crops that benefit from AFI include rabi crops like brinjal, tomato, potato, maize, and sunflower.
- Farmers have shown increasing interest in AFI due to its water-saving benefits and adaptability for smallholder farming. The multipurpose use of solar panels in this technology enhances its appeal.
- Successful adoption hinges on knowledge transfer to farmers and the development of skilled manpower to facilitate its implementation.

Alternate Furrow Irrigation (AFI) is a water-smart and energy-smart CSA technology that addresses water scarcity challenges in dryland crop cultivation. By optimizing irrigation practices, AFI offers significant water savings and enhanced water use efficiency. While it has demonstrated potential in drought-prone areas, successful adoption will require continued efforts in knowledge dissemination and capacity building among farmers in Bangladesh.

(54) Drip irrigation/fertigation technology

Drip Irrigation/Fertigation is a precision agriculture technology that offers efficient water and fertilizer management for high-value crop production. Developed by the BARI, this method allows precise application of water and nutrients directly to individual plants, enhancing irrigation and fertilizer use efficiency. Ma et al. (2020) found phosphorous (P) fertigation with high salinity water drip irrigation very effective in relieving soil and water pollution caused by the excessive application of P fertilizer. This technique helps achieve synergistic saving of both limited fresh water and non-renewable P resources.

Key Features of the Technology:

1. **Irrigation Method:** Drip irrigation involves the direct application of irrigation water to individual plants through low-cost emitters connected to plastic tubing at frequent intervals.
2. **Emitter Discharge Rate:** The emitter's discharge rate typically ranges from 3 to 4 liters per hour, depending on pressure and manufacturer specifications.
3. **Fertigation:** Water-soluble fertilizers, such as nitrogen and potash, are mixed with water at ratios of 1:100 to 1:200. This ensures precise and efficient nutrient delivery to crops.
4. **Irrigation Frequency:** Drip irrigation recommends irrigation intervals of 3 to 5 days for crop production.

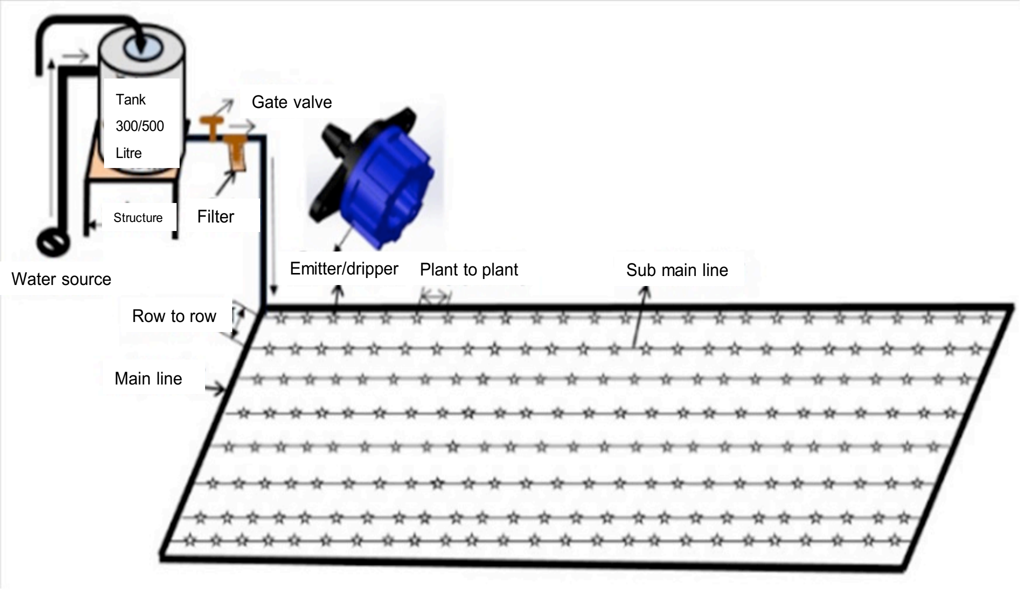

Fig. 62 Drip-fertigation system with low-cost emitter

Categorization of Technology: Drip Irrigation/Fertigation falls under the Water-smart category of CSA technology.

Benefits of the Technology:

- **Enhanced Water and Fertilizer Efficiency:** Drip irrigation increases water and fertilizer use efficiency, optimizing resource utilization.
- **Salinity Control:** This method can reduce soil salinity at the crop root zone while ensuring equal water distribution among all plants in the field.
- **Cost-Effective Emitters:** Locally made emitters are cost-competitive, with prices around Tk. 8-10, which is significantly cheaper than imported alternatives.
- **Nutrient Savings:** Drip fertigation systems can save around 40% of nitrogen and 30% of potash compared to traditional surface broadcasting fertilization (Sarker et al., 2019).
- **Water Savings:** Drip irrigation can save approximately 50% of irrigation water compared to conventional flooding methods (Sarker et al., 2019).
- **Yield Increase:** When compared to surface flooding irrigation systems, drip irrigation can lead to yield increases of around 20% (BARI, 2022).

***Fig. 63** Drip-fertigation system for high-value crop production*

Limitations of the Technology:

- **High Initial Investment:** The initial investment cost for drip irrigation systems can be high, making it challenging for smallholder farmers to afford.

Suitability and Adoption:

- Drip Irrigation/Fertigation is most suitable for drought-prone (e.g., Barind) and saline-prone (e.g., coastal) areas. Crops like sweet orange, watermelon, sweet gourd, strawberry, and summer tomato are well-suited for this technology.
- The adoption rate of this technology is currently low due to a lack of technical knowledge. Scaling up adoption requires government policies that support and promote its use.

Drip Irrigation/Fertigation is a water-smart CSA technology that offers precise water and fertilizer management for high-value crop cultivation. Despite its initial investment cost, this technology has the potential to significantly enhance water and nutrient use efficiency, reduce soil salinity, and increase crop yields. Its broader adoption in drought-prone and saline-affected areas can contribute to sustainable agriculture in Bangladesh.

(55) Conjunctive use of fresh and saline water in coastal areas

The conjunctive use of fresh and saline water is a promising irrigation method designed to address the challenges of crop cultivation in coastal saline zones of Bangladesh. Developed by the BARI, this technology enables farmers to expand crop cultivation in areas affected by salinity and, in turn, increase overall farm productivity (IWM Division, BARI, 2021).

Key Features of the Technology:

1. **Water Source:** Freshwater from ponds or controlled canals is applied during the initial growth stages of crops, while moderately saline water from the canal (with an Electrical Conductivity, EC, of ≤ 5-6 dS/m) is used during the mid or later growth stages.
2. **Purpose:** The conjunctive use of freshwater and saline water for irrigation is primarily aimed at supporting Rabi crops in coastal salt-affected areas where limited freshwater resources are available.

Fig. 64 Conjunctive use of fresh and saline water for Rabi crops cultivation such as Boro rice (a), Sunflower (b & c), and Sugarcane (d) in the coastal area

Categorization of Technology: The conjunctive use of fresh and saline water falls under the Water-smart category of CSA technology.

Benefits of the Technology:

- **Optimized Water Resources:** The main benefit of this technology is the utilization of moderately saline canal water as a convenient irrigation source for winter crops, particularly when freshwater availability is limited.
- **Yield Preservation:** By applying freshwater (low-saline) during the early sensitive stages of crop growth and transitioning to saline canal water at later stages, this technology helps minimize yield losses.

Limitations of the Technology:

- **Geographic Limitation:** This technology is most suitable for salt-affected coastal zones in southern regions of Bangladesh, where the Electrical Conductivity (EC) value of water does not exceed 6 dS/m.

Suitability and Adoption:

- **Geographical Area:** The conjunctive use of fresh and saline water is suitable for salt-affected coastal zones in the southern regions of Bangladesh.

- **Cropping Pattern/Season:** This technology is well-suited for Rabi crops such as maize, sunflower, watermelon, wheat, and barley that follow T. Aman rice cultivation.
- **Agro-ecosystem:** It is particularly applicable to the coastal saline ecosystem.
- **Popularity:** The technology is gaining popularity among coastal farmers who face challenges in crop production due to the scarcity of freshwater resources.
- **Target Audience:** The conjunctive use of fresh and saline water is suitable for smallholder and women farmers, contributing to increased crop production and enhanced livelihoods in coastal areas.

The conjunctive use of fresh and saline water is a water-smart CSA technology developed by BARI to address the unique challenges of crop cultivation in coastal saline zones of Bangladesh. By optimizing water resources and minimizing yield losses, this technology enables farmers to expand their crop cultivation in areas where freshwater is limited. Its adoption contributes to increased farm productivity and offers a viable solution for salt-affected coastal regions, benefiting smallholder and women farmers.

(56) Surface drainage technique

Coastal regions in Bangladesh often face the dual challenges of waterlogging and salinity, which can significantly restrict crop productivity (Barrett-Lennard and Shabala, 2013). These conditions lead to increased uptake of sodium (Na^+) and chloride (Cl^-) ions and decreased uptake of potassium (K^+) ions in crops, disrupting ion balance in plant tissues and adversely affecting yields. Surface drainage has been identified as an effective solution to address waterlogging and salinity issues in these areas (Islam et al., 2022a). This innovative technology, developed by the BARI, offers a solution to enhance crop productivity in the face of these challenges.

Key Features of the Technology:

1. **Bedding System:** The technology employs a bedding system with drains spaced at 8 meters apart and drain depths ranging from 20 to 30 centimeters.
2. **Random Field Ditches:** Additionally, random field ditches in the form of potholes with depths between 20 and 30 centimeters and lengths varying from 7 to 11 meters are utilized.

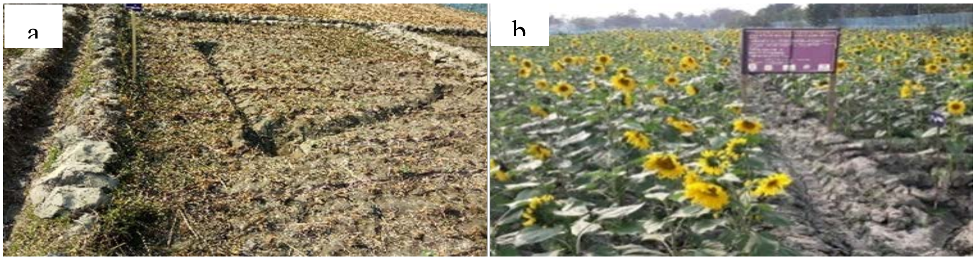

Fig. 65 *(a) Waterlogged saline field, and (b) Sunflower cultivation in waterlogged saline soil following surface drainage technique*

Categorization of Technology: This technology falls under the knowledge-smart category of CSA technology.

Benefits of the Technology:

- **Ion Balance:** Surface drainage helps restore ion balance in crop plants by reducing the excessive uptake of sodium (Na^+) and chloride (Cl^-) ions associated with waterlogging and salinity.
- **Waterlogging and Salinity Mitigation:** The practice of surface drainage effectively alleviates waterlogging and salinity conditions, creating more favorable conditions for crop growth.
- **Improved Crop Yield:** As a result of better ion balance and improved growing conditions, this technology ultimately leads to enhanced crop yields.

Limitations of the Technology:

- **Crop Rotation Challenges:** The use of bedding systems may pose challenges for subsequent crop cultivation, particularly for rice, which could be considered a limitation.

Suitability and Adoption:

- **Geographical Area:** This technology is well-suited for coastal regions, particularly for Rabi crops.
- **Crop Compatibility:** It is most suitable for Rabi season crops, and its adaptability rate is currently low. However, many farmers have shown interest in practicing this technology.
- **Impact on Smallholder Farmers:** Surface drainage has had a significant impact on smallholder crop growers in coastal regions, benefiting them during the Rabi season.
- **Engaging Women:** Increasing engagement of women in agriculture through training on this technology and field visits is an important consideration.

Challenges and Scaling Up:

- **Scaling Up:** Proper planning and support, both technical and financial, are essential for scaling up this technology among farmers.
- **Lack of Motivation:** One of the main challenges in scaling up this technology is the lack of motivation or support, hindering its widespread adoption.

Surface drainage, as an innovative knowledge-smart CSA technology developed by BARI, offers a promising solution to the challenges of waterlogging and salinity in coastal regions of Bangladesh. By restoring ion balance, mitigating waterlogging and salinity, and improving crop yields, this technology has the potential to significantly benefit smallholder farmers in the Rabi season. However, addressing challenges and providing support are critical steps in scaling up this technology for broader adoption in coastal agriculture.

E. Climate Resilient Farm Mechanization

Agricultural mechanization in Bangladesh has seen significant growth, thanks to both public and private sector initiatives. The Government of Bangladesh (GoB) has allocated 3020 crore taka to promote various mechanization tools such as transplanters, weeders, harvesters, threshers, and dryers, primarily through the Department of Agricultural Extension (DAE). Subsidies of 70% are provided in the haor and coastal areas, and 50% in other regions of the country. Presently, the available power for agricultural production stands at 3.13 kW/ha (Alam et al., 2022b). In contrast, countries like Japan, China, and India have 8.75, 5.7, and 2.22 kW/ha, respectively (FAO, 2015).

Research conducted by the Appropriate Scale Mechanization Innovation Hub (ASMIH) in Bangladesh has demonstrated that appropriately scaled machinery can save time, reduce costs, and minimize labor requirements. This technology can potentially lower paddy production costs by 40 to 50%. Additionally, the use of combined harvesters, BAU-STR dryers, and hermetic bags can reduce losses from 15.24% to 2.28% (ASMIH-BD, 2022).

CSA is crucial for sustaining agricultural production in the face of changing climate conditions in Bangladesh. Agricultural mechanization with suitable technologies is essential for facilitating and sustaining CSA practices.

To achieve sustainable development goals in Bangladesh, there is a need to promote Fourth Industrial Revolution (4IR)-based precision agricultural technologies. Priority interventions should focus on optimizing and enhancing the efficiency of agricultural production and processing systems. Key areas of focus include smart farming, precision agriculture (utilizing machine vision, drones, nano-technologies, etc.), controlled environment agriculture, dry and cold chain infrastructure, renewable biogas, and solar nexus smart micro-grids.

Implementing a climate-smart agriculture approach often requires capacity-building within institutions and the development of coordinated mechanisms to improve governance efficiency, accountability, and transparency. However, it is essential to emphasize that research, investment, and the sharing of advanced agricultural technology through national and global partnerships are critical for ensuring resilient food systems in Bangladesh.

(57) Raised bed planter

Traditional bed planting systems have been used by farmers for years to cultivate various crops like potatoes, maize, chilies, and vegetables, particularly to protect crops from excessive water due to heavy showers. However, manual bed formation is labor-intensive, time-consuming, and costly. To address these challenges, scientists at the BARI have developed a bed planter that not only saves labor costs but also performs multiple functions, including soil tillage, bed formation, fertilizer application, and seed sowing simultaneously in a single pass. This innovative technology offers benefits for water-smart, energy-smart, and knowledge-smart agriculture practices.

Key Features of the Technology:

- **Bed Planter Attachment:** The bed planter is an attachment that can be connected to a power tiller. It is designed to perform various functions in a single pass, including soil tillage, bed formation, fertilizer application, and seed sowing.
- **Bed Specifications:** The technology forms beds with specific dimensions, including a width of 60 cm, a top width of 40 cm, and a height of 15 cm, with a distance of 20 cm between two adjacent beds. Seed sowing is done on the ridge of the bed in either single or double lines, following recommended seed distances for different crops.

Fig. 66 *Bed planter*

- **Soil Tilling and Compaction:** Tines on the planter are arranged to throw loose soil from both sides inward for bed formation. A roller attached behind the rotating blades compacts the loose soil, ensuring proper seed and soil contact.

Categorization of Technology: This technology falls under the water-smart, energy-smart, and knowledge-smart categories of CSA technology.

Suitability and Benefits:

- **Crops:** The bed planter is suitable for cultivating upland crops such as wheat, maize, lentil, mung bean, mustard, and sesame in high to medium-high lands across various agro-ecosystems in Bangladesh.
- **Research and Adoption:** Research on the bed planting technology has been conducted at the farmer's level in several districts, including Rajshahi, Rangpur, Patuakhali, and Barishal. Farmers have shown a positive attitude toward adopting this technology, and some Local Service Providers (LSPs) have emerged in the Rajshahi region, indicating good adaptability.
- **Benefits:** The technology offers several advantages, including the completion of multiple operations in one pass, the ability to cover 0.10 ha of land in one-hour, adjustable line spacing and seeding depth, and increased yields for various crops, including cereals, pulses, and jute. Additionally, it reduces irrigation water usage by 25-30%, urea fertilizer by 10-15%, and seed rates by 15-20% (Hossain et al., 2012).

Challenges and Scaling Up:

- **LSP Development:** The development of LSPs and the manufacturing of quality machines are key factors for scaling up this technology.
- **Efficiency and Drudgery:** The bed planter attachment is based on a two-wheel tractor (2WT) with lower efficiency, covering 5-6 bighas of land in a working day. LSPs may not show interest in bed planting due to drudgery problems, as they have to walk behind the machine. Further research is needed to address this limitation.

Conclusion: The bed planter technology developed by BARI offers an innovative solution to labor-intensive bed formation and provides multiple benefits, including increased crop yields and reduced resource use. While challenges exist, such as the development of LSPs and addressing drudgery issues, the technology has the potential to significantly benefit smallholder farmers and promote sustainable agriculture practices in Bangladesh. Proper planning and support are essential for scaling up this technology and ensuring its widespread adoption.

(58) Laser land leveling

Traditional methods of land leveling in agriculture are often labor-intensive, time-consuming, and costly. In response to these challenges, modern methods such as Laser Land Leveling (LLL) have been introduced to achieve precise and efficient land leveling. LLL involves using laser-equipped drag buckets, large horsepower tractors, and soil movers with GPS and/or laser-guided instrumentation to create a desired slope or level on agricultural land (Jat et al., 2020). This technology offers significant advantages in terms of water efficiency, energy savings, and labor reduction. This analysis focuses on the adoption and benefits of LLL in the context of CSA in Bangladesh.

Categorization of Technology: Laser Land Leveling (LLL) technology falls under the water-smart and knowledge-smart categories of CSA technology.

Suitability and Benefits:

- **Applicability:** LLL technology is versatile and can be implemented across various regions, cropping systems, soil types, and environmental conditions in Bangladesh. It is particularly suitable for rainfed ecologies and areas facing water scarcity and soil moisture challenges, as it enhances crop production under these conditions.
- **Crop Systems:** LLL is highly beneficial in rice-wheat cropping systems, where rice cultivation typically requires significant irrigation water.
- **Environmental Impact:** LLL contributes to reduced greenhouse gas emissions and is environmentally friendly.
- **Benefits:** The technology offers several advantages, including higher water use efficiency, improved weed control, increased fertilizer use efficiency, and higher farm productivity, with potential yield gains ranging from 5% to 20%. It also leads to savings in terms of water, fertilizers, energy, and labor.

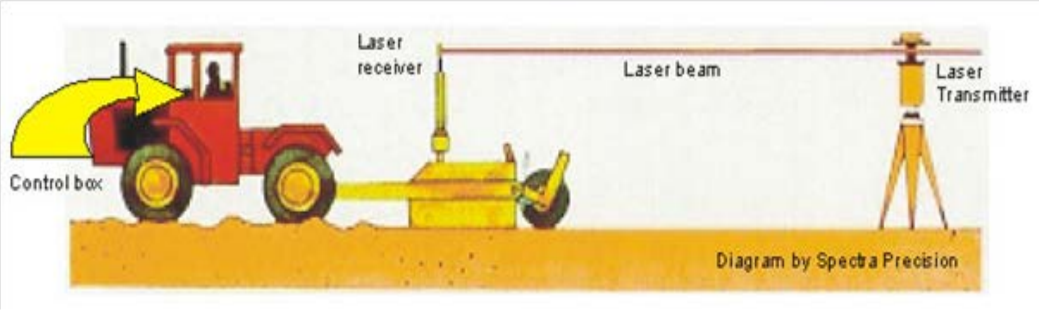

Fig. 67 Diagram of Laser Land Leveling

Adoption and Challenges:

- **Extension and Adaptation:** LLL technology has been primarily validated in North-West Bangladesh (Rajshahi) with limited extension efforts. While farmers in Rajshahi have shown a positive attitude toward the technology, the overall rate of adaptability remains low.
- **Scaling Up:** To promote the wider adoption of LLL technology, the development of quality machines and mechanization efforts are essential. Larger and more efficient machines should be developed to overcome existing challenges.
- **Socio-cultural Barriers:** Addressing socio-cultural barriers, particularly gender inequalities, is crucial to ensure equitable access to machinery by women farmers. LLL facilitates crop diversification, including the cultivation of vegetables, which can enhance food security and provide an additional income source, particularly for women.
- **Youth Engagement:** Youth can play a significant role in scaling up LLL technology by acting as service providers and establishing custom hiring centers at the village level.

***Fig. 68** Use of Laser Land Leveling*

Laser Land Leveling (LLL) technology offers a promising solution to labor-intensive land leveling practices in agriculture. Its adoption can lead to improved water and energy efficiency, reduced labor requirements, and increased farm productivity. However, to enhance the uptake of LLL technology in Bangladesh, efforts should focus on developing quality machines, addressing socio-cultural barriers, and engaging youth in promoting and providing LLL services. Proper extension and scaling-up initiatives are essential to maximize the benefits of this technology for smallholder farmers and women in agriculture.

(59) Non-puddled mechanical rice seedling transplanter

Traditional manual rice transplanting is a labor-intensive process that can negatively impact soil conditions and crop yields. Mechanization of rice transplanting offers a solution to reduce labor dependence, lower cultivation costs, and minimize soil disturbance caused by manual puddling. Mechanized rice transplanters, such as the manually operated rice transplanter developed by the Bangladesh Rice Research Institute (BRRI) (Hossen 2020), aim to address these challenges and ensure timely transplanting for higher rice yields. This analysis explores the adoption and benefits of mechanized rice transplanting technology in the context of CSA in Bangladesh.

Categorization of Technology: Mechanized rice transplanting technology falls under the energy-smart category of CSA technology.

Key Features and Benefits:

- **Seedling Quality:** The technology is suitable for planting young rice seedlings (15-18 day-old) raised in seedling trays, ensuring proper plant-to-plant and line-to-line spacing, which is crucial for increasing rice yields.
- **Components:** The manually operated rice transplanter consists of floats, a mainframe assembly made of MS pipe, a seeding tray made of G.I. sheet, a pushing lever, tray indexing mechanism, pickers in a bar, and two handles for seedling pushing and machine carrying during operator movement.
- **Field Capacity:** The field capacity of the developed rice transplanter is 0.05 ha-1.
- **Benefits:** Mechanized rice transplanting offers several advantages, including reduced labor requirements (saving approximately 60% on labor), lower transplanting costs (saving around 45% compared to manual transplanting), and increased field capacity compared to manual methods (Hossen and Rahman, 2020). This technology also allows for timely transplanting, reducing the risk of yield loss due to delayed planting.

***Fig. 69** Mechanical rice transplanter*

Limitations:

- **Seedling Raising:** The mat-type rice seedling raising technique required for mechanical transplanting can be complex, and some farmers may not be accustomed to following proper management practices, affecting the machine's performance.
- **Field Conditions:** Plot size, shape, farm roads, and soil-bearing capacity can significantly influence the machine's performance during operation. Small, fragmented fields are considered a major constraint for the dissemination of this technology.

Suitability and Adoption:

- **Geographical Suitability:** Mechanized rice transplanting is suitable for medium-high and medium-low lands where crop cultivation is intensive.
- **Adaptability:** The adaptability rate among farmers is increasing, but motivational training through the Department of Agricultural Extension (DAE) is needed to further promote the technology.

Mechanized rice transplanting technology, exemplified by the manually operated rice transplanter, offers significant benefits in terms of reduced labor dependency, lower cultivation costs, and timely transplanting. This technology is well-suited for medium-high and medium-low lands with intensive crop cultivation. While challenges related to seedling raising techniques and field conditions exist, the adoption rate is on the rise, and proper training and extension efforts can further enhance its uptake among farmers. The technology's potential to save on labor and transplanting costs makes it a valuable tool for smallholder farmers practicing rice cultivation in Bangladesh.

(60) Reduced tillage machinery for sugarcane cultivation

Conservation agriculture (CA) practices, including tillage reduction, are essential for sustainable crop production, global food security, and environmental safety. These practices focus on minimizing soil disturbance, maintaining permanent soil cover, implementing planned crop rotations, and integrating weed management. Tillage reduction is a key component of CA that offers several benefits for crop production while conserving soil and resources. In Bangladesh, the Bangladesh Sugarcrops Research Institute (BSRI) has developed technologies related to tillage reduction for sustainable sugarcane cultivation.

Categorization of Technology: Tillage reduction technology falls under the Energy-smart and weather-smart categories of CSA technology.

Key Features and Benefits:

Tillage Methods: Sugarcane can be planted using various tillage methods, including zero tillage trencher, strip tillage trencher, bed former cum trencher, tractor-mounted trencher, and conventional methods.

Single pass by bed former cum trencher (BT)
Single pass by zero tillage trencher (ZT)
Single pass by VMP- strip tillage (ST)

Fig. 70 *Sugarcane cultivation with reduced tillage machinery*

Benefits of Tillage Reduction:

1. **Cost Reduction:** Tillage reduction practices lead to cost savings in terms of fuel, machinery operating costs, maintenance, and labor expenses.
2. **Soil Health:** These practices enhance soil health by increasing soil organic matter content, reducing soil erosion, conserving soil moisture, improving soil structure, and enhancing the rooting zone for crops.
3. **Crop Yield:** Tillage reduction has the potential to increase crop yields by approximately 10-20% (BSRI Annual Research Report).

Limitations:

1. **Field Suitability:** Not all fields are suitable for tillage reduction, as suitability depends on factors such as the level of soil compaction and the presence of surface residue.
2. **Organic Matter Incorporation:** Tillage reduction methods may not effectively incorporate organic matter and weeds into the soil compared to traditional plowing.
3. **Hardpan Development:** Over time, tillage reduction practices can lead to the development of hardpans in the soil, which may impede root growth and water infiltration.

Suitability and Adoption:

Tillage reduction technology is suitable for both mill zone and non-mill zone areas under plain land ecosystems in Bangladesh. Its adoption can lead to sustainable sugarcane cultivation while offering cost savings and soil health benefits. Farmers who implement these practices can potentially achieve higher crop yields while reducing their environmental impact.

Tillage reduction practices are integral to conservation agriculture and contribute to sustainable crop production, cost savings, and soil health improvement. In the context of sugarcane cultivation, BSRI has developed various tillage methods that can be adopted by farmers in both mill and non-mill zone areas. While there are some limitations and considerations related to field suitability and organic matter incorporation, the benefits of tillage reduction make it a valuable technology for enhancing sugarcane production in Bangladesh. Proper training and extension efforts can further promote the adoption of these sustainable practices among farmers.

(61) Strip planting system

Fig. 71 Strip planting within the previous crop residue

The strip planting system (SP) is a crucial component of conservation agriculture (CA)-based technologies. It offers a resource-saving approach to crop cultivation, reducing time, labor, irrigation, and costs while preserving soil health. The SP system combines elements of both conventional and no-tillage systems (Bell et al., 2017; Kader et al., 2022), aiming to improve soil properties, seedbed environments, and crop productivity (Islam et al., 2022b).

Development and Adaptation: The International Maize and Wheat Improvement Centre (CIMMYT) initially developed a strip planter in 2001, based on a Chinese 2BG-6A seeder, which utilized a two-wheel tractor for planting seeds on new and permanent beds with the strip planting system. Subsequently, the Bangladesh Agricultural Research Institute, CIMMYT Bangladesh, and the Agricultural Implements Research Centre (AIRC) of Nepal modified and adapted the strip planting system to suit South Asian agricultural conditions (Johansen et al., 2012). This adaptation involved reconfiguring the planter by adding rotary blades in front of the furrow openers and attaching a fertilizer box to the strip planter device (Roy et al., 2009). Four tynes were also included for tilling each seeding line, and a press wheel was used to cover the seeds after planting. This approach allowed soil tillage, seeding, and laddering to be performed simultaneously in a single pass.

Categorization of Technology: The strip planting system encompasses all six categories of CSA, including being weather-smart, water-smart, carbon-smart, nutrient-smart, energy-smart, and knowledge-smart.

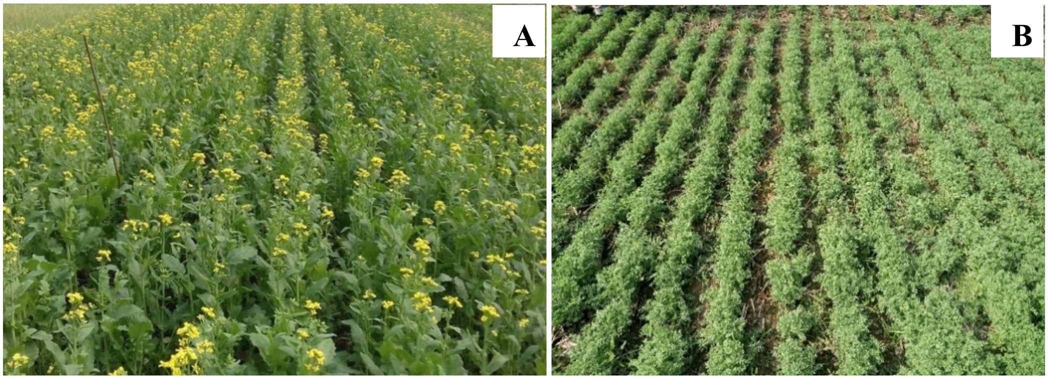

Fig. 72 Strip-planted mustard (A), and Strip-planted lentil (B)

Benefits of the Strip Planting System:

1. **Cost Reduction:** The SP system reduces cultivation costs (Hossain et al., 2012) by decreasing fuel consumption by 10-15% and labor costs by 25-30%.
2. **Soil Health:** It minimizes soil disturbance, fosters higher soil microbial activities, and sequesters soil carbon, leading to improved soil properties.
3. **Resource Efficiency:** The technology requires less irrigation, conserving water resources, and reduces greenhouse gas (GHG) emissions.

Table 7 Yield benefits of strip planting system over conventional tillage, and cost of production of lentil, wheat, mustard and chickpea

Tillage system	Crops	Yield (tha^{-1})	Increased over CT (%)	Production cost (US\$ ha^{-1})	References
SP	Lentil	2.3	23	1191	Islam et al., 2022b
CT		1.8		1268	
SP	Wheat	4.8	9	1057	Islam et al., 2022b
CT		4.3		1152	
SP	Mustard	1.5	15	-	Islam et al., 2022b
CT		1.3			
SP	Chickpea	1.9	6	51 (land cost and bank interest excluded)	Bell et al., 2017
CT		1.8		104 (cost and bank interest excluded)	

SP - Strip planting system; CT - Conventional tillage

Limitations:

1. **Availability:** Limited availability of strip planters is a hindrance to broader adoption.
2. **Knowledge Gap:** Many farmers lack awareness and knowledge of this new technology.
3. **Herbicide Dependence:** The system may rely on herbicides, which can have environmental implications.
4. **Residue Management:** Residue retention can sometimes hinder machine operation.

Suitability and Potential: The strip planting system holds significant potential for rabi season (winter) upland crops such as lentil, mustard, wheat, maize, chickpea, and groundnut, as well as pre-monsoon and monsoon season crops, excluding hilly and waterlogging areas. Its benefits include economic savings and environmental sustainability.

The strip planting system is a promising technology within the realm of conservation agriculture, offering numerous benefits related to cost reduction, improved soil health, and resource efficiency. Although it is currently in the research and demonstration stage, efforts are underway to scale up the technology in intensive rice-based systems in Bangladesh. Broader adoption and awareness among farmers will be essential to fully realize the potential benefits of this CSA technology.

6. Conclusions and Recommendations

Bangladesh has achieved remarkable progress in food production; however, the sustainability of this achievement faces numerous challenges, with climate change effects being a major concern. The country identifies five fragile ecosystems, referred to as hotspots in the Bangladesh Delta Plan 2100: Barind, Char, Coastal, Haor, and Hill ecosystems. In these areas, cropping intensity and crop productivity are generally low to very low. Consequently, there is an opportunity to develop and introduce suitable CSA technologies that align with the impacts of climate change, including salinity, drought, floods, erratic rainfall, and more.

We have compiled an inventory of 61 CSA technologies tailored to the vulnerable ecosystems experiencing rapid climate change. These technologies consist of both newly developed methods and age-old practices. The adoption of these technologies is essential for ensuring sustainable agricultural production and building resilience against the effects of climate change. These climate-resilient technologies can be categorized into five groups: (i) Improved crop varieties: These include varieties that are tolerant to salt, heat, drought, submergence, cold, diseases, and have shorter growth durations; (ii) Soil and crop management: Practices like biochar utilization, liming, composting, integrated nutrient management, floating agriculture, sorjan farming, silicon application, green manure, mulching, conservation agriculture, integrated rice-fish-vegetables systems, spaced transplanting (STP) for sugarcane, and agroforestry systems are beneficial in these contexts; (iii) Pest management: Techniques such as integrated pest management, bio-rational pest control, and biological pest control play a crucial role in controlling pests sustainably; (iv) Irrigation management: Methods such as rainwater harvesting, solar-powered irrigation, alternate wetting and drying (AWD), and drip irrigation contribute to efficient water use in agriculture; and (v) Farm mechanization: Technologies like raised bed planters, laser land leveling (LLP), strip and zero planting systems, and others promote efficiency in farming practices. The Conservation Agriculture (CA) approach encompasses reduced tillage, residue retention, and legume-based crop rotations, which hold significant value in improving soil health and crop productivity sustainably.

It's important to note that not all these CSA technologies are equally suitable for every ecosystem, cropping season, or farm category. Recognizing this diversity, the Bangladesh Government formulated the National Agriculture Policy 2018 and adopted strategies to promote sustainable and profitable agriculture across the country. Consequently, the future of food and nutrition security depends on the effective and widespread adoption of climate-resilient practices, particularly in ecologically challenged areas.

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Annexure

Annexure 1

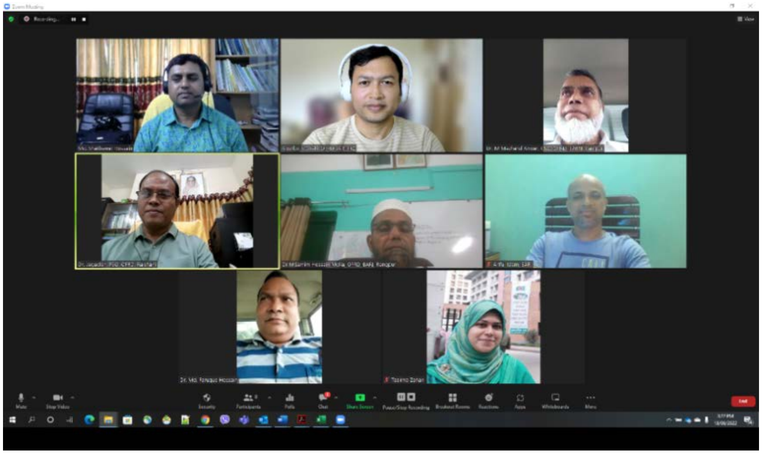
Pictorial view: Consultation workshops on Climate-Smart Agriculture Technologies in Bangladesh under the C-SUCSeS project

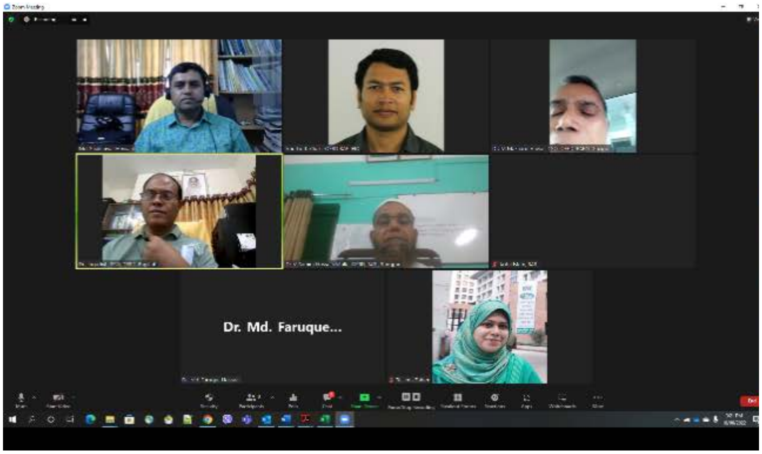
Annexure 2

Pictorial view: Consultation meetings with lead and progressive farmers, DAE personnel and NARS scientists under the C-SUCSeS project

Annexure 3

Pictorial view: Virtual and physical meetings of the working scientists under the C-SUCSeS project





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